Basic Geological Mapping

The Geological Field Guide Series

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Basic Geological Mapping

FOURTH EDITION

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Jossey-Bass, 989 Market Street, San Francisco, CA 94103-1741, USA

Wiley-VCH Verlag GmbH, Boschstr. 12, D-69469 Weinheim, Germany

John Wiley & Sons Australia Ltd, 33 Park Road, Milton, Queensland 4064, Australia

John Wiley & Sons (Asia) Pte Ltd, 2 Clementi Loop #02-01, Jin Xing Distripark, Singapore 129809

John Wiley & Sons Canada Ltd, 22 Worcester Road, Etobicoke, Ontario, Canada M9W 1L1

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Library of Congress Cataloging-in-Publication Data

Barnes, J.W. (John Wykeham), 1921-
Basic geological mapping.–4th ed. / John W. Barnes, with Richard J. Lisle
p. cm. – (The geological field guide series)
ISBN 0-470-84986-X (acid-free paper)
1. Geological mapping. I. Lisle, Richard J. II. Title. III. Series.
QE36.B33 1995
550′.22′3–dc22

2003062753

British Library Cataloguing in Publication Data

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

ISBN 0-470-84986-X

Typeset in 8.5/10.5pt Times by Laserwords Private Limited, Chennai, India
Printed and bound in Great Britain by Antony Rowe Ltd, Chippenham, Wiltshire
This book is printed on acid-free paper responsibly manufactured from sustainable forestry in which at least two trees are planted for each one used for paper production.

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PREFACE

This book is a *basic* guide to field techniques used in geological mapping. It is meant to be kept in camp with you and even carried in your rucksack in the field. In addition, because no piece of geological mapping can be considered complete until the geology has been interpreted and explained, chapters are provided on drawing cross-sections; on preparing and presenting 'fair copy' maps; and on presenting geological diagrams from your fieldwork suitable for inclusion in your report. A report explaining the geology is an essential part of any field project and a brief chapter on the essentials for writing and illustrating it concludes this book. Some emphasis, too, is given to field sketch-mapping because many reports lack those large-scale detailed maps of small areas which can often explain complex aspects of the geology that cannot be shown on the scale of the field map being used, and which are difficult to describe in words. Attention is also given to field notebooks which are, in many cases, deplorable.

It is assumed that readers of this book have already had at least one year of university or equivalent geology, and have already been told what to look for in the field. Geological mapping cannot, however, be taught in lectures and the laboratory: it must be learnt in the field. Unfortunately, only too often, trainee geologists are left largely to their own devices, to sink or swim, and to learn to map for themselves with a minimum of supervision on 'independent' mapping projects. It is hoped that this book will help them in that task.

John W. Barnes, Richard J. Lisle, 2003

ACKNOWLEDGMENTS

It is impossible to name everyone who has been associated with the production of this book. Among those who deserve special mention with the text or diagrams are the late D. V. Ager, M. G. Coulson, F. R. Cross, A. R. Gardiner, R. H. Graham, S. J. Matthews, the late T. R. O. Owen, P. Styles, and C. Tomlinson, all at that time of the University of Wales Swansea; also P. J. Brabham and A. Rogers of Cardiff University; M. H. de Freitas of Imperial College; and also my partner on eleven international mapping programmes in Asia and Africa, the late Edgar H. Bailey of the United States Geological Survey. Appreciation is also due to the Swansea University Earth Science Departmental drawing office staff, and particularly to the late Mrs V. M. Jenkins who typed the original drafts and to my late wife for reading the typescript and original proofs. I also wish to thank Richard Lisle for his help in preparing this fourth edition.

John W. Barnes, 2003

1
INTRODUCTION

There are many kinds of geological map, from small-scale reconnaissance surveys to large-scale detailed underground mine maps and engineering site plans, and each needs a different technique to make. Here, however, we are concerned only with the rudiments of geological mapping. The intention is to provide basic knowledge which can be built upon. We cannot tell you everything you need to know but we hope we can stimulate your imagination so that you can adapt your methods to most prevailing field conditions and to the scale and quality of your topographic base maps and, where necessary, to develop and devise new methods of your own. As a geologist, you must also remember that *accurate* geological maps are the basis of *all* geological work, even laboratory work, for it is pointless to make a detailed investigation of a specimen whose provenance is uncertain. As Wallace said in a 1975 Jacklin lecture: 'There is no substitute for the geological map and section – absolutely none. There never was and there never will be. The basic geology still must come first – and if it is wrong, everything that follows will probably be wrong.'

1.1 Outline and Approach

This book is arranged in what is hoped is a logical order for those about to go into the field on their first 'independent' mapping project. First it describes the equipment you will need; then you are introduced to the many types of geological map you may have to deal with some time during your professional career. A description follows of the different kinds of topographic base maps which may be available for you to plot your geological observations on in the field. Methods to locate yourself on a map are also described and advice is given on what to do if no topographic base maps at all are obtainable.

The next three chapters describe methods and techniques used in geological mapping, including a brief description of photogeology; that is the use of aerial photographs in interpreting geology on the ground. A further chapter is devoted to the use of field maps and those much neglected items, field notebooks.

The last three chapters concern 'office work', some of which may have to be done whilst still at your field camp. They cover methods of drawing

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cross-sections and the preparation of other diagrams to help your geological interpretation. Advice is also given on preparing a 'fair copy' geological map which shows your interpretation of the data from your field map. However, a geological map is not, as is sometimes supposed, an end in itself. The whole purpose is to *explain* the geology of the area and your map is only a part of that process: a report is also needed to explain the geological history of the area and the sequence of geological events. Chapter 10 is a guide on how to present this important part of any geological mapping project.

The approach here is practical: it is basically a 'how to do it' book. It avoids theoretical considerations. It is a guide to what to do in the field to collect the evidence from which geological conclusions can be drawn. What those conclusions are is up to you, but bear in mind what the geologist Lord Oxburgh has said; that making a geological map is one of the most intellectually challenging tasks in academia (Dixon 1999).

1.2 Field Behaviour

Geologists spend much of their time in the open air and more often than not their work takes them to the less inhabited parts of a country. If they did not like open country, presumably they would not have become geologists in the first place: consequently, it is taken for granted that geologists are conservation-minded and have a sympathetic regard for the countryside and those who live in it. So, do not leave gates open, climb dry-stone walls or trample crops, and do not leave litter or disturb communities of plants and animals. When you are collecting specimens do not strip or spoil sites where type fossils or rare minerals occur. Take only what you need. Always ask permission to enter land from the owners, their agents or other authorities; and this includes National Trust areas unless they are specifically known to be open to the public. Most owners are willing to cooperate if they are asked but are understandably annoyed to find strangers sampling their rocks uninvited. Bear in mind that upset landowners can inhibit geological activities in an area for years to come, and this has already happened in parts of Britain. Many other countries are less populated and have more open space, and the situation may be easier, but every country has some land where owners expect people to consult them before working there. If in doubt, ask! (See also the 'Geological fieldwork code' published by the Geologists' Association.)

1.3 Safety

A geologist must be fit if he is to do a full day's work in the field, perhaps in mountainous country, in poor weather, or in a difficult climate, either hot or cold. Geological fieldwork, in common with other outdoor pursuits, is not without physical hazards. However, many risks can be minimized by following fairly simple rules of behaviour, and discretion may often be the better part of valour when, say, faced with an exposure in a difficult position, for a geologist is often on his own, with no one to help him, should he get into difficulties. Experience is the best teacher but common sense is a good substitute. Field safety is more fully discussed in Appendix I from both the standpoint of the student (or employee) and his supervisor (or employer).

1.4 Ancillary Skills

A geologist should be able to swim, even when fully clothed. If you can swim, you are less likely to panic when you slip off an outcrop into a river; or from weed-covered rocks into the sea or a rock pool; or even if you just fall flat on your face when crossing a seemingly shallow stream. A ford often proves deeper than you thought and not all natural water is quite as pellucid as poets would have us believe. Such accidents happen to most of us sometime. If you are faced by something risky, play it safe, especially if you are on your own.

Geologists should also be able to drive. They sometimes have to ride, too. Horses, donkeys, and especially mules, are still used in some mountainous areas. They can save a great deal of tedious walking and backpacking, and mules in particular can clamber up astonishingly steep and rocky slopes. Field geologists spend a great deal of their time getting from place to place.

1.5 A Few Words of Comfort

Finally, some cheering words for those about to start their first piece of independent mapping. The first week or so of nearly every geological mapping project can be depressing, especially when you are on you own in a remote area. No matter how many hours are spent in the field each day, little seems to show on the map except unconnected fragments of information which have no semblance to an embryonic geological map. Do not lose heart: this is quite normal and the map will suddenly begin to take shape.

The last few days of fieldwork are also often frustrating for, no matter what you do, there always seems to be something left to be filled in. When this happens, check that you do have all the essential information and then work to a specific finishing date. Otherwise you never will finish your map.

2
FIELD EQUIPMENT

Geologists need a number of items for the field. A hammer (sometimes two) is essential and some chisels. Also essential are a compass, clinometer, pocket steel tape, and a handlens, plus a map case, notebook, map scales, protractor, pencils and eraser, an acid bottle and a jack-knife. A camera is a must and a small pair of binoculars can be most useful at times, as is a GPS instrument if it can be afforded (see Section 3.4.9). Sometimes a 30 m tape may be needed and a stereonet. If using aerial photographs you will need a pocket stereoscope; very occasionally a pedometer can be useful, although not essential. You will also need a felt-tipped marker pen and/or timber crayons for labelling specimens.

Finally, you need a rucksack to carry it all, plus a waterbottle, emergency rations, a first aid kit, perhaps an extra sweater, your mobile phone (see Appendix I), and of course your lunch.

Geologists must also wear appropriate clothing and footwear for the field if they are to work efficiently, often in wet cold weather, when other (perhaps more sensible) people stay indoors; inadequate clothing can put a geologist at risk of hypothermia (Appendix I). A checklist of what you may have to pack before a field trip is given in Appendix IV, but this is an exhaustive list to cover various types of geological fieldwork in various climates; refer to it before first setting out to your field area base. A more detailed description of the essentials is given in Figure 2.1.

2.1 Hammers and Chisels

Any geologist going into the field needs at least one hammer with which to break rock. Generally, a hammer weighing less than about $\frac{3}{4}$ kg ($1\frac{1}{2}$ lbs) is of little use except for very soft rocks; 1 kg ($2–2\frac{1}{2}$ lbs) is probably the most useful weight. The commonest pattern still used in Europe has one square-faced end and one chisel end. Many geologists now prefer a ‘prospecting pick’; it has a long pick-like end which can be inserted into cracks for levering out loose rock, and can also be used for digging in soil in search of float. Most hammers can be bought with either wooden or fibreglass handles, or with a steel shaft encased in a rubber grip (Figure 2.1). If a wooden handle

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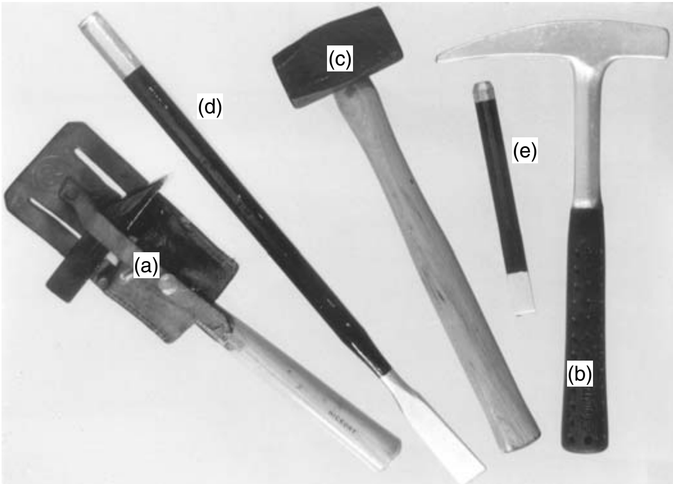


Figure 2.1 *Tools for the field: (a) traditional geologist's hammer in leather belt 'frog'; (b) steel-shafted 'prospecting pick'; (c) bricklayer's 'club' hammer with a replaced longer shaft; (d) 45 cm chisel with 2.5 cm edge; (e) 18 cm chisel with 2 cm cutting edge*

is chosen (it does have some advantages: it is more springy), buy some spare handles and some iron wedges to fix them on with.

Geologists working on igneous and metamorphic rocks may opt for heavier hammers. Although 2 kg/4 lb geological hammers are available, a bricklayer's 'club' hammer, with a head shaped like a small sledge hammer, can be bought more cheaply; but replace its rather short handle by a longer one bought from a hardware store.

Hammering alone is not always the best way to collect rock or fossil specimens. Sometimes a cold chisel is needed to break out a specific piece of rock or fossil. Its size depends on the work to be done. A 5 mm ($\frac{1}{4}$ inch) chisel may be ideal to delicately chip a small fossil free from shale, but to break out large pieces of harder rock a 20–25 mm ($\frac{3}{4}$ inch) chisel is required (Figure 2.1). Perhaps geologists should follow the lead of mine samplers, whose job it is to break off rock and ore and who find a 'moil' more effective. This is a steel bar, usually a piece of drill steel, 25–30 cm long, sharpened to a point and tempered. One thing which you must never do is to use one hammer as a chisel and hit it with another. The tempering of a hammer face is quite different from that of a chisel head, and small steel fragments may fly off the hammer face with unpleasant results.

Some geologists carry their hammers in a 'frog' or hammer holster, as this leaves their hands free for climbing, writing and plotting. They can be bought or easily made from heavy leather (Figure 2.1). Climbing shops stock them for piton hammers although some may be too small to take a geological hammer handle. Note also that using a geological hammer is a 'chipping action' and comes under the *Health and Safety at Work Act* as needing the use of approved goggles. Courts would probably take a less than liberal view of claims for compensation for eye injuries suffered if goggles were not being worn.

2.2 Compasses and Clinometers

The ideal geologist's compass has yet to be designed. Americans have their *Brunton*, the French the *Chaix-Universelle*, the Swiss have the *Meridian*, and there is also the *Clar* compass, popular in Europe. All are expensive. Many geologists now use the very much cheaper Swedish *Silva Ranger 15 TDCL* or the similar Finnish *Suunto* (Figure 2.2(a)). All the above have built-in clinometers. The Silva (Figure 2.3) and Suunto compasses, however, have a transparent base so that bearings can be plotted directly onto a map by using the compass itself as a protractor (Section 5.2). However, like the Brunton,

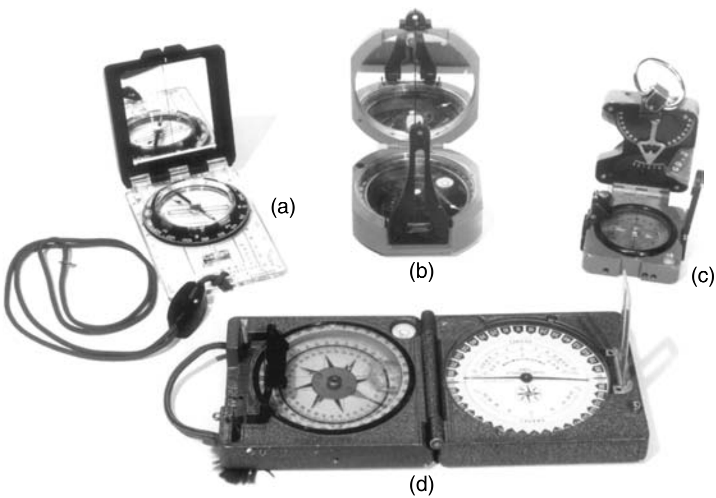


Figure 2.2 *Compasses designed for the geologist: (a) Finnish Suunto compass, similar to the Swedish Silva Ranger 15 TDCL; (b) American Brunton 'pocket transit'; (c) Swiss Meridian compass; (d) French Chaix-Universelle. The Brunton and Meridian can also be used as hand-levels*

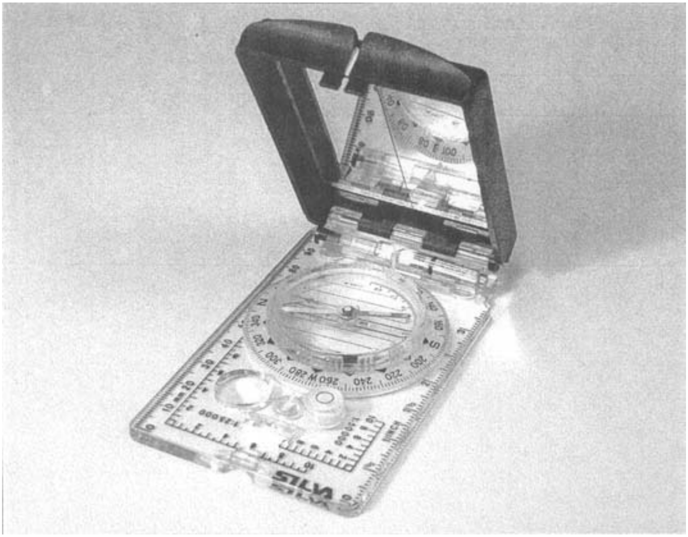


Figure 2.3 *The Swedish Silva Ranger 15 TDCL geologist's compass. Like the Suunto, an excellent and reasonably priced instrument*

the Silva and Suunto are needle compasses and are not as easy to take bearings with on distant points as are prismatic compasses which have a graduated card to carry the magnetic needle. Silva do make a prismatic card-compass (No. 54), but it lacks a clinometer (Figure 2.4(d)). All these compasses except the Brunton are liquid-filled to damp movement of the needle when taking a reading. The Brunton is induction-damped.

A compromise may be made by using a separate clinometer and a cheaper compass, such as the Japanese *Europleasure Lensatic* compass. This is liquid-damped and can be read like a prismatic (available from sports and camping shops). Another alternative is to buy a hand-bearing compass such as the *Meridian* or the very robust former British army compass (second-hand shops). The latter suffers from having no straight edge with which to measure strike with, but is excellent if you need to survey-in numerous distant points accurately.

2.2.1 Compass graduations

Compasses can be graduated in several ways. The basic choice is between the traditional 360 (degrees) and the continental 400 (grads) to a full circle. Both are used in continental Europe and if you do buy a compass there,

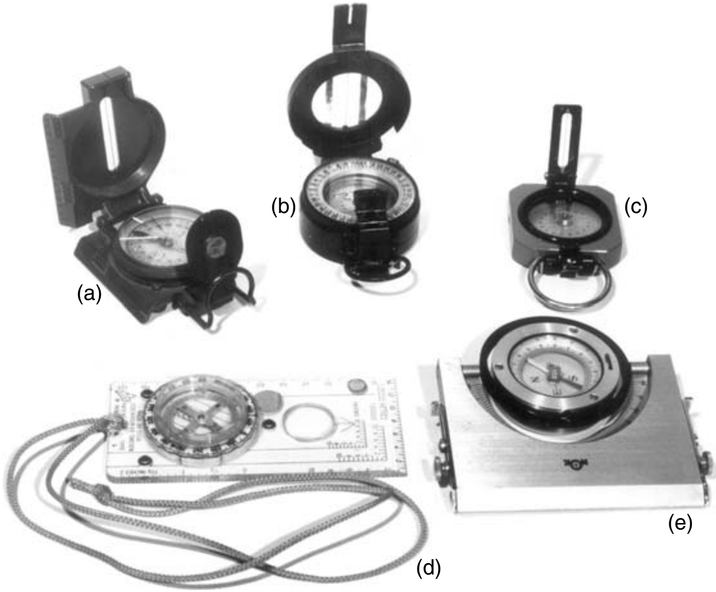


Figure 2.4 *Various other compasses: (a) Japanese Lensatic compass, with a good straight side for measuring strikes (some models have a clinometer), and can be read like a prismatic compass; (b) British army prismatic compass; very accurate, robust, and excellent for taking bearings, but very expensive and has no straight sides; (c) Swiss Meridian bearing compass; it has no clinometer; (d) Swedish Silva prismatic compass No. 54; (e) Japanese 'universal clinometer' made by Nihon Chikagasko Shaco, Kyoto (see also Figure 2.8)*

check it first. If you opt for degrees, you must then choose between graduation into four quadrants of 0–90° each, or to read a full circle of 0–360° ('azimuth' graduation). Here, we recommend azimuth, for bearings can be expressed more briefly and with less chance of error. Comparisons are made in Table 2.1.

2.2.2 Using compasses

Prismatic compasses and mirror compasses are used in different ways when sighting a distant point. A prismatic is held at eye level and aimed like a rifle, lining up the point, the hairline at the front of the compass and the slit just above the prism. The bearing can then be seen in the prism, reflected and enlarged from the compass card. A mirror compass can be read in two ways.

Table 2.1

Quadrant bearing	Azimuth bearing
N36°E	036°
N36°W	324°
S36°E	144°
S36°W	216°

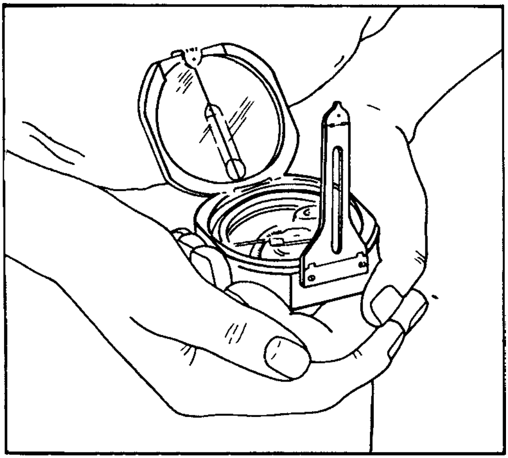


Figure 2.5 *The recommended way to use a Brunton compass when taking a bearing on a distant point (reproduced by courtesy of the Brunton company, Riverton, Wyoming)*

The Brunton company recommend that the compass is held at waist height and the distant point aligned with the front sight so that both are reflected in the mirror and are bisected by the hairline on the mirror (Figure 2.5). As the Brunton is undamped, do not wait until the needle has stopped swinging, wait until the swing is only a few degrees and read the average of the swing; it takes practice. This waist-high method is not easy to do with the Silva-type mirror compass, and many will find it more convenient to sight the distant point by holding the compass at eye level and reflecting the compass needle in the mirror. Some prefer to read a Brunton in the same way. Mirror compasses have a distinct advantage over prismatics in poor light such as underground.

2.2.3 Clinometers

Few compasses incorporate a clinometer into their construction. Clinometers can be bought separately and a few types, such as the Finnish *Suunto*, have the advantage that they can also be used as a hand-level. Some hand-levels, such as the *Abney* (Figure 2.7(d)), can be used as a clinometer, although rather inconveniently. The *Burgess level and angle indicator*, designed for do-it-yourself handymen, makes a cheap and effective clinometer (and it is sold under other names). *Rabone* also market a cheap builder's level which can be used as a clinometer. These DIY instruments (Figures 2.7(a) and (c)) often have a magnetic strip so they can be attached to metal gutters and downpipes. Remove it for obvious reasons.

Some builder's 'two-foot' rules have a brass middle joint graduated every 5°. Although not accurate enough for normal dip measurements, they are useful for measuring *lineations* Section 5.4.2.

Clinometers can be easily made either by using the pendulum principle or, better still, the Dr Dollar design, as follows: photocopy a 10 cm diameter ½-round protractor for a scale and glue it to a piece of Perspex after duffing

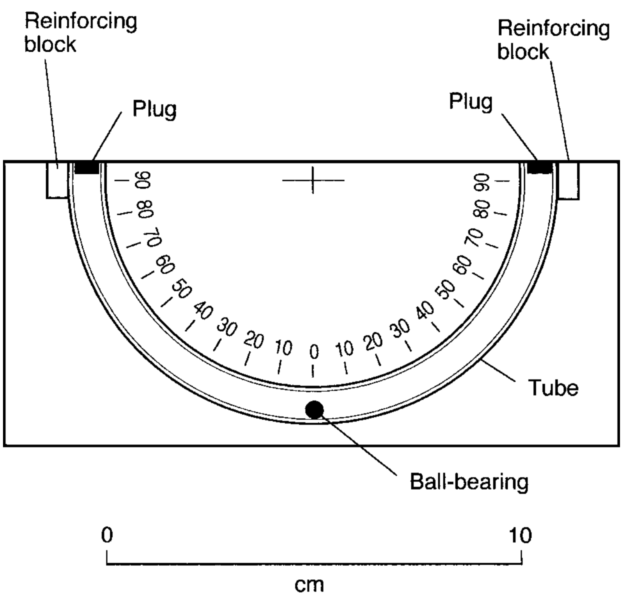


Figure 2.6 *A home-made clinometer (reproduced by permission of the Earth Science Teachers' Association)*

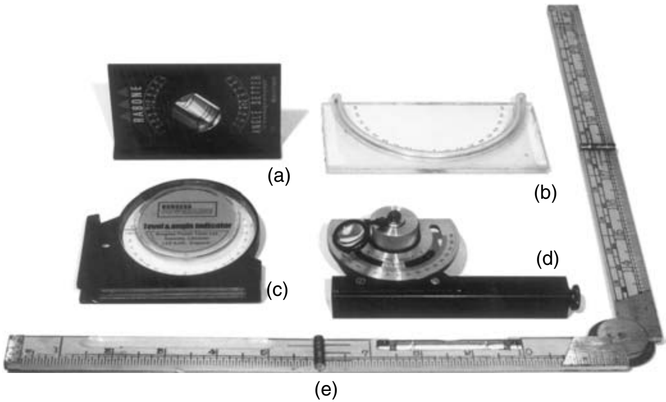


__Figure 2.7__ A selection of clinometers: (a) Rabone adjustable spirit level; (b) Home-made clinometer (see Figure 2.6); (c) Burgess 'level and angle indicator'; very cheap, if you can find one in a DIY shop (may be sold under other names); (d) Abney hand-level; can also be used as a clinometer; (e) builder's 'two-foot' rule with level bubble and 5° graduation at hinge; useful for measuring lineations

out the figures and re-numbering so that 0° is now at the centre. Cement transparent plastic tubing containing a ball-bearing around it and fill each end with plasticine or putty to keep the ball in (Barnes (1985), and see Figures 2.6 and 2.7(b)).

__Figure 2.8__ Japanese 'universal clinometer'. Based on the 'German miner's hanging compass. Trend can be measured directly from the compass, which always stays horizontal, and plunge is read by the pointer hanging below the compass box

2.2.4 Lineation compass

The Japanese produce a most useful compass designed to measure trend and plunge of lineation simultaneously. The compass case is on gimbals so that it always remains level whatever the angle of its frame. It is effective in even the most awkward places (Figures 2.4(e) and 2.8). The design is derived from the German miner's compass. The maker is Nihon Chikagasko Shaco, Kyoto.

2.3 Handlenses

Every geologist must have a handlens and should develop the habit of carrying it at all times, so that when he needs it he has it with him. A magnification of between 7 and 10 times is probably the most useful. Although there are cheap magnifiers on the market, a good quality lens is worth the extra cost in flatness of field and should last you a lifetime. To ensure that it does last a lifetime, attach a thin cord to hang it round your neck. Monocle cord is ideal if you can find it, as it does not twist into irritating knots. However, always keep a spare in camp, for your fieldwork could be jeopardised should you lose the only one you have with you.

2.4 Tapes

A short 'roll-up' steel tape has many uses. A 3 m tape takes up no more room than a 1 m tape and is much more useful. You can use it to measure everything from grain size to bed thickness, and if the tape has black numbering on a white background, you can use it as a scale when taking close-up photographs of rock surfaces or fossils. A geologist also occasionally needs a 10 m or 30 m 'linen' tape for small surveys. You might not need it every day but keep one in camp for when you do. Treat a tape with respect. Wind it back into its case only when clean, for dirt will wear off the graduations. If a long tape is muddy, coil it into loops between measurements. When you do eventually wind it back into its case, do so between fingers of your other hand or through a damp rag to wipe off the dirt. When finished for the day, wash and dry it before putting it away.

2.5 Map Cases

A map case is obviously essential where work may have to be done in the rain or mist; but even in warmer climes, protection from both the sun and sweaty hands is still needed. A map case must have a rigid base so that you can plot and write on the map easily; it must protect the map; and it must open easily, otherwise it will deter you from adding information to the map. If it is awkward to open, you will probably say 'I will remember that and add it later' and of course, being only human, you forget! The best map cases are probably home-made (Figure 2.9). Pencil holders make mapping easier, whether attached to your map case or your belt. Make your own.

2.6 Field Notebooks

Do not economise on your field notebook. It should have good quality 'rain-proof' paper, a strong hard cover and good binding. It will have to put up with hard usage, often in wet and windy conditions. Nothing is more discouraging than to see pages of field notes torn out of your notebook by a gust of wind and blowing across the landscape. Loose-leaf books are especially

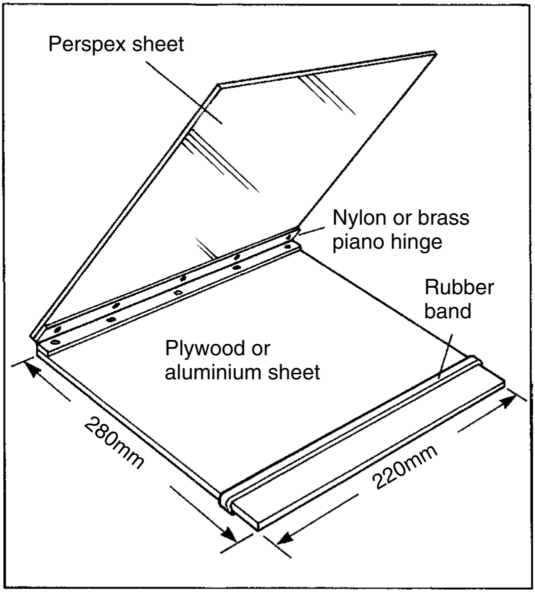


__Figure 2.9__ A map case made from a Perspex sheet attached to a plywood base by a nylon or brass 'piano hinge' (from a DIY), using 'pop' rivets. A wide elastic band is used to keep the map flat. Even simpler, use adhesive carpet tape for the hinge, but it will need frequent renewing

vulnerable. A hard cover is necessary to give a good surface for writing and sketching. A notebook should fit into your pocket so that it is always available, but big enough to write on in your hand. A good size is 12 cm × 20 cm so make sure you have a pocket or belt-pouch to fit it. Try to buy a book with squared, preferably metric squared, paper; it makes sketching so much easier. Half-centimetre squares are quite small enough. A surveyor's *chaining book* is the next best choice: the paper is rainproof, it is a convenient size, and it has a good hard cover. A wide elastic band will keep pages flat and also mark your place.

2.7 Scales

A geologist must use suitable scales, most conveniently about 15 cm long: a ruler is just not good enough. Rulers seldom have an edge thin enough for accurate plotting of distances, and trying to convert in your head a distance measured on the ground to the correct number of millimetres on the ruler for

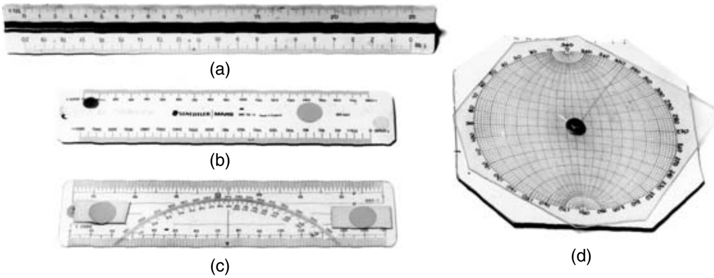


Figure 2.10 A selection of scales: (a) a triangular map scale which is not recommended for field use, but excellent in the office; (b) a plastic scale with different graduations on both edges and both sides; (c) a transparent combination of map scale and protractor – cheap with a wide choice of scales available (C-thru Ruler Company, Bloomfield, USA); (d) a home-made pocket stereonet for the field; the upper rotating Perspex disc is lightly sandpapered so that it can be drawn on in pencil and easily cleaned off again. Note the adhesive orange fluorescent 'spots' stuck to the scales to make them easier to find when dropped

the scale of your map just leads to errors. Scales are not expensive for the amount of use they get. Many are thinly oval in section and engraved on both sides to give four different graduations. The most convenient combination is probably 1:50 000, 1:25 000, 1:12 500 and 1:10 000. In the USA scales with 1:62 500 and 1:24 000 are needed. Colour code scale edges by painting each with a different coloured waterproof ink or coloured adhesive tape, even nail varnish, so that the scale you are currently using is instantly recognisable. Although triangular scales with six edges, each with a different scale may seem an even better bet and are excellent for the drawing office, their knife-sharp edges are easily chipped in the field (Figure 2.10).

The American transparent scale/protractor shown in Figure 2.10 only has two scales on it but they are available with many different combinations of scales and are cheap enough so that a selection can be bought with different graduations.

2.8 Protractors

Little needs to be said about protractors. They are easily obtainable and relatively cheap. For ease of plotting they should be 15–20 cm in diameter and semi-circular; circular protractors are no use for plotting with in the field (Section 5.2). Keep a couple of 10 cm protractors in your field kit in case of loss. Transparent protractors (and scales) are difficult to see when dropped in the field but are easier to find if marked with an orange fluorescent spot.

2.9 Pencils and Erasers

At least three pencils are needed for mapping in the field: a hard pencil (4H or 6H) for plotting bearings; a softer pencil (2H or 4H) for plotting strikes and writing notes on the map; and another pencil (2H, HB or F) kept only for writing in your notebook. The harder alternatives are for warmer climates, the softer for cold. Do not be tempted into using soft pencils, they smudge and they need frequent sharpening. A soft pencil is quite incapable of making the fineness of line needed on a geological map with sufficient permanency to last a full day's mapping in rigorous conditions, and keep a separate pencil for your notebook to avoid frequent sharpening. Buy only good quality pencils and, if possible, buy them with an eraser attached, alternatively buy erasers which fit over the end of the pencil. Attach a larger good quality eraser to your buttonhole or your mapcase with a piece of string or cord, and always carry a spare. Coloured pencils should also be of top quality; keep a list of the make and shade numbers you do use so that you can replace them with exactly the same shades again.

Do not use stylus-type ink pens in the field. They may be capable of fine lines and printing on a dry map, but not if the map is damp. Also Murphy's Law ensures that some notes are written just where a critical exposure will be found later in the day and the notes must be erased and re-written elsewhere. Waterproof ink (and only waterproof ink should ever be used on your map) is impossible to erase without damaging the surface of the map.

2.10 Acid Bottles

Always carry an acid bottle in your rucksack. It should contain a *small* amount of 10% hydrochloric acid. Five millilitres (5 ml) is usually ample for a full day's work even in limestone country, providing only a *drop* is used at a time, and one drop should be enough. Those tiny plastic dropping bottles in which some proprietary ear-drops and eye-drops are supplied make excellent field acid bottles. They have the advantage that they deliver only one drop at a time, are small, do not leak and will not break. Keep a supply of 10% acid back in camp.

2.11 Global Positioning System (GPS)

At times, locating yourself on a map can be time-consuming, especially where the map lacks detail. For this reason geologists are increasingly making use of the Global Positioning System (GPS) to locate themselves. GPS is a navigational method operated by the US government. A hand-held device, little bigger than a mobile phone (Figure 2.11), picks up radio signals from orbiting satellites that continuously transmit the exact time and their position. The time delay between transmission and reception allows the satellite to receiver

Figure 2.11 *A Garmin GPS-12, typical hand-held GPS instrument. It can locate you to within a few metres on the ground and assist you in following a specific route. It cannot be used in forest because it requires a clear view of several satellites. It also does not function well in icy conditions*

distance to be calculated. By simultaneously using signals from several satellites, the position of the receiver on the ground can be determined.

Accuracy (at the 95% confidence level) for the more basic GPS instruments is typically to within 15 m of horizontal distance, although the system can be deliberately degraded for military reasons (CA = Coarse Acquisition, or SA = Selective Availability). Greater accuracy can be achieved by the more sophisticated Differential GPS (DGPS). Noise errors, including those deliberately introduced by the system operators, are determined by putting a receiver at a base station with a known location, then using a roving receiver to communicate with the base station to obtain the necessary corrections.

Instruments weigh between 400 and 600 g and there are several makers. The price of the more basic handsets has plummeted since the third edition of this book to little over £100. Functions vary with makes and models: some give latitude and longitude, and grid references for different national grid systems. Most show your route, speed and bearing, and bleep when you reach designated 'way points'. As GPS needs line-of-sight to several satellites at the same time, it does not work in forests or steep valleys, nor in very cold conditions.

Although GPS can be invaluable for position fixing in some areas, do not rely on it too much. Keep track of your route by constantly referring to your base map. In this way you will always have a general idea of where you are relative to the alignment of the geological features of the terrain.

2.12 Other Instruments

These are listed below in the order in which they are most likely to be used.

2.12.1 Stereonets

A pocket stereonet is most useful when mapping lineations, intersection of planes and similar structural problems (Figure 2.10(d)). Plunge and trend can be calculated on the spot from strike and pitch measurements made on bedding and foliation planes, or from the intersection of planes (Lisle and Leyshon 2003). A stereonet is the geologist's slide rule and the structural geologist will find many uses for it in the field. Make one by glueing a 15 cm Wulff or Schmidt net to a piece of Perspex or even thin plywood, leaving a margin of 1 cm or so around edge of the net. Cut a slightly smaller piece of Perspex and attach to the net by a screw or any other method so that one can rotate over the other. Lightly frost the upper Perspex with fine sandpaper so that you can plot on it with a pencil and then rub the lines out again afterwards.

2.12.2 Stereoscopes

You will need a pocket stereoscope if you are using aerial photographs in the field. It will give you a three-dimensional image from stereopairs with a much exaggerated topographic relief; a great advantage, as minor topographic features controlled by geology, such as faults, joints and dykes stand out more clearly. However, also learn to get a 3D image from a stereo-pair of photos without a stereoscope; it just takes practice.

2.12.3 Pedometers

A pedometer is mostly useful in reconnaissance mapping, or at scales of 1:100 000 or smaller. It does not actually measure distance directly: it counts paces and expresses them in terms of distance after it has been set with your own pace length. Make allowances for your shorter paces on slopes, both up and downhill.

2.12.4 Altimeters

There are occasions when an altimeter, i.e. a barometer graduated in altitudes, can be a useful aid. Excellent, robust, pocket-watch sized instruments, such as the Thommen mountain altimeter, are sufficiently accurate for some geological uses, and they are not particularly expensive. It is better to keep them in your hand baggage when travelling by air, in case the baggage compartment is not pressurised. As most instruments read only to 5000 m above sea level, they are not likely to function properly if repeatedly exposed to the 10 000 or 15 000 m of modern air travel.

2.13 Field Clothing

To work efficiently a geologist must be properly clothed and you cannot work efficiently if soaking wet or frozen stiff. In warm or hot climates, bad sunburn will not lead to full concentration on your work, nor will being covered in insect bites. Note that in summer, arctic regions frequently swarm with mosquitos on lower ground and biting black-fly on hillsides; long sleeves and sometimes even a face net are needed.

In temperate and colder climates, wear loose-fitting trousers: tight jeans are not as warm, especially if they get wet, and geologists often do get wet. Consult your local climbing club and read the advice given in the British Mountaineering Council leaflets (Appendix I). Even when the weather appears warm, carry a sweater in your rucksack in hilly country, and when buying an anorak, choose bright oranges or yellows: they are more easily seen by search parties!

In some countries you can rely on the weather but not in Britain, and nights can be very cold if you get lost. Keep a knitted woollen hat in your bag; you don't have to wear it but heat is lost more rapidly through the scalp than from any other part of your body. As for gloves, fingerless mittens allow you to write on your map without removing them but keep an ordinary pair of gloves handy too. Gloves are probably lost in the field more often than any other piece of equipment except for pencils, protractors and scales, so keep a spare pair. A *gilet*, or 'fisherman's waistcoat', with its multiplicity of pockets is an ideal garment for the geologist in good weather. Clothing in warmer and tropical climates is at least less bulky. Wear long-sleeved shirts and long trousers until acclimatised. Wear a hat; a cheap cotton 'jungle hat' is excellent and the brim pulled down low over your eyes is a better shade from glare than sun glasses. And note, it can still get cold at night on higher ground even in the tropics. Boots in temperate, wet and cold climates should be strong and waterproof, with well-cleated soles. Leather boots may be expensive but they are a part of the well-dressed geologist's kit. Rubber Wellingtons can be worn when working in boggy ground, such as in parts of Scotland, and some have excellent soles, but they can be uncomfortable if you have to walk long distances in them. In warmer climates, lightweight half-boots ('chukka' boots), or even trainers, are popular; if they get wet, who cares, they soon dry out. Heavier boots, however, are still advisable in mountains, wherever you are.

3

GEOLOGICAL MAPS AND BASE MAPS

To make a geological map you need a topographic base map on which to plot your geological observations in the field. You will also need a second map on which to replot your interpretation of the geology as a 'fair copy map' to submit to your employer or supervisor, when your work is complete. In Britain, geologists have a wide selection of Ordnance Survey (OS) maps at their disposal, from a scale of 1:10 000 to even larger scales in many areas. In other countries the maps available are usually of much smaller scales. There may even be difficulty in getting a base map at all, for many countries restrict the issue of all but tourist maps to officials. You may even have to make your own topographic base – if you know how. Any geologist, especially one who intends to enter the mineral industry, is well advised to learn at least the rudiments of map making. It will stand them in very good stead later (Appendix III).

3.1 Types of Geological Map

Geological maps fall into four main groups. These are: reconnaissance maps; maps made of regional geology; large-scale maps of limited areas; and maps made for special purposes. Small-scale maps covering very large regions are usually compiled from information selected from one or more of these groups.

3.1.1 Geological reconnaissance maps

Reconnaissance maps are made to find out as much as possible about the geology of an area as quickly as possible. They are usually made at a scale of 1:250 000 or smaller, sometimes very much smaller. Some reconnaissance maps are made by *photogeology*, that is by interpreting geology from aerial photographs, with only a minimum of work done on the ground to identify rock types and to identify dubious structural features, such as lineaments. Reconnaissance maps have even been made by plotting the main geological features from a light aircraft or helicopter with, again, only brief confirmatory visits to the ground itself. Airborne methods are particularly useful in regions where field seasons are short, such as in northern Canada and Alaska.

Basic Geological Mapping, Fourth Edition. John W. Barnes with Richard J. Lisle
 ISBN: 0-470-84986-X

3.1.2 Regional geological maps

Reconnaissance may have given the outline of rock distribution and general structure; now the geology must be studied in more detail, most commonly at a scale of 1:50 000 or 1:25 000, although any resulting map will probably be published at 1:100 000.

Regional geological maps should be plotted on a reliable base. Unfortunately, in some countries, geological mapping outstrips topographic coverage when there is a sudden economic interest in a specific area and geologists must then survey the topography themselves. An accurate geological map loses much of its point if superimposed on an inadequate topographic base.

Regional geological mapping done on the ground may be supported by systematic photogeology, and it should be emphasised that photogeological evidence is *not* inferior to information obtained on the ground although it may differ in character. Some geological features seen on aerial photographs cannot even be detected on the ground while others can even be more conveniently followed on photographs than in surface exposures (see Section 4.10). All geological mapping should incorporate any techniques which can help in plotting the geology and which the budget will allow, including geophysics, pitting, augering, drilling and even the use of satellite images where available.

3.1.3 Detailed geological maps

Scales for detailed geological maps may be anything from 1:10 000 and larger. Such maps are made to investigate specific problems which have arisen during smaller-scale mapping, or from discoveries made during mineral exploration, or perhaps for the preliminary investigation of a dam site or for other engineering projects. In Britain 1:10 000 is now the scale used for regional maps by the Geological Survey to cover the whole country, replacing the older '6 inches to the mile' series (1:10 560). Few countries match this detail for their regional topographic and geological map coverage. This is also the scale most commonly used by British students for their own mapping projects.

3.1.4 Specialised maps

Specialised maps are many and various. They include large-scale maps of small areas made to record specific geological features in great detail. Some are for research, others for economic purposes, such as open pit mine plans at scales from 1:1000 to 1:2500; underground geological mine plans at 1:500 or larger; and engineering site investigations at similar scales. There are many other types of map with geological affiliations too. They include geophysical and geochemical maps; foliation and joint maps; and sampling plans. Most are superimposed over an outline of the geology, or drawn on transparencies to be superimposed on geological maps, to study their relationship with the solid geology.

3.2 Topographic Base Maps

Much of the information below has been condensed from that massive detailed work *Information Sources in Cartography* (Perkins and Parry 1990).

3.2.1 Great Britain

Frankly, geologists in Great Britain are spoilt for choice in regard to maps to work on. The mapping agency is the Ordnance Survey (OS) and all maps are based on Single Transverse Mercator (STM) projection, and covered by a 1 km National Grid. They are held on the National Topographic Database (NTD) and digitised so that they can be printed on demand. The scales are:

Urban areas	1:1250 printed as 500 m squares
Rural areas	1:2500 printed as 1 or 2 square km areas
Uncultivated areas and moorland	1:10 000 (also covers above areas)

The two larger scales are uncontoured, the 1:10 000 maps are contoured at 5 or 10 m vertical intervals (VI) depending on the steepness of the topography.

The Superplan Service will print up to AO size at any scale from 1:200 to 1:5000, or can provide the data on a 3.5 inch floppy disc in DXF format (Parry and Perkins 2000).

There are also educational and recreational maps at 1:25 000, 1:50 000 and 1:250 000. They are coloured and so are not useful for mapping geology, but can be used for planning. (Address: Ordnance Survey, Romsey Road, Southampton, SO16 4GU. http://www.ordsvy.gov.uk.)

3.2.2 Other countries

It is difficult to particularise the availability of maps in other countries. A summary of the maps in the countries students are most likely to choose for mapping projects is given below. The problem is that, although maps may be available at these scales, they may not be suitable as base maps. Many may be coloured with geographic information, such as forest areas, or colour-layered to indicate contour intervals, or contour-shaded and (even worse) hachured to emphasise topography. Again refer to Parry and Perkins (2000).

If no black on white maps are available, you have two alternatives: either you map on a transparent overlay and firmly tape it to the map below; or you must trace off the pertinent topographic detail and map on prints made from your tracing, preferably made on a good stable material.

If you work on an overlay, tape it on one edge only, so that it can be lifted if necessary to examine the map beneath more clearly. You will also find that during field use the map and overlay will distort differently, so mark grid intersections on the overlay so that it can be relocated when necessary, and use only 'low tack' drafting tape which can be lifted; do not use transparent office tape which you cannot lift without damage to the surface it is stuck to.

Note also that some countries can be most sensitive over who uses their maps, a problem which can sometimes be eased by cooperating with their geological survey or a local university.

France
The organisation responsible for French maps is the Institut Géographique Nationale (IGN). Their maps are printed with the Universal Transverse Mercator grid (UTM) to assist GPS use, at 1:25 000 (VI 5 m, 10 m in mountains). There is a wide range of digital products and local authorities may be able to provide larger scales. Go to http://www.ign.fr

Germany
Mapping is the responsibility of individual states. Some of the maps have relief shading or four-colour layering with VI at 12.5 to 25 m. There are many agencies, both private and official. Maps at 1:25 000 (VI 10 m) in outline monochrome are available. There are too many agencies to outline here. Again refer to Parry and Perkins (2000).

Norway
The official mapping organisation is Statens Kartsverk (SKV). Digitised 1:50 000 maps with 20 m VI are available. Go to http://www.statkart.no

Portugal
Maps are the responsibility of the Instituto Português de Cartografia e Cadastro (IPCC). Maps at 1:10 000 with a 5 m VI are available and there are orthophoto editions. Digitising is expected to be completed by 2006. Go to http://www.icpc.pt

Spain
Maps are produced by the Instituto Geográfico Nacional (IGNE). Scales are 1:50 000 and 1:25 000. Digitisation is probably now complete. Go to http://www.geo.ign.es/

Sweden
The official organisation is Lantmäteriverket (LMV). LMV publishes down to 1:20 000 gulakarten ('yellow maps') and there are also 1:20 000 and some 1:10 000 digitised photomaps with 5 m VI. URL http://www.lm.se

Switzerland
Bundesamt für Landestopografie (BLT) is responsible for maps which are produced at 1:50 000 and 1:25 000 with hill shading and also 1:25 000 with

VI at 10 m (20 m VI in mountains), but these are coloured. There are also Pixelkarten unshaded digital maps. Go to http://www.swisstopo.ch

United States of America
Although there is a confusion of agencies concerned with mapping, the main topographic agency is the US Geological Survey. Scales of maps vary depending on the area: some are 1:24 000 some 1:25 000. There are also smaller scale maps at 1:100 000 (with metric contours) and at 1:250 000. There is also a profusion of sources, both state and federal. Your first contact is best made to the National Cartographic Information Center (USGS) Reston, Virginia 22092, who will supply a free descriptive booklet.

Canada
Canada has two mapping agencies, federal and provincial, the former responsible for 1:50 000 and smaller scales and the latter for 1:20 000 and even larger scales, but basically for economic purposes.

3.3 Geographic Coordinates and Metric Grids

3.3.1 Geographic coordinates

Geographic coordinates represent the lines of latitude and longitude which sub-divide the terrestrial globe. To make a map, part of the curved surface of the globe is projected on to a flat surface. This may result in one or both sets of coordinates being shown as curved lines, depending on the type of projection being used. In Transverse Mercator's projection, however, the one most commonly used for the large-scale maps on which geologists work, latitude and longitude appear as intersecting sets of straight parallel lines. This results in some distortion because, of course, in reality lines of longitude converge towards the poles, but on any single map-sheet the distortion is negligible. What does matter is that as latitude increases towards either pole, 1° of latitude remains a constant length of 60 nautical miles, but 1° of longitude becomes progressively shorter until it becomes zero at the poles. In general, Mercator's projection is fine from the equator to moderate latitudes. Expressing locations in notebooks by geographical coordinates of degrees, minutes and seconds is, however, cumbersome when you bear in mind that 1° is a different length east to west, than 1° north to south. Hence the use of metric grids.

3.3.2 Metric grids

The metric grid printed on maps is a geometric not a geodetic device. The grid is superimposed on the flat map projection and has (almost) no relationship to the surface of the globe: it is merely a system of rectangular coordinates, usually printed as 1 km squares on maps from 1:10 000 to 1:50 000 and 10 km squares on maps of smaller scales. The grid covering Britain is numbered from an origin 90 km west of the Scilly Isles and extends 700 km eastwards and 1300 km to the north. The whole grid is divided into 100 km square blocks, each designated by two reference letters. This is merely a convenience so that the map reference of a point far from the origin, for example Lerwick in the Shetland Isles, does not become an unwieldy multi-digit number. Other countries have other origins for their grids; some use other systems.

The metric grid is a useful device for describing a point on a map. In Britain, a full map reference is given by first quoting the reference letters of the 100 km square block in which the point lies, e.g. SN if in southwest Wales. This is followed by the *easting*, i.e. the distance in kilometres from the western margin of square SN and then the *northing*, the distance from the southern margin of the square. The complete reference is written as a single group of letters and figures, easting always before northing. This figure will give the position of the point to the nearest kilometre. For instance, SN8747 means that Llanwrtyd Wells is 87 km east and 47 km north of the margins of square SN. This is good enough to indicate the general area of the town. SN87724615, however, is more specific and locates the position of the road

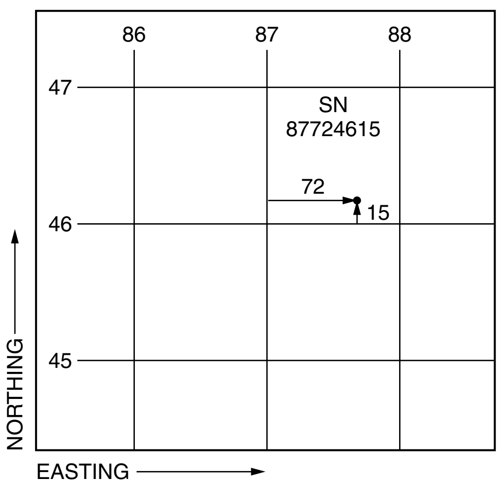


Figure 3.1 *Finding a map reference. The figure shows coordinates of a portion of 100 km square SN of the British National Grid. The point referred to lies 0.72 km east of the 87 km coordinate and 0.15 km north of the 46 km coordinate (eastings are always quoted before northings). The map reference of the point is therefore SN87724615*

junction to Henfron from the Llanwrtyd Wells main road to within 20 m: that is, 87.720 km east and 46.150 km north of the margins of square SN (Figure 3.1). These references are measured from the British 1:50 000 OS sheet No. 147. At larger scales, even more accurate references can be given.

Map (or grid) references are a convenient way of referring in a report or notebook to places on a map. They can designate areas, exposures, sample localities and geological observations. Geologists also usually find it convenient to plot their compass bearings from grid lines, yet many still adjust their compasses to offset the difference between *magnetic* and *true* north when they should adjust them for the difference between *magnetic* and *grid* north. In Britain, true north and grid north diverge by almost 5° in the Hebrides. Ensure that you do adjust your compasses against the proper variable (Section 3.5).

3.4 Position Finding on Maps

In the field a geologist should be able to position himself to better than 1 mm of his correct position on the map, whatever scale he is using; i.e. to within 10 m on the ground or better on a 1:10 000 map, and to within 25 m on a 1:25 000 sheet. On British 1:10 000 maps a point may often be fixed purely by inspection, or by pacing along a compass bearing from a field corner, building or stream junction printed on the map, or by resecting from known points. If not, temporary cairns (piles of stones) can be built in prominent places and their position fixed to provide additional points to resect from. Where maps of poorer quality must be used, a geologist may have to spend several days surveying in the positions of a network of cairns and other useful points to work off when mapping the geology. Now that GPS is no longer limited by coarse acquisition (CA) or selective availability (SA), position finding has been made very much simpler. But GPS may not always be available for a number of reasons: deep valleys, forest, you have run out of batteries, or perhaps you just cannot afford one. In any case, a geologist should know how to find out where he is without one.

3.4.1 Pacing

Every geologist should know his pace length. With practice he should be able to pace with an error of less than 3 m in 100 m even over moderately rough ground. This means that when using a 1:10 000 map he should be able to pace 300 m and still remain within the 1 mm allowable accuracy, and over half a kilometre if using a 1:25 000 map. However, pacing long distances is not to be recommended unless it is essential.

Establish pace length by taping out 200 m over the average type of ground found in the field (not along a nice flat tarmac road). Pace the distance twice in each direction counting *double* paces, for they are less likely to be miscounted when pacing long distances. Use a steady natural stride and on no account

Table 3.1 *Table for the rapid conversion of double paces to metres*

Double paces	Metres	Double paces	Metres
1	1.7	10	16.6
2	3.3	20	33.3
3	5.0	30	50.0
4	6.6	40	66.4
5	8.3	50	83.0
6	10.0	60	100.0
7	11.6	70	116.6
8	13.3	80	133.2
9	15.0	90	150.0
10	16.6	100	166.0

try to adjust your pace to a specific length, such as a yard or metre. Look straight ahead so that you do not unconsciously adjust your last few paces to get the same result each time. Every measurement should be within two double paces of the average of the four.

Prepare a table of paces and photocopy it (Table 3.1). Tape one copy into the back of your notebook and one in your map case. When using this table, remember that you shorten your pace when going both up and downhill, so you must make allowances to avoid overestimating; this is a matter of practice. If very long distances do have to be paced, pass a pebble from one hand to another, or from pocket to pocket, at the end of every 100 paces to save losing count.

A pedometer is dubiously useful for measuring moderate-to-long distances but you must still establish your pace length to set it. Its a waste of time for short distances.

3.4.2 Location by pacing and compass

The simplest way to locate yourself on a map, if mere inspection is insufficient, is to stand on the unknown point and measure the compass bearing to any nearby feature printed on the map, such as a house, field corner or road junction. Then, pace the distance, providing it lies within the limits of accuracy for the scale of map you are using; plot the back-bearing from the feature; convert the paced distance to metres and measure it off along the back-bearing with a scale.

3.4.3 Offsets

Offsetting is a simple method of plotting detail on a map. It is particularly useful where a large number of points are to be plotted in one small area.

Take a compass bearing from a known position to any convenient point in the general direction of the exposures you wish to locate on your map, for instance a tree. Pace along this line until you are opposite the first exposure to be examined. Drop your rucksack and then pace to the exposure at right angles to your main bearing line: this line is an offset. Plot the exposure and return to your rucksack and resume pacing towards the tree until opposite the next exposure. Carry on until you have completed plotting all the exposures (Figure 3.2). This method is comparatively fast, for once the direction of the traverse (or ‘chain line’ in surveyor’s parlance) has been determined, there is no real need to use your compass again; providing the offsets are short, you should be able to estimate the right angle of the offset from the chain line for short lengths, but check with a compass for longer offsets.

A variation of this method can be used on maps which show fences and walls. Use the fence as your chain line. Pace along it from a field corner and take your offsets from it. If the fence is long, take an occasional compass bearing to a distant point and plot the back bearing. It should intersect the wall where you are standing. Students seldom make as much use of walls and fences as they should, although they are printed on many maps; certainly they are on British 1:10 000 maps. Check your GPS instrument against map features, too.

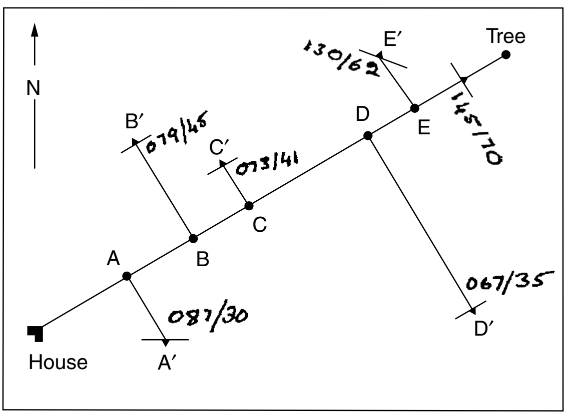


Figure 3.2 *Locating a point by offsets. A traverse (bearing 62°) is paced from the house, using the tree as an aiming point, until you reach point A, directly opposite an exposure at A′. Mark A with your rucksack and then pace the offset A–A′ at right angles to the traverse line. Plot the position of A′; make your observations of the exposure at A′; and return to your rucksack. Resume pacing and repeat the process for points B′, C′, etc*

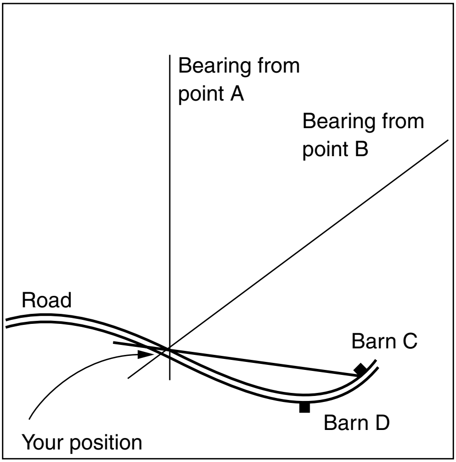


Figure 3.3 *Locating yourself on a road or similar longitudinal feature. Sight points which give good intersections with the road: a bearing to barn D, for instance, is not satisfactory*

3.4.4 Compass intersections

Your position on any lengthy feature shown on a map, such as a road, footpath, fence, river or stream can be found by taking a compass bearing on any point which can be identified on the map. Plot the back-bearing from this point to intersect the road, river, etc. and that is your position. Where possible, check with a second bearing from another point. Choose your points so that the back-bearings cut the fence or other linear feature at an angle of between 60° or 90° for the best results (Figure 3.3).

3.4.5 Compass resection

Compass resection is used where the ground is too rough, too steep, too boggy or the distances too long to pace. Compass bearings are taken from the unknown point to three easily recognisable features on the map, chosen so that back-bearings from them will intersect one another at angles between 60° and 90° wherever possible. Ideal intersections are, unfortunately, seldom possible, but every attempt should be made to approximate to them (Figure 3.4). Features on which bearings may be taken include field corners, farm houses, sheep pens, path or stream intersections, 'trig' points, or even a cairn that you yourself have erected on a prominent point for this very purpose.

All too frequently bearings do not intersect at a point but form a *triangle of error*. If the triangle is less than 1 mm across, take its centre as the correct

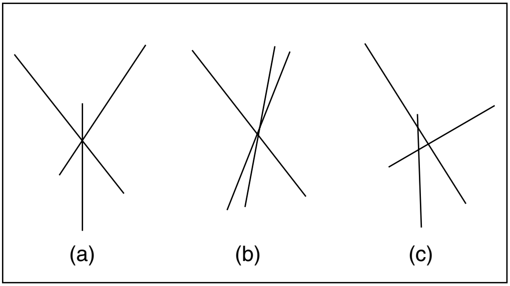


Figure 3.4 *Intersection of bearings: (a) relatively good; (b) poor; (c) shows a triangle of error*

position. If larger, check your bearings and your plotting. If there is still a triangle, sight a fourth point, if you can find one. If the error persists, it may be that you have set the wrong correction for magnetic declination on your compass (Section 3.5); or you may be standing on a magnetite-bearing rock, such as serpentinite, or too close to an iron gate or an electricity pylon; or you may have read your compass wearing a magnetic anti-rheumatism bracelet, or with your hammer dangling from a thong around your wrist – yes, it has been seen to be done! At the worst, perhaps your compass is just not up to the job.

When plotting, do not draw bearing lines all the way from the distant sighted point, but just long enough to intersect your supposed position; do not scribe the lines, just draw them lightly; and when your point has been established, erase them.

3.4.6 Compass and hand-level intersections

Where there is a lack of points from which compass bearings can be taken, the region hilly, and the map well-contoured, a hand-level can be useful. Such devices are built into the Brunton and Meridian geologist's compasses, while the Abney level is specifically designed as an accurate hand-level. The Suunto clinometer can also be used as a hand-level. To find your position set the level at 0°, i.e. horizontal. Then scan the topography to find a hill-top, saddle or ridge you can clearly identify which is at your own level; provided this feature is less than 1 km away and within $\frac{1}{2}°$ of your own level, you should be able to determine your own elevation, i.e. what contour you are standing on, to better than 10 m (allow for your own eye-height). Establish your position by a back-bearing from any point which will give a good intersection with the contour you have determined you are standing on. Although not precise, this may be all you can do in some places (Figure 3.5), notably on steep hillsides where your view is restricted.

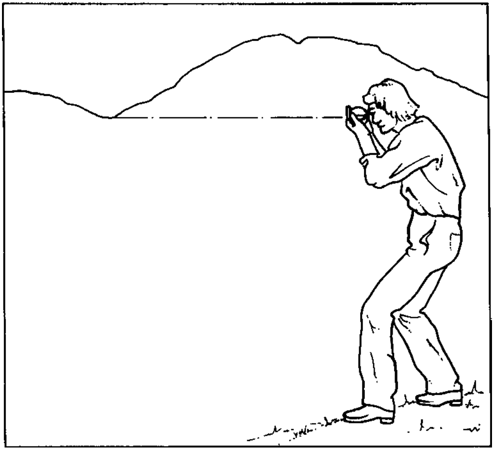


Figure 3.5 *Levelling-in a contour by hand-level. Set the level to zero and then search for a feature within $\frac{1}{2}°$ of your level line*

3.4.7 Compass and altimeter intersections

An altimeter is an aneroid barometer equipped with an additional adjustable scale graduated in metres above sea level. If set to read the correct altitude of your starting point, and providing the barometric pressure remains constant, the altimeter should show the true elevation wherever you go that day. Unfortunately, barometric pressure is not constant. It has a regular variation throughout the day (the diurnal variation) and superimposed on that are more erratic variations caused by changeable weather.

Use an altimeter in a similar way to a hand-level, that is, establish the contour you are standing on from the barometer so that a simple compass intersection will then determine your position on that contour. The main problem is the diurnal variation of barometric pressure; this can be controlled in several ways. In very stable conditions spend a day in camp recording pressure changes on a graph; this graph can then be used in the field to correct your readings against time of day. Check your altimeter every time you occupy a point of known elevation. If altitude readings are only occasionally needed, read your altimeter when you reach a point you cannot locate by other methods, then find the difference in altitude by returning to a point on a known contour. Better still, go back to a known elevation, return to the unknown, then continue to another known height. You can then correct for any pressure changes between readings.

3.4.8 Siting additional survey points

Temporary survey points can be erected to aid position finding, especially when working in a valley where it is difficult to see hilltop features. Build cairns of stones on the higher slopes and survey them in by compass resection from other points. If wood is cheap, tall flagged poles can be erected in place of cairns; they can be seen from considerable distances away.

3.4.9 Global positioning system (GPS)

GPS is a great boon to geological mapping and the cost has plummeted since the last edition of this book. Not only are the instruments useful in establishing the position of your geological observations, they can also point you along your way when lost. Some will give audible signals when you arrive at a point you are looking for. Most will give the alternatives of geographical or metric grid coordinates (see Section 2.11).

3.5 Magnetic Declination

At most places on the surface of the earth there is a difference between the direction of true north and the north shown by a magnetic compass. This is called *magnetic declination* or *magnetic variation* and it changes by a small amount every year. Magnetic declination and its annual change vary from place to place, and these values, together with the difference between true and grid north (which is of course constant), are shown as part of marginal information on map sheets. In Britain, the change is about 1° every 15 years.

Magnetic declination must be allowed for when plotting compass bearings. As in most instances bearings will be plotted on a map from a metric grid coordinate, the correction used must be taken as the difference between magnetic and grid north, not between magnetic and true north (see Section 3.3.2). On many needle compasses, such as the Silva, Suunto and Brunton, this correction can be compensated for by rotating the graduated ring by means of a small screw. The compass will from then on give its readings in relation to grid north. Card compasses cannot be compensated: they can show only magnetic bearings and so every reading must be corrected. With practice, you do this in your head without thinking about it.

Many people prefer to establish their own correction by taking a bearing between two points on the map, or along a long straight feature shown on the map, such as a moorland fence or wall, and then compare it with the bearing measured on the map itself. This satisfies the doubter that he is not subtracting a correction that should be added, or *vice versa*.

3.6 Planetable Mapping

Planetabling is a method of constructing a topographic map for which little training is needed. It is excellent for making a geological map when no topographic base is available.

In the first instance the map, both topographic and geological, is made in the field at one and the same time. The contours are drawn with the ground in front of you, so you can show all those subtle changes in topography which often have a geological significance. Surveyors seldom show these subtle differences on their tacheometric (stadia) surveys, for they plot the contours from field notebook readings after they return to their office. Secondly, the plan position and elevation of every geological observation is accurate because it has been surveyed in. There is considerable satisfaction in planetabling too, for your map grows before your eyes as geological and topographic detail is added. Planetabling makes you wholly independent of base maps of dubious quality or of the assistance of topographic surveyors, who are not always available. It is described in many books on field geology, such as Reedman (2002) or any textbook on surveying. For those with survey experience, a short summary of how to adapt planetabling to geological mapping is given in Appendix III.

3.7 Aerial Photographs

The value of aerial photographs to the geologist cannot be overestimated. In reconnaissance, large tracts can be mapped quickly with only a minimum amount of work done on the ground. In more detailed investigations, examination of stereopairs of photographs under a stereoscope can reveal many structures which are difficult to recognise in the field, and some which cannot be seen at all at ground level. Photographs are as much a tool to the field geologist as his hammer and handlens. Even good base maps do not obviate the need for photographs; they should be used together.

Aerial photographs can also be used where no base maps are available by building up an 'uncontrolled mosaic' as a substitute map on which geology can be plotted. It is not an accurate map, but it will serve its purpose for want of anything better. Information can also be plotted directly on to photographs in the field and then transferred to a base map later. This is particularly useful when the topographic detail on your map is so poor that finding your position in the field is difficult and time-consuming.

Excellent topographic maps can be made from photographs by a number of different techniques and most modern topographic maps are made in that way. However, such methods are beyond our present scope.

Figure 3.6 illustrates a typical aerial photograph. As each exposure is made, a photograph of a clock, altimeter and a circular level bubble is also recorded in the *title strip* at the bottom of the photograph to show time, altitude and tilt. The strip also shows the contract number, sortie number, and in some systems either the nominal scale of the photo or the focal length of the camera lens. On the face of each photograph, the exposure is numbered, usually in the bottom right-hand corner. *Fiducial marks* are printed at

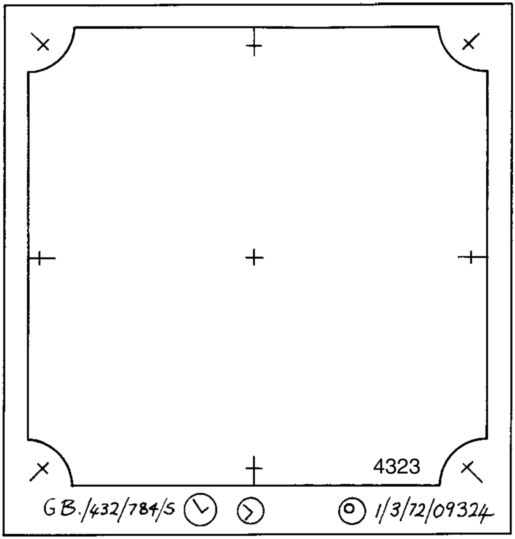


Figure 3.6 *Layout of a typical aerial photograph, showing the fiducial marks at the corners or midpoints of the sides (occasionally both); the principal point; and the photograph number in the bottom right-hand corner of the photo. Along the base, is the title strip which shows a circular bubble level, an altimeter, and a clock, all photographed at the time of exposure. Written in the title strip are the location and the contract number, etc*

either the corners or the middle of each side so that the *principal point* (see Section 3.7.1) can be marked on it; some cameras print the principal point automatically. Different makes of camera have different information on the title strip, or arrange it differently.

Aerial photographs are taken sequentially by an aircraft flying along a series of parallel flight paths which may be straight lines or arcs of a circle, depending on the method used to control direction. They are taken with a frequency such that each photograph on a flight line overlaps the next by 60%, and each line of photographs overlaps the next by 30%. This apparently wasteful overlap is so that adjacent photographs on a line can be viewed under a stereoscope to produce a stereographic three-dimensional image, and also to ensure that there are enough common points on photographs so that they can be linked together for topographic map making (see Figure 3.7).

Because the scale of an aerial photograph is a function of the focal length of the camera lens divided by the distance to the ground, the true scale of

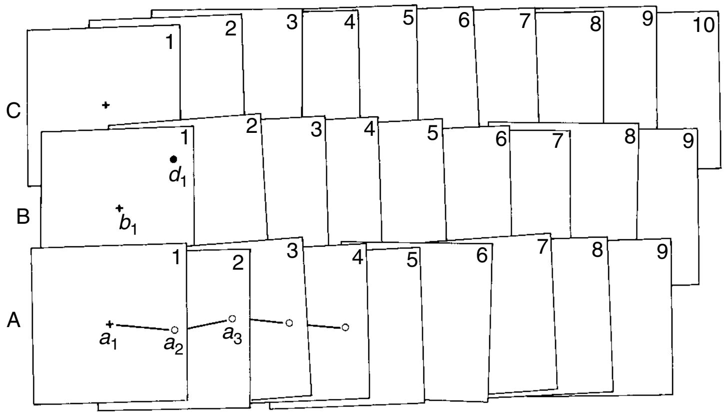


Figure 3.7 *A block of three runs of aerial photographs, A, B and C. Photographs in each run overlap each other by 60% so that the position on the ground of the principal point* (a_1) *of photograph A-1 can also be found on photograph A-2. Similarly the pp on photo A-2 is found on both photos A-1 and A-3. Adjacent runs overlap by about 30% so that a feature* d_1 *seen on photo B-1, can not only be found on photo B-2 and B-3, but also on photos C-1, C-2 and C-3 of the adjacent run*

a photograph varies from place to place; a hilltop is closer to the camera than a valley bottom, and the centre of the photograph closer than a corner. These differences cause distortions (Figures 3.8 and 3.9, and section 3.7.3). Distortion can be electronically removed to produce planimetrically correct orthoprints. These are normally in colour and are virtual maps in themselves. They are also expensive. Even ordinary black and white prints are by no means cheap although the more you order the cheaper the price per print becomes.

3.7.1 Preparation

Before an aerial photograph can be used it must be *base lined*. First mark the *principal point* (*pp*) on each consecutive photograph by means of the fiducial marks if it is not already been printed on them; this is the point where the optical axis of the lens meets the photograph (see Figure 3.6). Now, locate the exact position of the *pp* from photo No. 1 (a_1 on Figure 3.7) on the overlapping part of photo No.2 of the same run; do this by inspection using a handlens. Prick the point with a needle and draw a small circle around it. This *pp* transferred from the previous photograph is called a *conjugate point (cj)*. Now transfer the *pp* from Photo 2 to Photo 1 and this process

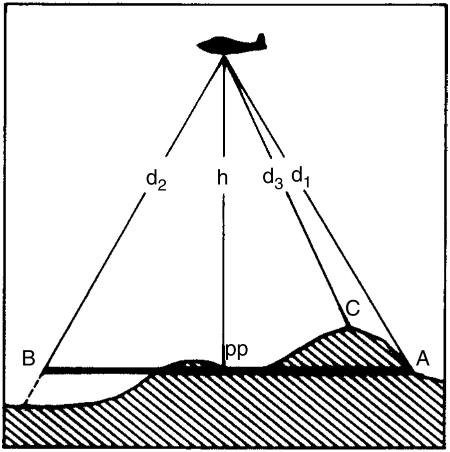


Figure 3.8 *Scale variations over an aerial photograph taken in undulating country. The line A–B shows the notional plane of a photograph; pp is its principal point. The nominal scale of the photograph is f/h, where f is the focal length of the camera lens and h is the height above ground at the point pp, i.e. the distance from the lens. At A the distance of the ground from the lens* d_1 *is greater than h, therefore the scale of the photograph there is smaller than the scale at its centre pp. At B the fall of the ground means that* d_2 *is even greater still than* d_1*, and consequently the scale is still smaller. Conversely, the distance* d_3 *from the top of hill C is less than h and the scale is thus greater*

is done for all photos in the run and lines are drawn between all *pps* and *cjs*: these are the *base lines*. The base line indicates the track of the aircraft between the taking of the consecutive photos. You will see that the track is seldom straight owing to drifting and yawing. However, the purpose of the base line for our purposes is to make it easier to align photographs under the stereoscope in the optimum position to give a three-dimensional image of the topography without eye-strain. Although your eyes will accommodate to produce a 3D image from even poorly aligned photographs, you will end the day with a headache.

3.7.2 Plotting on aerial photographs

The surface of a photograph is not easy to write on in the field, and if you do write on photographs from a film library, you will not be popular. The best method of recording information is on an overlay of ‘Permatrace’, ‘Mylar’ or similar transparent tracing material. Cut a piece for an overlay to the

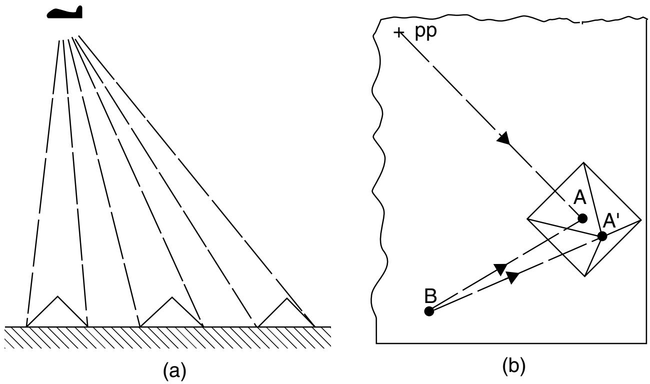


Figure 3.9 *(a) This shows how the aerial camera sees three similar pyramidal hills at increasing distances from it. The hill immediately below the camera (i.e. at the principal point of the resulting photo) shows all four sides equally. Those away from the pp show less and less of the hillsides which face the edge of the photo. The photo makes the outer hills appear to lean away from the pp. (b) This shows a portion of an aerial photograph with a pyramidal hill. Owing to the distortion seen in (a), the apex of the hill A′ is not vertically above the centre of its true base at A on the printed photo. Thus, although a compass bearing plotted from the pp to A′ is correct because it also passes through A, a bearing from any other point on the photo to A′, e.g. from point B, will not be correct because it does not also pass through A. The greater the difference in elevation between A′ and B, the greater the error will be*

same size as the complete photograph and tape it along *one* edge only by a hinge of low tack *drafting* tape so that it can be lifted whenever you need to examine the photo more clearly. Do not use transparent office tape, as it will damage the photo when it is removed. Mark the principal point and conjugate points on the overlay so that it can be repositioned on the photograph if it is necessary to do so at a later date.

Locating your position on a photograph is usually easy; it can be done either by inspection of a single photograph by identifying a nearby feature, or if in difficulty by using an adjacent photograph as a *stereopair* and viewing with a pocket stereoscope to give a 3D image. Note, however, that the 3-D image gives a very considerable vertical exaggeration to the topography. Small hills look like high hills, high hills look like saw-tooth mountains, and this exaggeration must be taken into account when locating yourself. What you cannot do on a photograph is locate yourself by compass resection (see below and Figure 3.9) unless you have orthoprints.

3.7.3 North points on photographs

Structural information is plotted on a photograph in the same way as onto a base map. However, photographs are seldom taken along north-south flight lines and even when they are, aircraft yaw sufficiently that the margin of any photo cannot be taken as a north–south line. Some photographs may have a compass printed in the title strip, but it is too small to give anything but a very general direction. Consequently a north point must be established for every individual photograph on each flight line. This can only be done on the ground. Position yourself on an identifiable point as close to the *pp* of the photograph as possible, and take a compass bearing to some distant feature on a line as nearly radial from the *pp* as possible. This is because, owing to linear (i.e. scale) distortions, the only true bearings between points on a photograph are those which originate from the principal point (Figure 3.9). This does not affect the plotting of strikes from single points on the photograph. Note all dip and strike information in your notebook so that it can be replotted on to your base map later. Although you may have established the north direction on the first photograph of a run and therefore the direction of the flight line *pp* to *cj*, and this must be the same as on the second photo, it is unwise to carry this direction to the end of a run without checking it whenever possible.

3.7.4 Transferring geology from photograph to base map

Geology plotted onto photographs or overlays in the field must be transferred to your base map later. So first you must identify the *pp* of photographs on your base maps. As the base map will most probably have been compiled from the same aerial photographs you are using, the *pp* of every photograph may already be printed on the map as a faint cross, and every fifth *pp* will show the photo number. The ends of each flight line will also give the sortie number. If the map was not made from the photographs which you are using, and this can happen, then you must locate the *pps* on the base map yourself.

Unfortunately, you cannot then just trace information directly from photograph to base map because they will never be the same scale. However, *camera lucidas* are available which enable you to view the map with the image of the photograph superimposed on it and optically adjusted to the same scale. Information can sometimes be transferred directly from photographs to the base map by inspection, depending on how detailed the map is. Dips and strikes can then be replotted from your recorded compass bearings. Often however, because of the lack of topographic map detail, it may not be possible to locate an observation point on the map by inspection. In this case draw a radial line from the principal point on the photograph to the observation; note the angle it makes with the base line on the photograph; then plot the same angle from the baseline you have already plotted on the map. The observation point lies along this line and its exact position can be

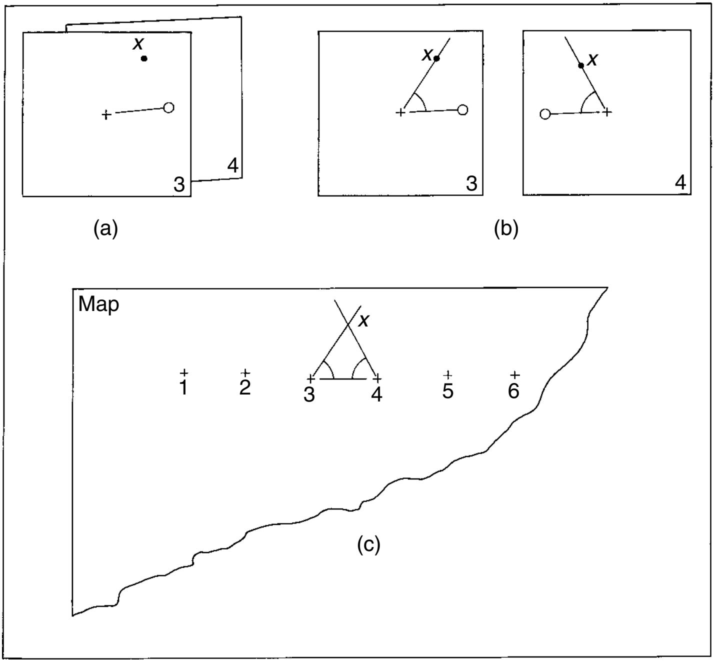


Figure 3.10 *To locate on a map the position of a point x seen on an aerial photograph: (a) locate the position of x seen on photo 3 on the overlapping photo No. 4; (b) draw a radial line from the pp of each photo through the point x and measure the angles made with the base lines; (c) join pps 3 and 4 on your base map, plot the angles measured on your photos and x will be at their intersection*

found by plotting its distance from the *pp* in proportion to the difference between the photograph and the map scales. This will not work in mountainous areas. In that event, locate the same observation point on the adjacent photograph and again measure the radial angle from the base line; plot the angles from the two ends of the same base line on your map, and the required point is at the intersection of the two radial lines (Figure 3.10).

3.7.5 Digital elevation data

The value of aerial photographs lies in the link between the layout of rock formations on a geological map and the geomorphology. Interpretation of the geology is assisted by viewing the photographs stereoscopically which gives an image of the terrain with a very much exaggerated vertical dimension, as has already been mentioned. An alternative method of visualising the terrain comes from the computer generated three-dimensional representation of the ground surface. These are generated from digital elevation models (DEMs), which are digital data sets of the elevations of the ground surface for regularly spaced ground positions.

DEMs composed of elevation data originally derived from land surveying, aerial photography or satellite images, or derived from contours on topographic maps, can be obtained for the area of interest. For example, elevation data from the UK Ordnance Survey can be downloaded by the Digimap service.

Computer software, e.g. *Surfer* (Golden Software), uses the digital elevation sets to produce a 3D representation of the topographic surface. These programs permit the viewing of the landscape from different angles, with different degrees of exaggeration of the relief. Slopes can be accentuated by shading. Such software permits an aerial photograph, or other remote image, to be draped over the 3D ground surface and thus bring out the link between the form of the landscape and the geology. The uses of DEMs for geological interpretation is explained in Gibson (2000), and Gibson and Power (2000).

3.7.6 Sources of aerial photographs

Aerial photography in Britain is contracted out to numerous private firms which are listed on the internet. Perhaps the first contact to make is via the Ordnance Survey Central Register of Aerial Photography, Romsey Road, Southampton (http://www.ordsvy.gov.uk), or Remote Sensing and Photogrammetry Society (http://www.rspsoc.org). You will need to define the area by grid references or geographic coordinates. Private contractors may also have photographs for sale, and are listed in *The Geologist's Directory* (2001). It may also be worthwhile to contact the British Geological Survey Enquiry Service (www.bgs.ac.uk). In the USA contact the Geological Survey for guidance or the EROS Data Centre, Sioux Falls, South Dakota. In other countries contact the organisations listed for maps, but again in a few countries aerial photographs come under the military and may be difficult to obtain. Again, attachment to a university or government department can ease the way.

3.7.7 Orthophotos

Orthophotos are orthorectified aerial photographs, that is they are planimetrically corrected by computer so that all parts of the topography have been reduced to their proper plan position. To all intents and purposes, they are maps.

3.8 Satellite Imagery

Satellite images (do not call them photographs) can be useful aids but are in general of too small a scale for anything but small-scale mapping although they may show gross regional features. They are generally either in colour or 'false-colour', that is where part of the non-visible spectrum (i.e. infrared) is shown, usually in red, to express certain features such as the condition of vegetation. The natural colours are then shifted in the spectrum so that anything in visible red appears as green, anything green as blue. Much of what is available in satellite images is from NASA (www.nasa.gov.satimages), but the French also produce images from their own SPOT (Satellite Probatoire pour l'Observation de la Terre). SPOT has the advantage that the system produces stereopairs. In general satellite imagery is expensive to produce and therefore expensive to buy. If you are interested in this aspect of mapping see Drury (2001), Gibson (2000) and Gibson and Power (2000). Treagus (1996) has commented that a SPOT image can be enlarged to 1:10 000 with at least as good resolution as an aerial photograph.

4

METHODS OF GEOLOGICAL MAPPING

Geological mapping is the process of making observations of geology in the field and recording them so that one of the several different types of geological map described in Chapter 3 can be produced. The information recorded must be factual, based on objective examination of the rocks and exposures, and made with an open mind: geology is too unpredictable to be approached with preconceived ideas. Obviously the thoroughness with which a region can be studied depends upon the type of mapping on which you are engaged. A reconnaissance map is based on fewer observations than, say, a regional map, but those observations must be just as thorough. Whatever the type of mapping, whatever your prior knowledge of an area, map with equal care and objectivity.

The author (JWB), when employed overseas, found that newly graduated geologists from Britain, trained on the excellent large-scale Ordnance Survey maps, often found themselves in a quandary when faced with the small-scale, poorly detailed maps they were sometimes expected to work with; sometimes there was no base map at all. This is why a selection of methods are described here, to cover most of the situations you may eventually find yourself in. At times you may even need to mix methods to suit conditions in different parts of an area, or even devise new methods of your own.

4.1 Traversing

Traversing is basically a method of controlling your progress across country, so that you do not have to relocate yourself from scratch every time you make an observation at an outcrop.

It is also a method of covering the ground in the detail required by your employer. A traverse is made by walking a more or less predetermined route from one point on the map to another, plotting the geology on the way. Traverses are an excellent way of controlling the density of your observations. They should be planned to cross the general geological grain of the part of the region you are working in, and in reconnaissance work, which is its main use, a number of roughly parallel traverses may be walked across country at widely spaced intervals. Contacts and other geological features are extrapolated between them. This leads to few complications in regions where

Basic Geological Mapping, Fourth Edition. John W. Barnes with Richard J. Lisle
 ISBN: 0-470-84986-X

the rocks are only moderately folded and dip faults are few, but reliability decreases as structures become more complex. Traversing can also be used to map areas in detail where rocks are well exposed, especially those where there is almost total exposure. In such cases, traverses are closely spaced. GPS is an obvious help in traversing.

Even with more detailed mapping, in open country where visibility is good and the base map adequate, traverse ‘legs’ with offsets may be walked from map feature to map feature, as a convenient way of locating exposures, as described in Section 3.4.3. If you wish to change direction on a traverse, mark your *turning point* on the ground, with something you can relocate later depending on where you are. Obviously you will not be popular if you build cairns in a farmer’s field; in such cases find some feature already there. Otherwise a flat rock marked with a felt-tipped pen may be adequate, or just a few stones. Plot geology on short traverses by pacing and resection.

Sometimes terrain makes traversing unavoidable and according to the late R.G. Seal (personal communication), when mapping in the dense forests of Guyana, parallel traverse lines were cut on compass bearings, with the distance measured by cycle wheel/cyclometer and elevations for contouring measured by altimeter. At the end of a traverse, a new line was cut at right angles for a distance determined by the scale of mapping needed, and a new parallel traverse cut on the reverse bearing with occasional cross-traverses to tie in with the previous line. This is one terrain where GPS would not have been much use, even if it had then been in existence, except as a check in any large clearing.

Plot geological observations along a traverse leg between two known points as it is walked. When working in the Middle East with the late Edgar Bailey of the USGS, Bailey distinguished geological fact (i.e. exposed rock) from inferred geology (i.e unexposed rock) by overlaying the pencil drawn traverse line by a solid line of the appropriate coloured pencil for exposed rock and a dashed traverse line where the rock could only be inferred. For more detailed work, use the methods described in below.

4.1.1 Controlling traverses

Unless traverses are strictly controlled, survey errors accumulate to an unacceptable level. If a traverse made on compass bearings consists of a number of legs, either start and finish on known points if possible; otherwise close the traverse by returning to the starting point. Invariably, when you plot this ‘closed’ traverse you will find that the last bearing does not fall exactly where it should do, owing to an accumulation of minor errors of direction and distance measurement. This *closure error* must be corrected by distributing it over the whole traverse, not by fudging the last leg. The proper method is shown in Appendix II.

Because a complex compass traverse will always need correcting, do not record geology directly on to the map in the field. Plot the traverse legs from turning point to turning point lightly on your map, but record the details in your notebook as a sketch on an exaggerated scale. If your notebook is a surveyor's 'chain book,' with two parallel red lines down the centre of the page, then borrow the surveyor's technique: use this column as if it were your traverse line and record the distance of each observation from the turning point along it and show the geology to either side of it (Figure 4.1). I prefer this to Ed Bailey's method, although in his case, in a desert, there was nothing to close on; but wherever possible correct traverses in the field.

4.1.2 Cross-section traverses

Whatever mapping method you do use, it can be useful where a succession is doubtful or structurally complex to traverse across the geological grain, plotting a cross-section as you go. Draw it in your notebook or on squared paper (kept in your map case for that purpose), but also show the traverse line on your field map. The advantages of drawing sections in the field are obvious: problems come to light immediately and can be promptly investigated.

4.1.3 Stream and ridge traverses

Streams and ridges are features which are usually identifiable on even poor quality maps. Streams often give excellent semi-continuous exposures and in some mountain areas may be so well spaced that a major part of the geology of that area can be mapped by traversing them, especially where slopes are partly covered by colluvium. Position finding on streams is often relatively easy from the shape and direction of bends, and the position of islands, water falls and stream junctions, or sometimes by resecting on distant points. In dense mountain rainforest, streams and rivers may be the only places where you can locate yourself, providing of course, the base map itself is accurate, or you are lucky enough to have photographs. Remember GPS is no good in forests.

Ridges, and the spurs which lead off them, may make excellent traverse locations. They can usually be identified easily on a map or aerial photograph. Even in dense forest, ridges may be relatively open, giving opportunity to take bearings to distant points. Exposures are usually good. Most ridges are there because they are the more erosion-resistant rock, and in sedimentary rocks tend to follow the strike. Traverses down spurs provide information on the succession although the streams between the spurs may be even better.

4.1.4 Road traverses

A rapid reconnaissance of an unmapped area can often be made along tracks and roads and by following paths between them. Roads in mountainous

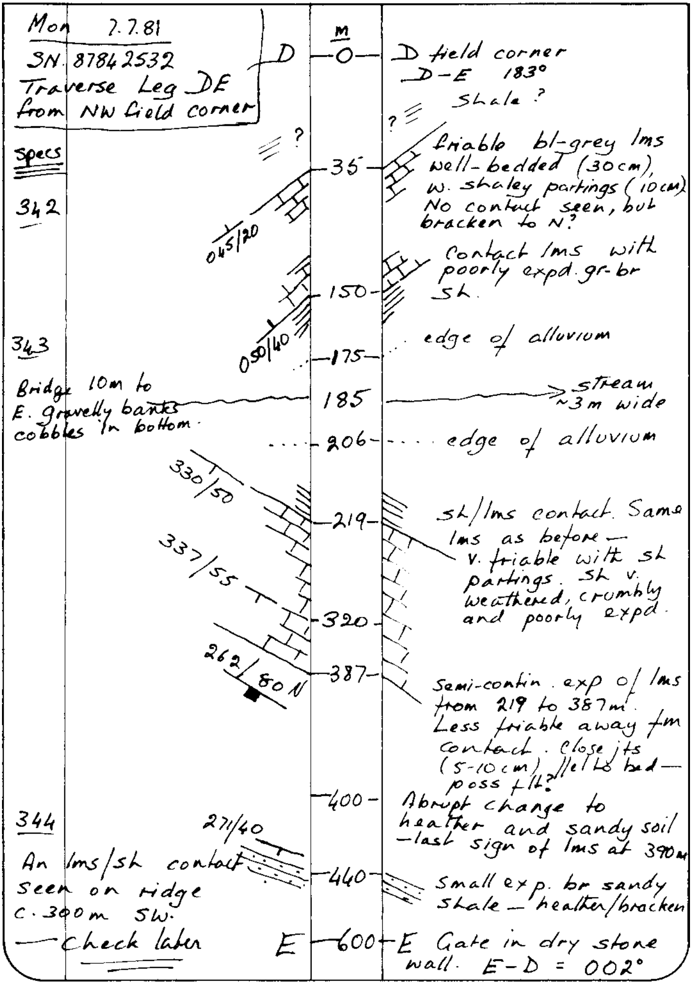


Figure 4.1 *Recording a traverse in a surveyor's chain book. The column down the centre of the page (often printed in red) represents the traverse or 'chain line'. It has no actual width on the ground, it is used merely to record the distance from the start of the traverse leg*

regions, in particular, usually exhibit excellent and sometimes almost continuous exposures in cuttings. In some places roads zigzag down mountainsides to repeat exposures of several different stratigraphic levels. A rapid traverse of all roads is an excellent way of introducing yourself to any new area you intend to map in detail.

4.2 Following Contacts

A primary object of mapping geology is to trace contacts between different rock formations, groups and types, and to show on a map where they occur. One way of doing this is to follow a contact on the ground as far as it is possible to do so. In some regions and with some types of geology this is easy; elsewhere it is often impossible because contacts are not continuously exposed. The continuation of contacts beneath drift and other superficial deposits can often be located by plotting structure (or stratum) contours (Section 4.4.4). Sometimes contacts can be followed more easily and more accurately on aerial photographs, using even just a pocket stereoscope, than on the ground. The photographs show small changes in topography and in vegetation which cannot be detected on the ground but which indicate the position of the contact even when it is concealed by colluvium or drift. Once traced on the photographs, check the position of the contact in the field at its more accessible points.

Wherever rocks are seen in contact, show the boundary as a continuous line on the map and mark each side of the line with the coloured pencil appropriate to those rocks. Where contacts are inferred, or interpolated by geometric methods, show the boundary with a broken line. Where a contact is concealed, perhaps by scree or alluvium, but is certainly there, show it by a dotted line. However, when tracing a contact, do not forget the ground between it and the next contact, either up the succession or down it; sometimes contacts are close enough to be traced at one and the same time, sometimes they are not.

4.3 Exposure or Green Line Mapping

Mapping by exposures is the mainstay of much detailed mapping at scales of 1:10 000 and larger. The extent of each exposure, or group of exposures, is indicated on the field map by colouring them in with the appropriate coloured pencil for that rock type or formation. Some geologists go further and mark the limits of the exposure by drawing a line round it, later inked in green, hence green line mapping. Green fades rapidly in the tropics and a fine black dotted line can be substituted. Whether or not you draw a line round each exposure is a matter of choice, but if a map is to be used in the field over long periods marked only by coloured pencil, without exposure boundaries, you will find the colouring will become blurred as pencil shading fades or is worn off by handling. If the boundaries are inked, the colouring can be touched up when needed; if not, exposure limits become vague and accurate recolouring difficult and the exposures tend to become larger with each recolouring!

Marking the boundaries of very large exposures helps objectivity in the field: outline the exposure, then map within it. If complex, or if there are specifically interesting features to be seen, a large-scale sketch map can be drawn in your notebook. Do not be too fastidious in plotting the outline of an exposure unless you are mapping at a very large scale (Figures 4.5–4.9); however, unless some care is taken the natural optimism of human nature nearly always results in an exposure being shown larger than it really is. Also remember that an exposure 10 m square is a mere 1 mm square on your 1:10 000 map; one the size of a football pitch is only 10 mm × 5 mm, or so (Table 4.1). Show groups of exposures which are obviously part of the same outcrop covered thinly by soil as a single exposure. Mark small isolated exposures by a dot with a note or symbol to indicate its nature beside it.

The reason for exposure mapping should be clear. It shows the factual evidence on which your interpretation of the geology will be based; it shows what you have seen, not what you infer. A properly prepared field map should leave no doubt of the quality of the evidence on which it is based. From the foregoing it will be apparent that there is no single mapping method to cover every eventuality. Sometimes you may have to use several different methods in different parts of a large mapping area. Plate 1 shows the general principles of several mapping methods (see inside front cover).

Table 4.1 *The equivalents of 1 mm on a map, at different scales*

Scale	Metres
1:500	$\frac{1}{2}$ m
1:1000	1 m
1:5000	5 m
1:10 000	10 m
1:25 000	25 m
1:50 000	50 m
1:100 000	100 m
1:250 000	250 m
1:500 000	500 m
1:1 000 000	1 km

4.3.1 Descriptive map symbols

There are some areas where the geology can be mapped only by identifying every exposure in turn; for instance, in Precambrian metamorphic terrains slates pass into phyllites, then to schists, migmatites and gneisses of several different kinds. Many boundaries are gradational and contacts have to be decided by textural and mineralogical characteristics. In these conditions, the usual colour coding used to distinguish formations on your map is inadequate, although it may serve to classify your rocks into broad groups. You must devise a letter code so that you can give a shorthand description of every exposure on your map to show how metamorphic lithologies change and so decide your geological boundaries. You may need to distinguish, say *microcline-porphyroblast coarse grained quartz-albite-microcline-muscovite-biotite gneiss* from other, not quite similar, gneisses. This could be condensed to *M c/gr q-ab-m-mu/bi gn*, where *M* stands for microcline porphyroblast and *m* for microcline in the groundmass, c/gr for coarse grain, etc. Devise your own code and note it in your notebook, so any others working after you can understand your map. Such codes give the *field names*. Try to keep them more concise than the extreme example quoted here although that was a designation once used by the author when mapping very variable granite gneisses in East African basement. Whatever code you devise, make it flexible, for you will invariably find that you have covered only a proportion of the possibilities you may eventually meet in the field.

With sedimentary rocks the situation is simpler. You either map recognised formations, which will already have a designated formation letter, or in some areas you must decide what is a recognisable formation and name it yourself (see Section 6.2).

4.3.2 Form line maps

The subdivision of rocks of an area into mappable units (or formations) may be hampered in some areas by the lack of variety of rock types. Some metamorphic rocks may show outcrop-scale size variations in lithology, but may appear monotonous in composition on a larger scale. If formation boundaries cannot be traced across the area, an understanding of the geological structure has to be based on strike and dip readings of compositional layering taken at numerous outcrops. This layering may represent bedding, but could be of tectono-metamorphic origin.

A form line map is an interpretation of the form of the geological structure based on the assumptions of the measured strikes, and dips arise from the sectioning of continuous geological surfaces. Although these maps are somewhat subjective and are drawn freehand, they are useful for the recognition of major changes of strike caused by folding. Figure 4.2 shows an example of a form line map drawn from measured attitudes of foliation. An attempt has been made to make the spacing of the form lines smaller in areas of steeper dip. Such maps are discussed by Marshak and Mitra (1988).

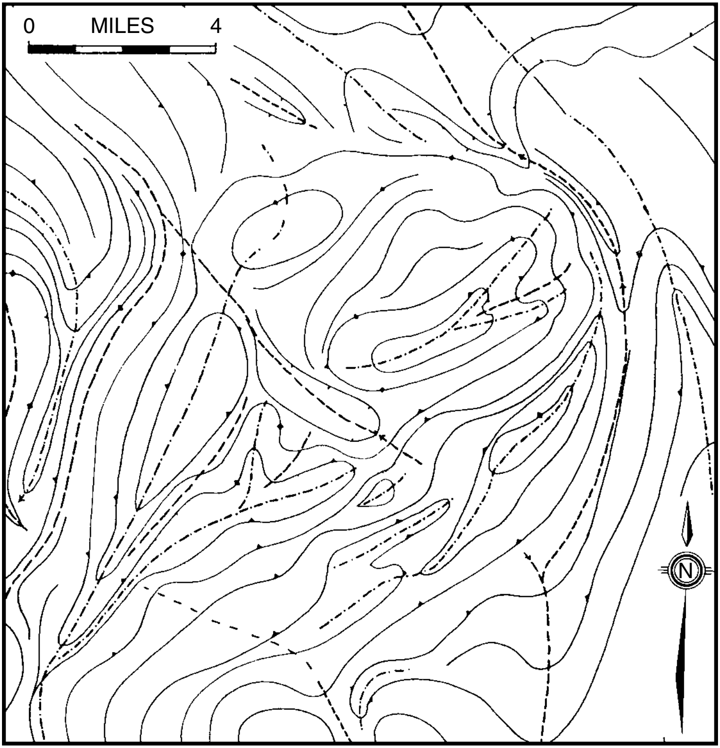


Figure 4.2 *A form line map in Precambrian gneisses in south-west Uganda (Barnes 1956)*

4.4 Mapping in Poorly Exposed Regions

If an area is poorly exposed, or the rocks are hidden by vegetation, climb to convenient high ground and mark on your map the positions of all the exposures you can see (this is where binoculars prove useful); then visit them. Of all rocks, mica schists probably form the poorest exposures but even they may show traces on footpaths where soil has been worn away by feet, or by rainwash channelled down them. Evidence of unexposed rocks may sometimes be found where trees have been uprooted by storms and in the spoil from holes dug for fence posts or wells, in road and railway cuttings, and from many other man-made, or even animal-made, excavations.

4.4.1 Indications of rocks from soils

Soils, providing they are not transported, reflect the rocks beneath, but to a much lesser extent than might be expected. Sandy soils are obviously derived from rocks containing quartz, and clayey soils from rocks whose constituents break down more completely. Dolerite (diabase) and other basic rocks tend to produce distinctive red-brown soils; more acidic igneous rocks form lighter-coloured soils in which mica may be visible, and often quartz. A soil depends not only on its parent rock, but also on climate and age. Differences tend to become blurred with time. When working in any area, poorly exposed or not, take notes wherever soils are seen to be associated with specific rocks so that they can be used as a guide when needed.

4.4.2 Vegetational guides

Plants are influenced by elements in the rocks beneath them where the soils are not too deep. As mapping guides they form three main groups: some thrive on limestones, some on acid rocks, others on serpentinous rocks. The list is long (Brooks 1983). Limestone flora include beech, juniper, dogwood and wild marjoram. Acid, lime-free, silica-rich soils show a number of easily recognised plants, including heather, gorse, broom, rhododendron, bracken, and rowan, spruce and hemlock. Serpentinous floras thrive on Ca, K and P deficient soils, rich in Fe, Mg, Cr and Ni, and the change at a contact is often sharp, with a sudden sparseness of vegetation. Unfortunately, serpentine-loving plant varieties tend to be regional and one must learn for oneself in any area. Some plant varieties are so specific that they may indicate metallic ores. There are numerous copper-indicator plants, whilst on the Colorado Plateau 80% of uranium deposits are associated with selenium-bearing poisonous vetch, the ‘locoweed’ of cowboy literature. That horsetails (*Equisetum*) indicate gold, however, is unfortunately a myth (Brooks 1983, Barnes 1990).

Vegetational guides vary with climate although some plants have wide tolerances; for instance, juniper even grows from grikey crevices on apparently soil-free arid karst limestone in Turkey, whilst the scent of marjoram fills the air at even 4000 m in the Iranian Alborze Mountains. Vegetational changes may often show more clearly on aerial photographs than on the ground.

4.4.3 Topography and geomorphology

Geomorphology is the science of landscapes (Stewart 2000) and a geologist needs to develop an eye for not only the scenery and major landforms, but also for the smaller scale features of the topography; taken as a whole, these all contribute to the recent geological and climatic history of an area. A typical example to be seen in Britain is the U-shaped valleys resulting from glaciation. This should prompt a search for smaller scale features on valley floors, such as *roches moutonées* and gouge marks on rock pavements, which establish the direction of ice movement. There may be other indications of glaciation, such as drumlins, boulder clay (till), remnants of moraines, and fluvio-glacial deposits (Young 2000).

Recent volcanic activity may be obvious from cratering, hot springs, ash deposits (*tephra*), and even lava flows, but even when the volcanic centre is outside your own area any material spread from it, such as ash, makes it also a part of your own local history.

Drainage patterns also need considering: how is drainage reflected by the underlying rocks? Is there a single linear control or more than one? Do directions suggest control by intersecting faults, joints, or both? Are there swallow holes (*dolines*), or grikey *karst* surfaces? Or is the drainage dendritic suggesting soft sediments? Do springs rise at specific geological contacts? There may be evidence that uplift or tilting has resulted in reversed or rejuvenated drainage, or in silted valleys and swamps. Where valleys are terraced, plot the terrace edges on your map if its scale will allow it (Figure 4.3). In some tropical countries, there may be raised laterite surfaces, the remnants of former peneplains.

4.4.4 Structure (stratum) contours

Formation boundaries (contacts) must be drawn on the field map even across unexposed ground. Where there is an absence of exposures and there is no

Figure 4.3 *Multiple terraces in fluvio-glacial gravels; Canterbury, New Zealand*

indirect evidence of the trend of boundaries as described above, make use of the structural measurements taken at the nearest exposures. A prediction of the course of a boundary across an unexposed tract of ground can be based on the assumption that the strike and dip of the formation remains the same as that measured at the nearest exposure. Figure 4.4(a) shows an exposure of a contact at which strike and dip have been measured. From any point P on the mapped contact, a structure contour is drawn for the contact. This contour runs parallel to the measured strike and has an elevation equal to the ground height at P. Parallel contours can then be drawn (Figure 4.4(b)) with a spacing given by

$$\text{spacing} = \frac{\text{contour interval}}{\tan(\text{angle of dip})}$$

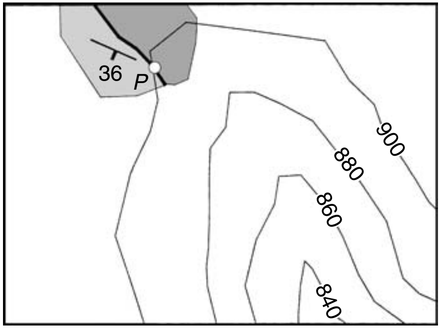
Predicted positions of outcrop are given by intersections of structure contours and topographic contours of the same elevation (Figure 4.4(c))

4.5 Superficial Deposits

Except for valley alluvium, superficial deposits, or drift, are commonly looked upon as a nuisance which hides the more interesting solid geology. Unconsolidated superficial deposits are the debris resulting from rock weathering during the formation of the landscape. They include scree (*talus*), which forms unstable slopes of mainly coarse unsorted fragments of broken rock. They also cover ‘colluvium’, a general term for the rocky hill-side soils shed by rock weathering and the poorly developed soils on the lower slopes. They also include the well-developed and thicker soils on lower-lying ground formed largely by rock weathering in place. Except for scree, these need not be shown on your final map although they appear on your field map as the material which occupies the space between rock outcrops. However, notes can be made, such as ‘red soils’ to justify the concealed continuation of a dolerite dyke; or ‘sandy soils’ to reflect underlying acid rocks (see Section 4.5.1).

Alluvium is the transported, washed and sorted result of rock weathering, and it includes everything from boulders and gravel, through sands, to silt and clay (Appendix V, Table AV.2). Then there are boulder clays, morraine and fluvio-glacial deposits of many types; beach deposits of many grain sizes; wind-blown sands forming dunes (yes, even in Britain) and fine-grained *loess*. In some countries wind-blown volcanic ashes cover huge areas. More consolidated, but still superficial weathering products, include laterites whilst some spring-fed streams may deposit travertine terraces. All these you do show on your maps.

In general select what is important to the later history of your area and for the principal purpose of the map. If necessary prepare a separate ‘drift map’.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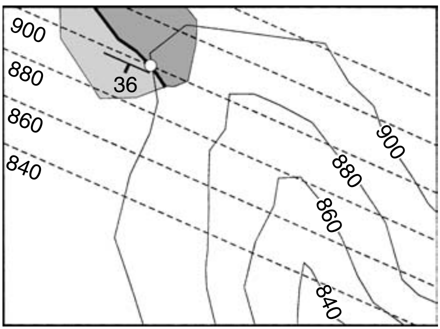
(a)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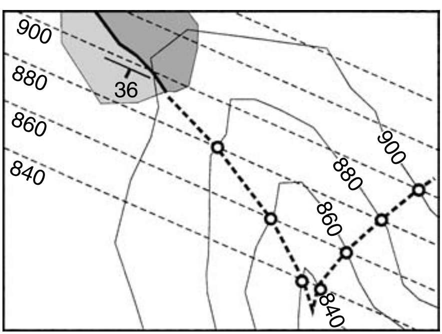
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(c)

4.5.1 Evidence from float

Many soils, particularly on hillslopes, contain rock fragments called float. Fragments from the more resistant rocks tend to be large and may lie on the surface. Those from softer rocks are smaller and usually buried; they have to be dug for with the sharp end of your hammer or with an entrenching tool. Contacts on hillsides can sometimes be located with considerable precision by searching for the upper limit of float derived from a formation which lies immediately below a contact with another rock (Figure 4.5). Care must obviously be taken in glaciated regions that the hillslope soils, the colluvium, have not been transported.

4.5.2 Landslides

Landslides are too often considered an academic irrelevance during geological mapping; sometimes they are not even recognised at all. Far more common than many geological maps would suggest, they are geological hazards and to ignore them is geological negligence. If not recognised, time can be wasted in trying to make structural sense from the diverse strikes and dips that sliding can produce. That an apparent outcrop is the size of a house is no guarantee that it is in place. Evidence of sliding is particularly important to developers, and to road and railway engineers, who may use your map for planning. They ignore them at their peril, as can be seen only too frequently in many parts of the world (Crozier 1986).

Slides can be recognised by the often arcuate scar where the slide starts and by the material that has slid (McDonald 2000). Some slides are huge (Figure 4.6). Although old scars may be eroded and overgrown, the slide debris may show several features: its average gradient is gentler than the rest of the hillside; its toe extends further out than the general line of the hillside; and its surface is different too. There may be small parallel ridges or hummocks caused by ‘earth flow’. Drainage is small-scale, often dendritic, and there may be small ponds and pools. In wooded areas, old slides may support only scrubby bush; newer ones have dead trees with new growth between them. Where sliding is in its early stage, trees may be ‘kneed’, that is, the lower few metres of young trees are curved as they strive to stay vertical to compensate for soil creep. Some slides may have massive displaced blocks poking through the hillside colluvium; some cover huge areas.

Figure 4.4 *Plotting structure contours: (a) strike and dip have been measured at point P; (b) contours are drawn parallel to strike through P at a spacing calculated by: contour interval/tan(angle of dip); (c) the predicted outcrop is where the calculated structure contours intersect the topographic ground contours*

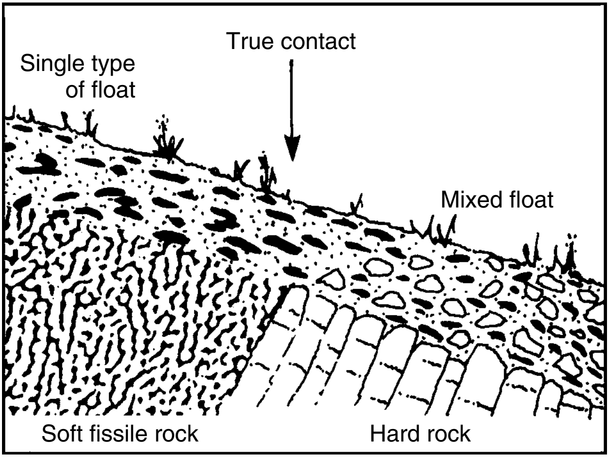


Figure 4.5 *Float in hillslope colluvium as an indicator of a contact; the contact is where the first signs of hard rock float appear in the soil*

Figure 4.6 *A major landslide at Livingstone, Wyoming, USA. Note the hummocky nature of the slipped ground in front of the stable slopes forming the hills on the skyline*

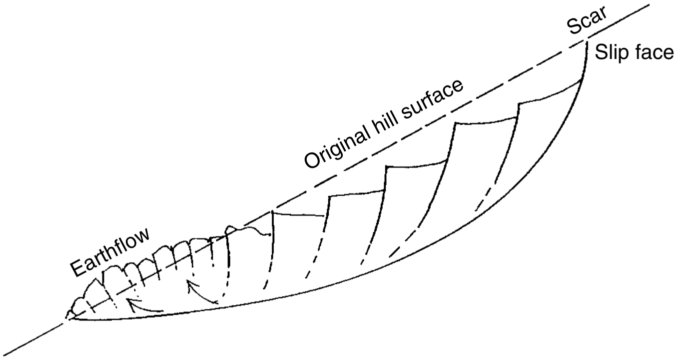


Figure 4.7 *A cross-section of a rotational landslide, showing why the toe of the slide extends further out than the original base of the hillslope, resulting in a lower average gradient, and why the surface of the slide consists of small ridges and hummocks with small streams and ponds between them. There are other types of slide too*

There are many types of slide; Figure 4.7 shows the general features of a rotational slide and why it tends to produce small subparallel ridges, small streams and pools. Map a slide as a distinct entity wherever possible, showing the line of the scar, the 'slip face', and the extent of the debris. If you see signs of imminent sliding, such as hillside fissures and kneed trees, note them on your map.

4.5.3 Pitting, trenching, augering and loaming

When it is essential to examine rock beneath the soil in a poorly exposed area, pits and trenches may have to be dug. A pit can be sunk quite rapidly so long as you do not become too ambitious over the size of the hole. The most economical pits, widely used in prospecting in Africa, are about 85 cm in diameter, excavated by a short handled hoe. They are too small to collapse except in sand and diggers can 'chimney' out of them without ladders. A skilled pit-digger can sink a pit to 6 m. Contacts are best located by trenches (*costeans*). Such methods are obviously only open to geologists who have at least some financial backing.

In many cases, identifiable fragments of weathered rock can be recovered from shallow hand-auger holes. A post-hole auger can rapidly sink a 10 or 20 cm diameter hole to 60 cm. Mechanised augers are quicker, but obviously cost a lot more (Moseley 1984, pp. 118–120).

Loaming is a method of mapping in poorly exposed, deeply weathered regions. Soils, collected from below the humus layer in pits and auger holes, are washed in a gold pan (Section 5.12) and the concentrates compared with 'heavy mineral suites' collected from soils lying above known formations. Large areas of Venezuela, and smaller laterite-covered parts of Africa, have been mapped in this way.

4.6 Drilling

Every professional geologist will be concerned with drilling at some stage of his career. It is most commonly employed to locate formations at depth; to confirm their presence in the lack of other evidence; to solve structural problems; and to sample rocks and ores. It is also used to find and exploit water, and of course oil.

Basically, there are two kinds of drill: percussion (or churn), and rotary. Percussion rigs drill by repeatedly raising a heavy drill bit attached to a wire cable and dropping it to strike the bottom of the hole. Rock is *crushed* and *chipped* away and the debris is bailed from the hole with water at intervals for examination. Rotary drills, on the other hand, rotate a drill bit attached to the end of a tubular drill pipe or rod: the rock is *ground* away. Frequently, but by no means always, the bit is set with diamonds, hence 'diamond drilling'. Some rotary bits are tubular and cut a ring-like hole which leaves a cylindrical 'core' of rock attached to the bottom of the hole. This core can be broken off and retrieved as a sample of solid rock. Percussion rigs can drill only vertical holes: they yield chippings and rock flour without a core sample from holes about 20 to 60 cm in diameter. Rotary rigs can drill inclined holes and they can, but do not have to, take a core. Holes can be about 4 to 60 cm in diameter, with the larger holes drilled by 'tricone bits' consisting of three conical cog-like cutting wheels. The sludge of ground-up rock flour formed during rotary drilling is pumped up from the hole by the circulating drilling fluid (usually water) and collected as sample material, whether core is taken or not. Figure 4.8 shows a light diamond drill drilling an inclined hole.

Figure 4.8 *A diamond drill rig drilling an inclined hole*

4.7 Geophysical Aids to Mapping

Geophysics plays an increasingly important role in geological investigations and every geologist should know how it can be applied so that he can ask for the appropriate help when needed. Most geophysical methods require a specialist geophysicist to apply and interpret them, but there are a few instruments that a geologist can use himself to help him to locate concealed contacts. They are available in most geological organisations and two are described below.

4.7.1 Magnetometers

Compact torsion-balance magnetometers are available, small enough to be operated in the hand. They are adequate for distinguishing between rocks with no magnetite and those with magnetite. For example, they can find the contact between serpentinite and the surrounding sedimentary rocks or locate unexposed dolerite (diabase) dykes. Still portable, but larger and more sensitive, are proton precession instruments.

4.7.2 Radiometry

Acid igneous rocks, rich in potassium feldspar, contain sufficient ^{40}K (potassium-40) to enable them to be distinguished from rocks with lesser K-feldspar nearby if a sufficiently sensitive instrument is used and the soil cover thin. A gamma-ray spectrometer (*scintillometer*) will detect these differences although the older *Geiger counter* cannot.

4.8 Large-scale Maps of Limited Areas

From time to time there is a need to map specific aspects of the geology on a far larger scale than that used for your main map. You may be able to photographically enlarge part of your base map or, in Britain, use a 1:2500 map. More satisfactory for those able to do it, is to use a planetable (Appendix III). This gives great flexibility in scale and accurate geological maps as large as 1:500 can be made this way. Even if no great accuracy is required, planetabling is often the easier way of making a large-scale map. It is certainly the best where the ground is rugged, broken or uneven, and whenever the correct vertical position of a point is as important as its plan position.

More often, the need arises for a very large-scale sketch map of a very limited area, sometimes only a few hundred square metres in extent. The need is to illustrate geology and no great precision is required. Thus methods can be used which might well be derided by a land surveyor. Some are described below; they can be modified and changed to meet contingencies. Ingenuity

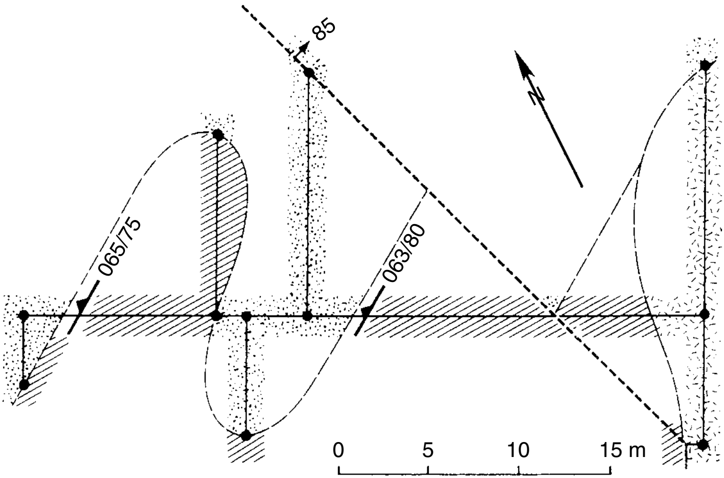


Figure 4.9 *A simple compass and tape traverse to plot in large-scale geological detail*

and a basic knowledge of surveying are assets. Keep sheets of squared paper in your map case should you need them.

4.8.1 Compass and tape traverse

The simplest method of plotting geological detail is by taking offsets from a chain line or traverse, as described in Section 3.4.3. A single traverse may even suffice (Figure 4.9). The same method can be used as a 'mini traverse' to map a single large exposure in detail.

4.8.2 Traverse with offsets

Where a number of exposures are spread over an area of more of less level ground, but scattered too far apart to be mapped by a single traverse line, geology can be rapidly mapped by running a series of traverse legs in a loop, ending at your start. Detail is mapped by offsets from the traverse legs (Figure 4.10). For small areas, measure the traverse legs first, marking the turning points on the ground so that they can be easily found again. Plot the traverses and correct the closure error (Appendix II), then plot the geological detail. The alternative is to enter all details, including the geology, in your notebook as you move along each leg in turn, and replot everything back in camp. The first is to be preferred because then you have the ground in front of you as you plot in the detail.

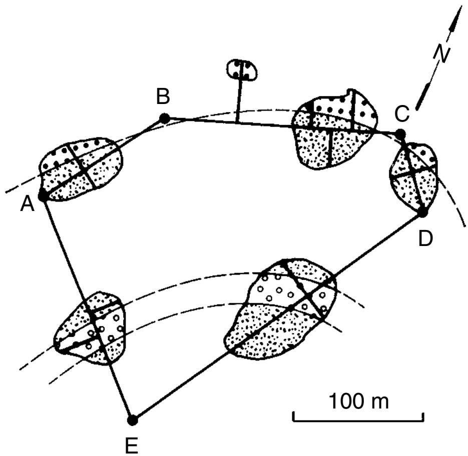


Figure 4.10 *A closed traverse of several legs to plot in a number of exposures for a medium-scale sketch map*

4.8.3 Mapping an exposure in detail

It is sometimes necessary to map a large exposure in detail. If the surface is more or less flat, lay down a base line; use stones to mark points along it at fixed intervals (say 10 m); then measure traverses at right angles from it, with stones again at 10 m intervals. The effect is to build up a grid to guide your sketch map (Figure 4.11). Where a great deal of sketch mapping is to be done, a cord grid which can be laid over an exposure and anchored there with stones will simplify the task. The grid shown in Figure 4.12 was constructed by pegging out an area of 16 m × 20 m (on the beach) with pegs every 4 m along the sides. Three-ply nylon chord was used to make a net with a 4 m mesh. Detail is plotted by estimation on squared water-resistant paper, with measurements by a steel pocket tape when necessary. Compass bearings are measured by assuming one side of the grid is 'grid north' and correcting your compass to read accordingly. Figure 4.13 shows structure mapped in the deformed 'Scourie' dyke shown in Figure 4.12.

Remember that other methods not described here may be used by other people. Use the methods that will suit you and the geology best, but ensure that those you do use give acceptable results in terms of the accuracy required. Different types of geological environment will affect the way you map, so will different terrains, different climates, and different base maps. Adapt and invent, never become hidebound.

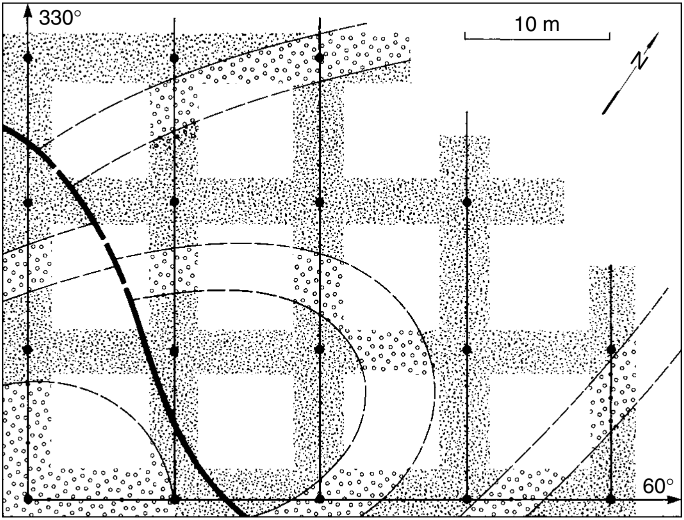


Figure 4.11 *Mapping a large exposed area by building up a rough grid*

Figure 4.12 *A 4 m mesh cord grid to aid sketch mapping laid over an exposure at Badcall, NW Scotland (see Figure 4.13); the cord has been retouched for clarity*

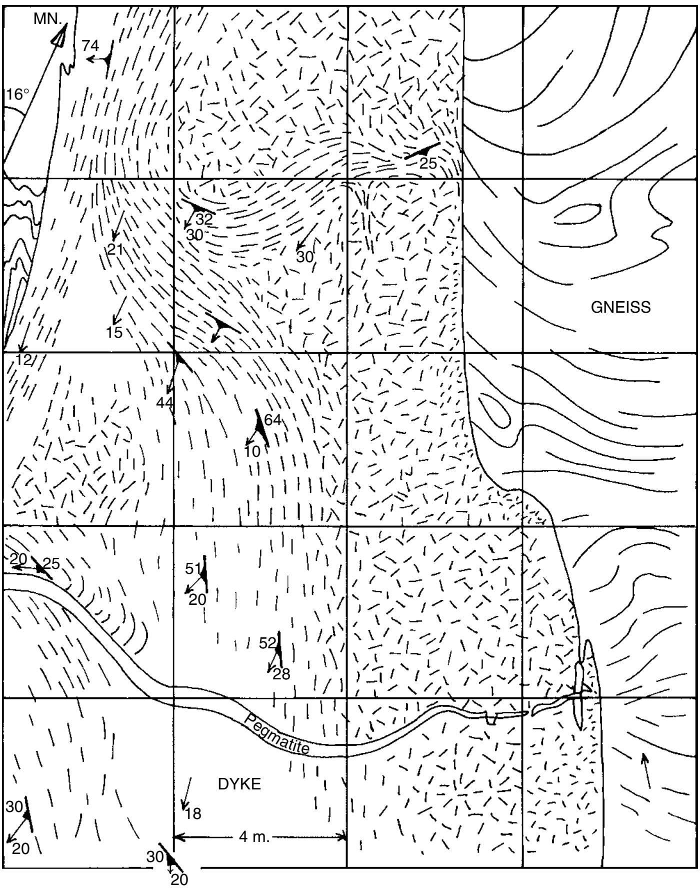


__Figure 4.13__ Structures mapped in a deformed 'Scourie' dyke at Badcall mapped by the 4 m mesh net grid shown in Figure 4.12 (courtesy of R.H. Graham)

4.9 Underground Mapping

Although mapping geology in underground workings, especially in metal mines or in caves, is not a subject for this small book, a few words may be usefully said. Those that do have ambitions for such projects would do well to consult Forrester (1964), if only for his excellent examples of coloured underground field sheets, and also Peters (1978). When consulting maps of underground workings (and they can be most useful in providing information on what underlies your field area even if you have no intention of going underground yourself) there is a convention that the geology in metal mines has normally been mapped in the walls at waist height, or projected to waist height. This is because the ‘back’ (i.e. the roof) is irregular and often too high to reach or even see properly, and the floor is covered in mud, debris, or even water.

It is often a temptation for geologists to enter old mine workings or caves in an area they are mapping. Resist it. If you have to enter old workings, do not go alone; find a guide who is familiar with the workings and always let someone know where you have gone and when to expect you back. By law, abandoned workings are supposed to be sealed but, especially internationally, this is not always done. There are many underground hazards for the unwary, including rotting timber covering ‘winzes’ (small internal shafts often in the floor), or props holding up, but only just, the back. Do not disturb old timbers, beware of odourless gases, including CO_2, and do not pull at lengths of old fuse or thin wires protruding from spoil heaps; they may have a misfired blasting charge at the other end! And do ensure that you wear a helmet, suitable boots and have adequate lighting.

4.10 Photogeology

Photogeology is the systematic interpretation of geology from aerial photographs. It can be used as a method of geological reconnaissance with only limited ground checking, or as an adjunct to orthodox geological mapping. Here, we consider only its second use.

4.10.1 Using aerial photographs

Before leaving for your field area, examine your photographs under a mirror stereoscope and make an interpretation of the main geological features. When you reach the field, carry the photographs in your map case in addition to your field map. Examine them at intervals with a pocket stereoscope to compare what you see on the ground with its appearance on the photographs. Back in camp, or in the evening, review your map and photographs together again using a stereoscope. You may well find that you can extend contacts and faults on your photographs which you could not do on the ground. This is because the vertical exaggeration of the 3D image accentuates quite minor features which reflect geology. Check in the field next day to see if you can now locate the features on the ground.

Also examine on the ground any other features you have seen on the photographs whose geological cause was not obvious; their geological significance may now become apparent. Often, photographs will point you towards places on the ground you might otherwise not have bothered to visit. Some indications on photographs, however, you may never be able to resolve. This does not mean that they do not exist; show them on your field and fair copy maps in purple so that future workers are aware of them. Eventually their significance may be found. Remember that photogeological evidence is not inferior to other geological evidence, it is merely different.

4.10.2 Photogeological features

Only a few indications of what can be inferred from photographs can be given here. Refer to Ray (1960 or later editions), and Lillesand and Kiefer (2003), for further information but experience is the best teacher. Note the following advice.

Tone results from ground reflectivity. It varies with changing light conditions. Sudden changes of tone on a single photograph may indicate a change in rock type owing to a change in vegetation or weathering characteristics.

Texture is a coarser feature caused by erosional characteristics. Limestones have a rough texture; soft shales are often recognisable by a microdrainage pattern.

Lineaments are any straight, arcuate or regularly sinuous features of geologically uncertain significance seen on photographs. They may show in the drainage; as vegetational changes; thin lines of lusher vegetation in arid bushland, perhaps resulting from faults, master joints, contacts, or for some other geological reason allowing water to seep closer to the surface. The cause of some lineaments may never be discovered.

Vegetation is an excellent guide to geology and changes can usually be more easily seen on photographs than on the ground. It contributes to both tone and texture.

Alluvium, swamps, marshes, etc. are quite distinctive on photographs and their boundaries can usually be mapped better from photographs than on the ground.

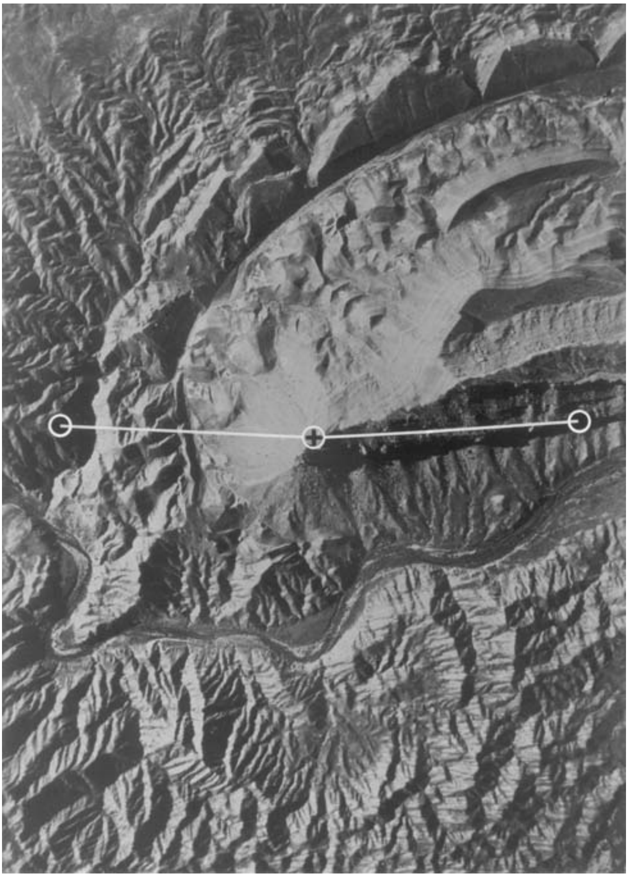
Strikes and dips can be seen from dip slopes, scarp edges and from the way in which beds 'vee' in valleys. There are even methods and instruments for calculating the amount of dip where large dip slopes are exposed.

4.10.3 Systematic analysis

Only a brief description of systematic photogeological analysis can be given here.

1. Tape an overlay of Permatrace, Mylar or similar plastic drawing film over one photograph of a stereopair (Figure 4.14(a)); mark on the *pp* and *cjs* (Section 3.7.1).

2. Under the stereoscope, trace the drainage onto the overlay (in black) to provide a topographic framework. Include alluvium and terrace boundaries. Outline areas of scree, landslide, outwash, etc.
3. Trace (in purple) scarp edges and indicate the direction of dip by arrows down the dip slopes: the steeper the dip, the more bars on the arrows (Figure 4.14(b)).



(a)

Figure 4.14a *Comparison of an aerial photograph (courtesy of BP Exploration) with (b) its geological interpretation*

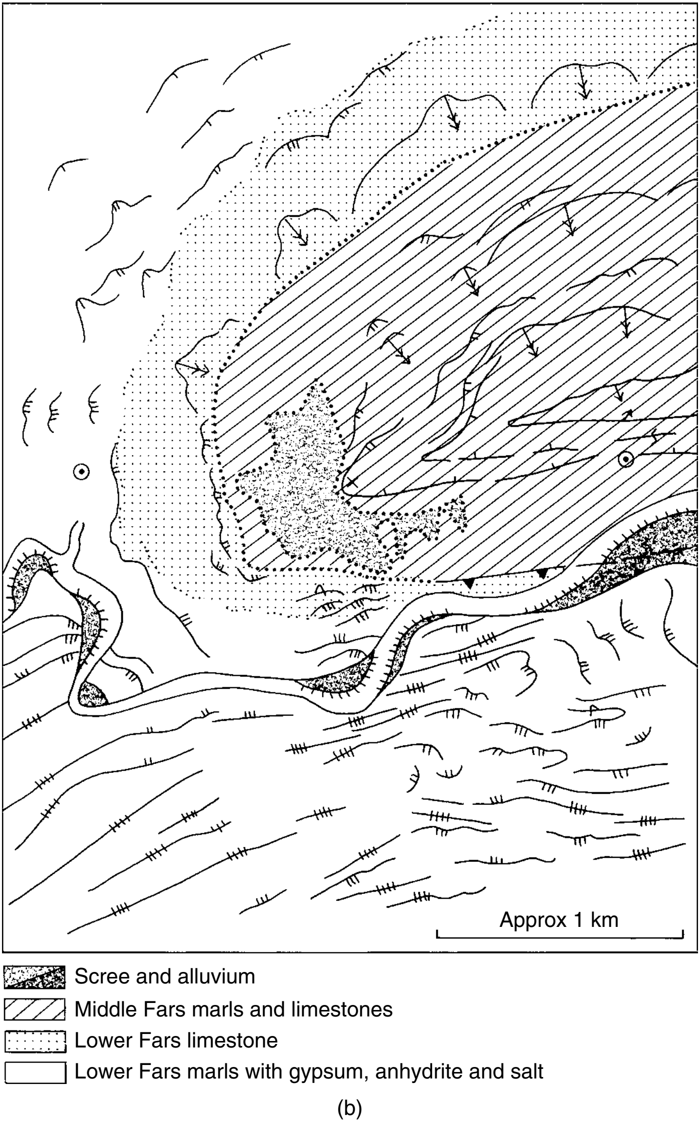


Figure 4.14b *(continued)*

4. Draw, again in purple, any known marker beds which can be traced. Indicate the dip by ‘ticks’: the steeper the bed, the greater the number of ticks (Figure 4.14(b)).
5. Show obvious faults in red.
6. Plot as lineaments all major linear and arcuate features whose cause is uncertain. Show them as purple lines, broken at intervals with three dots.
7. Draw contacts as dotted lines, again in purple.
8. Identify rocks and label formations.

Check your interpretation on the ground and against your field map. Amend as necessary and transfer your photogeological information to your field map in the appropriate colours to distinguish photogeological data from other information. If you are mapping directly onto transparent overlays to photographs in lieu of a field map, show any information mapped or confirmed on the ground in black. Always distinguish the two sources of information.

Figures 4.14(a) and (b) show an aerial photograph from Iran compared with its photogeological interpretation. Note that the symbols used are different from those used on ordinary geological field maps.

5

FIELD MEASUREMENTS AND TECHNIQUES

One object of geological mapping is to elucidate the structure and structural history of the region studied. This can only be done if measurements are made of: the attitude of planar structures such as the bedding and foliation; linear features including the intersection of bedding and cleavage; the trends of minor folds; and the directions of overturning. It is assumed that the reader already knows what these structures are, although many budding geologists do not always know the best way of measuring them. Measurements once made must be plotted and recorded, and there are several ways of doing this too, some easier than others. Structures must also be investigated, specimens collected, photographs taken, and possibly even soils panned to determine heavy mineral suits where no rocks are exposed (see Section 4.5.3). These are all part of the technique of mapping.

5.1 Measuring Strike and Dip

Measurements of strike and dip of bedding, cleavage, foliation and jointing are fundamental. Without them, a geological map means little. A useful rule of thumb is to take readings to give an average density of about one for every 5 cm^2 or 1 $inch^2$ of map surface regardless of the scale of mapping. Naturally there will be greater concentrations of measurements where strikes vary and fewer where structure is more consistent or exposures poor. If there is a greater concentration, perhaps you need to map those areas at a larger scale.

Strikes and dips can be measured in a number of different ways. Suit your method to the type of exposure. Limestones, for instance, often have uneven bedding surfaces and a method which allows you to measure strike and dip over a wide area of surface will give more representative values than one where only a point on the surface is measured. Metamorphic rocks offer additional problems. Measurements of cleavage often have to be made on very small parts of a surface, sometimes even overhanging ones. There may even be more than one cleavage or foliation and at least one of them may be obscure and difficult to measure. You must use your ingenuity. Many granite gneisses crop out as pavements or turtle-backs where the trace of foliation is clear enough but the dip is difficult to see. Like limestone bedding planes, joints tend to have uneven surfaces; take this into consideration when

Basic Geological Mapping, Fourth Edition. John W. Barnes with Richard J. Lisle
 ISBN: 0-470-84986-X

measuring them. One point must be emphasised: you must plot measurements on to your map immediately after you have taken them, so that any mistakes made in reading your compass, and they do happen, are obvious. Only in very bad weather is it permissible to log readings in your notebook and plot them back in camp. Joints are an exception. They tend to clutter a map without adding to a direct understanding of the structure. Record joint directions in your notebook and plot them onto map overlays later, or treat them statistically. Another exception to the rule of the immediate plotting of structural measurements is where structures are locally complex: then you may have to draw an enlarged sketch in your notebook and plot the measurements on it. Several different methods of measuring strike and dip are described below; modify them as occasion demands.

5.1.1 Method 1

This, the *contact method*, is commonest of all. Use it where the surface is smooth and even. If there are *small* irregularities, lay your map case on the rock surface and make your measurements on that, but sometimes such a small area of bedding or cleavage is exposed that direct contact is the only method that can be used. Place the edge of your compass on the surface, hold it horizontally, align it parallel to strike and read the bearing (Figure 5.1). Some compasses are provided with a level bubble so that there is no difficulty in establishing strike. With others, you may first have to determine strike with your clinometer, as follows: rotate the clinometer on the rock until it reads zero dip and, if necessary, scratch a line parallel to it with your hammer or lay your scale down beside it. With practice you can usually estimate strike with sufficient accuracy, but where surfaces are close to horizontal, strike may be more difficult to estimate. Then it may be easier to determine the direction of maximum dip, or if you have water to spare, let a little run over the surface to determine the dip direction. Measure dip with your clinometer at right angles to the strike (Figure 5.2).

5.1.2 Method 2

On large uneven planes of relatively low dip, estimate a strike line of a metre or more long (if necessary, mark it with a couple of pebbles), then stand over it with your compass opened out and held parallel with it at waist height (Figure 5.3). In a stream or on a lake shore nature may help, for the water line makes an excellent strike line to measure. The same method can be used to measure the strike of foliation on turtlebacks, or of veinlets on flat surfaces. Because you measure a greater strike length with this method, it gives more accurate readings than the contact method, and it is particularly useful where foliation is indistinct and seen better in the rock as a whole. Dip is often difficult to measure in some pavement exposures, because there

Figure 5.1 *Measuring strike by the contact method*

Figure 5.2 *Using a 'Dollar' type clinometer to measure dip*

may be little dip exposed. The *end-on* method must then be used; sometimes you may even have to lie down to do it. Move back a few metres, hold your clinometer at arm's length in front of you and align it with the trace of foliation seen in the end of the exposure, ensuring that your sight line is horizontal and *in the strike of the plane measured*. Figure 5.4 shows an excellent exposure suitable for end-on dip measurement, but it can be used on far poorer exposures of dip than that.

Figure 5.3 *Measuring the strike of a veinlet on a rough horizontal surface by Method 2*

5.1.3 Method 3

This gives reliable measurements of strike and dip in regions where large areas of moderately dipping bedding planes are exposed or where surfaces are too uneven to measure in any other way. Extreme examples are the dip slopes often seen in semi-arid countries, but the method can also be used on smaller uneven surfaces, including joint planes. Stand at the end of the exposure (kneel or lie if necessary) and ensure that your eye is in the plane of the surface to be measured. Sight a horizontal (strike) line across the surface with a hand-level, then sight your compass along the same line and measure its bearing. This will give a reading which averages out the unevenness of the plane (Figure 5.5). To measure dip, move far enough back so that you can see as much dip surface as possible, then take an end-on reading (Figure 5.6). Compasses with built-in hand-levels, such as the Brunton, are ideal to establish the strike line for this type of measurement.

Figure 5.4 *An ideal exposure for the end-on measurement of dip*

5.2 Plotting Strike and Dip

Plot dip and strike immediately after you have measured them. The quickest way to plot a bearing is by the pencil-on-point (POP) method. It takes only a few seconds, as follows.

1. Place your pencil on the point on the map where the observation was made (Figure 5.7(a)).
2. Using the pencil as a fulcrum, slide your protractor along it until the origin of the protractor lies on the nearest north-south grid line; then, still keeping the origin of the protractor on the grid line, slide and rotate your protractor around your pencil still further, until it reads the correct bearing (Figure 5.7(b)).
3. Draw the strike line through the observation point along the edge of the protractor.

The larger the protractor, the better: 15 cm is recommended. If necessary draw extra grid lines if those printed on your field map are too far apart.

Some bearings, such as those lying between 330° and 030°, are easier to plot from the east–west grid lines.

Suunto and Silva compasses have the advantage that you can use the compasses themselves as protractors. Briefly: take your strike reading and then, without disturbing the setting of the rotating graduated ring, align the N grid lines inscribed on the transparent base of the compass box with the grid line on the map and slide it into position (Figure 5.8).

Figure 5.5 *Measuring the strike of an uneven surface with a prismatic compass (Method 3)*

5.3 Recording Strike and Dip

Whether you enter your strike and dip readings in your notebook as well as on your map is debatable, but if you lose your field map, you will have to start all over again from scratch anyway. It takes little extra time, however, to record the strike and dip on the map against the strike/dip symbol. This is particularly convenient when mapping on aerial photographs when you must later re-plot your field information onto a base map of a different scale.

5.3.1 Right-hand rule

Strikes and dips must be recorded in a manner where there can be no possible confusion over the direction of dip; the recording of dip 180° in error is a common mistake. Many geologists write the bearing of the strike, followed by a stroke and then the amount of dip, and then the quadrant it points to: 223/45NW (or S43W/45NW if your compass is graduated in quadrants). *The right-hand rule* is simple if applied as follows, when only a contortionist can get it wrong: always record strike in the direction that your right-hand index finger points when your thumb points down the dip (Figure 5.9). Quadrant letters can now be omitted and the reading of 223/45NW now becomes 043/45. All types of planar information can be noted in this form. There are other versions of this notation with which it can be confused, so note the method used in the front of your notebook.

Whatever method you decide to use to record strike and dip on your field map, it is *your* field map and *you* will be replotting the information on your fair copy map at a later date. It is up to you to choose the methods which suit you best. However, remember that although the fair copy map is the final product, it is the field map which provides the evidence.

Figure 5.6 *Measuring the dip of an uneven surface by Method 3*

5.4 Measuring Linear Features

Linear features related to tectonic structures are termed *lineations* and the methods of measuring them described here can be used for any other linear features, whether resulting from glaciation, currents associated with sedimentation, or flowage in igneous intrusions.

5.4.1 Trend, plunge and pitch (or rake)

A lineation is defined in space by its *trend* (the bearing of an imaginary vertical plane passing through it) and by its inclination or *plunge* in that plane (Figure 5.10). Some lineations appear as lines on an inclined surface, such

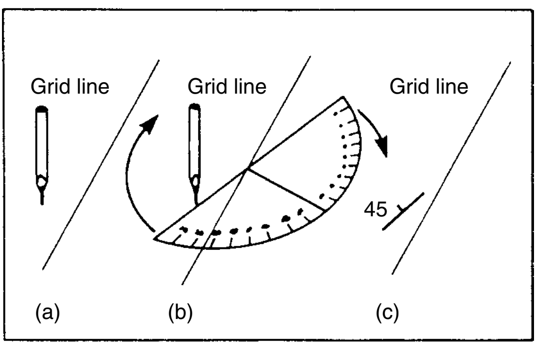


Figure 5.7 *Plotting a bearing by POP (pencil-on-point)*

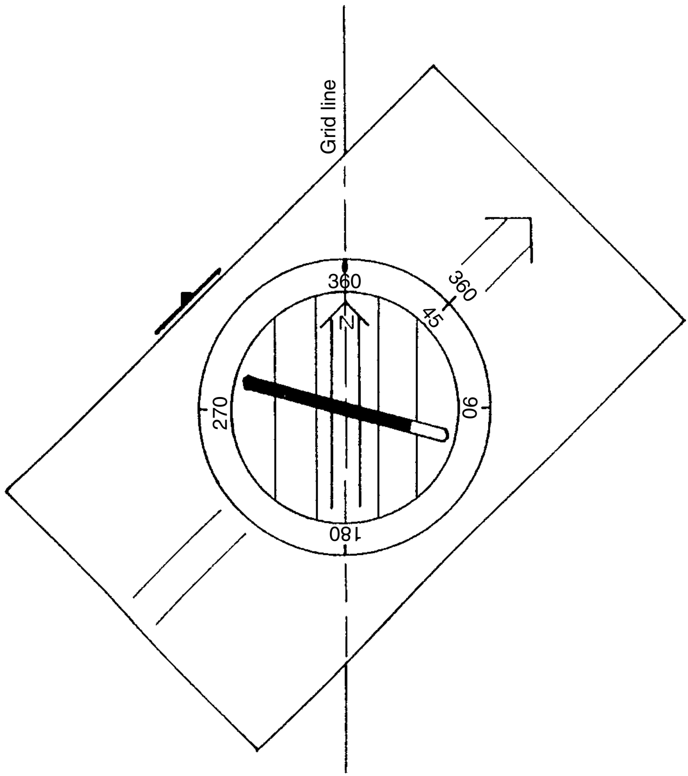


Figure 5.8 *Plotting a bearing with a Silva type compass*

as where the trace of bedding can be seen on a cleavage plane. These lineations can often be measured more easily by their *pitch* (rake), that is, the angle the lineation makes with the strike of the surface on which it occurs (Figure 5.11(a)). Provided the strike and dip of the surface have been measured, trend and plunge can then be calculated on a stereographic net. Log the angle of pitch in your notebook by the clockwise angle so that there is no ambiguity over its direction on the surface (Figure 5.11(b)). Pitch can be measured with a common transparent protractor, the bigger the better.

5.4.2 Measuring lineations

Although some lineations can be measured by their pitch on a surface, many must be measured directly with a compass. Sometimes this is simple, as

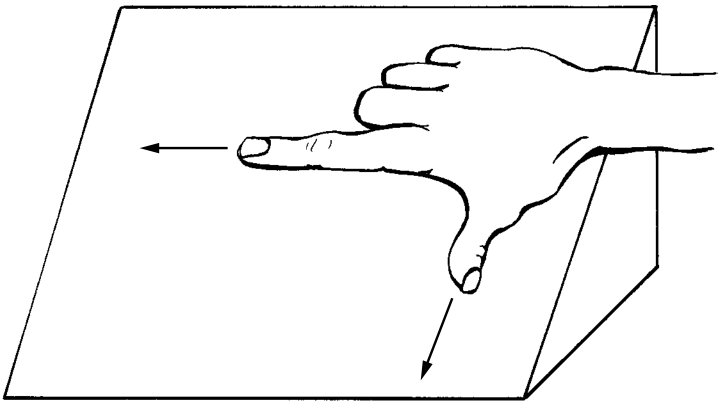


Figure 5.9 *The right-hand rule method for measuring and recording dip and strike*

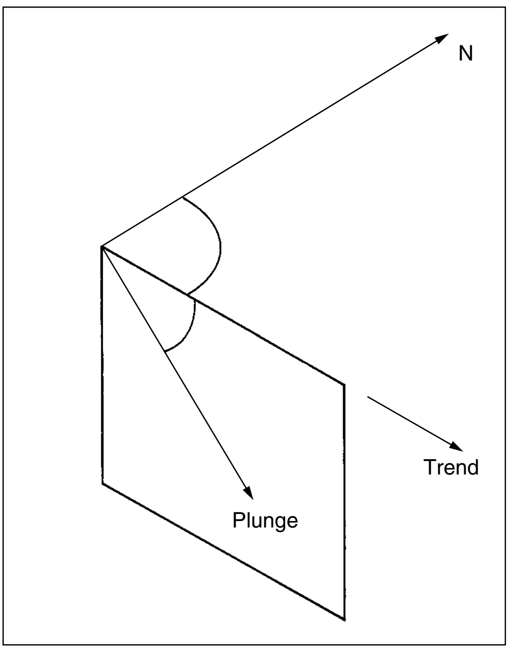


Figure 5.10 *The geometry of trend and plunge*

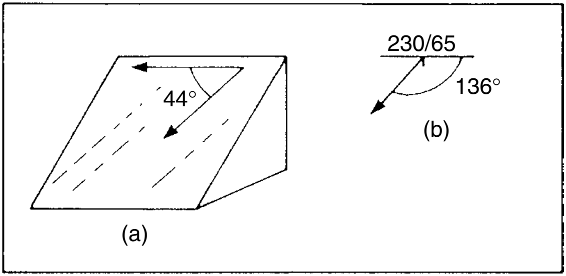


Figure 5.11 *(a) Geometry of pitch on a lineated dip slope. (b) Record pitch in your notebook by a diagram; record its angle together with the strike and dip of the surface it lies on*

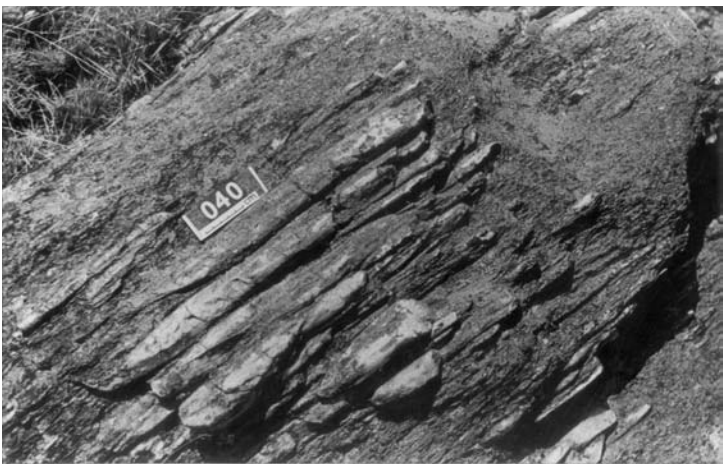


Figure 5.12 *Stretched conglomerate pebbles in SW Uganda; trend and plunge can be measured directly*

in the case of the stretched conglomerate pebbles shown in Figure 5.12. All that needs to be done is to stand above the exposure and measure the trend vertically below. Plunge can then be measured by contact or by end-on methods. Direct measurements of trend and plunge can also be made for lineations on moderately dipping surfaces but, as surfaces become steeper, it is increasingly more difficult to measure trend accurately. Figure 5.13 shows one way it can be done if your compass is suitable. Lay the edge of the

Figure 5.13 *Measuring lineation on a steep surface using a compass with a hinged lid*

compass lid along the lineation; level the compass case by noting whether the compass card or needle floats horizontally (some instruments have a circular level bubble). If the compass case is truly horizontal the edge of the compass must, geometrically, lie in the trend plane. Read the bearing for trend. Plunge is measured by direct contact in the trend plane. Very serious errors in trend may arise from measurements merely 'eyed-in' from above. Lineations can be measured both accurately and easily by the Japanese compass illustrated in Figures 2.4(e) and 2.8.

Some lineations are most difficult to measure, especially those related to minor folds in granitoid gneisses when exposed in flat turtle-backs and pavements. At first sight such folds appear to show up beautifully but, on closer inspection it may be found that although the hinge lines can be seen, the plunge cannot, and has to be estimated (Figure 5.14).

5.5 Folds

Minor folds are quite frequently seen in outcrop; major folds seldom are except in the more arid countries. Minor folds can, however, often provide the key to the major folds they are related to. They reflect the same shape and style, the direction in which the closures of the major folds lie, and their cleavage indicates the attitude of the axial planes of the major folds and their

Figure 5.14 *Minor folds in Precambrian granite gneiss in SW Uganda*

direction of overturning. For example, the *Z* fold shown in Figure 5.15 indicates that the major antiformal closure is to the right of the picture (NE), the synformal to the left (SW). It also indicates inclination of the axial plane. Minor folds such as this are too small to show in an outcrop on your geological map except as a symbol selected from the list of symbols printed on the inside back cover of this book.

Figure 5.15 *A minor fold in Precambrian (Karagwe-Ankolean) sedimentary rocks in SW Uganda. The major antiform closes to the NE (to the right of the photograph)*

There is an extensive terminology for the description of folds and before going into the field you are well advised to read Fleuty's paper 'The description of folds' (1964). In general, map the directions and inclination of axial planes of folds where it is possible to do so, and note fold shapes, attitudes and sizes. Measure any cleavages related to them and all lineations and intersections of cleavages, such as those with bedding. Show by symbols the trends, plunges and shapes of all folds too small to show in any other way. Make notebook sketches.

Fleuty (1964) gives numerical values for terms defining the attitudes of folds; open, closed, tight, etc. In the field *make measurements* where you can, and avoid terms such as gently, moderately, steeply plunging, in your notebook. Make sure that you are well prepared in the basic concepts of structural geology, and keep a textbook on the subject in camp with you (McClay 2003). Much of the difficulty you will encounter is in recognising structures in the field when you see them for the first time; they seldom resemble those idealised diagrams in textbooks.

5.5.1 Folds with axial plane cleavage

Cleavages and other foliations formed during the folding of rocks usually adopt a special orientation in relation to the associated folds. Cleavage has

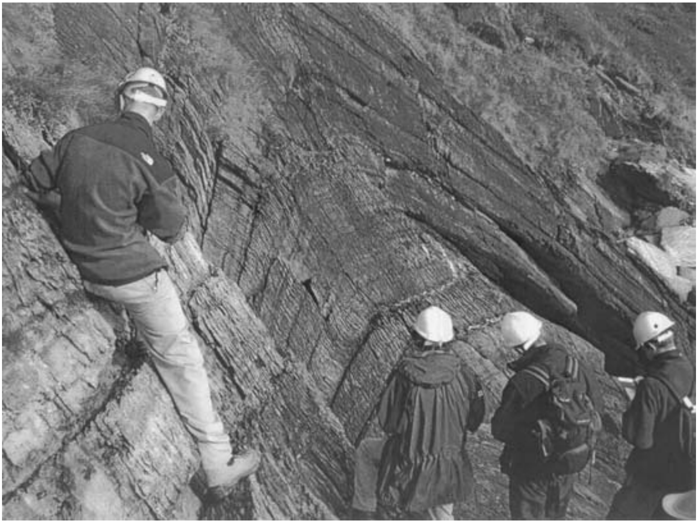


Figure 5.16 *Axial-plane cleavage in Devonikan slates at Combe Martin, North Devon. North is to the left of the photo*

an orientation approximately parallel to the axial plane of the fold and this is a useful tool when mapping fold structures; it uses the relative orientations of bedding and cleavage (Figure 5.16). At outcrops where both bedding and cleavage can be seen, make a field notebook sketch of their dips (Figure 5.17). Hold the notebook up to the outcrop and rotate it until the cleavage appears to be vertical. When this is done, the dip direction of the bedding in the rotated drawing indicates the direction in which the nearest synform is to be found. For example, if the rotated bedding dips to the east, the nearest synform is located to the east of the exposure. If such observations are made repeatedly across an area and recorded on the map, large-scale antiforms and synforms can be mapped out.

5.6 Faults

Most smaller faults never get mapped because they are never seen. Many have such small displacements that it matters little if they are individually missed, but record those you do see in your notebook to help you to establish a fracture pattern. Major faults are more likely to be found, but even those with displacements of tens of metres may be missed where exposures are poor. Compare the multiplicity of faults on a coalfield geological map with a map from a non-coalbearing area. The ground is probably just as faulted on

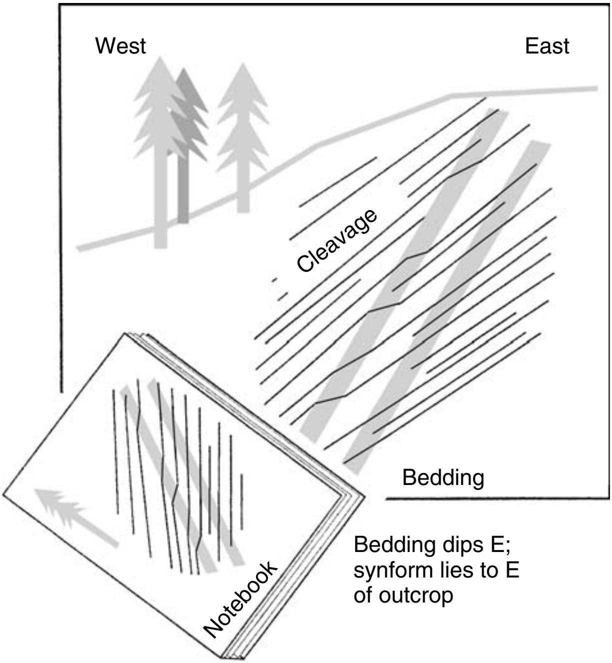


Figure 5.17 *Mapping out fold structures from cleavage and bedding; make a notebook sketch of the dip, hold it up to the outcrop and rotate until the cleavage appears to be vertical; the dip direction of the bedding now indicates the direction of the nearest synform*

both maps, but in the coalfield the faults have been detected underground and projected to the surface. Many faults have to be mapped by inference. Suspect a fault: where there are unaccountable changes in lithology; where sequences are repeated; where strikes of specific beds cannot be projected to the next exposure; or where rocks suddenly become flaggy with joint spacing suddenly decreasing to a few centimetres. Topography is often a good guide. Faults may result in spring lines, boggy hollows, seepages, or in semi-arid countries a line of taller greener trees, flanked by lower flat-topped acacia. However, beware; although most fault zones erode a little faster than the adjacent rocks, to form longitudinal depressions, some faults in limestones may form low ridges owing to slight silicification which helps to resist erosion. Faults are most easily traced on aerial photographs, where the vertical exaggeration of topography seen under a stereoscope accentuates those minor linear features called *lineaments*, features often difficult to find on the ground; many of them are probably faults.

The sense of displacement of a fault, that is, distinguishing the downthrown side, may become evident only by noting the different stratigraphy on each side of a fault. In textbooks much is made of slickensides, and if they are seen they should be noted, but do not put too much faith in them, they merely reflect the last phase of movement. Most faults have moved several times, although not always in the same direction. Note also that faults may have a thickness wide enough to show on your map. Faults may also be breccia or gouge filled, or even mineralised, perhaps with calcite or even fluorite. Note such facts in your notebook.

5.7 Thrusts and Unconformities

Thrusts and unconformities are treated here together because one can easily be mistaken for the other. Large thrusts are usually obvious, with older rocks overlying younger ones; but not all thrusts show such a clear relationship. Sometimes thrusting may be discovered only by unexpected changes in stratigraphy. If the thrust surface is not properly exposed, the upper and the lower ‘plates’ may show no angular conformity with their expected positions, or the thrust surface may show complete disregard for the stratigraphy of the upper plate. If the surface is exposed, the position should be clearer. The lower part of the upper plate should not show any of the sedimentary features you would expect in a stratigraphic unconformity: there may be shearing along the surface, or there may be mylonite. Where mylonite does occur it may be thick enough to map as a formation in itself and form a useful marker. However not all thrusts are major thrusts. Some are merely reverse faults, others may form imbricate zones, consisting of numerous small sub-parallel thrusts associated with major thrusts, as in the Scottish Moine thrust zone. Such zones are marked by multiple repetitions of partial sequences which, if poorly exposed, are impossible to map completely. Sometimes the spacing between individual thrusts may be only a few metres, sometimes tens of metres.

Stratigraphic unconformities show younger rocks lying on older rocks below, usually with angular unconformity between them (Figure 5.18). The rocks just above an unconformity should show features indicating that they were deposited on an already eroded surface, Unfortunately, this relationship is not always as clear as textbooks suggest, especially where rocks have been metamorphosed. Sometimes, to confuse matters, there is angular unconformity on both sides of the break if the later rocks were deposited on a sloping surface.

Figure 5.18 *An unconformity at Sully Island, Glamorgan, South Wales; Triassic mudstones lie unconformably on Carboniferous Limestone*

A *disconformity* may be even more difficult to recognise; it represents a break in sedimentation and the beds are parallel both above and below it. It should be discovered during sedimentary logging by the evidence of erosion between the two stages of deposition.

5.8 Joints

Joints occur in every type of rock, sedimentary, pyroclastic, plutonic, hypabyssal, volcanic and metamorphic. Do record joints, but do not clutter your map with them. Enter them into your notebook and later plot them on transparent overlays to your fair copy map, or plot them as statistical diagrams, such as stereograms and rose diagrams in equal area 'cells' spread over the surface of your map overlay. Master joints, those dominant major joints, are an exception. They can sometimes warrant being shown on your map. Follow them on the ground or on aerial photographs, and plot them in a similar manner to faults, but with the appropriate 'joint-dip' symbol. In general, keep joints off your maps, but do not forget about them. They are important to water supply, pollution control and hydrocarbon reservoirs.

Measure the strike and dip of joints in much the same way as bedding. Often their surfaces are uneven and contact methods unsuitable. Book readings in your notebook using the right-hand rule, or whatever your chosen notation is, and estimate where possible, the length and the spacing of joints in each set, and what formations each set penetrates. Master joints may show up well on aerial photographs, especially in limestone regions where they may be indicated by *karst* patterns and lines of sinkholes (*dolines*). Joint patterns on photographs can sometimes be used to distinguish one formation from another.

5.9 Map Symbols

There are internationally accepted geological map symbols; unfortunately every national organisation has its own interpretation of them. A short list of the main symbols is printed on the inside back cover of this book. Berkman (2001) gives a comprehensive list spread over many pages which must cover practically every geological possibility.

Note, a strike line is drawn on a map with its *centre* at the point where the reading was taken. The point of a lineation arrow head is the point where that reading was made. The exception is where several readings are made at one point: in that case the symbols radiate from the observation point.

5.10 Specimen Collecting

Collect representative specimens of every formation and rock type you show on your map. Often, several specimens of the same formation are needed if it varies in composition over the region. Even if it does not vary, you may need specimens from different parts to prove that it does not. Some variations in composition may not, of course, be obvious in a hand specimen so extra specimens are needed as a safeguard. The size of specimen you collect must depend on the purpose you wish to put it to, not on what you think you can carry. See your rock cutter *before* you go into the field to find out what he needs for thin-sectioning. Whenever possible, choose specimens showing both weathered and unweathered surfaces and if necessary collect two specimens to show both aspects. Do not collect just any piece of rock you can knock off an exposure with your hammer. The easiest piece to break off may not be representative of the exposure as a whole. You may have to spend considerable time in breaking out a good specimen with hammer and chisel.

Having broken off a specimen, trim it. Mark sedimentary rock specimens to show which is their top. Metamorphic specimens may need to be oriented so that directional thin-sections can be cut; either mark the strike and dip directions on the rock with a marker pen before you break it off, or fit it back into place and mark it after breaking it off and record whether top or bottom surface. Much depends on the outcrop itself.

5.10.1 Marking specimens

Specimens are best marked with a waterproof felt-tipped pen, or for dark rocks with either a yellow timber crayon or a numbered piece of surgical sticking plaster. Wrap each specimen in newspaper to protect it from bruising in your rucksack, and incidentally to protect your rucksack too. In camp, scrub your specimens and dry them, add a spot of white paint, and when that is dry number it with black paint, or with a fine black marker; do not use Indian ink as it rubs off too easily. Re-wrap the specimens in newspaper and number each packet on the outside with a felt-tipped marker so that you can easily locate any specimen you might wish to look at again, without having to unwrap half a dozen others to find it.

5.10.2 Fossils

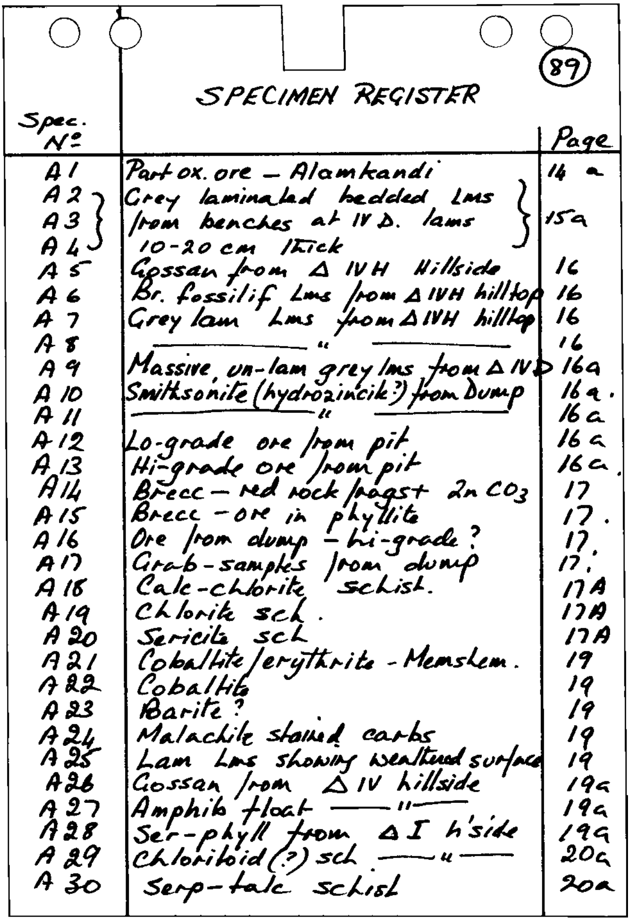
Some fossils are easy to remove from their parent rock, others are not. Many are deeply embedded with only a small portion showing; scrape away enough rock with a knife to see whether the specimen is worth collecting, and if so then break out the rock containing it. Many fossils are casts or impressions in the rock; again collect the piece of rock containing them. Wherever possible collect both external and internal casts: both are important. Sometimes you may have to collect several kilograms of fossiliferous rock so that individual fossils can be extracted in the laboratory. This is particularly so where micro-fossils are needed. Mark all specimens with the way up in which they were found.

Pack delicate specimens in boxes or tins and pad them with cotton wool, tissue paper or newspaper, or use expanded polystyrene ceiling tiles cut to fit the boxes. Use grass if there is nothing else. Carry a selection of boxes, from matchbox upwards in size. Wrap non-fragile specimens in newspaper and treat them in the same way as rock specimens.

As with rock specimens, do not collect more than you need; do not clean out a good locality to sell to dealers and report anybody you see doing so, and this applies equally for mineral localities.

5.10.3 Booking specimens

Log specimens in your notebook immediately after you have collected them. Preferably, write the specimen numbers in the left-hand margin of the page so that their details can be relocated easily. If their numbers are written with red pencil, they can be even more easily distinguished from field observation numbers listed in the same column. Alternatively, if you are collecting large numbers of specimens, add a column to your notebook specifically for specimen numbers. In addition to logging specimens on the working pages of your notebook, register them with a brief description in a specific index at the back of your notebook too. This avoids finding yourself with two almost identical specimens from different places with the same number, and no way to tell which is which. A register also helps you to ensure that you have collected specimens of everything you should have collected, and if you give



(89)

SPECIMEN REGISTER

Spec. Nº		Page
A 1	Part ox. ore – Alamkandi	14 a
A 2	Grey laminated bedded Lms	
A 3	from benches at IV Δ. lams	15a
A 4	10-20 cm thick	
A 5	Gossan from Δ IVH Hillside	16
A 6	Br. fossilif Lms from Δ IVH hilltop	16
A 7	Grey lam Lms from Δ IVH hilltop	16
A 8	——— " ———	16
A 9	Massive, un-lam grey lms from Δ IVD	16a
A 10	Smithsonite (hydrozincite?) from Dump	16 a.
A 11	——— " ———	16 a
A 12	Lo-grade ore from pit	16 a
A 13	Hi-grade ore from pit	16 a.
A 14	Brecc – red rock prgst Zn CO_3	17
A 15	Brecc – ore in phyllite	17.
A 16	Ore from dump – hi-grade?	17.
A 17	Grab-samples from dump	17.
A 18	Calc-chlorite schist.	17A
A 19	Chlorite sch.	17A
A 20	Sericite sch	17A
A 21	Cobaltite/erythrite - Memshem.	19
A 22	Cobaltite	19
A 23	Barite?	19
A 24	Malachite stained carbs	19
A 25	Lam Lms showing weathered surface	19
A 26	Gossan from Δ IV hillside	19a
A 27	Amphib float ——— " ———	19a
A 28	Ser-phyll from Δ I h'side	19a
A 29	Chloritoid (?) sch ——— " ———	20a
A 30	Serp-talc schist	20a

Figure 5.19 *A specimen register in a field notebook*

the notebook page numbers where they are more fully described, it acts as a handy ready-reference (Figure 5.19).

5.10.4 Shipping specimens

Geological specimens are heavy and if shipped in a box which is too large can only be accepted as freight. Smaller boxes, which one man can lift easily, can go much more quickly by passenger transport. A box about 25 × 30 × 25 cm made of timber about 1 cm thick, battened and steel banded, is acceptable by TIR, railway passenger services and airlines. Steel small-arms ammunition boxes make ideal containers too, if you can find them in a junk shop. Mark your name and address on top and on at least one side, and add ROCK SPECIMENS FOR SCIENTIFIC RESEARCH. Never write 'ore specimens' or 'mineral specimens' on boxes or in customs' declarations. Most countries do not appear to have export regulations controlling 'rocks' but do so for *minerals* and *ores*. 'Rocks' is an honest declaration for any geological material, avoids bureaucratic delays, and gets your rocks back to your laboratory more quickly. If possible, employ an agent to see them through customs too.

5.11 Field Photography

A camera is essential in the field. There is a wide choice depending on your pocket. It can be a traditional film camera or a digital camera. The one essential is that it is capable of taking close-up photographs as well as of scenery. The selection of lenses depends again on your pocket.

Whenever you take a photo, roughly sketch the scene in your notebook to show what to look for on the print, and the general direction in which the photo was taken, so that you can identify topographic features again later. Also mark each side of the notebook sketch with its direction, e.g. NW and SE, or WSW and ENE, etc. If there is room on your field slip, add an arrow pointing in the direction it was taken. When photographing rock exposures, provide a scale: for a large exposure, include a human; for a smaller exposure, include a hammer, compass, or any familiar object; for a close-up, use a scale. Do not use coins; they vary from country to country. Log in your notebook every picture taken and give it a number, and keep a register of photos in the back of your notebook (as for specimens) and for the same reason. Log photo numbers in coloured pencil, as with specimens, but of course in another colour. To keep track of photographs of exposures, make a device from two strips of perspex taped together, between which you can slip large-sized numbers (cut from a calendar) mounted on thin card, as in Figure 5.12. Add a scale to it; it also gives you a point to focus on, not always easy when photographing some rock surfaces. Use an ultra-violet filter with colour film when photographing at over 1500 m, or over sea and other large bodies of water, to eliminate the blue cast which such conditions cause. As a UV filter is virtually colourless, it can be left on all the time, wherever you are. If you are using black and white film for B/W photos to illustrate a report, a yellow filter gives better contrast in close-ups of granitoid rocks. Also remember that in some areas you may not see the prints of your photos for several weeks, or sometimes even months, so do keep good notes, otherwise you may end scratching your head and wondering why on earth you ever took some photographs.

5.11.1 Digital cameras

Digital cameras are becoming popular for geological use and have several advantages over film cameras in the field. First and foremost, because the image is stored electronically, the picture can be manipulated in terms of its properties, such as size, brightness, contrast, etc. Once modified to enhance the feature being recorded, the image can be pasted directly into the computer file containing your report or dissertation. Some cameras can in addition construct a mosaic automatically from a series of overlapping pictures. This is useful for recording panoramas. Also important is that an immediate preview of the shot is given, allowing a check to be made on its success, before moving on to the next locality.

Technological developments mean that some of the disadvantages of digital photography are rapidly being overcome. For a given specification the cost of buying a digital camera is falling, and although still more expensive than a traditional film camera, this is offset in that no developing costs are involved. The more expensive cameras take high-resolution images which survive enlargement without becoming blocky (pixely) in texture. For fieldwork the sturdiness of digital cameras remains a consideration; like all electronic instruments they do not like moisture, and sea water is fatal.

The storage of images can also pose a problem for fieldwork. Depending on the memory capabilities of the camera, and the resolution chosen for the images, there is a limit to the number of pictures that the camera can store. However if you have access to a laptop computer at base camp, you will be able to download the images and free the camera's memory for further work. Finally, remember that digital cameras are heavy on batteries; disposable batteries for a field season would be a significant cost, so consider whether rechargeable batteries could be used.

5.12 Panning

To be able to use a gold pan is a useful accomplishment for a geologist. It needs little practice. Gold and cassiterite can be panned from streams, but many rock minerals which survive erosion can be concentrated by panning too. These include garnet, rutile, zircon, epidote, monazite, magnetite, haematite and ilmenite. Differences in the 'heavy mineral suites' extracted by panning soils are useful guides to the underlying geology in poorly exposed regions (see *loaming*, Section 4.5.3)

Because of its density, native gold (SG 16.6–19.3 depending on purity) is easy to concentrate in a pan, but garnet and epidote (SG 3.2–4.3) are only a

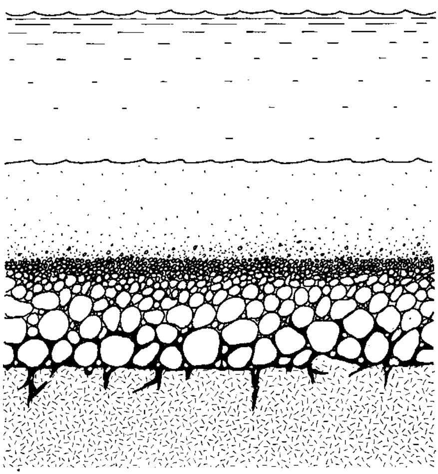


Figure 5.20 *A simplified profile through stream gravels; the heavy-mineral sands accumulate at the base of the coarser material and may even penetrate cracks in the bed rock. Note that the sands and gravels of the stream are in constant movement which allows the 'heavies' to pass downwards through them*

little denser than sand and rock debris (SG 2.7) and more skill is needed to concentrate them. A 30 cm diameter pan is sufficient for purely geological purposes. Keep it spotless and free from rust and grease, so do not use it as a camp frying pan. Collect *stream gravel* from the coarsest material you can find, for that is where the heavier minerals concentrate (Figure 5.20). Dig for it with a trowel or entrenching tool and get down to bedrock if possible. Collect *soils* from below the humus. Heap the pan full of material, then shake it vigorously underwater in a stream, or even in a tin bath. The finer heavies will pass down through the coarser light material, a process known to the mineral dresser as *jigging* (and this is what, with the constant movement of stream gravels, helps to concentrate the 'heavies' on bedrock). Larger pebbles can be scraped off the top and discarded. Gradually wash off the finer, lighter materials by: tilting the pan, dipping it into the water; lifting it out, swirling it around; dipping again; until only a small amount of usually darker and sand-size material is left. Then, using only a small amount of water, give a final careful swirl with the pan at an angle of about 30° to form a *tail* of sediment, graded with the 'heavies' at one end in order of their densities, leaving the lighter material at the other end (Figure 5.21). Now,

Figure 5.21 *A geologist panning in the Euphrates valley*

under a cover of a little water, identify any minerals you can, using your hand lens. Wash the concentrates into a phial for future examination, using a plastic funnel and a camel-hair brush. Label it. Decant the surplus water back in camp. Panning is like fishing: you do not have to find anything to enjoy it.

6

ROCKS, FOSSILS AND ORES

This chapter assumes that readers are already familiar with systematic methods of rock naming in the laboratory, know basic palaeontology and can recognise the mineral materials mentioned. Here you are told how to apply that knowledge in the field.

6.1 Rock Descriptions

When you have mapped a rock unit for long enough to be familiar with it and its variations, describe it fully and systematically in your notebook. Rock descriptions are essential when you come to write your report later. A rock description made from memory, perhaps weeks later, is unlikely to be accurate or complete. One made in the field describes the rock as seen, with measurements of specific features, and factual comments on those subtle characteristics that are impossible to remember properly later. It also ensures that you record *all* the details needed.

Systematically describe each rock unit shown on your map in turn. Preferably work from the general to the particular. Describe first the appearance of the ground it covers: its topography, its vegetation, land use, and any economic activity associated with it. If the soils are distinctive, describe them too. Next describe the rock exposures themselves: their size frequency and shape; whether they are turtlebacks, pavements, or tors; or rounded or jagged ridges, gentle scarps or cliffs. Comment on joint spacing, bedding and laminations (see Appendix V), structures, textures, cleavage and foliation. Support your observations with *measurements*. Describe the colour of the rock on both weathered and freshly broken surfaces. Weathering often emphasises textures; note its effect, such as the honeycomb of quartz left on the surface of granites after feldspars have been leached away, which immediately distinguishes silicic from less silicic varieties. Finally describe the features seen in a hand specimen, both with and without a hand lens. Note texture, grain-size and the relationship between grains. Identify the minerals and estimate their relative quantities (Appendix V, Figure AV.1), bearing in mind the tendency to over-estimate the proportion of dark minerals over paler varieties. Name the rock. Where appropriate, prepare a sedimentary section and/or log (Sections 6.3.2 and 6.3.3). A *formation letter(s)* will eventually be assigned to

Basic Geological Mapping, Fourth Edition. John W. Barnes with Richard J. Lisle
 ISBN: 0-470-84986-X

every mappable rock unit, but that is something to be done later. Remember, you can take a specimen home with you, but not an exposure. Ensure that you do have all the information you need before you leave the field.

6.2 Identifying and Naming Rocks in the Field

There are two problems here. The first is to find out what the rock is in petrographic terms, the second to give it an identifying name to use on your fair copy map and in your report. The first is the *field name*, the second the *formation name*.

6.2.1 Field names

A field name should be descriptive. It should say succinctly what the rock is, but you cannot name a rock until you have identified it. A field geologist should be able to determine the texture, the relationship between minerals, and estimate their relative abundances in most rocks under a hand lens. He should be able to distinguish plagioclase from orthoclase, and augite from hornblende in all but the finer-grained rocks. He should be able to give some sort of field name to any rock. Dietrich and Skinner's *Rocks and Rock Minerals* (1979) is an excellent guide to identifying rocks without a microscope.

A field name should indicate structure, texture, grain-size, colour, mineral content and the general classification the rock falls into, e.g. *thin-bedded fine-grained buff sandstone* and *porphyritic medium-grained red muscovite granite*. These are the full field names but shortened versions, or even initials, can be used on your field map. Avoid at all costs calling your rocks, A, B, C, etc., on the assumption that you can name them properly in the laboratory later: this is the coward's way out. If you are really stuck for a name, and with the finer-grained rocks it does happen, then call it *spotted green rock*, or even *red-spotted green rock* to distinguish it from *white-spotted green rock*, if need be. Ensure, however, that you have a type specimen of every rock named. Sometimes you may find it helps to carry small chips around with you in the field, for comparison.

6.3 Litho-stratigraphy and Sedimentary Rocks

In the previous section the word formation has been used in a very general sense for a mappable rock unit as a matter of convenience, and for the lack of a better word. However, for formal use there is an accepted conventional litho-stratigraphical hierarchy of terms to describe the grouping of rock units (Holland *et al.* 1978, p. 8). These are described as:

supergroup
group
formation
member
bed

6.3.1 Sedimentary formations

A sedimentary *formation* has internal lithological homogeneity, or distinctive lithological features that constitute a form of unity in comparison with adjacent strata. It is the basic local mappable unit. It crops out and can be traced sub-surface to other exposures; you show it on your map with a distinctive colour. It is the primary local unit (Holland *et al.* 1978). *For convenience, it may be sub-divided into members*. If a formation has not already been formally named, name it yourself in the approved manner, attaching a place name to the rock name, e.g. *Casterbridge Limestone Formation*, or for working purposes just call it the *Casterbridge Limestone*. Avoid terms, such as *White Limestone* or *Brachiopod Bed*. Establish a type section for every named formation for reference or comparison in case problems arise. See the Geological Society of London guide (1972) on the subject. The US Geological Survey offers similar advice (Cohee 1962).

A formation may consist of several *members*, which may not be continuous but have a distinct lithological character. The smallest division of a formation is a *bed*, which is a unit with a well-marked difference from the strata both above and below it.

A *group* consists of two or more naturally related formations. A *supergroup* consists of two or more associated groups. Groups do not have to be collected into supergroups.

6.3.2 Stratigraphic sections

Stratigraphic sections show the sequence of rocks in a mapped region, distinguishing and naming the formations and members that comprise them. They show the thickness of the units, the relationships between them, any unconformities or breaks in succession, and the fossils found. It is impossible to find one continuous exposure that will exhibit the complete succession of a region (even in the Grand Canyon) and a complete succession is built up from a number of overlapping partial sections. There may even be gaps where formations are incompletely exposed.

Sections can be measured in a number of different ways and some guidelines are given here. The first task is to find a suitable place with good exposure. Make measurements of the true thicknesses of the beds, starting at the base of the sequence, and log them in your notebook as a vertical column. In measuring thickness, corrections must be made for the dip of the beds and the slope of the surface on which they crop out. This can be done graphically or trignometrically (Figure 6.1). Compton (1966) illustrates several methods of measuring true thickness directly.

Indicate on the stratigraphical section the name and extent of every lithological unit, together with the rock types within it. Take specimens of everything logged. Mark and note the names of any fossils found; collect specimens

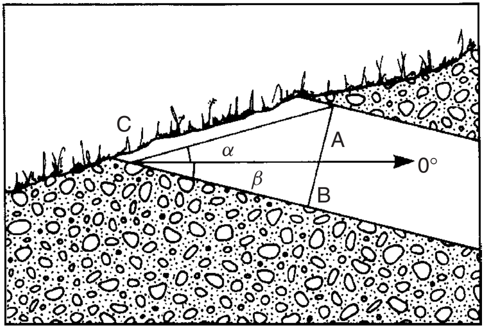


Figure 6.1 Correcting for the true thickness of a bed. The stratigraphic thickness $AB = AC \sin(\alpha + \beta)$

for later identification where necessary. Note the position of every section on your field map. Redraw to scale in camp the sections from your notebook on squared paper. Later the section may be simplified and combined with sections from other parts of your mapping area as a columnar section or a fence diagram (Sections 9.2.6 and 9.3.4). Stratigraphic sections may also include igneous and metamorphic rocks.

6.3.3 Sedimentary (graphic) logs

Although there are similarities, sedimentary logs and stratigraphic sections differ in their purposes. Sedimentary logs are detailed graphic displays of the lithologies, sedimentary structures, and the fauna of a succession. The succession is broken down into homogeneous units termed *sedimentary facies* which contain distinctive combinations of features. The manner of deposition of a unit can be inferred from its facies, and the overall environment of deposition from its vertical and lateral variations. There are a number of conventions in recording logs. As with stratigraphic sections, the thickness of beds is shown to scale in a vertical column. However, in a sedimentary log there is also a horizontal scale: the width of the column is a measure of the grain size of each rock unit portrayed (Figure 6.2). Symbols are used to indicate a wide variety of sedimentary features, such as different forms

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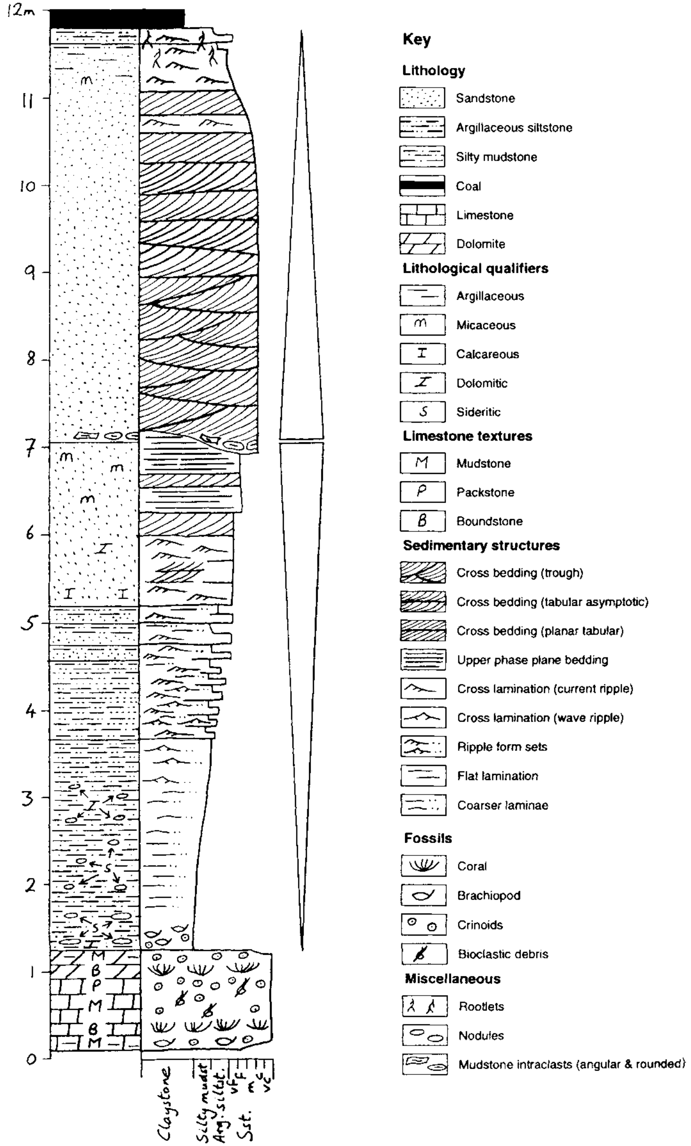
Figure 6.2 A graphic sedimentary log. The horizontal scale is a measure of grain-size. Divisions are unequal because the ϕ-scale range for silt is only four fifths that for sand (see Appendix V). The vertical triangles to the right indicate coarsening and fining in the sequence (from North Wales, courtesy of A.R. Gardiner) (facing page)


12m
11
10
9
8
7
6
5
4
3
2
1
0
Claystone
Silty mudst
Arg. siltst.
Sst.
vf
f
m
c
vc
Key
Lithology
Sandstone
Argillaceous siltstone
Silty mudstone
Coal
Limestone
Dolomite
Lithological qualifiers
Argillaceous
Micaceous
Calcareous
Dolomitic
Sideritic
Limestone textures
Mudstone
Packstone
Boundstone
Sedimentary structures
Cross bedding (trough)
Cross bedding (tabular asymptotic)
Cross bedding (planar tabular)
Upper phase plane bedding
Cross lamination (current ripple)
Cross lamination (wave ripple)
Ripple form sets
Flat lamination
Coarser laminae
Fossils
Coral
Brachiopod
Crinoids
Bioclastic debris
Miscellaneous
Rootlets
Nodules
Mudstone intraclasts (angular & rounded)

of ripples, cross-bedding, rootlets and mud-flakes. So far no convention of symbols has been universally accepted. Devise your own in a form which makes them easy to understand.

Choose a site for a sedimentary log as for a stratigraphic section. Measure the thickness of each lithological unit and record its sedimentological features in your notebook. Take special note of the boundaries between units, i.e. whether they are erosive, sharp or gradational, and see whether there are any lateral variations. Draw logs before leaving the field so that any gaps in your notebook information can be identified and rectified. Tucker (1996) gives full details.

6.3.4 Way-up of beds

Symbols indicating which way beds 'young' are frequently omitted on maps in strongly folded areas. There are ways of telling which way-up a bed is. *Sedimentological* indications are the most abundant and include cross-bedding, ripple marks, sole marks, graded bedding, down-cutting erosive boundaries, load casts and many others. Palaeontological evidence includes trace fossils, burrows and pipes left by boring animals, and roots of crinoids and corals in their growing position. Many palaeontological pointers to way-up are fairly obvious, but one alone is not always reliable. Look at a number of different indicators before making a decision.

In structurally disturbed zones, where it may be difficult to tell which way-up beds are, use the 'overturned' dip and strike symbols on your map where you are sure beds are wrong-way-up and add a dot to the pointer where you know they are right-way-up (see list of symbols on inside of back cover); uncommitted symbols then indicate lack of evidence either way.

Wherever there is evidence of way-up in such areas, note what it is, such as *c.b*, for cross-bedding, *r.m.* for ripple marks, *t.p.* for trumpet pipes, etc. That is all part of your field evidence.

6.3.5 Grain sizes

Many sedimentary rocks can be classified by their grain size. Anything greater than 2 mm is gravel; anything less than 4 microns is mud; what lies between is sand or silt. Each of these groups is sub-divided into coarse, medium and fine, etc. (Appendix V, Table AV.2). Measure larger grains in the field with a transparent plastic scale placed over a freshly broken surface; use a handlens with the scale for the finer sizes. Generally, if a piece of rock is gritty between your teeth (no need to bite!), then silt is present, and if grains lodge between your teeth there is fine sand, but that should be visible under your handlens.

6.3.6 Smell

Some sandy rocks also contain clay. Breathe on a fresh surface and note whether it returns a clayey smell. This is not infallible, for if the rock has been too indurated, the clay minerals will have been altered to new minerals. Other rocks, namely those which once had a high organic content, emit a sulphurous smell when hit with a hammer. Iron staining indicates an iron cement.

6.3.7 Hardness

Always test a very fine-grained or apparently grainless rock by scraping the point of your hammer across it. If it scratches, it is probably a sedimentary rock, if not it may be a chert or hornfels, or an igneous or pyroclastic rock. Some white, cream or grey rocks, can be scratched with your fingernail. They are probably gypsum or anhydrite; possibly even rock salt, but one lick can settle that!

6.3.8 Acid

Every geologist should carry a small bottle of 10% hydrochloric acid in the field. To use it, break off a fresh piece of rock, *blow off any rock dust*, and add *one* drop of acid. If the reaction is vigorous, the rock is *limestone*. If it does not fizz, scrape up a small heap of rock powder with your knife and add another drop of acid to it. Gentle reaction indicates *dolomite*. Many carbonate rocks contain both calcite and dolomite, so collect specimens for staining when you return to base. Remember, however, that some rarer carbonates react to acid too. Do note that one drop of acid is enough to test for reactions. Do not flood the surface with it, all you need is a very small plastic bottle, the type used for eye-drops.

6.4 Fossils

Fossils cannot be considered in isolation from their environment. All the features found in a fossiliferous rock must be recorded if you are to gain the full benefit from the fossil itself. Note their abundance in each fossiliferous horizon of the locality. Are they widespread or clustered in groups? Did the fossils die where found or were they transported there after death? Do they show alignments due to currents? Different fossils may occur in different parts of the same horizon and there may be lateral changes that can be traced over considerable distances, indicating a changing environment. There may also be a vertical change as the depth of water the rocks were deposited in changed. All this must be recorded in your notebook, either on a measured section or, if the occurrence is suitable, on a stratigraphic section or graphic log.

Do not be over-anxious to collect a fossil when you find it. First study it in place, noting its attitude and surroundings: make notes and sketches. Probably you will see only a small part of the fossil, perhaps because only a small part of it is exposed, or because only small fragments occur. Decide how best to remove it from the rock, then remove the specimen carefully, trying to keep it intact. Use a chisel or even scrape around it with your knife. Sometimes it is better to remove a large piece of rock and carry it around all day, than to be too ambitious in trying to extract a specimen in the field. If you find a whole fossil, one specimen of that species will probably be enough; leave the rest for others. Usually, however, you will only be able to collect incomplete specimens. Some may show external features, some internal casts. Collect both. As with rocks, name fossils in the field but before going into the field, refer to the types you may expect to see in the rocks you will be looking at. Do not be discouraged if you cannot name in detail every fossil you find. Expert help is often needed.

Once you have discovered a sequence containing specific fossils in one part of your mapping area, you may then find that you can use it for mapping on a wider basis, especially where you have a series of repeated sequences or cyclothems. The fossils will tell you which part of the series you are in. Again, where you have beds of great thickness, your fossiliferous horizon will tell you where in that bed you are. It can even tell you the displacement, where both sides of a fault are in the same rock type. Mark rich, or important, fossil localities on your map with a symbol, so that others can find them again later.

6.5 Phaneritic Igneous Rocks

Phaneritic igneous rocks are easily recognised and the acid to intermediate (leucocratic) varieties can usually be readily named. Dark-coloured (melanocratic) phanerites are perhaps a little more difficult to identify, but you can usually put some field name to them which is nearly correct. Before you go into the field, try to look at specimens of the types of rock you expect to encounter; if possible, those from the area you are going to.

6.5.1 Grain-size in phaneritic rocks

Grain-size terminology in igneous rocks differs from that used for sediments, namely:

Coarse-grained	>5 mm
Medium-grained	1–5 mm
Fine-grained	<1 mm

Use the terms coarse, medium and fine when discussing a rock, but in formal descriptions state grain sizes in millimetres. If a rock is porphyritic or porphyroblastic, remember to quote the size of the phenocrysts or porphyroblasts too; a phenocryst or porphyroblast 10 mm long may appear to be ‘large’ in a fine-grained rock, but not in a coarse one.

6.5.2 Igneous mineralogy

When naming a rock, identify the principal minerals and estimate their relative abundances, using the chart in Appendix V. Without a chart, you will almost certainly overestimate the quantity of the dark minerals by a factor of up to two. Look at a *selection* of the grains of every mineral present, not just one or two of them. Identify each mineral in turn, using your handlens. Note the relationships between different minerals. Rotate the specimen in the light to catch reflections from poly-synthetic twinning in plagioclase; it is remarkable how many geologists have never recognised this except under a microscope. Dark minerals are the most difficult to identify in a hand specimen, and pyroxene, amphibole, epidote and tourmaline are easily confused. The different cross-sections and cleavages in pyroxene and amphibole should be known to all geologists. Note also that the cleavage in amphibole is much better than in pyroxene; epidote has only one cleavage; and tourmaline has virtually none. Refer to Dietrich and Skinner (1979) to name the darker rocks.

6.6 Aphanitic Igneous Rocks

Aphanitic igneous rocks can be difficult to name in the field. Hard and compact, at first sight they appear to give little indication of their identity. Divide them into light-coloured aphanites, ranging up to medium red, brown, green and purple; and darker aphanites covering colours up to black. Use the old term *felsite* for the first group and mafite for the second. Table 6.1 shows how the two groups divide. Careful examination of aphanites under a handlens usually gives some pointers to their identity, and many contain phenocrysts, which also helps. Basalt is by far the commonest of all black aphanites. In the field, refer to the 'spotted black rock' type of terminology if all else fails.

6.7 Veins and Pegmatites

Quartz veins are common and should give no trouble in identification. Some are deposited by hydrothermal solutions along fractures and may show coarsely zoned structures and, sometimes, crystal lined vughs. Others have been formed by replacement of rock and may even show 'ghosts' of the replaced rock with structures still parallel to those in the walls. Some veins are clearly emplaced on faults and may enclose breccia fragments; some may

Table 6.1

Felsites	Mafites
Rhyolites	Andesites (a few)
Dacites	Basalts
Trachytes	Picrites
Andesites (most)	Tephrites
Phonolites	Basanites
Latites (trachyandesites)	

contain barite and fluorspar and even sulphides. If pyrite is present, check for ore minerals (but see Figure 6.3). However, not all veins are quartz veins. Some contain calcite, dolomite, ankerite or siderite, or mixtures of them, and they may be mineralised too. Note, however, that veins do not necessarily have igneous associations.

Pegmatites always have igneous associations. They are usually, but not exclusively, of granitoid composition. Grain size may be from 10 mm upwards to over metre size (Figure 6.3). 'Granite pegmatites' fall into two main groups, *simple* and *complex*. Simple pegmatites are usually vein-like bodies consisting of coarse-textured quartz, microcline, albite, muscovite, sometimes biotite

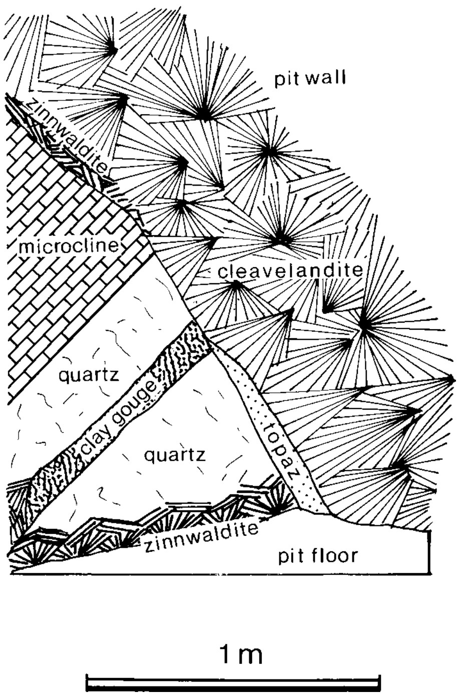


Figure 6.3 *Part of a complex pegmatite in Buganda Province, Uganda, redrawn from a notebook sketch of the wall of a prospecting pit. Note the large radiating sheaves of 'cleavelandite' albite; the massive microcline; the granular topaz (not gem form); and large books of zinnwaldite, a lithium-bearing form of biotite*

and, rarely, hornblende. Complex pegmatites can be huge, some may be tens of metres long, and often podlike in shape with several distinct zones of different composition around a core of massive quartz. They may be mineralised, with beryl, spodumene, large crystals of commercial muscovite, and various other micas, including zinnwaldite and lepidolite. They may also contain ore minerals such as cassiterite and sometimes rarer ore minerals, including columbite (niobite) and tantalite.

6.8 Igneous Rocks in General

Always examine an igneous contact thoroughly. Look at both sides carefully and make sure that it is not an unconformity or a fault contact. Note any alteration and *measure* its extent: a ‘narrow’ chill zone will mean little to the reader of your report. Sketch contact zones and sample them. Contact metamorphism converts mudstones to hornfelses, hard, dense fine-grained rocks, often spotted with aluminium silicates. They can be difficult to identify; map them as appropriate, e.g. *grey hornfels*, or *spotted black hornfels*, or *garnetiferous green hornfels*. Sandstones are metamorphosed to quartzites near contacts. Carbonate rocks become *tactites* or *skarns*, diverse mixtures of silicate minerals. Search skarns with special care for ore minerals, for they are very susceptible to mineralisation. Examine contacts between lavas (and the rocks both above and below them) closely and do not forget the contacts between individual flows.

Few large intrusions are homogeneous, yet many maps give that impression, for they are often shown on a map by only one pattern or colour. Map the interior zones of an intrusion with the same care you would give to an equivalent area of sedimentary rocks. Boundaries between phases may be irregular and gradational, but differences in mineral composition and texture, and very often flow-banding, can usually be seen if looked for. Map them. Map also all dykes and veins in intrusions, or at least note their frequency and strikes if small. Record joint patterns.

6.9 Pyroclastic Rocks

Treat pyroclastic rocks as if they were sedimentary rocks and apply the same rules when mapping them. They are important markers in sedimentary sequences because they may be deposited over wide areas in relatively short periods of time. Pyroclastic materials are essentially glassy ashes. Unconsolidated they are called *tephra*, when consolidated *tuff*. *Agglomerates* are pyroclastics composed mostly of fragments larger than 64 mm, *lapilli tuff* of fragments (usually rounded) of 64 mm down to 2 mm, and *ashy tuff* anything below 2 mm. *Welded tuffs* are those in which the ashy fragments fused during deposition. *Ignimbrite* is a special name reserved *only* for rhyolitic welded tuffs. Name tuffs, where possible, for their related lavas, e.g. *andesite tuff*, or *ashy andesite tuff*, but many fine-grained varieties are difficult to identify in the field and more non-committal names are justifiable. Some tuffs are so glassy, or even apparently flow-banded, that they can be mistaken for lavas in the field. Tuffs tend to devitrify to give spherulitic and perlitic textures. Many weather easily to industrially useful products, such as *bentonite* and *perlite*. Thorpe and Brown (1991) give more detailed accounts of how to map igneous rocks.

6.10 Metamorphic Rocks

Contact metamorphism has been dealt with under igneous rocks. Here we are concerned only with rocks resulting from *regional* metamorphism. Two factors need to be considered when mapping them: the original lithology/stratigraphy, and present lithology. Whenever possible, map them separately.

6.10.1 Naming metamorphic rocks

Sedimentary rocks change with increasing metamorphism, first to slates, then to phyllites, schists and gneisses. Igneous rocks deform and recrystallise to genisses or schists and many basic igneous rocks, including volcanics, become *amphibolites*.

Name *slates* for their colour, such as brown, green, grey, blue or purple and for their recognisable minerals, e.g. *pyritic black slate* or *green chiastolite slate*, and do remember that most slates are not hard roofing-quality slates. *Phyllites* cleave more readily than slates, leaving lustrous faces shining with sericite scales.

Geologists seldom agree where to put their boundary between phyllites and schists in the field: the division tends to be subjective. In general, if *individual* mica or chlorite flakes can be clearly seen, call it a schist, if not, it is a phyllite. *Mica schist* is a common ‘sack name’. Where possible, define ‘mica schists’ as *chlorite schist, muscovite schist, biotite-garnet schist*, etc., but not all schists are micaceous; there are *actinolite schists, tremolite schists*, and many others. Unfortunately, schists tend to weather easily and so are often poorly exposed.

Gneisses are medium to coarse-grained foliated rocks in which bands and lenses of different composition alternate. Some gneisses split roughly parallel to their foliation owing to the alignment of platy minerals, such as micas; others do not. Always qualify the word *gneiss* by a compositional name when first used: not all gneisses are granite gneisses as is too often assumed. Like all other rocks, a locality name can be used as a prefix, or even a more general name, such as *Lewisian gneiss*, to denote gneisses of a certain age.

Gneisses may also be named for their textures, such as *banded gneiss*. Some may contain apparent phenocrysts or *augen*. They may be cataclased *augen*, or they may be *porphyroblasts* of large new crystals growing in the rock, perhaps replacing former augen. You probably cannot tell which until seen in thin section, but *augen gneiss* is a convenient field name in either case, even if not always strictly correct.

Migmatites are, literally, mixed rocks. They contain mixtures of schistose, gneissose and igneous-looking material. Treat them in the same way as other gneisses: name them for composition, texture and structure. For all these rocks, measure the dips and strikes of foliation and the direction and amount of plunge of any minor folds (see Figure 5.14). In many instances, some structure can be obtained by drawing form-lines as described in Section 4.3.2 and shown in Figure 4.2 and also see Marshak and Mitra (1988).

6.10.2 Contacts

Contacts between many metamorphic rocks are just as sharp as those between most sedimentary rocks or igneous rocks. Some, however, may be gradational, especially within schists and gneisses. Identify every exposure compositionally when mapping them so that gradiational boundaries can be inferred where necessary (Section 4.3.1).

6.10.3 Foliation

Where structure is fairly regular, map the cleavage, schistosity and other foliations at much the same density as for sedimentary rocks. If structure becomes so complex that it is impossible to show it adequately on your map, map it at a larger scale, or make numerous sketch maps and notebook diagrams. A map cluttered with tightly crowded clusters of symbols is difficult to interpret by its author, let alone by those who may have to refer to it later on.

In addition to foliation, there are many other structures which need to be mapped in metamorphic rocks. These include the plunge and trend of any minor folds, whether in bedding, cleavage or other foliations, or even in ptygmatic veins. The sense of folding should be noted too, to indicate where the major fold closures lie. Style of folding is also important. Look for lineations, including intersections of planar features, such as bedding/cleavage, cleavage/cleavage, etc.; or mineral alignments, rodding, mullions and stretched conglomerate pebbles (Figure 5.12). In fact, map any structure, even if you do not know its significance at the time. Its meaning may become clearer later, or it may not, but at least you have it on record if it does. For further information refer to Fry (1984) and Lisle (2003).

6.11 Economic Geology

Any geologists worth their salt should be able to recognise the principal economic minerals and rocks, for it is their duty to consider the economic, as well as the purely scientific, aspects of any area they map. To ignore them, or to consider them beneath their scientific dignity, as some do and freely admit, is intellectual snobbery.

Before going into the field, review any literature concerning the minerals in the region you are about to map, both metalliferous and industrial. Note records of quarries and mines. Find out what ores have been mined, and particularly, whether they were associated with sulphides, for these ores have distinctive outcrops. Also note the rocks the ores were associated with and keep them in mind when mapping.

6.11.1 Types of body

Ore bodies do not necessarily crop out at the surface in easily recognisable form. Some are just rock in which metallic minerals are disseminated and often sparsely disseminated at that. Some *stratiform* zinc-lead ores are merely shales with finely dispersed zinc and lead sulphides, similar in grain-size to the rock minerals themselves. *Porphyry copper* deposits, those large stock-like granitoid intrusions which supply more than half the world's copper, often contain less than one per cent metal, and look much like any other intrusion. Take nothing for granted.

6.11.2 Oxidation

Ore bodies do not stand up out of the ground with fresh shining crystals of ore minerals glinting in the sun. Sulphides, in particular, are usually extensively altered above the water-table by oxidation. Some oxidise to a highly soluble state (copper, zinc and silver ores are examples) and the metals are leached downwards to be re-deposited near the water-table as a zone of *secondary (supergene) enrichment*, leaving the upper part of the ore body depleted in these metals. Those redeposited in the oxidised environment just above the water-table form an enriched zone of oxide and carbonate ores, those redeposited below it are reduced again by reaction with the other sulphides present to form a zone of *secondary sulphide enrichment*. Native metals, such as silver and copper, may also result from secondary enrichment, depending on conditions (Figure 6.4). The iron sulphides, invariably associated with sulphide ores, form insoluble oxides which remain at, and close to, the surface to accumulate during erosion resulting in a mass of cellular limonite called *gossan*. Gossans, and the reddish-brown soils associated with them, form distinctive indications of sulphide mineralisation, but that does not necessarily mean that any useful ores are associated with them; only too frequently you find only pyrite below.

Where small groundwater springs near mineralisation have leaked out, rocks may be stained by the brightly coloured copper carbonates azurite and malachite, or coated with tiny green crystals of the lead chloro-phosphate *pyromorphite*, so easily mistaken for moss.

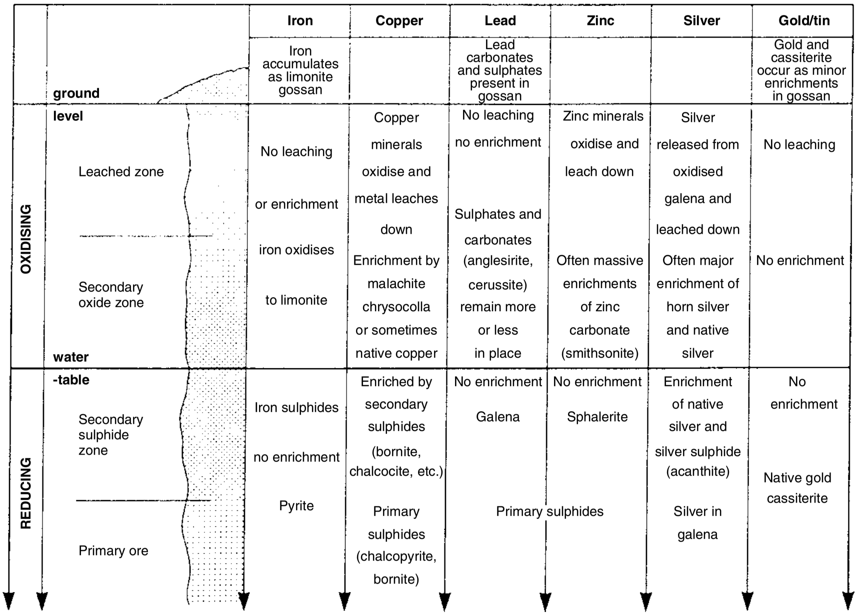


Figure 6.4 *Oxidation of sulphide ore deposits, showing how some ore minerals are oxidised and carried downwards; some to reprecipitate above the water-table; some to be reduced again to deposit as new sulphides, or as native metal, just below it, enriching sulphide ores already there. The insoluble iron-oxides remain at surface as a mass of rather cellular insoluble iron-oxide gossan*

6.11.3 Structural control

Pay particular attention to the fracture pattern in any mineralised district, for ore deposition may have been controlled by faults or joints. However, ore may also be controlled by folds, bedding planes, unconformities, lithological changes, and by contacts where granites and diorites have intruded limestones or dolomites. Ore bodies can be any shape. Some are vein-like, some are irregular masses grading into their host-rocks, some are mineralised rock breccias in collapsed carbonate rock caverns; others are merely an ore-bearing part of an otherwise barren rock, sedimentary, metamorphic or igneous, and these are the most easily missed.

6.11.4 Industrial minerals and rocks

Many of the materials you map have an economic use. The range is extensive and covers rocks themselves, such as: limestone (building, cement, chemical neutraliser); marble (building, monuments, etc.); granite (monuments, building facing, ballast); slate; and superficial deposits such as gravels and sands (concrete aggregate, moulding sands); clays (bricks, ceramics, fillers). The list is extensive. Note the gravel pits, some of them possibly now lakes, and also the quarries in your area. Build up your background of industrial minerals and refer to Knill (1978) and Harbin and Bates (1984), and look around you and note the mineral products in everyday life, from glass in your windows to the buildings in your streets. In one 300 m stretch of Swansea High Street there were nine different types of polished facing stone. In cemeteries, note which type of gravestone has weathered best; just look at the dates on them.

6.11.5 Fuels

Coal is the most likely fuel to be encountered when mapping in Carboniferous areas of the United Kingdom and the coal fields are well-documented. Overseas, not all coals are Carboniferous, and in some countries brown coals and lignites are important. Oil shales are an often forgotten potential energy source, for when petroleum sources are depleted and/or the price of liquid and gaseous fuels rises too high to be economic; ironically they are largely confined to the non-OPEC countries: China, the USSR and Estonia exploit them. Britain has large potential resources associated with the Jurassic Kimmeridge Clay and, in fact, shale oil was produced from a small Carboniferous field in the Midland Valley of Scotland from 1850 until 1964 (Barnes 1988). Oil shales can be any age from Palaeozoic upwards. However, liquid oil and gas are unlikely resources to be encountered when field mapping unless in OPEC areas.

6.11.6 Water

Water has been described as the ‘essential mineral’ and geologists in many countries spend a considerable part of their time looking for it. Much of the

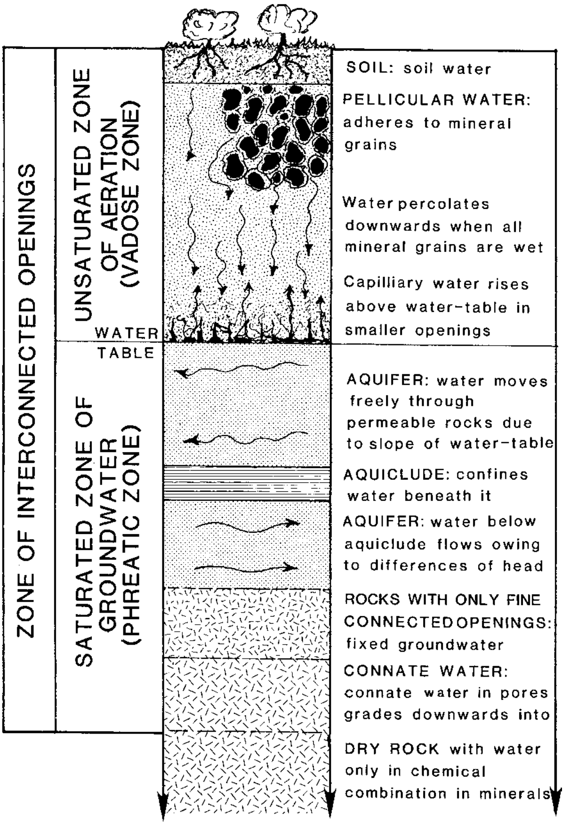


Figure 6.5 *The water profile of soil and rocks*

search for water is geological common sense. Note its occurrence in any area you map and learn from it; the general water profile is shown in Figure 6.5. There are two basic forms of water supply, namely wells and reservoirs.

Shallow wells are common in any country. They are sunk to a water-bearing horizon, sometimes to weathered rock but often to sands or gravels. The water is raised by a bucket, a hand-pump, or a mechanical pump of some sort. They have the drawback of being subject to contamination unless lined to prevent contamination by soil water. Deep wells (i.e. boreholes) are of two general types; those drilled to an *aquifer* of water-bearing permeable rock, and artesian and sub-artesian wells drilled to an aquifer below a

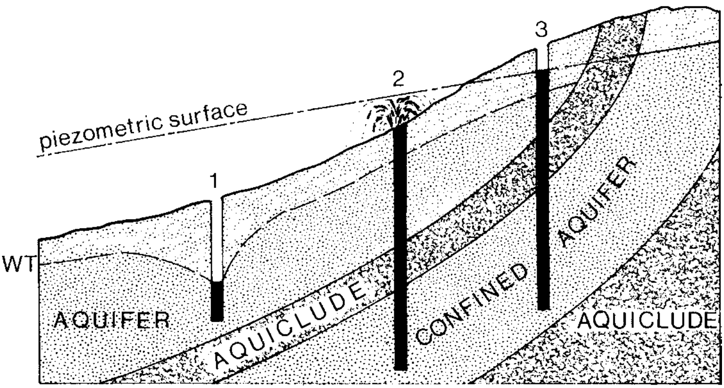


Figure 6.6 *Wells: well no. 1 penetrates to an aquifer and the water must be pumped. Over-pumping will draw down the rest-level and locally deplete the water-table until it is re-charged. Well no. 2 has penetrated through the aquiclude which confines the water within the aquifer and, because the well-head is below the piezometric surface (the level of the water-table in the aquifer where it crops out), the well is artesian and water flows without pumping. Well-head no. 3, however, is above the piezometric surface and needs to be pumped. Note that the piezometric surface slopes downwards towards the centre of the artesian basin*

non-permeable *aquiclude* (Figure 6.6). Deep wells are cased, i.e. lined by pipes to prevent contamination from shallow groundwater.

Carbonate rocks make excellent aquifers, largely because of their jointing, often enlarged by solution. However, any well-jointed rock can be an aquifer, and in southern Africa Karroo dolerites are an important water source, whilst in East Africa quartzites confined by phyllites serve as aquifers too; and yet again in the apparently unpromising African basement, granitoid rocks supply water where open-jointed water-bearing zones are sandwiched between tighter-jointed unaltered rock below and deeply weathered and partly kaolinised granite above (Barnes 1988). Do not be too hidebound over your idea of what an aquifer should be. However, wells in an unconfined aquifer can soon be depleted by over-pumping and, despite their usually far larger reserve, artesian wells can be depleted too so that they are no longer artesian and must be pumped to maintain supply. The London Basin is an example.

Reservoirs depend on being sited in a valley with catchment which will have a sufficient amount of water to fill it: reservoirs which did not fill are not unknown! Geologically, the dam wall must be sited so that it neither leaks around the walls nor beneath it. Cavernous limestones are not good foundation rocks: again, this has been done. There are two types of dam wall: *gravity dams*, held in place by earth- or rock-fill supporting a clay core which prevents the leakage of water through the dam wall, or beneath or around its sides; and concrete *arch dams*. Both are matters of engineering geology, beyond our remit here.

7

FIELD MAPS AND FIELD NOTEBOOKS

Field maps and notebooks are valuable documents which constitute part of the record of field evidence on which the interpretation of geology depends. Both are the property of your employers and will be retained by them as part of their permanent records when you leave them. The reason is obvious: if your erstwhile employers wish to reinvestigate an area you mapped, then it will be necessary to refer back to the original records. If you have taken them away with you, they may be unable to retrieve them. You may be in another country, or otherwise untraceable. Remember, your employers are the ones who paid for the work to be done. Students are obviously not in the same position as employees but they are often taken aback when in their first job their employers demand their field maps and notebooks for *their* permanent records.

7.1 Field Maps

7.1.1 Data needed

A field map is an aid to the systematic collection of geological data in the field and shows the evidence on which the interpretation of the geology was made. It shows the geological features you actually *saw* in the field; it also shows geology you have *inferred* from indirect evidence, such as changes in topography or vegetation, spring lines or float. A field map is not an interpretative map as such and, if possible, all contacts should be plotted on it when you are in the field, though some may be inferred from minor indirect evidence or sometimes merely by your judgement of where they most probably occur, helped by interpretation from aerial photographs and by interpolating stratum contours back in camp. However, fact must always be clearly distinguished from inference. A field map is not merely a rough worksheet on which to temporarily plot information before transferring it on to a ‘fair copy’ map back at camp or base; it is a valuable research document which you or others may wish to refer to again at some later date. No evidence should be erased from it to ‘tidy it up’, or because it is not needed to aid the present interpretation, nor should you add anything to it at a later date which you think you saw in the field but did not record at the time. The type of information to be recorded on a field map is:

Basic Geological Mapping, Fourth Edition. John W. Barnes with Richard J. Lisle
 ISBN: 0-470-84986-X

1. the location of all rock exposures examined;
2. brief notes on the rocks seen;
3. structural symbols and measurements, such as those for dip and strike;
4. locations to which more detailed notes in your notebooks refer;
5. the location from which each rock or fossil specimen was collected;
6. the location at which every photograph was taken or field sketch made;
7. topographic features from which geology may be indirectly inferred but which are not already printed on the map; changes of slope or vegetation and the position of seeps and spring-lines are examples;
8. all contacts, including faults, both certain and inferred;
9. river terraces, beach terraces, and other similar features;
10. alluvium, scree, boulder clay and any other superficial materials, including landslide debris;
11. cuttings, quarries and other man-made excavations exposing geology, e.g. pits and boreholes; even mine spoil heaps can indicate geology beneath the surface;
12. comments on the degree of exposure or lack of exposure, and on soil cover.

Because they are valuable, field maps should, as far as possible, be kept clean and protected from rain and damp. This is not always possible and important information must not remain unplotted for fear that the map may get wet or dirty if the map case is opened in the rain.

Ink-in your day's work in the evening the work was done, including your map notes written in small but legible printing, using a fine pen and *waterproof* ink.

7.1.2 Preparation

Before using a new map sheet, cut it into a number of sections or 'field slips' to fit into your map case without having to fold them. Folding ruins a map: it is difficult to plot any information close to folded edges (especially if folded over twice) and any information plotted close to the fold, or on it, is soon smeared and eventually worn off. On the reverse of every field slip print the title of the (complete) map, the number of the field slip, and a diagram to show how the several field slips which constitute the whole map are arranged. This is in case field slips are mislaid in the headquarters filing system, as has been known to happen! Also state the scale, and on the reverse of at least one slip give a full explanation of the colours and symbols used (Figure 7.1). Any unconventional colours or symbols used on a single slip should be shown and explained on the back of that slip. On the face side of the map, the north direction from which all readings have been measured should be shown, true, grid or magnetic north, as the case may be; preferably

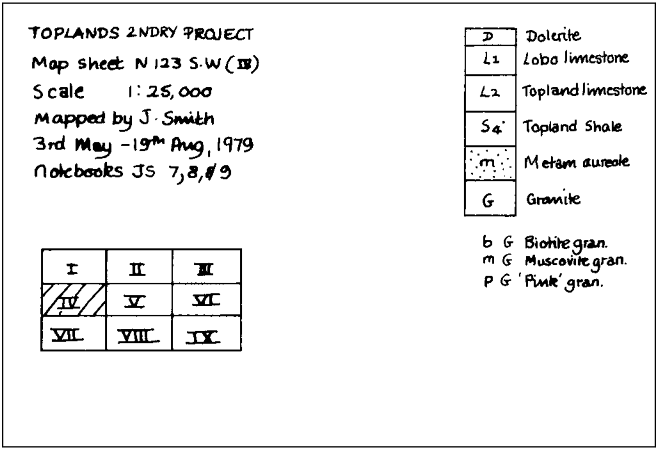


Figure 7.1 *Reverse side of a field slip with the information it should carry. Note the index showing how this slip relates to those that make up the whole field sheet*

this should be true north. In addition, the slip should show its author's name, the dates covering its production, and the notebook numbers relating to it.

Do not stick your field slips together with transparent adhesive tape when fieldwork is complete. It makes the map awkward to use again in the field if new information is to be added, and also most adhesive tapes shrink and dry out with time at a different rate to the paper of the map. This distorts the map, or the tape comes adrift, leaving a dirty stain which may penetrate from the back to the front of the map.

7.1.3 How and what to plot

A field map is a record of field observations of the type listed in Section 7.1.1. Plot the position of exposures seen and indicate rock-type by formation letters, letter symbols, or by colouring, supported where necessary by notes on the rock condition. Keep notes short and use abbreviations such as: fg (fine-grained), lam (laminated), shd (sheared). Refer to Section 4.3.1. Many exposures need no more than an outline to show their limits, shaded with the appropriate coloured pencil. Exposures which are so small that they can be shown only by a dot should, however, always be supported by a letter symbol, otherwise they tend to be overlooked when inking in the map later. If notebook notes are made at an exposure, then its location on the map must be linked to the notebook record (see Section 7.1.5). Structural observations

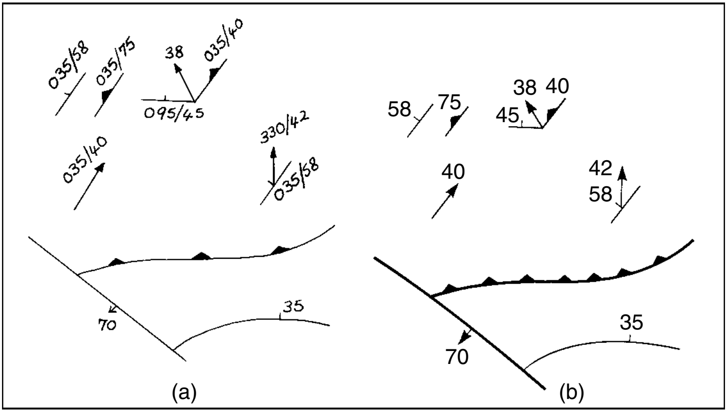


Figure 7.2 *Symbols for field (a) and fair copy (b) maps compared. Strike and trend, dip and plunge, are shown on the field map, but only dip and plunge on the fair copy*

are shown by the appropriate symbols, drawn large enough to enable them to be traced off accurately onto the fair copy map on a light-table: 6–7 mm is a suitable length for strike symbols on a field map. Print the numerical value of dip or plunge legibly in such a position that there is no ambiguity over which symbol the figures refer to. Even better, record both strike and dip together by using the 'right-hand rule' (Figure 7.2). It is a matter of debate whether to enter every dip and strike, trend and plunge in your notebook, provided you draw your symbols large enough on the map itself and record strike and dip, etc., in figures beside them. Booking unnecessary information merely consumes time better spent on mapping but this really depends upon who is your paymaster.

Contacts should be shown as continuous lines where seen on the ground, with a note or symbol to indicate their type. Do not try to distinguish between different types of contact by different pencil line thicknesses. Distinguish faults by the letter 'f' or, if the dip is known, by a dip arrow (see list of symbols inside back cover). Inferred contacts are shown by broken lines and different reliabilities of inferred contacts can be distinguished by the frequency of the breaks. Keep breaks in broken ('pecked') lines small, otherwise the lines look untidy. Show thrusts with the traditional 'saw teeth' on the *upper plate*, but do not try to draw the teeth as closely as those you see on printed maps: a tooth every 1–2 cm is quite adequate on a field map, and if you do make a mistake is far easier to erase after inking in (Figure 7.2).

Although a field map is essentially a factual data map, this does not prevent you from plotting the inferred positions of contacts deduced from indirect evidence such as vegetation, spring-lines and breaks of slope. In fact, the field is the proper place to infer contacts, for there is usually some evidence, however slim, of their positions. The drawing of contacts in the office, or back in camp, is only justified if you have to resort to geometrical constructions, such as stratum contours, where there is a complete lack of evidence on the ground, or when you have geophysical or photogeological information to help you.

Any topographic features which may reflect concealed geology but are not already printed on your base map should be added to it. These include: break of slope, vegetational changes, distinctive soils, springs and swampy patches. Show also landslides, scree and alluvial terraces. Outline mine tips because they can often provide fresh specimens of materials which are otherwise seen at surface only in a heavily weathered state (this is particularly so in humid tropical climates) or even prove that certain rocks which are not exposed, or are quite unsuspected in the area, do occur at depth.

The amount of detail that can be shown on a map obviously depends on the scale you are working on. A field slip should not be so cluttered with information that the ‘wood cannot be seen for the trees’, but even more difficult to interpret is the map which shows almost nothing but a series of numbers referring to notebook entries. There is a happy medium between these two extremes. The face of the map should contain all relevant *basic* geological information; the notebook should expand on it and provide details of features too small to show on the map. The complexity of the geology and its degree of exposure also, of course, determine how much can be shown. Sometimes a small scale may be deliberately chosen by an employer to restrict the amount of detail in a reconnaissance survey when a larger scale might tempt a geologist to spend too much time on details. On the other hand, if the main object of the work is to solve a specific geological problem, then the scale must be large enough to show, without crowding, the type of detail that must be mapped to solve the problem, and if a map of suitable scale is not available, then one must be made. Often, however, the complexity of geology and degree of exposure vary from one part of a region to another, so that very large scale maps only need to be made over limited areas, with a considerable saving in cost. Frequently, the results of small scale mapping indicate areas which require re-mapping on a larger scale; this is particularly so in mineral exploration where larger and larger scale maps of smaller and smaller areas may be made as the more interesting localities are recognised and unmineralised ground eliminated. If *occasionally* you are forced to make more extensive annotations on a map than space will allow, then make a small needle hole at the locality, write PTO against it, and write your notes on the back of the map, if not already written on, but do not make a general practice of it. If you need more space, use a larger scale, or make a detailed map of a limited area as described in Section 4.8.

7.1.4 Neatness

Information written on the map in the field must be written as legibly as circumstances allow. Keep one pencil, and a reasonably hard one at that, for plotting on your map, and another for your notebook. Keep your plotting pencil needle sharp, otherwise you cannot write legibly on your map. If you use the same pencil for map and notebook, you will be constantly sharpening it between notetaking and plotting. Write on your map in a fine, clear *printed* script. Do not use miniature cursive 'joined-up' handwriting; it is far less legible, especially when written with ice-cold hands under the often difficult conditions of fieldwork. Do not use stylus-type pens in the field; everyone makes mistakes and they are far more difficult to remedy if made in waterproof drawing ink; secondly, notes frequently have to be erased and rewritten because they overlap some geological feature you had not found when you first wrote them. Even when inking-in pencil written notes, you frequently have to rearrange them so that they are neater, more legible and parallel to one another. Drawing and draftsmanship is an essential skill for a geologist; if he cannot draw neatly, he cannot map accurately. Much of this skill can be acquired by effort and practice. An example of a complex field slip is shown by Ramsay and Huber (1987, p. 682).

7.1.5 Linkage of map localities to notebooks

The most practical permanent way to link map localities to notebook notes is to use map (grid) references (Section 3.3.2). Map references have the advantage that points can be located by a group of figures with great accuracy and without ambiguity and, even if the original field slip is lost, the points can be relocated on any map of any scale covering that area. In general, however, relocating map references on your map during interpretation is slow and irritating. Easier to use is simple consecutive numbering of observations. This works well, provided the points on the map are fairly closely spaced along more or less specific directions, such as traverse lines. Consecutive numbering is improved by designating each grid square printed on the map by a letter, or by the map reference of the SW corner of each grid square and then giving consecutive numbers to the observations made within those squares. Whatever you do, always enclose observation numbers written on the map within a circle to avoid confusing them with dip readings. Notebook entries are numbered A1, A2, . . . , A23, or 8746/1, 8746/2, . . . , 8746/23, etc. (Figure 3.1) and there is seldom any difficulty of relocating them on the map, but always draw a diagram in the front of your notebook to show later readers how the letter symbols relate to map squares. The drawback is that if you do lose the field map, the notebook becomes virtually useless.

Map localities can also be identified by notebook page numbers. If several notes are made on the same page, designate them a, b, c. When more than one notebook is used for a project, prefix the page number with the book number: locality 5/23b, for example, means note b on page 23 of notebook number 5. Much depends on whether you are mapping purely for your own purposes, such as on a training course or for your own research project, or whether you are working for an organisation. Organisations usually have their own rules so that later workers can use your field maps and notes for later re-assessment of a region.

7.1.6 Inking and colouring field slips

Observations made on field slips during the day should be inked-in that night. Even on the best protected maps, fine pencil lines become blurred or lost with time. When green line mapping, exposure margins should be outlined with green *waterproof* ink or, in sunnier climates, with a fine closely dotted (not dashed) line in black waterproof ink. After inking, recolour each exposure with the appropriate coloured pencil. Ink traverse lines with a continuous line where geology is exposed or certain, and a broken line where inferred, then overlay the traverse line, continuous or broken, with a pencil line of appropriate colour.

Inked contacts can now be distinguished by lines of different thickness drawn with stylus-type pens, to distinguish faults and unconformities from other rock contacts, but notes should still be added to confirm their characters: abbreviations such as ‘f’ for fault, and ‘uc’ for unconformity are sufficient. Unmarked contacts are presumed to be normal.

Ink all structural symbols and rewrite the amounts of strike and dip, etc. Rewrite notes in fine neat script so that they cover no geological features and align them so that all, as far is possible, are parallel with the same direction. It is irritating having to turn a field slip first one way, then another, to read the information on it.

There may well be interpretative lines shown on a field slip at the end of a day which are still uncertain; leave them un-inked until you can confirm their validity, even if it means re-pencilling their traces each evening to avoid losing them. Add any information from aerial photographs to your map in waterproof ink (purple for general geology, red for faults) to distinguish this information from that found on the ground. This discrimination in no way diminishes the validity of photogeological information; but it does distinguish its sources and also indicates where features should be sought on the ground.

Having inked-in your map and reviewed your day’s work, then, if you must, *lightly* shade or cross-hatch those areas which you now infer are underlain by specific formations. Do not colour in your map heavily, as if it were a final 'fair copy' map. Do, however, recolour your traverse lines and areas of exposure more strongly, so that they stand out as the evidence which justifies your interpretation. Geologists only too often map exposure by exposure during the day, carefully distinguishing what they have observed from what they have inferred, only to obliterate all their field evidence in the evening by swamping the map with solid colour in an endeavour to make it look like a geological map. A field map is an 'evidence' map; it is not a rougher version of a fair copy, and it should not look like one. Make sure that fact can be distinguished from inference on it.

7.2 Field Notebooks

Like field maps, field notebooks are valuable documents that form part of the record of field evidence on which the interpretation of geology depends. A field notebook will be referred to by later workers reinvestigating the area it concerns at least as often as they refer to the field map it relates to; perhaps to elucidate data on the map, perhaps to obtain details of specimens or fossils collected. Later workers may also want further details of specific exposures or lithological sections, to discover why you drew the conclusion you did, or your notebooks may provide information which is no longer available: exposures may have been built on or dug away, pits and quarries may have been filled, or their records lost or destroyed. Notebooks must therefore be kept in a manner that others can understand and, above all, they must be legible. The US Geological Survey insists that notebooks must be written in hand-printed script. This helps to make even those notes written with ice-cold hands on a wet and windy day more legible. Sketches and diagrams too must be properly drawn and labelled, dimensions given and, where appropriate, tinted by coloured pencil.

Develop a habit of using your notebook. During a project, non-geological records need to be kept too, such as expenses; where better than in the back of your field notebook? Use your notebook as a diary, and even if no work is done on a particular day, such as on a Sunday, or because it is pouring with rain, record it. Even visits to a cinema or a pub can be noted as such social occasions may jog your memory over geological occurrences that you saw the same day. Do remember, however, that others may read your notes later! Only too often notebooks suffer the fate of new diaries: copious neat notes are written on the first day or two, fewer and rougher ones over the next few days, and by the end of the week, notes are sketchy, untidy and illegible. Your field notebook is as important as your field map. Use it properly.

7.2.1 Preliminaries

Write the name of the project, the year, and the notebook number, on the cover of every book. Inside the cover write your own name and address in waterproof ink, and offer a reward for its return if found. Be generous: the loss of your notebook can be disastrous. If necessary, repeat the information in the language, and the calligraphy, of the country you are working in. Number notebook pages but leave the first few free for an index to be filled in day by day, with the date, what was done and the page numbers. This helps not only others who have to use your notebook, but also yourself when you come to look for information when writing your report from notes made weeks, sometimes months, later. Remember that you keep a notebook to refer to, so make it easy to do so. Ask yourself ‘What use would this notebook be if I had to refer to it again a year, two years, even five years from now?’. If you doubt that you could understand it yourself, no one else will be able to do so.

Add also to your notebook registers of rock specimens and fossil specimens collected, and photographs taken (see Section 5.10.3). Tape on to the last few pages photocopied tables of pace lengths, and charts such as the percentage chart in Appendix V. Also fasten a small piece of fine sandpaper onto the inside of the back cover too, to keep your pencils sharp.

7.2.2 Linking notes to map localities

Methods to link observations made on your map to notes in your notebook, and *vice versa*, are given in Section 7.1.5. Write the map references or note numbers in a column on the left-hand side of the notebook page. Use this column only for locality notes, specimen and photograph numbers. Write note numbers in pencil, specimen and photo numbers in red and blue coloured pencil, respectively, so that they can be quickly spotted. If numerous, give specimens and photos a column of their own.

7.2.3 Recording information

The purpose of a field notebook is to expand information from your field map, not to duplicate it. For instance, normally there is little point in writing down the values of strikes and dips plotted on the map unless weather conditions are so bad that you cannot plot them in the field (although some geologists have other views). If for any reason strikes and dips have to be recorded, joints for example, then make the information easier to retrieve by recording it on the right-hand side of the page. Write your notes as briefly as possible, even omitting verbs at times, provided that you do not lose the sense or meaning. Use abbreviations where appropriate; there are many all geologists understand, such as: ls for limestone; sst for sandstone; sch for schist; f/t for fault; and jt for joint. Tabulate in the front of your book any non-standard abbreviations you use unless their meanings are obvious. Use any short cuts in the field which save time without loss of information. Whether to ink-in your day’s notes is up to you. This author (JWB) has never done so, nor did Dr Bailey. Figures 7.3 and 7.4 are examples of pages from field notebooks.

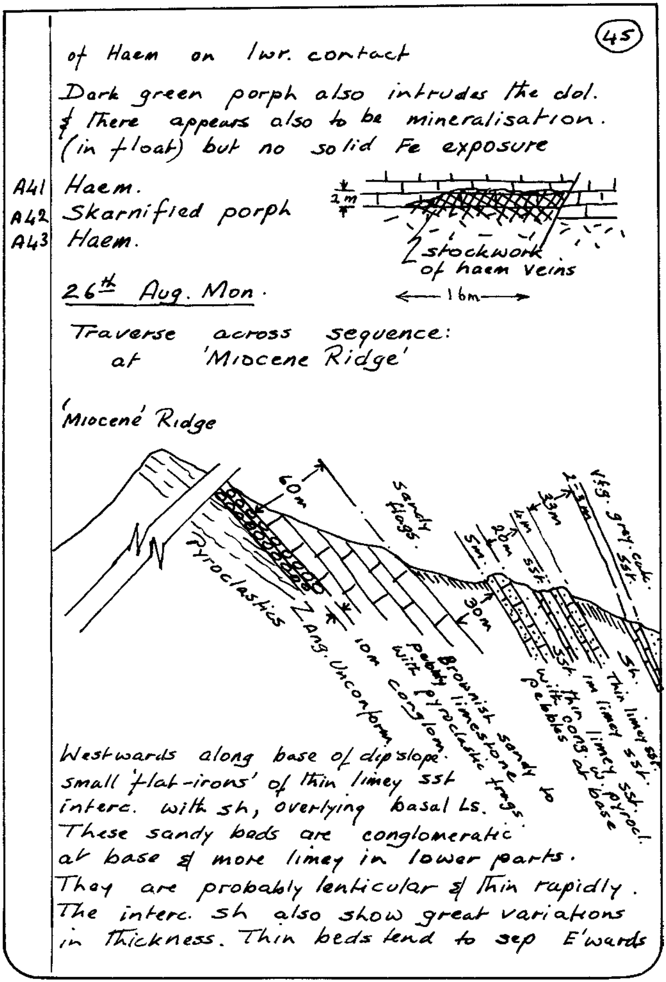
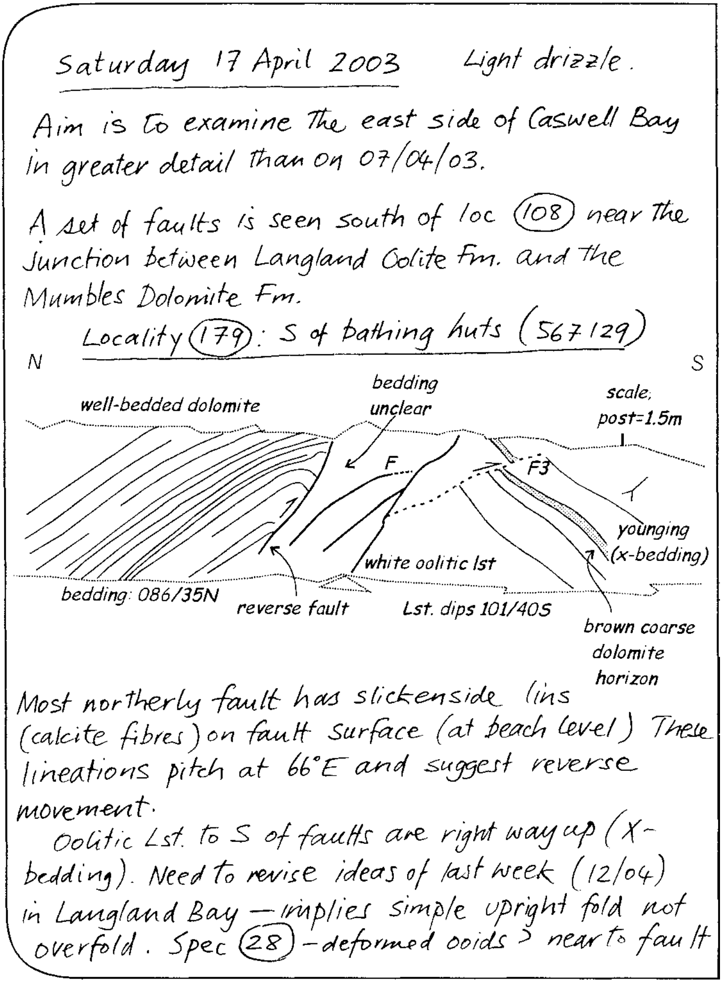


Figure 7.3 *Page from a field notebook (JWB). The column on the left shows the registered number of specimens collected. The observation number referring to the locality (Ravange, Iran) appears in the same column on the previous notebook page. The cross-section on the lower part of the page needs no locality/observation number, as the section line is shown on the field slip and on the map*



Saturday 17 April 2003 Light drizzle.

Aim is to examine the east side of Caswell Bay in greater detail than on 07/04/03.

A set of faults is seen south of loc (108) near the junction between Langland Oolite Fm. and the Mumbles Dolomite Fm.

Locality (179): S of bathing huts (567 129)

Most northerly fault has slickenside lins (calcite fibres) on fault surface (at beach level) These lineations pitch at 66°E and suggest reverse movement.

Oolitic Lst. to S of faults are right way up (X-bedding). Need to revise ideas of last week (12/04) in Langland Bay — implies simple upright fold not overfold. Spec (28) — deformed ooids ? near to fault

Figure 7.4 *Another specimen notebook page (RJL). Note the comment on weather, and the reason for the re-examination. There is both a locality number (179) and a grid reference (567 129) given, plus a description, i.e. south of the bathing huts. The cross-section has been cleaned up in the office later, for inclusion in a report*

7.2.4 Sketches

Use sketches to supplement notebook descriptions whenever possible. Sketches should show dimensions, or at the very least, some indication of scale. Ink-in complex sketches later, especially those which show very fine details. Figure 6.3 is an example of a notebook sketch redrawn for publication (Barnes 1988).

7.2.5 Cross-sections

The understanding of the structure of an area is aided by plotting cross-sections in your notebook along selected lines in the field (Section 4.1.2). Their presence in a notebook is most useful for anybody reviewing the geology of the region later and sometimes to show the validity of an interpretation far better than the often beautifully drawn and coloured cross-sections which accompany 'fair copies.'

8

FAIR COPY MAPS AND OTHER ILLUSTRATIONS

8.1 Fair Copy Maps

Geological field maps are records of factual observations made in the field: they are not interpretative maps. Therefore, when mapping has been completed, you must compile a 'fair copy' map interpreted from your field maps; your notebook notes; your follow-up laboratory work on rock and fossil specimens; and your library research. This fair copy may be a hand-drawn 'manuscript' map, or it may be aided and drawn by a computer program. The advantage of a computerised map is that it can be easily modified and redrawn to accommodate new data. However, every geologist should be capable of producing a manuscript map and the following describes the process.

A fair copy map is not merely a redrawn version of the field map; geological formations are now shown as continuous units instead of disconnected exposures. It is also a selective map and it may well be that some formations distinguished on the field slips are no longer differentiated when transferred to the fair copy. This may be because distinctions made in the field were found to be geologically less important than first thought, because they were so discontinuous that they could only be traced over short distances, or because your employer's policy is to map geology at a larger scale than they intend to publish at.

Alluvium, swamp, peat and bog are shown on the fair copy, as are also laterite and boulder clay, but soils are not. The general rule is to show any features which add to the understanding of the geology and geological history, and to omit those that do not.

Much of the information gathered during fieldwork is not transferred to the fair copy. For instance, the notes made on the face of the field map are not normally shown on the fair copy, although generalised comments may be made, such as 'cordierite schist' if this zone is not represented by a specific colour, pattern or symbol of its own, or 'red soils' to justify the continuation of an unexposed dolerite dyke. More specific notes, such as 'malachite stains', may on occasion be needed, but otherwise notes are usually only made to emphasise specific or unusual details, or to justify the geology. Specimen locality numbers should not be shown on the fair copy although rich fossil or ore mineral localities may be marked where their presence is geologically or

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 ISBN: 0-470-84986-X

economically significant. The criterion of what to show is mainly a matter of common sense. The finished fair copy should show the geology of the region in such a manner that the geological formations can clearly be distinguished, one from the other and, if they are continuous units, it should be possible to trace them from place to place across the map even though poorly exposed on the ground. Structural symbols should be sufficiently clear that the sequence of events can be elucidated and the stratigraphy determined. Above all, the map should be neatly drawn, the colours smooth and distinctive, and the printing legible.

It may be asked why so much information, painstakingly collected in the field, is omitted from the fair copy. It is because the fair copy is only a part of your interpretation. It is essentially an index which provides the basis for understanding any accompanying explanatory report. The map is not an end in itself, but it should still be able to stand on its own, showing the general features of the geology in a clear and concise manner.

8.2 Transferring Topography

A faircopy map is usually drawn on a fresh copy of the original topographic base map used in the field. If for the lack of an original base map, or because the only base map you had was heavily cluttered with coloured geographic information or with colour layered contours, the fair copy will have to be made on tracing film, then sufficient topography must be traced off it to make the geology understandable. This is tedious but it is necessary. In very mountainous districts, sufficient relief may sometimes be shown by tracing off every second or even fifth contour. Draw the contours in brown unless 'dye line' (ozalid) copies are to be made (brown ink reproduces patchily), in which case draw contours in black as very fine lines, or as broken lines, so that they can be distinguished clearly from geological boundaries.

If you have to make your base map from aerial photographs, as one sometimes has to, trace off the main drainage and hill tops to at least give some geographic frame for your geology.

8.3 Transferring Geology

When preparing a fair copy map, information has to be transferred from the field slips onto a clean base map. There are several ways of doing this. The first is to copy from field slip to the fair copy purely by inspection; this can only be done where there is sufficient printed detail on the map to serve as reference points. If there is not enough background, then divide the grid squares into smaller squares on both slips and base map, and transfer information square by square. In both cases, strike symbols must be replotted from the original data. A better way is to use a *light-table*, so that detail can be traced directly from field slips to fair copy, even if the fair copy is a non-transparent paper map. If the printed geographic detail on the well-used field slips does not fit that on the brand new fair copy base map, do not be surprised. This is owing to shrinkage due to weathering, and is probably slightly different across the paper than it is up and down it, a result of how the paper was made. If grid squares are not already on both slips and base map, draw your own grid, and adjust each field slip to the best fit as you trace the geology, square by square. A light-table is not difficult to make. Sink a window of opalescent Perspex or frosted glass (about 20–30 cms square) flush into a piece of plywood larger than your fair copy map. Mount it on a well-ventilated box. Light the window from below with two short tube lights (you can even use battery-powered fluorescent lights). To use, move the part of the map you are working on over the window: you will find this less tiring (and cooler) to use than a light-table window the size of the base map, and cheaper to make.

8.4 Lettering and Symbols

Bad printing can ruin an otherwise well-drawn map whilst good lettering can often improve a poorly drafted one. 'Transfer lettering' is one solution, but it is expensive. Many organisations have machines to print map lettering of different styles and sizes onto transparent adhesive tape which can be stuck down on the map (after colouring). Stencils can also be used in default of any other method, and although they do not give such a good result as printed lettering, they can be used over and over again, but mistakes are difficult to remedy. You can also print your lettering on a word processor, using different styles and sizes, cut them out and stick them down with paste. This is a quick and excellent way of lettering text figures; Figure 4.7 was lettered in this way. It all depends on what your department or organisation has available.

Despite such aids, every geologist should develop a good legible hand-lettering style, for there will be many occasions in his life when this is the only way he can letter his map; inking-in your field map is a good way to get practice. *Italic* letters are easier to hand-print than upright, and always use parallel guide lines except for the very smallest lettering, to control the regularity in size of lettering of different import.

Draw all strike symbols on a fair copy exactly the same size: 5 mm long is suggested. Lineation arrows can be a little longer. Draw arrow-heads neatly with an ordinary mapping pen or, better, use transfer symbols. Print figures for dip (bearing for strike is now omitted) either parallel to the symbol, or parallel to the bottom edge of the map, but not in both directions in different parts of the same map (Figure 7.2). The symbols printed inside the back cover conform to those generally accepted around the world. A much more extensive list compiled by the staff of the Australian Bureau of Mineral Resources is given in the *Field Geologist's Manual* (Berkman 2001).

8.5 Formation Letters

Every rock unit which appears on the face of the map, whether sedimentary, metamorphic or igneous, must have a distinguishing symbol or 'formation letter(s)' assigned to it. Established formations may already have officially recognised symbols such as d^{6a} for the *Lower Pennant Measures* of the British Carboniferous System, M1d for the Mississippian *Leadville Dolomite* (Formation) in the United States, and M2 for the *Upper Red Formation*, better known as the 'Fars', of Iran. If no symbol has been allocated to a formation, you must do this yourself, following the convention of the country, if there is one. Otherwise, use the initial of the unit wherever possible, as this acts as a mnemonic. Avoid calling your units A, B, C, or 1, 2, 3. Show formation letters on every area of each rock unit that appears on the map. Where a unit covers a very wide area, repeat the formation letters in several places, but where an area is too small to contain them, print the letter beside it with a 'leader' (zig-zag) pointing to it.

8.6 Layout

A fair copy map should be properly laid out. It should have a proper title, a scale, northpoints (true, grid and magnetic), and an explanation of the symbols used, together with a record of the authorship(s) of the map and an accreditation of any other sources used, including the source of the base map itself. It should also show the dates the fieldwork started and finished and the date of publication. The arrangement of this matter requires some thought and may warrant making a mock-up on tracing paper, or at the very least, a rough sketch so the sheet looks properly balanced. If the map is stuck down on a larger sheet of good quality paper, the ancillary information can be arranged around it, or at one side of it, as in Figure 8.1. Express the scale of the map in figures as a 'representative fraction' (e.g. 1:10 000), and graphically, as a bar scale (Figure 8.2). Northpoints should be as plain as possible, so that they are quite unambiguous; avoid those fancy northpoints that draftsmen love to draw if left to themselves. Exaggerate the differences of the angles of grid and magnetic norths from true north so that there can be no mistake of their relative positions. Print the amounts they deviate from true north beside them, and do not forget to give the annual rate of magnetic change. In the explanation, draw the symbols at exactly the same size as you used on the face of the map; unfortunately, this is not always done.

8.7 Colouring

A manuscript fair copy map is normally hand-coloured by its author. Colour your map by whatever method you think you are capable of doing neatly, and which the paper will take. Many maps are spoilt by this final colouring. Watercolours probably give the more finished look to a map but they are

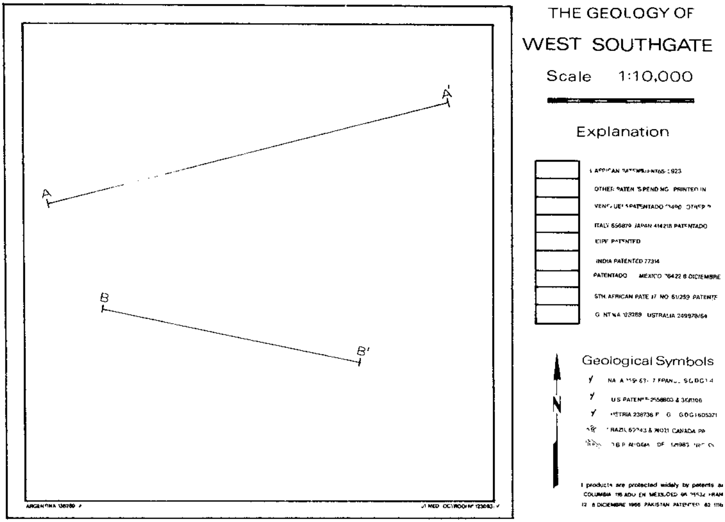

Figure 8.1 *Layout of a fair copy map, showing the arrangement of explanatory matter. Note the terminations to the cross-section lines shown on the face of the map; this is to ensure that there is no ambiguity over the exact positions where section lines end*

difficult to apply over large areas, especially if those areas have intricate boundaries: irregular drying marks spoil the result. Coloured pencils give excellent results with a minimum of practice. Lay on the colour gently and with care and, if not dark enough, add another layer on top of the first. Smooth the colour to a more even tint by rubbing the surface with a tissue or cotton swab, or by using a ‘pastel stump’ (from an art shop). Some coloured pencils react better if the swab is first slightly damped with water, petrol or cigarette lighter fluid, but test them first. Coloured pencils will give patterned effects if a textured surface, such as coarse sandpaper or a textured book cover is placed beneath the map when colouring. Different textures of the same colour can be used to distinguish related formations and so extend even a limited range of colours. Alternatively coloured dots can be added to a lighter base colour with a felt-tipped pen. Dots can even cross geological boundaries to indicate, for instance, a thermal aureole.

Choose colours with care and with due consideration for tradition. In general, use pale colours for formations which cover wide areas and strong colours for those with limited outcrops, such as thin beds and narrow dykes.

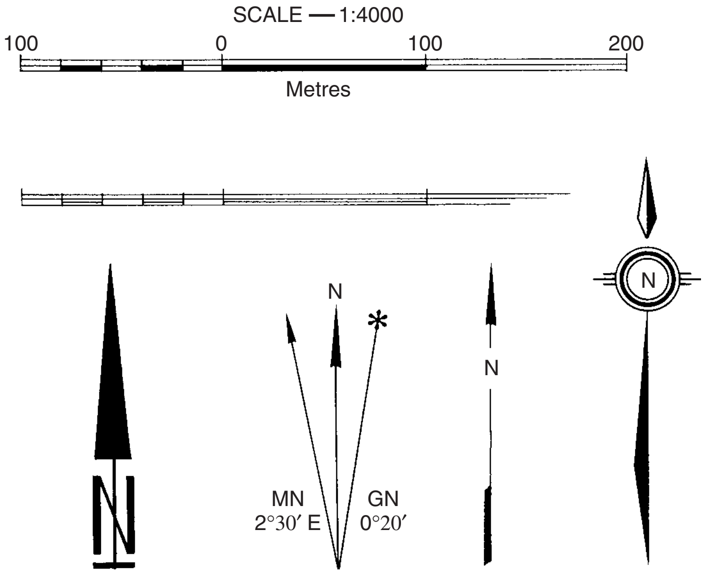

Figure 8.2 *Scales and northpoints for fair copy maps. Two examples of a bar scale are shown, and a selection of northpoints. Avoid the arty N-point on the left. The two simple true N-points on the far right are from transfer lettering sheets. The composite northpoint in the centre is made up from transfer sheets. Note that MN and GN are representative only: they show exaggerated angles because the true angles are too small to plot clearly, especially GN 0°20′ E. This is conventional*

Always keep your reader in mind: try to follow a system which does not force him to keep looking back to the explanation to find out what things mean. Relate your colours to mineralogy. For instance, if a hornblende schist is shown in pale green, or overlaid with green dots, and a biotite schist is shown in brown, or is overlaid with brown dots, then your readers will probably find your map easier to follow, than if those areas were shown in purple or blue. Note, however, that the use of colour does not obviate the need for formation letters: they also help you, yourself, to colour your map correctly.

8.8 Cross-sections

Display cross-sections in the map margins whenever possible, so that all geological information is kept together. If sections have to be drawn separately, draw them all on the same sheet so that they can be easily compared. Show on the fair copy map the positions of all sections presented by lines drawn on the face of the map, with the ends of each section line clearly indicated by a short cross-line, as in Figure 8.1; and always draw cross-sections so that their northern or eastern ends are at the right-hand side of the sheet they are drawn on. Although the horizontal and vertical scales of the section will usually be the same, both a horizontal bar scale and a graduated vertical scale should be provided. Finally, geologists should curb their imagination on fair copy sections and not show interpretations down to improbable depths for which they can have no possible evidence. This does not mean that hypothetical cross-sections should never be drawn, but their proper place is in your report, with supporting text. Only factual sections should form part of a factual map.

8.9 Overlays

Do not overcrowd a fair copy map with specialised information in addition to geology, such as rose diagrams, joint measurements and structural statistics. This information is better drawn on transparent paper or film as an overlay to the map. You need not limit the number of overlays. In addition to those mentioned above, they can include: fold axes; sub-surface contours on specific beds determined from drillholes; isopachytes, isopleths, geochemical contours and even geophysical information. Not only can overlays be superimposed on the fair copy map, they may be usefully overlaid on each other.

An overlay should be the same size as the fair copy sheet and have the same general format. Show the margins of the map area and, because the overlay and the map are of different materials which distort differently with time, draw ‘register’ marks to fit the grid intersections on the fair copy.

Title overlays and give them simplified bar scales, a northpoint and an explanation of symbols used. Add a subtitle to indicate to which map the overlay refers and the source of any information which does not originate from you. Add your own name as the author of the map and overlay, and the start and finishing dates of the fieldwork.

8.10 Computer Drafting of the Fair Copy Map

The production of the fair copy map can be assisted by ‘mapping-software’ which draws the map from digitised data. Field data can be entered from a paper map, from an external file, or on the screen using the mouse. The advantage of such an approach is that the map can be easily modified and redrawn to accommodate new interpretations, new field data, etc.

Many programs exist for the analysis and presentation of data associated with map coordinates, e.g. *Archview, ER Viewer, Terrain Tools (Softree)*. These Geographic Information System (GIS) programs are versatile but may be too complex for the task of producing a fair copy geological map.

Drawing packages such as *CorelDraw* and *Adobe Illustrator* allow field slips to be converted into a professional-looking final fair copy map. Using these software products, boundary lines, geological symbols, and coloured formations can be drawn on scanned base maps or scanned field slips.

8.11 Text Illustrations

Black and white text illustrations are needed in nearly all geological reports, including maps of various sorts, such as enlarged details of small areas, as in Figure 4.13, and redrawn notebook sketches, as in Figure 6.3. Keep such figures as simple as possible; show only the salient points. Sometimes sketches can be traced from photographs, but again trace off only the principal outlines. Outline sketches are far more comprehensible to the reader than unskilled artistic attempts to show every detail faithfully (Figure 6.3). Stick-down sheets of stipples and cross-hatching, sold under the names of *Letratone, Chartpak* and *Zip-a-tone* can enhance your drawing, as in Figure 9.3. Sketches can also be computer-drawn, as in Figure 5.17.

9

CROSS-SECTIONS AND THREE-DIMENSIONAL ILLUSTRATIONS

No geological map can be considered complete until at least one cross-section has been drawn to show the geology at depth. Cross-sections explain the structure of a region far more clearly than a planimetric map. They may be drawn as adjuncts to your fair copy map, and simplified as text illustrations in your report. In addition to cross-sections, columnar sections can be drawn to show changes in stratigraphy from place to place, or ‘fence’ or ‘panel’ diagrams to show their variations in three dimensions. Refinements in three-dimensional illustrations include block diagrams, which show the structure of the top and two sides of a solid block of ground, and models to aid interpretation, such as ‘egg-crates’. Although much of this kind of drawing can now be done on a computer, you should learn the basics of this type of illustration by drawing them yourself, and you must also bear in mind that you may not have a computer with you in the field.

9.1 Cross-sections

Cross-sections are either trial sections, drawn to solve structural problems, or are drawn to supplement a fair copy map or illustrate a report. They are also drawn to site boreholes in the search for a lost aquifer or ore body.

9.1.1 Trial cross-sections

Draw a cross-section whenever a problem of interpretation arises. Do it whenever possible whilst still in your field camp so that you can take additional structural measurements if needed. Even when you have no problems, sections should still be drawn during the fieldwork stage to ensure that nothing is going to be missed. In geologically complex areas there may be more than one apparent interpretation of the structure and trial cross-sections will at least show which is the most probable. Drawing cross-sections should become second nature to a geologist.

9.1.2 Fair copy cross-sections

A fair copy cross-section is drawn to accompany a fair copy map. Draw it to the same standards and colour it with the same tints as your map, for it is

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to all intents and purposes part of that map; you may even redraw it later in the margin of your final map.

Draw cross-sections as if you are looking in a general westerly or northerly direction, so that the southern, south-western and western ends of the section always appear on the left-hand side of the sheet of paper it is drawn on and the northern, north-eastern and western ends on the right. Whenever possible draw them to cut across the strike of beds as close to a right angle as possible; if there is a broad swing in strike across the map, change the direction of your section-line at a few well-separated points to keep it as nearly perpendicular to the strike as possible. Normally, to avoid distortion, horizontal and vertical scales should be the same, but where dips are no more than 10°, an exaggerated vertical scale is permissible, but always state the true dip on the section.

9.1.3 Serial cross-sections

Serial cross-sections are drawn along regularly spaced parallel lines, usually on large-scale plans used for mining or engineering purposes. They may be drawn at right angles to the strike of the structure, but more usually they are drawn parallel to one set of grid coordinates. Their object is to show progressive changes in the geology (see below in Section 9.3.3 and Figure 9.5).

9.1.4 Text figures

Simplified cross-sections are frequently used as text figures to illustrate specific structures described in a report. The vertical scale can be legitimately exaggerated to clarify specific points.

9.2 Plotting and Drawing Cross-sections

9.2.1 Construction

Poorly drawn cross-sections are so often encountered in professional life that a résumé of the process is given below, although most readers will have already been taught this method early in their geology courses.

1. Draw the line of section (A–A′) on the face of the map, marking each end of the line with a short cross-line (Figure 8.1).
2. Fasten the map to a drawing board with the section-line parallel to the bottom edge of the board.
3. Tape to the map, a few centimetres below the section line, a strip of paper on which plot the section.
4. Draw a base line on the tracing paper parallel to the section line on the map. Then draw a series of parallel lines at the chosen contour interval above it (Figure 9.1(a)).

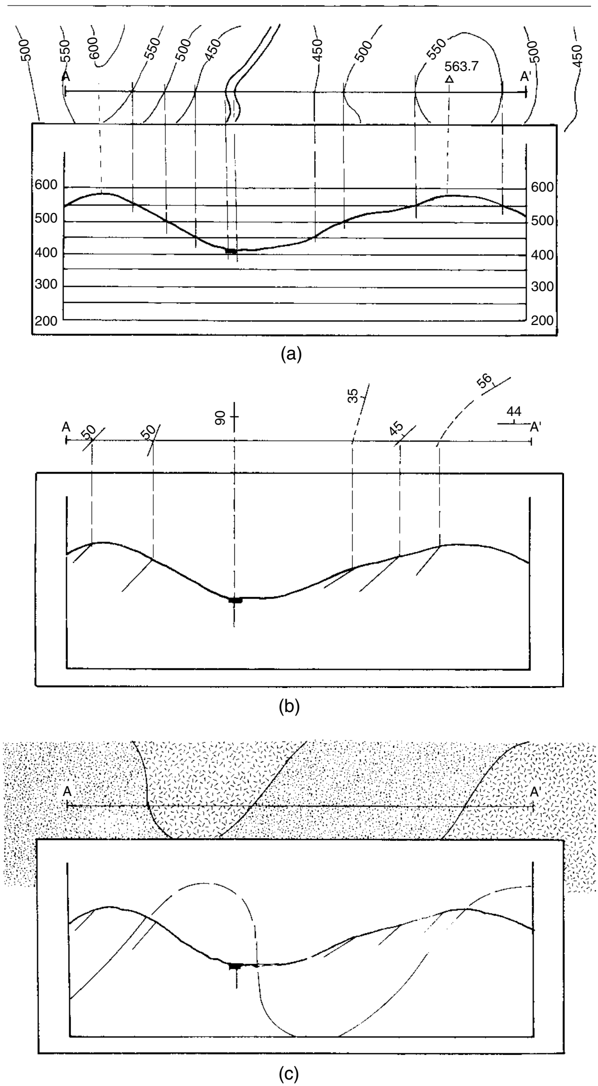

Figure 9.1 *Drawing a cross-section*

5. Tape down a plastic rule or steel straight-edge so that it cannot move, well below and parallel to the base line.
6. By sliding a set-square (triangle) along the straight-edge, drop a perpendicular down to the appropriate elevation on the section paper from every point where the section cuts a contour line on the map (Figure 9.1(a)). Join these points to give the profile of the topography.
7. Calculate the *apparent dip* in the line of section for every strike/dip intersected by the section line (see Section 9.2.2). Mark the position of each strike/dip symbol on the profile and plot the apparent dip as a short line (1–2 cm) (Figure 9.1(b)).
8. Extend the strike line of any strike/dip symbol until it meets the section line on the map, for any strike symbol lying close to the cross-section but not actually crossing it. Calculate its apparent dip, and plot it on the cross-section profile as before. The distance you may project a strike is a matter of geological judgement. Where there is obvious flexure, extend the strike line to follow its curve to meet the line of section (Figure 9.1(b)).
9. Still using the set-square, drop a perpendicular wherever the section line crosses a geological contact on the map and lightly mark the position on the profile of the topography.
10. Lightly sketch in the structure by extending 'dip lines' and drawing contacts parallel to them. Then modify the interpretation to allow for thickening and thinning of beds, and for any further suspected change in straightforward folding or tilting. Do not interpret geology to improbable depths beneath the surface. Test your interpretation by continuing the structure above the topographic surface; you have just as much evidence there as for your interpretation below the surface (Figure 9.1(c)). Finally, ink in your interpretation, including where appropriate dashed lines for parts of the structure now eroded away above the land surface.

The task is made easier if a 'T' square or drafting machine is available. There are other methods of constructing cross-sections in many types of structural setting, including geometric constructions, such as the Busk method (Badgely 1959).

9.2.2 Calculating apparent dips

Unless a cross-section line cuts the strike at right angles, the angle of dip must be modified in the cross-section because *apparent* dip must always be less than the *true* dip; this is purely a matter of geometry. Apparent dip can be determined by graphical methods, trigonometrical methods or, more easily, by conversion tables or charts in most books on structural geology or in Berkman (2001). Stereonets, the geologist's sliderule, can also be used.

9.2.3 Down-plunge projections

The down-plunge method of cross-section construction is the preferred method in areas where the geological structure is dominated by folding and where folds have hinge lines with a constant angle of plunge. The method assumes that the geometry of the structures remains unchanged if followed in the direction of the fold hinge lines. This allows points lying on a geological contact on the map to be projected in the direction of the hinge lines onto the section plane.

9.2.4 Construction

1. Draw the selected line of section A–A′ on the map, and a cross-section template with a baseline of length A–A′ and a set of horizontals representing different elevations (Figure 9.2).
2. Select a geological contact on the map.
3. Choose an arbitrary point P on the contact and draw a line through it in the plunge direction to meet the section at P′. P′ is the projected position of P in the cross-section.
4. Measure the distance *d* from P to P′ in real units. The distance *d* is positive or negative depending on whether the direction of plunge is from P towards P′ or from P′ towards P respectively.

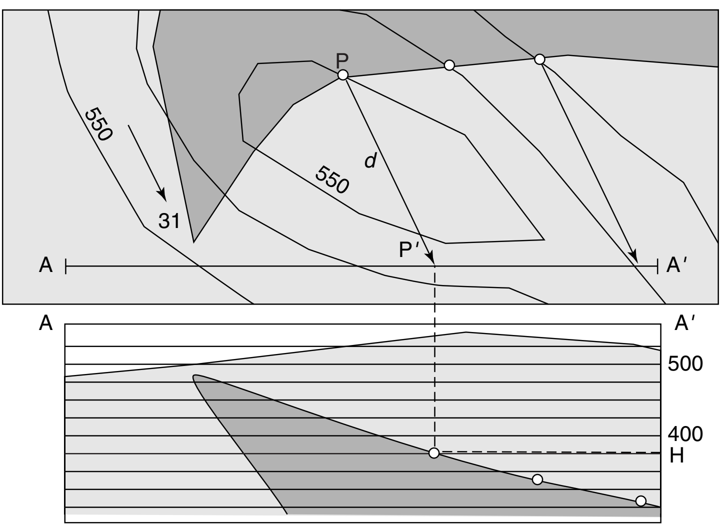

Figure 9.2 *Drawing a cross-section, down plunge method*

5. Plot the projected point in the cross-section at an elevation H given by:

$$H = h - d \tan \text{ (angle of plunge)}$$

   where h is the elevation of the ground at P (rather than P′).
6. Repeat steps 3–5 for other points on the contact, and join the projected points in the cross-section. This shows the folded shape of the contact in the cross-section.
7. Repeat for other boundaries.

An important advantage of this method is that the cross-section is constructed from information taken from across the map, not just from along the line of section.

9.2.5 Balanced sections

This is a method of reconstructing the unfolded original surface and eliminating thrust sheets to calculate the amount of shortening. Balanced sections have no place in a book on 'basic' mapping but those interested should refer to McClay (2003).

9.2.6 Columnar sections

Columnar sections consist of a number of simplified stratigraphic columns shown side by side to illustrate how stratigraphy changes from place to place (Figure 9.3). They are prepared from surface outcrops and drillhole logs.

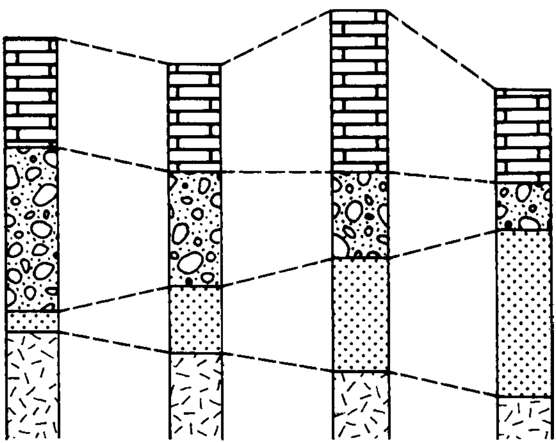

Figure 9.3 *Columnar section*

9.3 Three-dimensional Illustrations

Three-dimensional diagrams greatly help readers of reports to understand the solid geology of the area concerned. Their preparation may also help your own understanding too. There are two basic projections: *isometric* and *oblique*. Both are simple to construct.

9.3.1 Isometric projection

Unlike true perspective, isometric projections have no vanishing points: all parallel lines remain parallel in the diagram. The two horizontal coordinates are inclined at 30° to the E–W baseline (Figure 9.4). The viewer sees the faces of a cube, for instance, as three equal-sided parallelograms (Figure 9.4(a)). Geological information drawn on the faces of an isometric block must be distorted to fit them. Do this by drawing a grid over your geological information, map or cross-section, and also on the faces of the isometric block, then transfer information to the block by eye, grid square by grid square, or by rectangular coordinates.

You can also use isometric projection as a framework for illustrations. Figure 9.4(b) shows the principle. Pads of isometric paper can be bought and are a useful aid to drawing such diagrams. Perspective paper is also available but best avoided.

9.3.2 Block diagrams

Block diagrams are the application of isometric projections where the cube has been made into a rectangular block. They can be split in two or more slices, or have steps cut into the block to illustrate specific points, but avoid overhangs (Figure 9.6).

9.3.3 Oblique projection

In oblique projection, the front face of the basic cube is an undistorted cross-section in the plane of the paper (Figure 9.4(c)). The side of the cube,

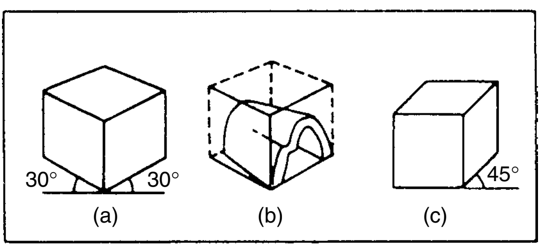

Figure 9.4 *(a) An isometric cube; (b) a fold drawn using the cube as a guide; (c) an oblique projection of the same cube*

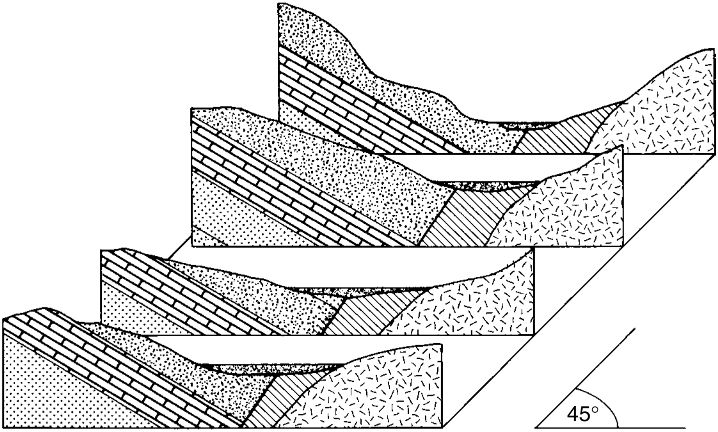

Figure 9.5 *Oblique projection of serial cross-sections. Each cross-section is a true cross-section, but the distance between them is foreshortened by one-third*

however, is a parallelogram inclined at 45° to the E–W baseline, with distances receding from the viewer foreshortened by one-third to prevent the cube appearing rectangular. Oblique projection can also be adapted as a block diagram, but one particular use is in drawing serial cross-sections (Figure 9.5).

9.3.4 Fence (panel) diagrams

Fence diagrams, as distinct from columnar sections, are three-dimensional illustrations. Stratigraphy or lithology is shown on ‘fences’ or ‘panels’ connecting the different sites. Again, either isometric or oblique projection can be used (Figure 9.7). Their principal use is in plotting information from borehole logs.

9.4 Models

Geological problems can sometimes be solved by constructing three-dimensional models which can be viewed from every direction. They need no embellishment if used only as interpretive aids.

9.4.1 Egg-crate models

An egg-crate model is constructed from a series of intersecting cross-sections. Draw the sections on heavy cartridge paper or Bristol board; then cut them out and slot them together by cutting slits where they intersect. Such models

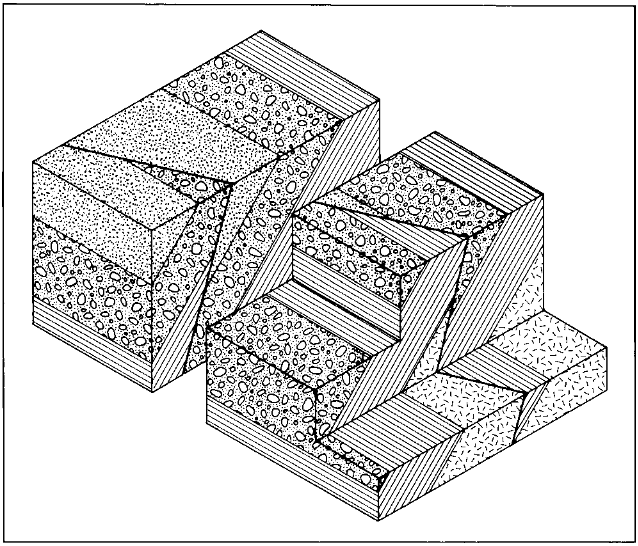

Figure 9.6 *Simple block diagram, split, with two halves separated, and with steps*

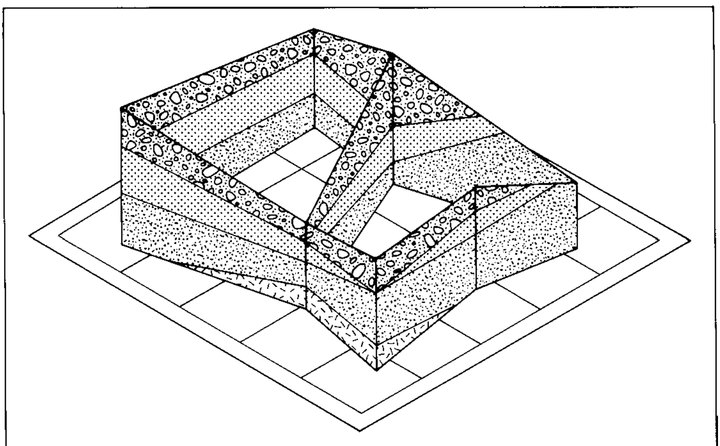

Figure 9.7 *Fence or panel diagram illustrating stratigraphic variations in a region. It gives a better spatial impression than a columnar section (c.f. Figure 9.3)*

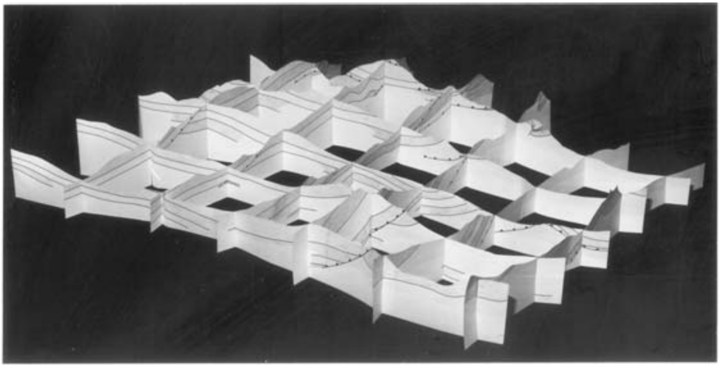

Figure 9.8 *Photograph of an egg-crate model (courtesy of S.J. Matthews)*

are particularly useful in mountainous regions where the geology has been complicated by *nappes* and overthrusting (Figure 9.8).

9.4.2 Glass-sheet models

For solving large-scale localised problems in depth, models can be made quickly from window glass or Perspex sheets. Trace parallel cross-sections onto the glass with the pens used to write on overhead projector transparencies. Support them vertically in a grooved trough-like open-ended box. Corrugated cardboard stuck to the side of the box will usually give grooves in positions sufficiently accurate to serve the purpose of the model.

Glass models are frequently used by the mining industry to show the solid geology when planning operations. In mining, models can also be made with horizontal level plans drawn on glass sheets and mounted one above another. The writer has used Meccano as supports for this purpose.

10
GEOLOGICAL REPORTS

The completion of any period of geological mapping is usually followed by a geological report to explain the geology of the region covered. In fact, professional geologists probably spend more of their time preparing reports (with the attendant laboratory work and map drafting) than they do in the field. The object of writing a report, or for that matter a paper or thesis, is to communicate ideas to others and, although there is no reason whatsoever why geological writing should not be in good clear English, it seldom is; and 'unclear English and the inability to be brief' are major complaints among employers and clients (Opinion 2002, *Geoscientist* 12(6), 19). Geological literature is all too often obscure, ambiguous, circumlocutory and irritating to read. Sad to say, that whilst most young geologists take trouble to improve their mapping techniques, they appear reluctant to improve their ability to produce literate reports. This brief chapter is but an introduction to report writing; fuller information can be found in the many excellent books on the subject. First, however, every geologist, young or old, should read Vansberg's 'How to write geologese' (1952), a beautifully researched tongue-in-cheek letter to *Economic Geology* in which he quotes many extracts from geological literature. In it we can all recognise many of our own mistakes in examples from other writers. Among books that can be recommended are: *Suggestions to Authors of Reports of the United States Geological Survey* (Bishop *et al*. 1978) and *Scientists Must Write* (Barrass 1978). In addition, the Penguin edition of *The Complete Plain Words* (Gowers 1986), originally written to teach civil servants to be comprehensible, is an amusing guide to sensible grammatical English. There are many more recent books on the same subject, mostly addressed to scientists and engineers, who all suffer from incomprehensibility.

10.1 Preparation

It is just not possible to sit down and write a report at one sitting. If you do try, your report will be incomplete and badly written; report writing takes effort. First you must plan the layout, section by section; then draft each section using all your notes, maps, laboratory results and references gathered from other sources. This is the stage where you get your thoughts down on

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paper without too much regard to grammar and literacy; there is not even any need to draft the sections in the order they will appear in the finished report. Do not spare the paper; allow plenty of room between the lines and at the margins for corrections, alterations and additions. As you write, list the illustrations needed to support the text; they can be roughed out whenever you need a break from writing. Even in these days of word processors, this stage is best carried out on paper, so that you can shuffle sections, additions and alterations more easily, and lay sections out on your bench in your chosen order, before gathering them together to edit them.

10.2 Revision and Editing

Your first rough draft gets the essential facts and information in order and allows your ideas to develop. The next stage is to revise it. Earlier ideas may need to be changed, new ideas may emerge; but, still, more attention should be given to ideas than to English. Now print out your rough draft, double spaced and with wide margins, and re-edit. The order of some paragraphs may need changing, spelling mistakes corrected, grammar improved. Indicate where illustrations should be inserted. Now read it through as a whole and improve the English: this owes more to hard work than art; refer to dictionaries and check references. You may need more than one revision to get the right result; Hemingway rewrote the last page of one book 39 times before he was satisfied. Make a final check of the whole report for punctuation, and ruthlessly prune out anything that does not contribute to meaning. Aim at concise, direct, plain English. Look especially for repetition; geologists have a blind spot for some words which they use over and over again, with irritating monotony. ‘Area’ is one of them, e.g. ‘. . . the Falmouth *area* was part of the *area* mapped and covered 10 km^2 in *area*.’ Such a sentence is not unusual: it needs recasting. The last ‘area’ in the sentence is redundant, and ‘region’ or ‘district’ could be substituted for at least one of the other areas. Most repetitions can be eliminated by rewriting, but not all repetition is bad. Occasionally it can be used for emphasis and it is always better than ambiguity.

Geologists have another fault. They are teased throughout the mining industry for their inability to make a decisive statement or to commit themselves to a wholly positive opinion. Their reports are peppered with the words possibly, probably, perhaps, apparently and generally, and with phrases such as ‘. . . it may be that . . .’. For instance: ‘After sinking a number of relatively shallow pits the results generally seem to indicate that there is apparently no gravel containing what might be economic amounts of probable gold.’

An exaggeration, yes (but not a great one) of what employers have to put up with. Geology may be an inexact science but its practitioners must not hedge their responsibilities. They should have the courage to commit themselves to their opinions on paper; that is what they are paid for.

10.3 Layout

Any scientific report can be broken down into a number of basic parts. These are:

Title page
(contents)
Abstract
Introduction
Main body
Conclusions
References
Appendices

In short reports, some of these parts may be only a few lines long. In others, even the Introduction may include several sub-sections and the 'body' itself may consist of many sections and sub-sections. The composition of each part is described below.

10.3.1 Title page

This is more important than many writers think. It shows what the report is about, who wrote it, and when. Lay it out carefully, for it is the first thing your reader will see and first impressions are always important. Packaging it may be, but if you do not think your report is worth presenting properly, why should your reader?

10.3.2 List of contents

Any report longer than twenty pages needs a list of contents to show readers how the subject has been covered and to help them to relocate information they may wish to refer to again.

10.3.3 Abstract

The abstract (or summary) follows immediately after the title page (and contents list, if any). It must be written last, after you have already formulated your ideas and conclusions. This does not mean that it can be dashed off as an afterthought. It must be as literate as the report itself and concisely review the work done and its results. Preferably, it should not exceed 200 words and, in a short report, very much less.

10.3.4 Headings and sub-headings

The body of the report will usually be divided into sections, and further sub-divided into two lower categories, each with its own type of heading. The main sections are equivalent to the chapters of a book. Each starts on a fresh page with its headings capitalised and centred on the page. Sections contain sub-sections with their headings either centralised or at the left hand margin, depending on the house rules of your employer, but now using upper and lower case. Do not underline headings for if your report (or paper) is sent to a printer for publication, underlining tells compositors to print those words in italics. Sub-sub-headings break sub-sections up into smaller units and these headings are again typed at the left-hand margin of the page and usually italicised, sometimes followed by a dash, colon or a wider space. With the widespread use of word-processors, you can of course produce your own italics, and also bold type, and larger types to emphasise the hierarchy of headings. Here we only make generalised suggestions.

> **9 Section Heading**
>
> 9.1 Sub-section heading
>
> *9.1.1 Sub-sub-heading*
>
> By an extension of the system, if further sub-divisions are needed, logically they should be numbered *9.1.1.1, 9.1.1.2*, etc., or even *9.7.11.5*. Such designations are unwieldy and it is better to use lower case Roman numerals i, ii, iii, or bracketed lower case letters (a), (b), (c). This category of heading should only be needed occasionally.

Plan your headings from the start as part of an outline for your report. Commercial companies often provide staff with a detailed list of headings and sub-headings to cover every eventuality, often many pages long, to ensure nothing is forgotten, although not every heading is expected to be used in any single report

10.4 Introduction

A report needs an introduction so that your readers know what it is about. They need to know what you did, why you did it, how you did it, when you did it and where you did it. They also want to know what has been done before and by whom. Include an index or 'place-fix' map to show where the area is in relation to the region around it, and its general geography, topography and communications, how to get there and the main place names. The introduction should also give a brief review of the vegetation, land use and economy of the region, emphasising aspects that are geologically related.

It is also a useful place to acknowledge any help given to the writer, both in the field and in the preparation of the report.

10.5 Main Body of the Report

Hard and fast rules cannot be given on what should be included in a report; that depends on the subject, but many geological reports are basically a description and explanation of the geology of a limited area, sometimes covering only a few tens of square kilometres. Normally, the main body of such a report will consist of sections with headings similar to those shown below.

10.5.1 Regional geology

Before embarking on a detailed account of the geology mapped, it helps the reader if the main features of the area are outlined first. In very short reports, general geology can be included in the introduction, together with the regional geology. In longer reports, a separate section is needed, supported by at least one text figure showing the bare outlines of the main geological units on a small-scale map, preferably with some indication of structure and place names. Note that the US Geological Survey insists that any place name mentioned in the text must appear on some map within the report. This is not always adhered to by other organisations, to the frustration of readers of their reports.

10.5.2 Stratigraphy, etc

This section describes the rocks in geological sequence, that is, the oldest rocks first. If the stratigraphy is complex, an introductory sub-section may be needed, with separate sections for each of the main formation groupings. A text figure showing the geological succession and thicknesses, coloured with the *same* tints as those on the main geological map, is a great help to the reader. The rocks may be described in much the same way as they are described in your field notes (Section 6.1) except now you also have the benefit of examining thin sections, laboratory work, consultations with colleagues and reference to literature.

The way in which the stratigraphy is treated must depend on the geology itself. In some cases, section headings may be devoted to 'Devonian rocks', 'Carboniferous Limestone', the 'Lias', etc.; in others, the groupings may be broader, such as the 'Precambrian', 'Mesozoic rocks' or 'Vulcanicity'. Arrangement depends entirely on the importance and extent of the formations, and the detail of the report. This may also be a convenient point to describe fossils; or fossils may deserve a section of their own.

10.5.3 Structure

Regional structure has already been introduced under 'Regional Geology'. Now describe the more specific details of the area mapped, based on your own field evidence. Structural geology is an excellent example of a subject where one diagram can save a wealth of text. Isometric diagrams are especially helpful and are much easier to draw than they look, and even more so using a computer (Section 9.3).

10.5.4 Metamorphism

Metamorphism may deserve a section of its own, but logically, it may often be part of the structural section. The way in which these two subjects are treated is a matter for the judgement of the writer.

10.5.5 Igneous activity

Igneous activity covers a wide spectrum, from plutonism to vulcanicity. Again, its treatment depends on the geology of the area under discussion.

10.5.6 Economic geology

All too often economic geology is glossed over. Quarries will normally be examined during fieldwork, if only because rocks can be seen in them. Sand, gravel and clay pits are, however, seldom mentioned in reports, yet they are mineral assets of the region. If metallic minerals occur, relate them to the geology. The potential value of other mineral materials must not be ignored either. Limestone, for instance, is often described in considerable academic detail in reports, yet its suitability as a cement material, flux, industrial chemical, pigment, decorative stone, or its many other industrial uses, seldom gets a mention. Refer to Scott and Bristow (2002) for the uses and geology of industrial minerals. Water is another natural resource only too often ignored.

10.6 Conclusions

The foregoing sections of the report are factual and depend on observation, supported by interpretation based on established geological processes. Hypothesis should have been avoided. Now, however, results are brought together and conclusions drawn from them. Sometimes this section can be called Geological History, for that is often what it amounts to. In more specialised reports, the conclusions may be of a different character, and may also include Recommendations to tell the reader what he should do next, why, how it should be done, and sometimes how much it will cost. In professional reports the recommendations may warrant a section of their own.

10.7 References

Any reference you make in the text to work done by anyone else must be acknowledged, whether the information is from published work, an unpublished report, or merely by word of mouth. This is scientific ethics. There are accepted forms of referencing. The Harvard system is the one used by the

Geological Society of London and is suitable for both typescript (manuscript) reports and for publications. Briefly, a reference is acknowledged in the text by the name of the author and the year in which it was published. The various forms of text references are illustrated in the fictitious example below:

> The first suggestion that these ores were syngenetic followed a sedimentological study in 1963 (Brown 1964). Later workers confirmed Brown's findings and produced a number of hypotheses to explain the sources of the ore metals (Smith 1969, 1970a, 1970b, 1971; Smith and Brown 1971; Smith *et al*. 1973). Still later, Brown (1975 p. 19) concluded that these ores were synvolcanic and Smith now agrees with this view (personal communication).

Note the punctuation: no commas between the name and the date; the use of *et al*. where a paper has more than two authors; and the different ways in which parentheses are used. If an actual quotation is to be made in the text, it should be enclosed in inverted commas, and three dots (no more, no less) must be inserted wherever part of the quotation is omitted as immaterial, e.g. '... such ores were epigenetic and ... the syngenetic ores are quite distinct from them'. Partial quotations are best avoided wherever possible, they can be most misleading because every reader puts their own convenient and often erroneous interpretation on what has been left out.

To save repetition of the same reference, insert (*loc. cit.*) which means 'in the same place'; *(op. cit.)* 'in the work already mentioned'; or *(ibid.)* 'in the same source'.

References are listed at the end of the report in alphabetical order of the principal author of each entry, and where there are multiple authors, all are listed; *et al*. is not used in the references list. The following fictitious examples cover most types of publication to be found in a reference list:

Brown, A.B. (1964) The sedimentology of some ore shales. *Q. Jl Geol. Soc. London.* **120**, 184–196.
– (1975) Syngenetic ores in Iran. *Econ. Geol.* **61**, 2–20.
Price, T.W. (1959) Welsh copper deposits. Unpub. report, Welsh Mines Soc.
Smith, P.S. (1969) Metal sources in syngenetic ores. *Min. Deposita*, **2**, 23 only.
– (1970a) Metal sources of Iranian ores. *Econ. Geol.* **56**, 423–444.
– (1970b) *Copper in Asia*. New York (Wiley).
Smith, P.S. and Brown, A.B. (1971) Syngenetic ores. In *Sources of metals in volcanogenic deposits*. Proc. 25th Internat. geol. congr., Montreal for 1970, **5**(5), 23–28.

Smith, P.S., Jones, C.D. and Brown, A.B. (1973) Copper deposits in Asia. Inst. Geol. Sciences, UK, Bull. 25.
Williams, J. (1966) Sulphide copper minerals. In *Sulphide ore deposits*. ed. A.B. Brown, New York (McGraw-Hill), 1450–1483.
Zahedi, K. (1979) *Copper in Iran*. [transl. P.S. Smith], Teheran (IUP).

The title of the publication in which the reference appears is italicised (underlined if in typescript). Note the punctuation, and particularly the omission of 'vol.' or 'v.' for volume and 'p.' or 'pp.' for page(s): volume and page numbers are given without prefix although the volume number is set in bold type.

10.8 Appendices

Appendices or appendixes (both are correct), contain the 'unreadable' factual evidence on which many reports rely but which is difficult to include in the text. It includes long lists of analytical data, statistical information, sample localities, and graphs and curves used in standardising instruments. It may even include permissions and other letters. Some industrial reports consist of more appendices than text. Appendices must be properly arranged and any explanatory matter should be just as literate as any other part of the report. Appendices are not junk heaps for the haphazard collection of inconvenient material.

This brief review is intended only as an indication of how a report should be written. Report writing is such an important adjunct to geological fieldwork that students should be actively encouraged to study the subject in just as much detail as any other branch of the science. Unfortunately, this is seldom done and graduates are usually left to learn for themselves after graduation, much to the exasperation of their employers. Finally, those about to write a report might well take heed of what Samuel Coleridge said 180 years ago: 'If men would only say what they have to say in plain terms, how much more eloquent they would be' (Barrass 1978). In other words, write in plain direct English; avoid journalistic, civil service and geological jargon: prune out unnecessary words and phrases; and write for your reader's benefit rather than your own.

APPENDIX I

SAFETY IN THE FIELD

Geological fieldwork is not without its hazards. In Britain field safety is covered by the *Health and Safety at Work Act 1974*, and its subsequent amendments. Both employers and workers have obligations under the Act and they extend equally to teachers and students. A brief list of *dos* and *don'ts* for the field is given below:

1. Do not run down hills.
2. Do not climb rock faces unless it is essential to do so, and then only if you are a trained climber and you have a friend present.
3. Do not enter old mine workings or cave systems except by arrangement, and then always in company. Use proper lighting, headgear and clothing and ensure that someone knows where you are; when you went underground; and when you expect to be back. Report your return so that people do not organise unnecessary search parties.
4. Always work in pairs or in close association in rugged mountains and wear easily visible clothing.
5. Always wear a safety helmet in quarries, under cliffs and scree slopes, and of course underground. Wear goggles when hammering rocks; this is a legal requirement in Britain under the Act, i.e. it is a 'chipping action'.
6. Never use one hammer as a chisel and hit it with another. Hammers may chip; use only a properly tempered chisel.
7. Do not hammer close to other people.
8. Never pick up unexploded explosives or blasting caps from rock piles in quarries or in mine dumps. Report them to an official. Do not pull at pieces of fuse or wires protruding from rock piles; they may have an unexploded charge at the other end.

Whenever possible note the weather forecast before going into the field in mountainous country and if you are going into a remote part of your area, leave your route and expected time of return with a responsible person. 'Tagcards', available in packs of ten from Youth Hostels and sports shops, are designed for the purpose. If mist comes down when you are in mountains, do not panic. If you are on a path and the mist is light, keep to the path:

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if the mist is heavy, stay where you are until it clears. The same applies if you are caught in the dark. If you are lost in mountains or on moors in clear weather, follow the drainage, it will usually bring you to habitation, but beware of sudden drops on mountain streams. Forest tracks can be difficult; one looks very much like another. 'Blaze' your trail if necessary, and learn to recognise your own footprints, so you can recognise the path you came in by.

I.1 Emergency Kit

As a geologist, it is a good idea to take a course in first aid. You should always keep a first aid kit and manual in camp, and also carry a small emergency kit in your rucksack, including dressings for blisters, and for emergency a whistle and a torch (and a mirror if your compass does not have one). Include also matches sealed in a waterproof container, and an aluminised foil 'space blanket' (it weighs almost nothing). In hot climates, carry a water bottle and a packet of effervescent water-purifying tablets. Always carry some form of emergency ration in case you have to spend the night on a hillside in mist or snow. One of the very bitter forms of 'sportsman's' chocolate is best as it will deter you from eating it until it is really necessary. With sugar, it can be made into cocoa if you carry a metal cup and methylated spirit tablets. Carry glucose tablets, or pick-me-ups such as Kendal mint cake, to give that extra bit of energy towards the end of a long hard day in the field.

I.2 Distress Signals

The accepted field distress signal is six blasts of a whistle or six flashes with a mirror or flashlight, repeated at minute intervals. Rescuers should reply with only three blasts or flashes to prevent search parties from homing in on each other.

A mobile phone is obviously an asset in an emergency, provided it can be used in your area. In very remote areas, a radio distress beacon worn on your belt is an asset. When activated, it emits a signal on the international distress satellite frequency so that its source can be pinpointed.

I.3 Exposure

All geologists working in cold or even temperate climates, and in mountains anywhere, should learn the dangers of exposure (*mountain hypothermia*); it can be fatal. Exposure results from extreme chilling. It is not confined to mountains, nor is it limited to winter months; sudden drops in temperature can occur at any time of the year and on any high ground. Geologists are particularly at risk because they work in weather when most other people stay indoors. Learn to recognise the symptoms of exposure in both yourself and your companions, and know how to treat it. Prevention is mainly a matter of proper field clothing. Too often, students short of money economise on equipment. This is false economy. So is the lack of a good breakfast before going into the field, or saving on the cost of food for a midday snack. Warm waterproof clothing, good boots and adequate food, all contribute to keeping warm. Do not forget a hat, for heat is lost more rapidly through your scalp than from any other part of your body. However, it is not only cold weather which causes exposure: wind increases the effects of cold: the *wind chill factor*. At 0°C, a wind speed of 16 km/h (what is termed a gentle breeze on the Beaufort Scale) produces an effective temperature of −8°C; or −14°C at twice that speed (Beaufort's fresh breeze). Wet clothing intensifies the problem, chilling by evaporation, even at quite modest temperatures. Make sure your clothing is both *waterproof and windproof*.

Victims of exposure are not always aware of what is happening to them. If someone lags behind and resents attempts to hurry them up, constantly stumbles, slurs their speech and shows a general lack of interest in anything, take shelter from the wind. Get them into dry clothes if possible and wrap them in windproof material, such as a space blanket, or into an emergency bivouac, if you have one. Even get in with them to provide gentle warmth. If possible give a hot sugary, or glucose, drink, but *do not give them alcohol*, it can *kill* them. Alcohol dilates the smaller blood vessels so that blood flows to the extremities more rapidly and so accelerates heat loss.

If the victim is in a state of complete collapse, get help quickly for if their temperature drops below 31°C (88°F) only medical treatment can save them. If you carry the victim on a stretcher, keep their head lower than their feet. Back at base, let them warm slowly in a warm room. Do not put them in front of a fire, or in a warm bath, as was once recommended. Give only *warm* drinks. Ensure you warm the victim slowly, but get medical help whenever possible.

I.4 Lightning

Even in the United Kingdom, lightning kills four to ten people each year. Try not to be caught out in the open at the highest point around. Take cover if you can, but not under an isolated tree; lightning can flash from the tree to you. Shelter by a stone wall, or even in a hollow and reduce yourself to as small and low an object as possible, with feet together and hands on knees, with as small an area in contact with the ground as possible.

I.5 Health in Warm Climates

If you intend to work in a warm climate, whether tropical or not, familiarise yourself with the elementary rules of tropical hygiene. Ensure that you have all the vaccinations and inoculations required for the country you are going to, and certificates to say so, well before you leave, and make sure your passport has at least six months left to run. If you are going to a malarial area, obtain medical advice so that you can start taking malarial drugs three weeks before departure (and continue taking them for several weeks after your return). Typhoid-paratyphoid and antitetanus inoculations are highly desirable if you are to live under field conditions, and for that matter, even if you are to live in a hostel. Your doctor may also advise inoculations against cholera and hepatitis. Also ask your doctor to provide tablets for those stomach upsets that travellers can seldom avoid. Do not rely on patent medicines; many are ineffective, some are harmful.

In camp, ensure a pure water supply by boiling or filtering your water, or both. Carry an adequate water bottle in the field and do not drink from springs and streams unless you are sure of their purity. Village wells are particularly suspect. Carry effervescent water purifying tablets against emergencies; they are not wholly reliable, but they are better than nothing. When travelling, drink only tea, coffee, or well accredited bottled soft drinks; it works out cheaper in the long run. Dawood's *Travellers Health: how to stay healthy abroad* (2002) is a relatively cheap paperback, full of useful advice. More advice can be obtained from MASTA, the Medical Advisory Service for Travellers Abroad (tel: 020 729 9333, or www.masta.org).

I.6 Students in the Field

Special considerations affect students in the field. A supervisor with a group cannot watch everyone in his party all the time, they may be scattered over a wide area. He does, however, have some responsibility for their safety and must refuse to have anyone with him who is not equipped with boots and clothing suitable for the conditions of the excursion or field trip, or who wilfully disobeys safety instructions; otherwise he could be deemed negligent in the event of an accident. Students may also be asked to 'sign off' at a checkpoint at the end of a day's fieldwork to ensure that no one is left behind, lost or injured on a hillside. The checkpoint is also a convenient point to keep a comprehensive first aid kit, packed in a clearly labelled sealed waterproof plastic bag. It should include a mountain stretcher, an emergency bivouac or polybag (a large plastic bag sold by sports shops), a torch and a first aid manual. A separate minor injuries kit is also useful to save the main kit from being opened to treat minor cuts, grazes and blisters.

Students engaged on independent mapping must look after their own safety. There is no one to check whether they are properly clothed, wear goggles, or use their safety helmets under cliffs or scree slopes. That must be taken on trust. Even so, a supervisor still has some responsibility and may later have to justify his decision to send into the field a student who has proved incapable of looking after his own safety.

The British Mountaineering Council in Manchester (tel: 087 0010 4878 or www.thebmc.co.uk) publishes a number of guides relevant to geologists, such as *Safety in Mountains* (Anon 2001), *First Aid on Mountains* (Boller 1989) and *The Mountain Traveller's Handbook* (Deegan 2001); and they also issue a free leaflet *Tread Lightly*, a guide to behaviour on mountains.

APPENDIX II

ADJUSTMENT OF A CLOSED COMPASS TRAVERSE

A compass traverse will seldom close without error, e.g. a traverse started at A and passed through turning points B, C, D, E and F, and finished back at the starting point A again (Figure AII.1). On plotting the traverse, the last leg, F–A failed to close back on A by a *closure error* (A–A′) of 110 m. To adjust, draw lines parallel to A–A′ through each of the turning points B, C, D, E and F. Distribute the error of 110 m at each turning point in proportion to the *total* distance travelled to reach that point:

Closure error A–A′ = 110 m

Total distance travelled = 3000 m

Correction factor = 110/3000 = 0.03 m/traverse metre

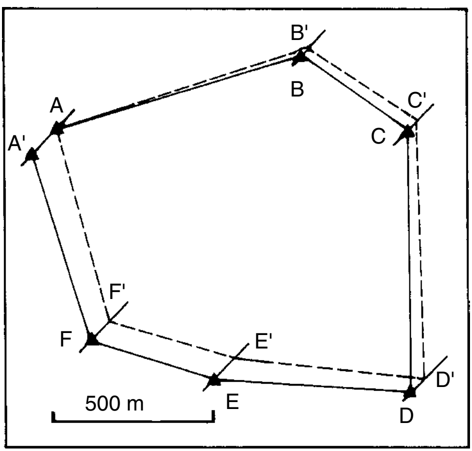

Figure AII.1 *Adjustment of a closed compass traverse*

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APPENDIX III
GEOLOGICAL PLANETABLING

For those who have taken a geography course which included surveying and who have already had some practice in planetabling, a summary of how planetabling can be adapted to geological mapping follows. It is a two-person job and, although it is more easily done in the company of another geologist, this is not essential and you may have to work with a non-geologist. The method is not difficult to learn and the writer has taught it for many years in summer training programmes to geologists in western Asia and Africa who had no previous surveying experience. By the end of four weeks they were producing excellent contoured geological maps (Barnes *et al*. 1977, Bailey *et al*. 1983). The method is suitable for scales between 1:1000 and 1:5000 where accurate detail is needed. It is especially suitable for mineral and engineering investigations.

The equipment required is a pocket calculator, a steel tape for base line measurement, a planetable, a telescopic alidade and a 4 m surveyor's staff, preferably graduated for tacheometric (i.e. stadia) survey. Forrester (1964) recommends repainting the rod in a pattern (which he illustrates) to make it easier to read in the bush conditions geologists often have to work in.

The first step of the survey is to construct a triangulation network of the area to be surveyed from a measured base line, and plot the trig points on the planetable sheet. Next calculate the elevation of the trig points from the vertical angles measured by the alidade from the two ends of the base line, giving one end of the base line an arbitrary elevation if its true height cannot be established from other information. This is normal surveying practice.

Geology and topography can now be mapped together by tacheometry using the surveyor's staff to measure distance and difference in elevation. An alternative is to use EDM (electronic distance measurement); this instrument is bulkier and heavier than tacheometric equipment, but more accurate, and can also be used to measure the base line. Much depends on the methods of transport available to you in the field (man, mule, etc.).

In essence, the surveyor stays at the planetable to make and plot the measurements to the staff (rod) which is carried by the geologist, who chooses the points of geological interest to be plotted by the surveyor. The geologist numbers these points by marking a stone with a felt-tipped pen or timber

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crayon (so they can be relocated if necessary), and makes a compass and pacing sketch-map in the rod-book around each point. After every ten points measured and noted, the geologist returns to the planetable to plot the detail from the rod-book. Checking back after every ten points, or fewer, is to ensure that points on the planetable map check with the points in the rod-book. As the two workers may at times be some distance apart, perhaps in thick bush or long grass, things can get out of kilter at times. A set of hand signals may be needed to avoid confusion, such as ‘please re-occupy the last point again’, or ‘have you finished the reading?’ The ‘surveyor’ at the table may or may not be a geologist. It helps if so, but the surveyor’s main task at this stage is to calculate elevations, draw contours, and to fill in the geographic detail. The surveyor may also ask the geologist to occupy extra points so that contours can be filled-in in places where the geologist has found no geological interest, or to plot in buildings, roads and streams. The actual calculation of vertical distances, and the correction of inclined sight-lines to horizontal distances, is mostly a matter of simple arithmetic and trigonometry, using a pocket calculator with trigonometric functions or by a tacheometric slide rule designed for the purpose. Most telescopic alidades have a ‘Beaman arc’ which does most of the work for you.

The great advantage of planetabling is that a reliable large-scale contoured map can be made with a minimum of portable equipment. It is not

Figure AIII.1 *Geologists planetabling, Sizma, Turkey* impossible for the geologist to be both rodman and surveyor, with the help of an untrained assistant to hold the rod where told to. It is hard work, but it can be done. Maps at scales of 1:25 000 and smaller have also been made in bush conditions using an artillery rangefinder for distance measurement and an 'Indian clinometer' to measure vertical angles; but you do need a carrying party.

APPENDIX IV

FIELD EQUIPMENT CHECKLIST

The following is a list of field equipment. Checking it before leaving your home base for the field will save you from the embarrassment of arriving in the field lacking essential items. Add to it from your own experience and for your own special needs. Not every item on the list is needed for every trip, but we have tried to cover every need.

Mapping equipment

Rucksack
Map case
Pencils for plotting
Coloured pencils
Scales
Protractors (half-round, 15 cm dia, and 10 cm spares)
Pencil case (for belt or attached to map case)
Hammers (with spare shafts and wedges)
Chisels
Belt and hammer frog
Pocket tape
Long tape (30 m)
String or cord
Field acid bottle; spare acid
Compass/clinometer/hand-level
Camera, lenshood and tripod
Filters (especially UV)
Flash equipment
Films
Binoculars
GPS instrument
Handlens and spares
Notebooks
Pocket stereoscope
Protective goggles
Safety helmet

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Specimen bags
Newspaper for wrapping specimens
Boxes/cotton wool for fossils
Felt-tipped pens/timber crayons
Photocopied charts, tables, stereograms, etc

Sampling equipment

Entrenching tool
Trowel
Shovel/pick
Chisels/moils
Auger
Sieves
Gold pan
Camel-hair brush
Tubes for concentrates
Funnel

Rucksack kit

Spare sweater and socks
Waterproof anorak/cagoule
Waterproof trousers
Leggings
Lunch box
Thermos (vacuum) flask
Water bottle
Tin/bottle openers
Corkscrew (France?)
Knife (Swiss army?)
Insect repellent
Sunburn cream
Lip salve
Toilet paper

Rucksack emergency kit

Whistle
Torch/spare batteries
Small spare compass
Radio beacon/flares
Mobile phone
Space blanket
Emergency bivouac (‘polybag’)

Emergency rations (chocolate, etc.)
Waterproof/windproof matches
Water purifying tablets
First aid kit (plasters, etc.)
Army-type sealed field dressing
Sealed antiseptic wipes

Field clothing (temperate and cold climates)

Anorak/cagoule/padded jacket
Sweaters
Socks (ample supply)
Boots
Rubber wellington boots
Gloves and spares
Shirts (long and short sleeved)
Trousers/jeans/chinos
Woolly hat
'Long johns'/vests, etc.
Mosquito face net (arctic areas)

Field clothing (warm climates)

Shirts (long and short sleeved)
Jeans/chinos/shorts
Jungle hat
Sun glasses

Drawing, plotting, 'office' equipment

Maps (road, district, etc.)
Maps for plotting on
Aerial photographs
Handbooks (local geology, etc.)
Reference manuals
Permatrace, Mylar, tracing film, tracing paper
Squared paper
Stereonets
Probability paper
Pocket calculator
Drafting tape
Black waterproof ink
Coloured inks
Mapping pens (for very fine work)
Stylus type pens (black/colours)

Stencils
Straight edge
60/30 set-squares (i.e. triangles)
45/45 set-squares (i.e. triangles)
Gerber scale (for contouring)
Protractors and scales
Map scales
Craft knives/erasing lances (razor blades?)
Pencils: 2H, 4H, 6H (9H for planetable)
Erasers
Emery boards for pencil sharpening
Coloured pencils
Pastel stubbs for smoothing colours
Needle and needle holder for pricking through points on aerial photos
Scissors
Mirror stereoscope
Writing paper (duplicate book: useful for copies of official letters)
Pads of paper for drafting reports
Envelopes
Stamps
Laptop computer

Items for camp use

Tent and pegs
Bed/bedding
Mosquito/sandfly net
Fly spray
Insect repellent cream
Primus stove
Pressure lamp
Paraffin/kerosene
Candles
Water container
Water filter
Cooking utensils
Plates, cutlery, etc.
Tables, chairs
Wash basin / camp bath
Toilet soap, towels
Soap for clothes washing
Toilet paper

Pick and shovel/entrenching tool (for digging pits for latrine and rubbish disposal)
More comprehensive first aid kit
First aid manual

Paperwork

Passport; must have at least six months to run, otherwise, most countries will not grant entry, nor will airlines accept you
Visas
Vaccination/inoculation certificates
Driving licence
International driving permit
'Green card' insurance
Car spares
Tickets
Foreign currency
Traveller's cheques
Cards: cheque, Visa, Amex, etc.
Any authorisations, work permits
Foreign dictionary/phrase book

Also!

Start taking anti-malarials well ahead of departure
Leave your address and contact phone number so you can be contacted
Leave dates of going and return
Pay all bills. Use direct debit to pay continuing expenses, such as credit card accounts, rent etc., if away for more than 6–8 weeks

APPENDIX V

USEFUL CHARTS AND TABLES

Table AV.1 *Spacing for bedding and jointing*

Spacing (mm)	Bedding	Jointing
0–1	Very thinly laminated	
1–10	Thinly to thickly laminated	
10–100	Very thin to thinly bedded	Very close to close jointed
100–1000	Medium bedded	Medium jointed
Over 1000	Thick bedded	Wide jointed

Table AV.2 *Abridged grain-size scales*

Size class (Wentworth)		ϕ-scale	Metric Scale
Gravel	Boulders	−12	4.096 m
	Cobbles	−8	256 mm
	Pebbles	−6	64
	Granules	−2	4
		−1	2
Sand	Very coarse sand		
	Course sand	0	1
	Medium sand	1	0.5($\frac{1}{2}$ mm)
	Fine sand	2	0.25($\frac{1}{4}$ mm)
	Very fine sand	3	0.125($\frac{1}{8}$ mm)
		4	0.063($\frac{1}{16}$ mm)
Silt	Coarse silt		
	Medium to very fine silts	5	32 μm
		8	4 μm
Clay	Clay or mud	14	

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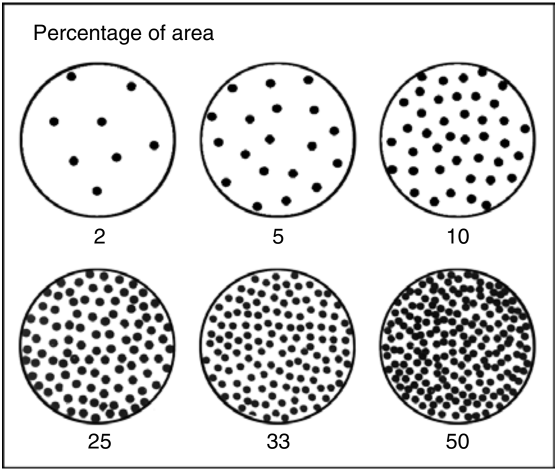

Chart AV.1 *Percentage area chart*

REFERENCES AND FURTHER READING

Anon (2001) *Safety on Mountains*. Manchester, British Mountaineering Council

Anon *Tread Lightly*. Manchester, British Mountaineering Council leaflet

Badgely, P.C. (1959) *Structural Methods for the Exploration Geologist*. New York, Harper Bros

Bailey, E.H., Barnes, J.W. and Nackowski, M.P. (1983) *First UNESCO Regional Training Programme in Mining Geology*. UNESCO Regional Office for Science and Technology for Africa, Nairobi, Kenya

Barnes, J.W. (1956) *Precambrian structure and the origin of granitoid rocks in South-West Uganda*. PhD Thesis, University of London

Barnes, J.W. (1985) Another home-made clinometer. *Geology Teaching*, **10**(2), 61

Barnes, J.W. (1988) *Ores and Minerals: Introducing Economic Geology*. Chichester, Wiley

Barnes, J.W. (1990) The horsetail's tale. *New Scientist*, London, Feb., 74

Barnes, J.W. (2000) Geological maps and map-making. In *The Oxford Companion to the Earth*. Oxford, OUP, 408–410

Barnes, J.W., Bailey, E.H. and Nackowski, M.P. (1977) Field training in mining geology: a multinational experiment. *Trans. Inst. Mining & Metallurgy, London.* **86B**, 17–26

Barrass, R. (1978) *Scientists Must Write*. London, Chapman and Hall

Berkman, D.A. (Compiler) (2001) *Field Geologist's Manual*. 4th edn, Monograph 9, Australian Inst. Min. Met., Parkville, Australia

Bishop, E.E. *et al*. (1978) *Suggestions to Authors of the Reports of the United States Geological Survey*. 6th edition, Washington, US Government Printing Office

Boller, S. (1989) *First Aid on Mountains*. Manchester, British Mountaineering Council

Boundary Associates (compilers) (2002) *The Geologist's Directory*. 12th edn, Withyham, Boundary I-Media, Ltd

Basic Geological Mapping, Fourth Edition. John W. Barnes with Richard J. Lisle

ISBN: 0-470-84986-X

Brooks, R.R. (1983) *Biological Methods of Prospecting for Minerals*. New York, Wiley

Cohee, G.V. (Chairman) (1962) *Stratigraphic Nomenclature in the Reports of the United States Geological Survey*. Washington, US Government Printing Office

Compton, R.R. (1966) *Manual of Field Geology*. 2nd edn, New York, Wiley

Crozier, M.J. (1986) *Landslides: Causes and Consequences*. London, Croom Helm

Curran, P.J. (1985) *Principles of Remote Sensing*. London, Longman

Dawood, R. (2002) *Traveller's Health: how to stay healthy abroad*. 4th edn, Oxford, OUP

Deegan (2001) *The Mountain Travellers Handbook.* Manchester, British Mountaineering Council leaflet.

Dietrich, R.V. and Skinner, B.J. (1979) *Rocks and Rock Minerals*. New York, Wiley

Dineley, D., Hawkes, D., Hancock, P. and Williams, B. (1976) *Earth Resources: a dictionary of terms and concepts*. London, Arrow Books Ltd

Dixon, C. (1999) letter in *Geoscientist*. London. **9**(13), 13

Drury, S.A. (2001) *Image Interpretation in Geology*. 3rd edn, London, Allen and Unwin

Fleuty, M.J. (1964) The description of folds. *Proc. Geol. Ass. London*, **75**, 461–492

Forrester, J.D. (1964) *Principles of Field and Mining Geology*. New York, Wiley

Fry, N. (1984) *The Field Description of Metamorphic Rocks*, Geological Field Guide Series, Chichester, Wiley

Geologists' Association (2000) Geological Fieldwork Code. Leaflet

Geological Society (1972) A concise guide to stratigraphical procedure. *Journal of the Geological Society of London*, **138**, 295–305

Gibson, P.J. (2000) *Introducing Remote Sensing: Principles and Concepts*. Routledge

Gibson, P.J. and Power, C.H. (2000) *Introducing Remote Sensing: Digital Image Processing and Applications*. Routledge

Gowers, Sir E. (1986) *The Complete Plain Words*. London, Pelican

Hancock, P.L., Skinner, B.J. and Dineley, D.L. (eds) (2000) *The Oxford Companion to the Earth*. Oxford, OUP

Harbin, P.W. and Bates, R.L. (1984) *Geology of the Non-metallics*. New York, Metal Bulletin Inc

Holland, C.H. (chairperson), Audley-Charles, M.G., Bassett, M.G., Cowie, J.W., Curry, D., Fitch, F.J., Hancock, J.M., House, M.R., Ingham, J.K., Kent, P.E., Morton, N., Ramsbottom, W.H.C., Rawson, P.F., Smith, D.B., Stubblefield, C.J., Torrens, H.S., Wallace, P. and Woodland, A.W. (1978)

A guide to stratigraphical procedure. Special Report of the Geol. Soc. London

Knill, J.L. (ed.) (1978) *Industrial Geology*. Oxford, Oxford University Press

Lillesand, T.M. and Kiefer, R.W. (2003) *Remote Sensing and Image Interpretation*. 4th edn, New York, Wiley

Lisle, R.J. (2003) *Geological Structures and Maps*. 3rd edn, London, Butterworth-Heinemann

Lisle, R.J. and Leyshon, P.R. (2003) *Stereographic Projection Techniques in Structural Geology*. 2nd edn, Cambridge University Press

McClay, K. (2003) *The Mapping of Geological Structures*. 2nd edn, The Geological Field Guide Series. Chichester, Wiley

McDonald, C. (2000) Slope stability and landslides. In *The Oxford Companion to the Earth*. Oxford, OUP, 977–980

Maltman, A. (1990) *Geological Maps: an Introduction*. Chichester, Wiley

Marshak, S. and Mitra, G. (1988) *Basic Methods of Structural Geology*. New Jersey, Prentice-Hall

Milsom, J. (1989) *Field Geophysics*. The Geological Field Guide Series. Chichester, Wiley

Moseley, F. (1984) *Methods in Field Geology*. Oxford/San Francisco, Freeman

Opinion (2002) in *Geoscientist*, London, The Geological Society, **12**(6), 19

Parry, R.B. and Perkins, C.R. (2000) *World Mapping Today*. 2nd edn, London, Bowker-Saur

Perkins, C.R. and Parry, R.B. (1990) *Information Sources in Cartography*. London, Bowker-Saur

Peters, W.C. (1978) *Exploration and Mining Geology*. New York, Wiley

Phillips, F.C. (1971) *The Use of Stereographic Projection in Structural Geology*. 3rd edn, Sevenoaks, Edward Arnold

Ramsay, J.G. and Huber, M. (1987) *Techniques of Modern Structural Geology, vol. 2*. London, Academic Press

Ray, R.G. (1960) Aerial Photographs in Geologic Interpretation and Mapping. *US Geol. Surv., Prop. Paper 37*. Washington, US Government Printing Office

Reading, H.G. (ed) (1996) *Sedimentary Environments: Processes, Facies and Stratigraphy*. 3rd edn, Oxford, Blackwell Scientific Publications

Reedman, J.H. (2002) *Techniques in Mineral Exploration*. London, Applied Science Publishers

Scott, P.W. and Bristow, C.M. (eds) (2002) *Industrial Minerals and Extractive Industry Geology*. Bath, The Geological Society Publishing House

Stewart, I.S. (2000) *Geomorphology*. In *The Oxford Companion to the Earth*. Oxford, OUP, 430–431

Thorpe, R. and Brown, G. (1991) *The Field Description of Igneous Rocks*. The Geological Field Guide Series. Chichester, Wiley

Treagus, J.E. (1996) Mapping again. Review in *Journal of Structural Geology*, **18**(7)

Tucker, M. (1996) *Sedimentary Rocks in the Field*. 2nd edn, Chichester, Wiley

Vansberg, N. (1952) How to write geologese, *Econ. Geol.*, **47**(2), 220–223

Wallace, S.R. (1975) The Henderson ore body – elements of discovery, reflections, *Mining Engineering*, **27**(6), 34–36

Whitten, D.G.A. with Brooks, J.R.V. (1987) *Dictionary of Geology*. Harmondsworth, Penguin Books Ltd

Young, R.R. (2000) Glacial landforms. In *The Oxford Companion to the Earth*, Oxford, OUP, 441–447

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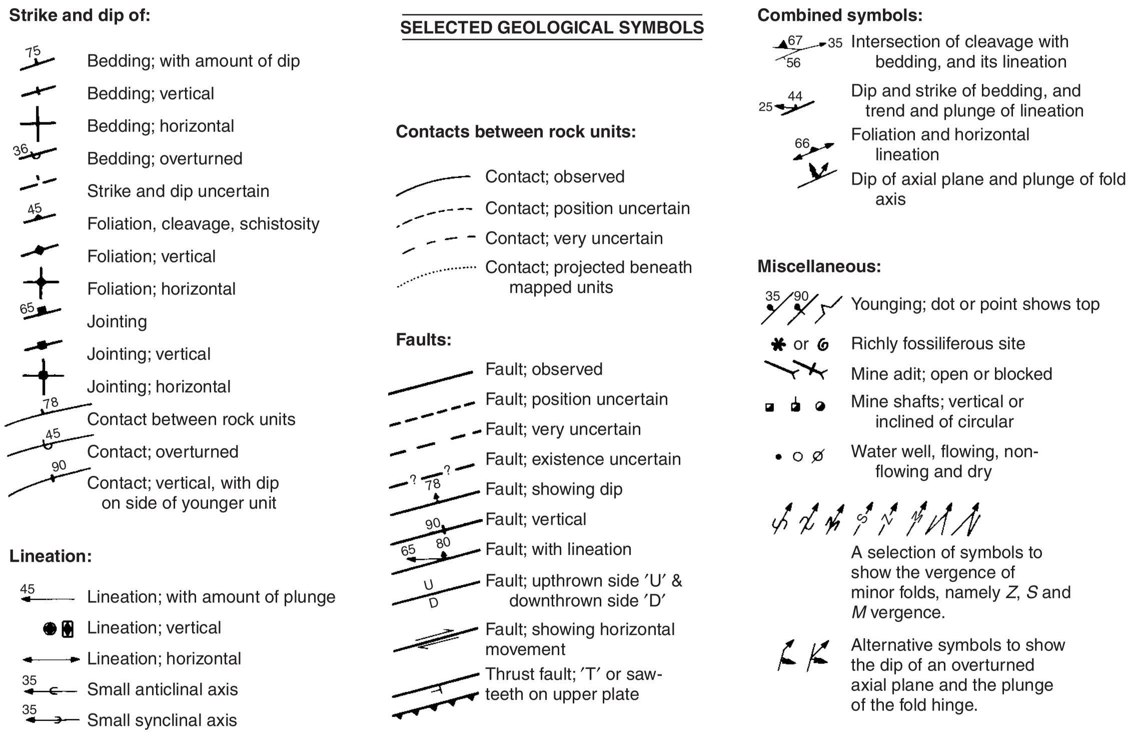
ISBN: 0-470-84986-X

SELECTED GEOLOGICAL SYMBOLS



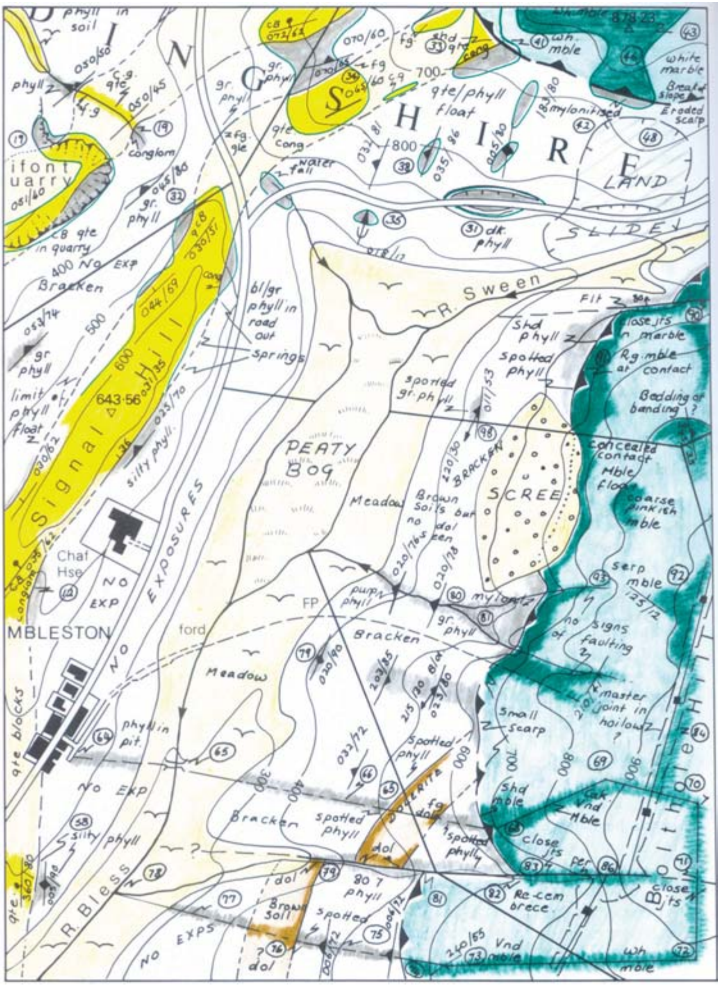


Plate 1 *Portion of an inked-in field slip showing: green-line mapping in the north; exposure mapping without the green-lining in the centre; and a closed traverse (points 64–78) and a stream traverse (points 78–84) in the south. Unexposed ground has been lightly coloured to distinguish ground already covered from that yet to be mapped.*