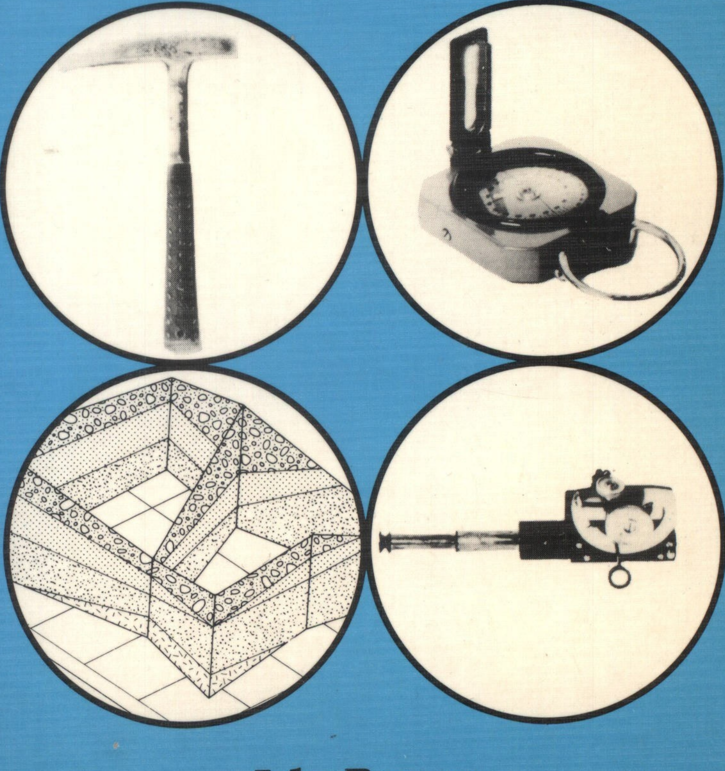
Geological Society of London
Handbook Series

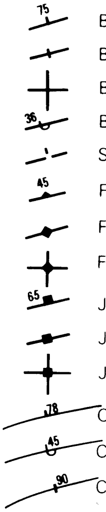
Basic Geological Mapping



John Barnes

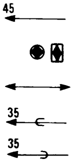
SELECTED GEOLOGICAL SYMBOLS

Strike and dip of:



- Bedding; with amount of dip
- Bedding; vertical
- Bedding; horizontal
- Bedding; overturned
- Strike and dip uncertain
- Foliation, cleavage, schistosity
- Foliation; vertical
- Foliation; horizontal
- Jointing
- Jointing; vertical
- Jointing; horizontal
- Contact between rock units
- Contact; overturned
- Contact; vertical, with dip on side of younger unit

Lineation:

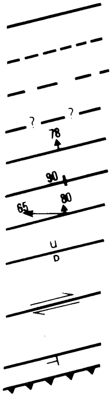


- Lineation; with amount of plunge
- Lineation; vertical
- Lineation; horizontal
- Small anticlinal axis
- Small synclinal axis

Contacts between rock units:

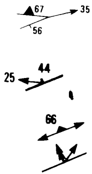
- Contact; observed
- Contact; position uncertain
- Contact; very uncertain
- Contact; projected beneath mapped units

Faults:



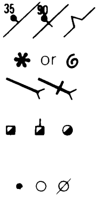
- Fault; observed
- Fault; position uncertain
- Fault; very uncertain
- Fault; existence uncertain
- Fault; showing dip
- Fault; vertical
- Fault; with lineation
- Fault; upthrown side 'U' & downthrown side 'D'
- Fault: showing horizontal movement
- Thrust fault: 'T' or saw-teeth on upper plate

Combined symbols:

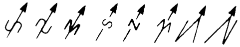


- Intersection of cleavage with bedding, and its lineation
- Dip and strike of bedding, and trend and plunge of lineation
- Foliation and horizontal lineation
- Dip of axial plane and plunge of fold axis

Miscellaneous:



- Younging; dot or point shows top
- Richly fossiliferous site
- Mine adit: open or blocked
- Mine shafts; vertical or inclined or circular
- Water well, flowing, non-flowing and dry



A selection of symbols to show the vergence of minor folds, namely *Z*, *S* and *M* vergence.

Alternative symbols to show the dip of an overturned axial plane and the plunge of the fold hinge.

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Tucker: *The Field Description of Sedimentary Rocks*
Fry: *The Field Description of Metamorphic Rocks*
Thorpe and Brown: *The Field Description of Igneous Rocks*

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Basic Geological Mapping

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Preface

This book is a *basic* guide to field techniques. It is meant to be kept in camp with you and even, at times, to be 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 preparing geological diagrams from your fieldwork suitable for inclusion in your report. Report writing itself cannot be covered here, but it must be borne in mind that a report explaining the geology is an essential part of any field project. 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 normal scale of 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 been told what to look for in the field. Geological mapping cannot, however, be taught in lectures and 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, together with others in the same series, will help them in that task.

John W. Barnes
1981

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It is impossible to name everyone who has been associated with the production of this book. Among those who deserve special mention for help with text or diagrams are D.V. Ager, F.R. Cross, A.R. Gardiner, R.H. Graham, T.R. Owen, S.J. Matthews and P. Styles, all of the University College of Swansea; M.H. de Freitas of Imperial College; and also my colleague on ten international mapping projects, the late E.H. Bailey of U.S.G.S. Appreciation is also due to departmental drawing office staff and particularly to Mrs V.M. Jenkins who typed the drafts.

1

Introduction

There are many kinds of geological map, from small-scale reconnaissance surveys to detailed underground mine maps and large-scale engineering site plans, and each needs a different technique. This book, however, is concerned only with the rudiments of geological mapping. Its intention is to give the young geologist a basic knowledge upon which he can build. It cannot tell him everything he needs to know but it is hoped that it will stimulate his imagination so that he can adapt his methods to prevailing field conditions and develop and invent new methods when necessary. A geologist 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 (1975) said in his 1974 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 someone about to go into the field on his first 'independent mapping' project. First, it describes the equipment he will need; then he is introduced to the many types of geological maps he may have to deal with at some time during his professional career. A description of the different kinds of topographic base maps which are available to him and on which he may plot his geology in the field follows. Methods of locating himself on his maps are also described and advice is given on what to do when no maps at all are obtainable.

The next three chapters describe the methods and techniques of geological mapping, including a brief description of photogeology. Another chapter is devoted to the use of field maps and those much neglected items, field notebooks.

The last two chapters concern 'office work', some of which may be done in your field camp. They cover methods of drawing cross-sections and the preparation of other diagrams to help interpretation; including the construction of 'egg-crate' models which make complex structures easier to visualize. Advice is also given for preparing a 'fair drawn' copy of your field map, and on illustrating your report on the geology mapped, for no mapping is complete until the geology has been explained. A geological map is not, as sometimes supposed, an end in itself. The object is to *explain* the geology and the map is only part of that process.

The approach throughout is practical. This is a 'how to do it' book and avoids any theoretical considerations of geology. Those can be found elsewhere. The object is to tell the reader what to do in the field to collect the evidence from which to draw his conclusions. What conclusions he draws is up to the reader himself.

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 one presumes they would not have become geologists, 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: 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, agents or authorities unless it is specifically known to be open to the public. Most owners are willing to cooperate if they are asked to but are understandably annoyed to find strangers sampling their rocks uninvited. Geologists should 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 overpopulated 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!

1.3 Safety

A geologist must be fit if he is to do a full day's work in the field, perhaps in poor weather or a difficult climate. Geological fieldwork, in common with other outdoor pursuits, is not without physical hazards. However, most risks can be minimized by following fairly simple rules of behaviour, and discretion may often be the better part of valour, say, when faced with a rock exposure in a difficult position. A geologist is very 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 discussed further in Appendix I from the standpoint of both the student (or employee) and his supervisor (or employer).

Finally, a few words of comfort 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 your 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 semblence to an embryo 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

Instruments and equipment

A geologist needs relatively little equipment in the field. A hammer is essential, so is a compass, clinometer, short steel tape and a handlens. He also needs a map case, notebook, map scale, protractor, pencils and eraser, plus an acid bottle and a pen-knife. On occasion, he needs a 30 m tape, an altimeter, a pedometer, a stereonet and a pocket stereoscope. Felt-tipped pens and timber crayons are excellent for marking specimens; chisels and moils may be needed to break them off. Although not essential, a camera and binoculars can be helpful. Finally he needs a rucksack to carry everything in, including, of course, his lunch.

A geologist must also wear proper footwear and clothes if he is to work efficiently, often in wet, cold weather, when other people stay indoors. Poor clothing may even put him at risk. Make a checklist of what you need to pack for field trips and always refer to it before setting out for the field.

2.1 Hammers and chisels

Any geologist going into the field needs at least one hammer with which to break rock. Taken generally, any hammer weighing less than 1½ lbs (0.7 kg) is of little use except for very soft rocks: 2–2½ lbs (0.9–1.2 kg) is probably the most useful weight. The commonest pattern still used in Europe has one square-faced end, and one chisel-end. Geologists associated with the mining industry tend to favour a 'prospecting pick': it has a long pick-like end whch can be inserted into cracks for levering out loose rock, and can also be used for digging into soil in search of float. Both types can be bought with a choice of wooden or fibreglass handles, or with a steel shaft encased by a rubber grip (Fig. 2.1). If a wooden handle is chosen, buy spare handles and some iron wedges to fasten them on with.

Geologists working in granite and gneissic regions may opt for heavier hammers. Four-pound (1.8 kg) geological hammers are available but a bricklayer's 'club' hammer, shaped like a small sledge hammer, can be bought more cheaply. It is even more effective if its rather short handle is replaced by a longer one.

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 type of work to be done. A ¼-inch (or 5 mm) chisel may be ideal to chip a small fossil free from shale, but for breaking out large pieces of hard rock a ¾- to 1-inch (or 20 mm) chisel is needed (Fig. 2.1). Perhaps geologists should follow the lead of mine samplers who find a 'moil' more effective. This is a steel bar, 25–30 cm long and 2.5 cm diameter, which has been sharpened to a point and tempered. One thing a geologist should never do, however, is to use one hammer as a chisel, and hit it with another. The tempering of a hammer is quite different from that of a chisel: a hammer face is hardened, a chisel top is not, and small steel fragments may fly off the hammer face with unpleasant results.

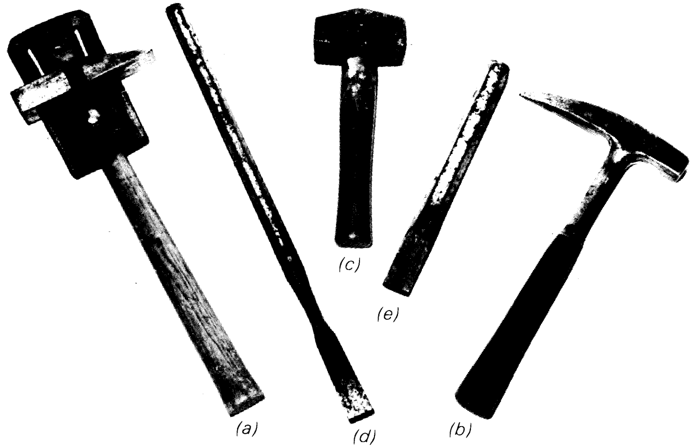


Fig. 2.1 Tools for the field: (a)—traditional geologist's hammer in leather belt 'frog'; (b)—steel-shafted 'prospecting pick'; (c)—bricklayer's 'club' hammer; (d)—45 cm long chisel with 2.5 cm edge; (e)—2.5 cm chisel 25 cm long.

Some geologists carry their hammers in a 'frog' or hammer holster, as this leaves their hands free for climbing, writing and plotting. Hammer frogs are essential when mapping underground mine workings where ladders must be climbed. They can be bought or easily made from heavy leather (Fig. 2.1). Note that the use of a geological hammer is a 'chipping action', an operation specifically mentioned by the British *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 when 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*, but many geologists now use Swedish *Silva* compasses (Fig. 2.2). These are reasonably priced, well-damped needle compasses. The 15TD.CL model incorporates a

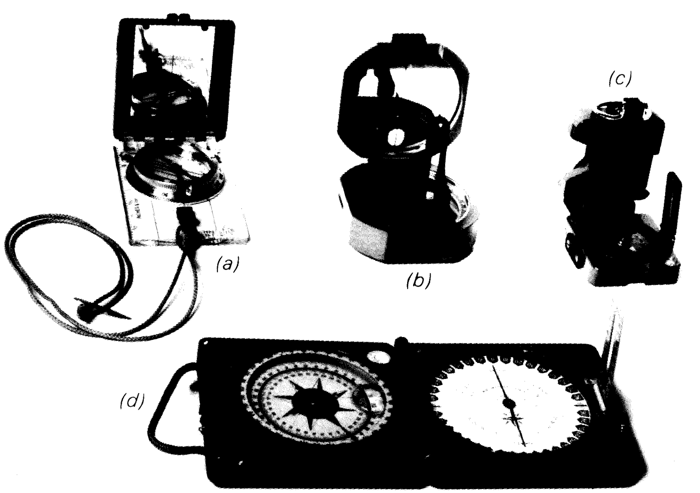


Fig. 2.2 Compasses designed for the geologist: all incorporate a clinometer. (a)—Swedish *Silva* compass type 15TD.CL; (b)—American *Brunton* 'pocket transit'; (c)—Swiss *Meridian* compass; (d)—French *Chaix-Universelle*. The Brunton and Meridian can be used as hand-levels.

clinometer and has been designed specifically for geologists. One convenience is that bearings can be plotted onto the map immediately after they have been measured by using the compass itself as a protractor (see Section 5.2). Like the Brunton, Silva needle compasses are not ideal for sighting distant points and the makers now produce a neat card-type prismatic model (No. 54) but it has no clinometer (Fig. 2.3). The drawback of nearly every compass available, except for the Brunton and the Swiss Meridian is, however, the lack of a hand-levelling device, so necessary for many geological tasks.

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^g (grads) to a full circle. Both are used in continental Europe. If you opt for degrees, you must then choose between graduation of the compass into four quadrants of 0°–90° each, or to read a full circle of 0°–360° ('azimuth' graduation). The writer recommends azimuth, for bearings can be expressed more briefly and with less chance of error. Comparisons are made in Table 2.1.

Table 2.1

Quadrant bearing	Azimuth bearing
N 36° E	036°
N 36°W	324°
S 36°E	144°
S 36° W	216°

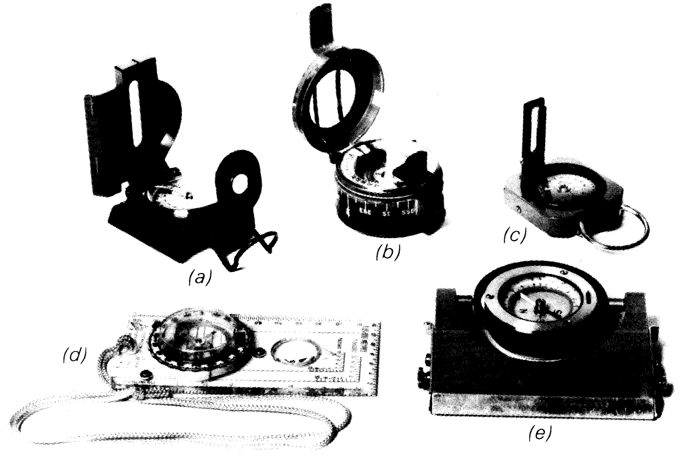
2.2.2 *Using compasses*

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 so that the point is aligned with the compass fore-sight and the slot in the top of its prism; the bearing is read simultaneously through the prism. A mirror compass, such as a Brunton or Silva, is held at waist height and the distant point aligned with the front-sight so that both are reflected in the mirror, and bisected by its hair-line (Fig. 2.4). If the compass is not liquid damped, the bearing is read when the needle has *almost* settled by averaging the limits of its swing. A mirror compass can be used, if awkwardly, in a similar manner to a prismatic by holding it at eye level and reflecting the needle in the mirror. Mirror compasses have a specific advantage over prismatics in poor light, such as underground.

2.2.3 *Clinometers*

Not all 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*, can also be used as a clinometer, but rather

Fig. 2.3 Various other compasses: (a)—Japanese *Europleasure Lensatic* compass. This can be read like a prismatic compass, and is liquid filled: (b)—standard British prismatic compass made by a variety of manufacturers. They are robust and liquid filled. (c)—Swiss *Meridian* liquid-filled prismatic compass; (d)—Swedish *Silva* liquid-filled prismatic compass, No. 54; (e)—Japanese *'universal clinometer'* an adaptation of the traditional miner's 'hanging compass': for the measurement of lineations (see also Fig. 2.6).



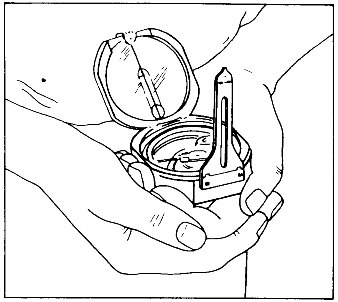


Fig. 2.4 Correct way to hold a Brunton (or any other mirror-type compass) to sight a distant point (reproduced by courtesy of the Brunton Company, Riverton, Wyoming, USA).

inconveniently. The *Burgess* 'level and angle indicator', designed for do-it-yourself handymen, makes a cheap and effective clinometer. A builder's 'two-foot' clinometer rule is useful for measuring lineations. Clinometers can be made, either by using the pendulum principle or, more easily, as follows: stick half a semicircular protractor—zero-point downwards—to a rectangle of perspex and cement a piece of plastic (windscreen-washer) tubing around its edge: Insert a small bead into the tube and plug its ends: the bead acts as a point as it rolls round the tube (devised by G. Bryn Thomas). A selection of clinometers is shown in Figure 2.5.

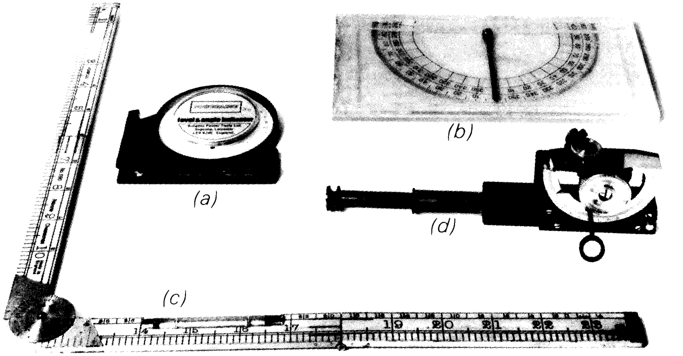
2.2.4 *Lineation compass*

The Japanese produce a compass designed to measure trend and plunge simultaneously. The compass case is in gimbals so that it always remains level whatever the angle of its framework. It is effective even in the most awkward places (Figs. 2.3e and 2.6).

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 from 7 to 10 times is probably the most useful. Although there are cheap ones on the market, a good quality lens is worth the extra cost in flatness of field, and should last a lifetime. To ensure that it does last a lifetime, attach a thin cord to it to go round your neck.

Fig. 2.5 A selection of clinometers: (a)—*Burgess* 'level and angle indicator'; (b)—home-made clinometer; (c)—builder's 'two-foot' rule with level bubble and hinge graduated at 5° intervals; (d)—*Abney* hand-level—can be used as a clinometer too.



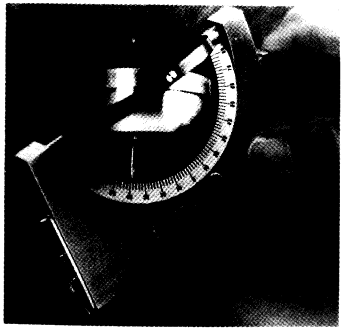


Fig. 2.6 Japanese *universal clinometer.* Trend can be read directly off the compass and plunge from the pointer which can be seen below the compass box. It can be used in many awkward places, including overhangs (made by Nihon Chikagakso Shaco, Kyoto).

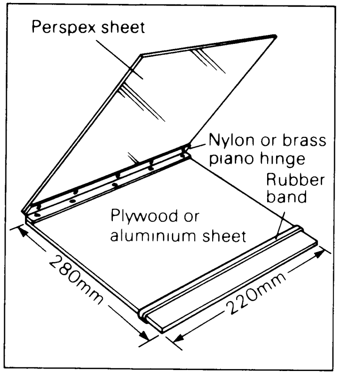
2.4 Tapes

Always carry a short 'roll-up' steel tape. A 3 m tape takes up no more room than one 1 m long and is only slightly heavier and much more useful. A geologist also occasionally needs a 10 or 30 m 'linen' tape for small surveys. He might not need it every day but should keep one in camp for when he does. Treat tapes with respect. Wind them back into their cases only when clean for dirt will wear off their graduations. If a linen tape is muddy, coil it into loops between measurements. When you do eventually wind it back into its case, do so between two fingers of the left 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 rain or in 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 the map can be written on and bearings plotted; it must protect the map; and it *must* open easily, otherwise it will deter you from adding information to your map. The best are probably home made (Fig. 2.7). Pencil holders make mapping easier whether attached to your map case or your belt. Make your own.

Fig. 2.7 A map case made from a perspex sheet attached to a plywood sheet by a nylon (or brass) 'piano hinge'. The hinge is fixed by 'pop-rivets'. A wide rubber band keeps maps flat.



2.6 Field notebooks

Do not economize on your field notebook. It should have good quality 'rainproof' paper, a strong hard cover and good binding. It has to put up with rough usage, often in wet and windy conditions. Nothing is more discouraging than to see pages of field notes torn out of your book by the wind and blown across the countryside. Loose-leaf books are particularly vulnerable. A hard cover is necessary to give a good surface for writing and for sketching. A notebook should fit into your pocket so that it is always available but be big enough to write on in your hand. A good size is 12 cm x 20 cm. Try to buy one with squared—preferably metric squared—paper; it makes field sketching so much easier. Half-centimetre squares are quite small enough.

2.7 Scales

A geologist must use a proper scale, most conveniently about 15 cm long. A ruler is just not good enough: it seldom has an edge thin enough to allow accurate plotting of distances, and converting in your head a distance measured in metres on the ground to the correct number of millimetres on the scale, leads to errors. Scales are not expensive for the amount of use they get. Most are 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 Britain a scale graduated for 1 : 10,560 is useful, for 6 inches = 1 mile sheets still exist in many areas. In the USA scales with 1:62,500 and 1:24,000 graduations are needed. Colour code scale edges by painting each with a transparent waterproof ink, or attach coloured adhesive tape, so that the edge you need is immediately recognizable.

2.8 Protractors

Little need be said about protractors. They are easily obtainable and relatively cheap. They should be 15–20 cm in diameter and semi-circular: circular protractors are unsuitable for plotting bearings in the field. Always carry at least two spare smaller protractors (10 cm diameter) to guard against loss. Transparent protractors are difficult to see when dropped but are easier to find if marked with an orange fluorescent adhesive 'spot'. Fig. 2.8 shows a selection of scales and protractors.

2.9 Pencils and erasers

At least three lead pencils are needed in the normal course of mapping: 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 a further pencil (2H) 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 required on a geological map with sufficient permanency to last a full day's mapping in rigorous conditions. Buy only good quality pencils, and when possible, buy them with an eraser attached. Alternatively buy erasers which fit over the end of a pencil. Attach a larger, good quality eraser to your buttonhole or map case by a piece of string, 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 you can replace them with exactly the same colours again.

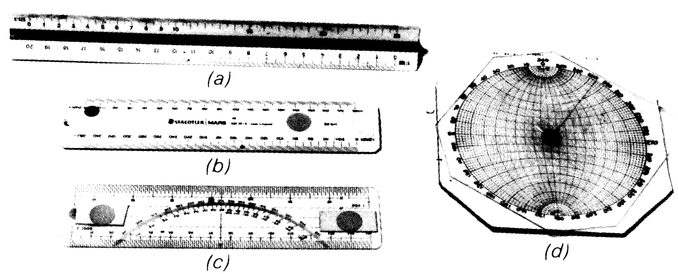


Fig. 2.8 A selection of scales, and protractors: (a)—a triangular map scale which is not recommended for field use; (b)—a plastic scale with graduations on both sides; (c)—transparent combined protractor and map scale (C-thru Ruler Company, Bloomfield, USA); (d)—a home-made pocket stereonet for field use. The upper rotating surface is slightly matt so that it can be drawn on in pencil and easily cleaned. Note that orange fluorescent adhesive 'spots' have been stuck to the scales to make them easier to find if dropped.

2.10 Acid bottles

Always carry an acid bottle in your rucksack. It should contain a *small* quantity of 10% hydrochloric acid. Five 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 acid bottles. They have the advantages that they deliver only one drop at a time, are small, do not leak and will not break.

2.11 Other instruments

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

2.11.1 Stereonets

A pocket stereonet is most useful when mapping lineations. Plunge and trend can be calculated on the spot from strike and pitch measurements made on bedding and foliation planes or from the intersections of planes. A stereonet is the geologist's slide rule and the structural geologist will find many uses for it in the field. Make your own but remember a Wulff equal-angular net not the Schmidt equal area net (Fig. 2.8) is needed for calculating angles and directions.

2.11.2 Stereoscopes

You need a pocket stereoscope when mapping on aerial photographs. It allows you to obtain a 3-dimensional stereoscopic image from stereo-pairs of photographs in the field.

2.11.3 *Pedometers*

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

2.11.4 *Aneroid barometers*

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 many geological purposes and are not particularly expensive. Remember to carry them in your hand baggage when travelling by air: the cabin is pressurized, the baggage compartment is not. As most instruments read only to about 5000 m above sea level, they are unlikely to function properly if exposed to the 10,000 or 15,000 m of modern air travel.

2.12 Field clothing

To work efficiently, a geologist must be properly clothed. In temperate and colder climates, wear loose-fitting trousers: tight jeans are not as warm. In very cold weather, wear 'long johns' or pyjama trousers underneath your field trousers, or put on your waterproof overtrousers. Carry a sweater and a waterproof anorak or cagoule in your rucksack in warm weather, but as it gets colder wear a padded field jacket, a thicker shirt, and a warm vest beneath. Make sure that you always carry waterproof and windproof overclothing for use in bad weather. Take also a woolly hat: heat is lost rapidly through your scalp and it is not always convenient to wear the hood of your anorak. Use gloves in cold weather. Some geologists prefer fingerless mittens so that they can write on their map with them on, but keep a pair of water-resistant gloves with you too. Gloves are probably lost more frequently than any other piece of equipment, so keep a spare pair in camp. Clothing in warm climates is less important, but long-sleeved shirts and long trousers should be worn in the field until you are fully acclimatized to strong sunlight. Sunburn is painful at best, and can be dangerous. A 'jungle hat' is also recommended. The brim pulled down over your eyes is probably a far more effective shade from glare than sun glasses.

Boots for fieldwork in temperate, wet and cold climates should be strong and waterproof, with well-cleated soles. Leather boots are expensive but they are a part of a geologist's essential equipment. Rubber 'Wellington' boots can be worn when working in boggy ground and some types now have excellent soles which allow them to be used on rock. Rubber boots are not, however, comfortable for walking long distances. In warm, dry climates, lightweight half-boots of the 'chukka boot' type, or even hockey boots, are ideal. Heavier boots, however, are still advisable in mountains wherever you are.

When buying field clothing, choose a yellow, orange or red anorak for preference as this is more easily seen by search parties in an emergency.

3

Geological maps and base maps

To make a geological map a geologist requires a topographic base map on which to plot his geology in the field. He also needs a topographic base on which to plot his interpretation of the geology to form the 'fair copy' map he submits to his employer when his work is complete. In Britain, a geologist has 'Ordnance Survey' (OS) maps at his disposal at a scale of 1:10,000, and even larger in many areas. Elsewhere, the scales of the maps available to him are probably smaller; he may even have difficulty in getting a base map at all, for many countries restrict the issue of all but tourist maps to officials. He may even have to make his own topographic map—if he knows how. Any geologist, especially if he intends to enter the mineral industry, is well advised to learn at least the rudiments of map making. It will stand him in very good stead.

3.1 Types of geological map

Geological maps fall into four main groups. These are reconnaissance maps, maps of regional geology, large-scale maps of limited areas and maps made for specialist 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*

A reconnaissance map is made to find out as much as possible about the geology of an unknown area as quickly as possible. It is usually made at a scale of 1:250,000 or less, sometimes very much less. Some reconnaissance maps are made by *photogeology*, that is, by interpreting geology from aerial photographs with only a minimum amount of work done on the ground to identify rock types. Reconnaissance mapping may even occasionally be done by plotting the main geological features onto a base map 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.

3.1.2 *Regional geological maps*

Reconnaissance has given the outline of rock distribution and general structure, now the geology must be studied in more detail, most commonly at a scale of 1:25,000 or 1:50,000.

Regional maps should be plotted on a reliable base. Unfortunately, in some countries, geological mapping outstrips topographic coverage and the geologist must survey the topography himself. 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 emphasized that photogeological information is *not* inferior to that obtained on the ground although it may differ. Some geological features seen on aerial photographs cannot even be detected on the ground while others can be more conveniently followed on photographs than in surface exposures. Regional geological mapping should incorporate any techniques which can help in plotting geology and which the budget will allow, including geophysics, pitting, augering and drilling.

3.1.3 *Detailed geological maps*

Here, scale is anything from 1:10,000 upwards and they are usually made to investigate a specific geological problem, perhaps resulting from discoveries made during regional mapping, or perhaps with an economic objective, such as a dam site or mineral investigation.

3.1.4 *Specialized maps*

Specialized maps are many and varied. They include large-scale maps made in great detail of small areas to record specific geological features. Many are made for economic purposes, such as open pit mine plans at scales from 1:1000 to 1:2500; underground geological plans at 1:500 and even larger; and engineering site investigations at similar scales. There are many other types of maps with geological affiliations too. They include geophysical and geochemical maps, foliation and joint maps, sampling plans with outline geology, maps of drift coverage and maps of the sub-surface. Many are prepared as transparent overlays to be superimposed on a normal geological map at the same scale.

3.2 Topographic base maps

3.2.1 *Great Britain*

The Ordnance Survey (OS) produces several large-scale topographic map series for geologists to choose from. Particularly useful are those at 1:10,000 (now rapidly replacing the older 6 inches = 1 mile maps) and 1:25,000. The wealth of detail printed on these maps, including hedges and fences, makes the accurate location of geological observations relatively simple except, perhaps, in moorland, where it becomes only a little more difficult.

Maps at still larger scales are available. These are the 1:2500 series, referred to as '25-inch maps' although their true scale is 25.344 inches to a mile, and the 1:1250 series ('50-inch maps'). Neither are contoured but 'spot heights' are shown. The 1:2500 series covers the greater part of Britain except for mountains and moors, but the 1:1250 plans are available only for urban areas with populations over 20,000. Both can be obtained as printed plans on paper; as photographic 'printouts' from *SIM* (Survey Information Microfilm); and as 'copycards' (35 mm film in cardboard mounts) from which you can make your own photographic copies. OS maps can be bought from approved distributors throughout the country who carry maps covering their own areas. If in difficulties, contact: Ordnance Survey, Department 32, Romsey Road, Maybush, Southampton SO9 4DH.

3.2.2 *North America*

The Geological Survey is responsible for publishing most of the topographic maps of the United States. Maps are published of the United States itself, Puerto Rico, Guam, American Samoa and the Virgin Islands at 1:1,000,000, 1:250,000 and, in certain areas only, at 1:62,500 and 1:24,000. Special maps are also printed at other scales. A free descriptive booklet can be obtained from: National Cartographic Information Center, Geological Survey, Reston, Virginia 22092. Maps can be bought from the Branch of Distribution, Geological Survey, at either Arlington, Virginia 22202 or the Federal Center, Denver, Colorado 80225.

In Canada the situation is more complex because both the federal and provincial governments produce maps. Enquiries should be made to the Map Distribution Office, 615 Booth Street, Ottawa 4. Maps likely to be used by field geologists are published at 1:250,000, 1:125,000 (in progress), 1:50,000 (in progress) and, in urban areas, 1:25,000.

3.2.3 *Australasia*

Australia produces maps at 1:1,000,000 and 1:250,000, with incomplete coverage at 1:100,000 and 1:50,000. They are available from: Map Sales Section of the Department of National Development, Tasman House, P.O. Box 850, Canberra City, ACT 2601; 460 Bourke Street, Melbourne, Victoria; and the Commonwealth Centre, Sydney, N.S.W. 2000. Maps and aerial photographs are also available from the Surveyor General, Department of Lands in each state or territorial capital, including both Tasmania and Papua.

New Zealand produces only two topographic map series of interest to the field geologist, namely one at 1:250,000 and an incomplete coverage at 1:63,360 (1 inch = 1 mile). Maps may be obtained from the Map Centre, Department of Lands and Survey, P.O. Box 6452, Te Aro, Wellington.

3.2.4 *Other countries*

Only general advice can be given on the availability of maps of other countries. Conditions vary greatly. Most countries of western Europe have good maps at 1:25,000 and 1:50,000. A few countries have 1:10,000 maps of limited areas and those of Switzerland are superb. There is little difficulty in getting maps of western Europe but those of eastern Europe and Asia are more difficult to come by. In many countries foreigners cannot obtain maps at all unless attached to a government department, and even then you must return them before leaving the country. Fortunately, in those countries, academic research is often tied to the mapping programmes of the official geological surveys, and this does ease the problem if you collaborate with their universities. In British Commonwealth and ex-Commonwealth countries there are usually good 1:50,000 topographic maps available but there are still many countries which have no maps suitable for geological purposes. In such places a geologist must work with a surveyor, or make his own base map by plane-tabling or from aerial photographs. An alternative is sometimes possible where good quality small-scale maps can be found, by photographically enlarging them to three or four times their original scale.

3.3 Geographic coordinates and metric grids

3.3.1 Geographic coordinates

Geographic coordinates represent the lines of latitude and longitude which subdivide the terrestrial globe. To make a map, part of the curved surface of the globe is projected onto a flat surface. This may result in one or both sets of coordinates being shown as curved lines, depending on the projection 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 interecting sets of straight parallel lines. This results in some distortion because, of course, lines of longitude in reality converge towards the poles, but on any single map sheet, the distortion is negligible. What does matter is that as latitude increases north or south of the equator, 1° of latitude remains almost (the earth is not a perfect sphere) a constant length of 60 nautical miles, but 1° of longitude becomes progressively shorter. Consequently, the use of geographic coordinates for pinpointing locations in the field, is to say the least, cumbersome.

3.3.2 Metric grids

The 'kilometre 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 metric coordinates, usually printed to give 1 km squares on maps of from 10,000 to 50,000 and 10 km squares on 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. For convenience, it is divided into 100 km square blocks, each designated by two reference letters. Other countries have other origins for their grids, and some use other systems.

The metric grid is a useful device for describing a location 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. For instance, SN8747 means that Llanwrtyd Wells is 87 km east and 47 km north of the margins of square SN. This reference is good enough to indicate a general area or a town. SN87724615, however, is more specific and locates to within 20 m the turn-off to Henfron from the Llanwrtyd Wells main road (Fig. 3.1), i.e., 87.720 km east and 46.150 km north of the square margins. These references are taken from the British 1:50,000 OS sheet No. 147. At larger scales, even more accurate references can be given.

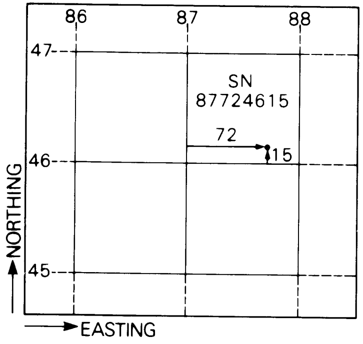


Fig. 3.1 Finding a map reference. The figure shows coordinates of a portion of 100 km square 'SN' of the British National Grid. The point referred to lies 0.72 km east of the 87 km coordinate and 0.15 km north of the 46 km coordinate. Eastings are always quoted before Northings.

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 plot their compass bearings from the grid lines on their maps rather than from lines of longitude, yet many still adjust their compasses to offset the difference between *magnetic* north and *true* north when they should be adjusting them for the difference between *magnetic* and *grid* north. In Britain, true north and grid north diverge to almost 5° in the Hebrides. Ensure that you adjust your compass against the proper variable (see Section 3.5).

3.4 Position finding on maps

In the field a geologist should be able to pinpoint himself to better than 1 mm of his correct position on the map, whatever the 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 merely 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 can be built to help him to locate himself. Where maps of poorer quality have to be used, a geologist may have to spend several days erecting points to work off and in surveying in their positions.

3.4.1 Pacing

Every geologist should know his pace length. With practice he should be able to pace with an error of under 3 m per 100 m over even 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 to over half a kilometre if using a scale of 1:25,000.

Establish pace length by taping out 200 m over the average type of ground found in the field. Pace the distance twice in each direction and always count double paces, for they are less likely to be miscounted when pacing very long distances. Use a steady natural stride and on no account try to adjust it to a specific length, such as a yard or metre. Look straight ahead so that you do not alter your stride in the last few paces of each measurement to try to get the same number as last time.Every measurement should be within two double paces of the average of the four.

Prepare a table of paces, xerox it, and tape one copy into the back of your notebook and one into your map case (Table 3.1). When using this table, remember that you shorten pace when going both up and down hill so that allowances must be made to avoid overestimating. This is a matter of practice. If very long distances need pacing, pass a pebble from one hand to another, or from pocket to pocket, at the end of every 100 paces to save losing count.

Table 3.1 Example of a table of pace lengths in metres arranged for quick estimation of distances

Paces	*Metres*	*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

3.4.2 Location by pacing and compass bearing

The simplest method of finding your position on a map—if mere inspection is insufficient—is to stand on the unknown point and measure the compass bearing to any nearby feature which can be identified on the map. Then pace the distance to the feature, providing it lies within the limits of allowable accuracy for the scale of map used. Plot the back-bearing from the feature, convert paces to metres, and mark the distance along the bearing with a scale.

3.4.3 Offsets

Offsetting is a simple method of plotting detail onto a map. It is particularly useful where a large number of points are to be plotted in one small area. Pace a line from a known position along a compass bearing until a point is reached directly opposite the first exposure to be examined. Drop your rucksack and then pace to the exposure at right angles to the main bearing line. This side line is an *offset*. Make your observations and then return to your rucksack and resume your 'traverse' along the same bearing as before until opposite the next exposure (Fig. 3.2). This method is comparatively fast for once the direction of the traverse or 'chain line' has been determined, preferably by lining in on a feature such as a tree, there is no real need to use your compass again except as a check; the right angles for the offsets can usually be estimated providing offsets are kept short. All you need to do is to count paces.

A variation of this method can be used on maps which show fences and walls. Pace the distance along a fence from a field corner and measure offsets from the fence-line to any exposure and observation points which need to be recorded. If the fence is long, take an occasional compass bearing to a distant point to check your position by 'intersection'. Students seldom make enough use of walls and fences although they are clearly marked on many maps.

3.4.4 Compass intersection

Your position on any lengthy feature marked on the map, such as a road, wall, fence, footpath, stream or river, can easily be found by taking a compass bearing on to a point which can be identified on the map. Plot the back-bearing from this point and your position is where it intersects the road, wall, fence, etc. Check with a second bearing from another point. Choose your points so that bearings intersect your feature at angles between 60°–90° for the best results (Fig. 3.3).

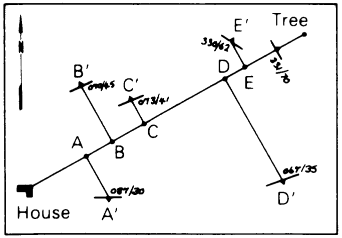


Fig. 3.2 Locating points by offsets. A traverse (bearing 62°) is paced from the house, using the tree as an aiming point, until you reach point A, directly opposite an exposure at A'. Mark A with your rucksack and then pace the offset A–A' at right angles to the traverse line. Plot the position of A'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

3.4.5 Compass resection

Compass resection is used where ground is too rough or too steep, or distances too large, to pace. Compass bearings are taken from the unknown point to three easily recognizable features on the map, chosen so that back-bearings from them will intersect one another at angles of between 60°–90° whenever possible. Ideal intersections, unfortunately, are seldom possible, but every attempt should be made to approximate to them (Fig. 3.4). Features on which bearings may be taken include a field corner, a farmhouse, a sheep pen, a road, path or stream junction, a 'trig' point, or even a cairn that you yourself may have erected on a prominent point for this very purpose.

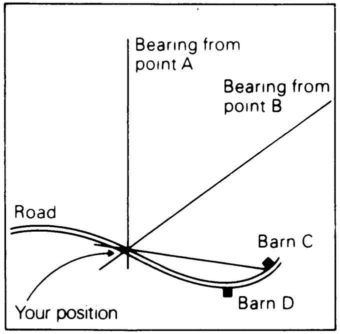


Fig. 3.3 Locating yourself on a road or similar longitudinal feature. Sight points which give good intersections with the road; a bearing to the nearby barn, for instance, is not satisfactory.

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 your correct position, if larger, check your bearings and your plotting. If the triangle still persists, sight a fourth point, if one can be found. If the error cannot be eliminated, it may be

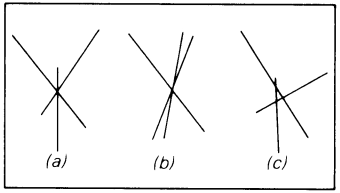


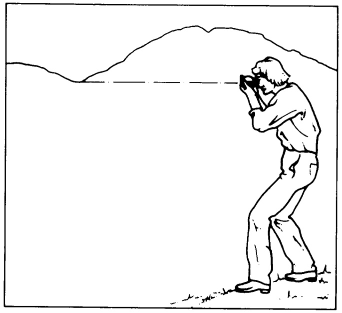
Fig. 3.4 Intersection of bearings; (*a*) relatively good; (*b*) poor; (*c*) shows a triangle of error.

because the correction for magnetic declination has been wrongly set on your compass, or you may be standing on a magnetite-bearing rock such as serpentine, or you may be too close to an iron gate or under a power line. You may even have read your compass with your hammer dangling from a loop round your wrist—yes, it has been seen to be done! Or perhaps your compass is just not good enough for the job.

3.4.6 Compass and hand-level intersections

Where there is a lack of points on which compass bearings can be taken, a hand-level can be most useful. This is a device which allows you to sight a truly horizontal line. Such devices are built into the Brunton and Meridian geologist's compasses, while the Abney level is specifically designed as a hand-level. Some clinometers can also be used in the same way. To find your position, establish the contour you are standing on by scanning the surrounding hilltops, ridges and saddles with the hand-level until one is found at your own elevation. Providing you can find a feature less than 1 km away within ½° of your own level, you should be able to determine your contour to better than 10 m. Your position can then be established by a back-bearing from any point which will give a good intersection with your contour. Although not precise, the method may be all you can do in some places (Fig. 3.5).

Fig. 3.5 Levelling in a contour by hand-level. Set the level to zero and then search for a feature within ½° of your level-line.



3.4.7 Compass and altimeter intersections

An altimeter is an aneroid barometer equipped with an adjustable additional scale graduated in altitude above sea level. If set to read the correct altitude at the start of a traverse, 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 weather. The usefulness of altimeters is probably undervalued owing to geologists who have become exasperated in trying to use them in the wrong conditions for the wrong purposes.

Use them in a similar way to a hand-level, that is, establish the contour on which you are standing so that a simple compass intersection will then determine your position on that contour. The method is particularly useful in featureless country. The main problem is the variation in barometric pressure. This can be controlled in several ways. In very stable conditions spend a day in camp recording pressure changes on a graph which can then be used in the field to correct diurnal variation. In the field, check your barometer every time you occupy a point of known elevation on the map. If altitude readings are only occasionally needed, read your altimeter when you reach a point you cannot locate by other methods, and 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, and then continue to another known height. You can then correct for any changes in pressure 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 higher slopes and survey them in by resection from well-established points. If wood is cheap, tall, flagged poles can be used in place of cairns.

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 variation, and its annual change, varies 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 the marginal information printed on a map sheet. 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 the map from a grid coordinate, the correction used must be 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 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 taken 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, such as a moorland fence or wall, and then comparing 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 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 geological significance, differences which surveyors cannot show on tacheometer surveys where contours are drawn from spot heights plotted back in the office. Second, the plan position and elevation of every geological observation is accurate because it has been surveyed in. There is considerable satisfaction in plane-tabling, too, for your map grows before your eyes as geological and topographic detail is added. Plane-tabling 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 (1979), and Compton (1966), and any textbook on surveying.

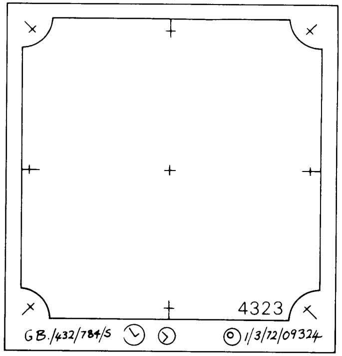
3.7 Aerial photographs

The value of aerial photographs to the geologist cannot be overestimated. In reconnaissance, large tracts can be mapped quickly with only a minimum of work done on the ground. In more detailed investigations, examination of photographs under a stereoscope can reveal many structures which are difficult to see in the field, and some which cannot be seen at all at ground level. Photographs are as much a tool for the field geologist as his hammer and handlens. 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 an 'uncontrolled mosaic' as a substitute on which geology can be plotted. It is not an accurate map, but it will serve its purpose for want of anything else. Information may also be plotted in the field directly onto photographs and then transferred to a base map later. This is particularly useful when the topographic detail on the base map is so poor that position-finding is difficult and time-consuming in the field. Excellent topographic maps can be made from photographs by a number of different techniques, but this is beyond our present scope.

Fig. 3.6 is a diagram of a typical aerial photograph. As each exposure is made, a photograph of a clock, altimeter, compass and circular level is also recorded in the *title strip* at the bottom of the photograph, to show time, height and tilt. The strip also shows the contract number, sortie number, and often, either the nominal scale of the photo or the focal length of the camera lens. Each exposure is numbered. *Fiducial marks* are printed at the corners or midway along each side of each photograph so that the *principal point* (see Section 3.7.1) can be marked on it if the camera does not print it on automatically. Different makes of camera have different title strip information, and arrange it differently.

Fig. 3.6 Layout of a typical aerial photograph, showing the fiducial marks at corners and mid-points of sides, the principal point, the title strip at the bottom, and the photograph number in the right- hand corner.



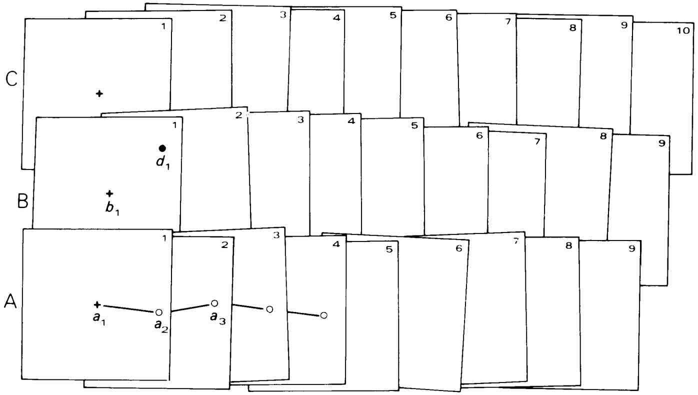
Aerial photographs are taken sequentially by an aircraft flying along a series of parallel flight paths which may be straight lines or arcs of circles, depending on the method of controlling direction. They are taken with a frequency such that each photograph on a flight line overlaps the next by 60%, 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 three-dimensional image, and also to ensure that there are enough common points on photographs to link them together for topographic map-making (Fig. 3.7).

Because the scale of an aerial photograph is a function of the focal length of the camera lens divided by the height of the camera above the ground, the true scale on an aerial photograph varies from place to place. A hilltop is closer to the camera than a valley bottom, and the centre of the photo closer than a corner of the photo. These differences cause distortions (Fig. 3.8). Distortion can, however, be removed to produce true-to-scale 'orthoprints'.

3.7.1 *Preparation*

Before they can be used, aerial photographs must be *base lined*. First mark the *principal point* (*pp*) on each consecutive photograph: this is the point where the optical axis of the lens meets the negative (Fig. 3.6). Now, locate the position of the *pp* (a_1 on Fig. 3.7) of your first photograph on the overlapping part of the second

Fig. 3.7 A block of three runs of aerial photographs, A, B, and C. Photographs in each run overlap 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* a_2 on photo A–2 is found on both photographs A–1 and A–3. Adjacent runs overlap by about 30% so that the feature d_1, seen on photograph B–1, can not only be found on photographs B–2 and B–3, but also on photographs C–1, C–2 and C–3 of the adjacent run.



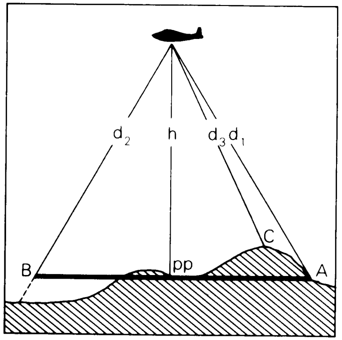


Fig. 3.8 Scale variations in an aerial photograph taken in undulating country. A–B represents the notional plane of the photograph; *pp* is its principal point. The nominal scale of the photograph is *f*/*h*, where *f* is the focal length of the camera lens and *h* is the height above the ground at *pp*, i.e., its distance from the lens. At A, the distance from the lens (d_1) is greater than *h*, therefore the scale of the photograph there is smaller than at its centre, *pp*. At B, the fall of the land means that d_2 is even greater than d_1 and consequently, the scale is smaller still. The distance d_3 to hilltop C, however, is less than *h*; the scale on high ground is therefore less than at *pp*.

photograph in the run. Do this by inspection with a handlens and prick its exact position on photograph No. 2 with a needle. Draw a small circle round the needle hole. This transferred principal point is called a *conjugate point* (*cj*). Now transfer the *pp* of photograph No. 2 to photograph No. 1 (point a_2), and to photograph No. 3, and so on. Draw base lines between the *pp* and the two *cjs* on every photograph (Fig. 3.7). Base lines indicate the track of the aircraft between photographs and show that the flight line is seldom straight owing to drifting and yawing. The purpose of the base line here, however, is to make it easier to align your stereopairs of photographs under the stereoscope in their optimum position to give a 3-dimensional image. Although your eyes will accommodate the strain needed to produce a 3-D image from poorly positioned photographs you will end the day with a headache.

3.7.2 *Plotting on aerial photographs*

The surface of the photograph is not easy to write on in the field. The best method of recording information is on an overlay of tracing film, such as 'Permatrace' or 'Mylar'. Cut the overlay to the same size as the photograph and tape it on along *one* edge only by a hinge of *drafting* tape, so that it can be lifted whenever you wish to examine the photograph more clearly. Do not use transparent tape as it damages the photograph when it is removed. Mark the photograph number and the *principal* and *conjugate points* on the overlay, so that it can be repositioned on the photograph if it is necessary to do so at some later date.

Locating your position on a photograph is usually easy. It can be done either by inspection of a single photograph to identify a nearby feature, or if in difficulty, the 'stereopair' can be used with a pocket stereoscope to give a 3-D image of the ground. Note that the three-dimensional image seen under a stereoscope gives 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 in locating yourself. What you cannot do on a photograph is locate yourself by compass resection.

3.7.3 *Northpoints on photographs*

Structural information is plotted onto a photograph in the same way as onto a base map. Photographs, however, are seldom taken along flight lines which run north–south and even if they were, aircraft yaw sufficiently that the margin of the photograph could still not be taken as the intended flight direction. Therefore a northpoint must be established for every individual photograph on every flight line. This can only be done on the ground. Position yourself as close to the centre of the photograph (the *principal point*) as possible and take a compass bearing on some easily identifiable feature on a line as nearly radial from the photo-centre 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. This does not affect the plotting of strikes and lineations at single points on a photograph.

3.7.4 *Transferring geology from photograph to base map*

Geology plotted onto photographs or overlays in the field must be transferred to a base map later. You cannot trace information directly from one to the other because they will never be exactly the same scale. *Camera lucidas* are available which enable the map to be viewed with an image of the photograph adjusted to the same scale superimposed upon it. Information can also be transferred directly from photographs by inspection. Dips and strikes must then be replotted from recorded compass bearings. Because of a lack of fine topographic map detail, however, it may not always be possible to locate on the map an observation point marked on the photograph. In that case, draw a radial line from the principal point on the photograph to the observation, measure the angle it makes with the northpoint on the photograph; then plot the same bearing from the position of the principal point marked on the map. The observation lies along this line and its exact position can usually be found from other information. If not, establish the difference in scale between map and photograph and plot the distance from the *pp* proportionately. This will not work in mountainous areas. In that event, measure the angle between the radial line and the *base line*; locate the same observation point on the adjacent photograph and measure the angle between the base line and that radial line; plot the angles from the ends of the same base line marked on your map. The point lies at the intersection of the radial lines (Fig. 3.9). This is 'radial line plotting'.

Before transferring any information from photographs by any method, the principal points of every photograph must be marked on the map. Some maps may even have the *pp*'s of the photographs from which they were compiled already printed on them, with the photo-numbers shown in very fine type beside them.

3.7.5 *Sources of aerial photographs*

In Britain photographs can be bought through the Central Register of Air Photographs of England and Wales, London; the Welsh Office in Cardiff; or the Scottish Development Depart-

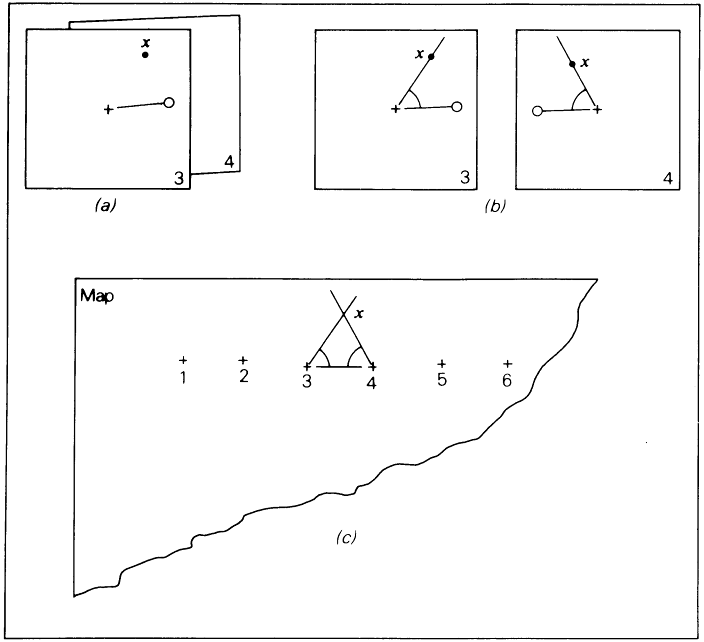


Fig. 3.9 To locate on a map the position of a point *x* seen on aerial photographs:
(a) Locate the position of *x* seen on photograph 3 on the overlapping photograph No. 4.
(b) Draw a radial line from the principal point of each photograph through the point *x*. Measure the angles made with the base lines.
(c) Join *pp*'s 3 and 4 on your base map; plot the angles measured from the photographs; *x* lies at their intersection.

ment in Edinburgh. They will tell you what photographs are available and at what scales, provided you give them the map references of the corners of the area you need cover for. Private contractors listed in the *Geologist's Directory* (Institute of Geologists 1980) may also have photographs for sale. In the USA photographs can be supplied by the Geological Survey, EROS Data Center, Sioux Falls, S. Dakota 57198.

Sources in Australasia are given in Section 3.2.3. Elsewhere, photographs may be more difficult to obtain. They are often under direct military control and may be restricted even for a country's own nationals. As with maps, photographs may sometimes be obtained if you are attached to a government organization or a university of the country concerned.

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 map described in Chapter 2 can be produced. The information recorded must be factual, based on objective examination of rocks and exposures, and made with an open mind. Geology is too unpredictable to be appoached 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.

Although in this chapter distinctions may still be made at times between reconnaissance, regional and detailed mapping, the methods described are not exclusive to any one of them. Methods must be suited to the conditions, and varied as occasion requires. If none of the methods suggested here are adequate for a particular task, then develop new ones of your own.

4.1 Traversing

Traversing is basically a method of keeping track of your progress across country. Traverses are made by walking a more or less predetermined route from one point on the map to another, plotting the geology along the way. They should be planned to cross the general geological grain of the region. Traversing is an excellent way of controlling the density of your observations. In reconnaissance work a number of roughly parallel traverses may be run across country at widely-spaced intervals. Contacts and other geological features are extrapolated between them. This leads to few complications in regions where the rocks are only moderately folded and dip faults are few, but reliability decreases as structure becomes more complex. Traverses can also be used to map in detail areas where rocks are well exposed, especially those where there is almost total exposure. In these cases, traverses are closely spaced.

In open country, where visibility is good and the base map adequate, traverse 'legs' may be walked from geographic feature to geographic feature; for instance from a hilltop to a bend in the river, or, on a larger scale, from farmhouse to field corner. Each leg should be a straight line, and the hilltop, farmhouse and field corners where the traverse changes direction are called 'turning points'. In forests, thick bush, broken topography, or where the base map is poor or non-existent, direction must be controlled by compass bearings. If the base map is good, the positions of geological observations on a leg are estimated from features or by compass resection, or by pacing, pedometer or cyclometer wheel, depending on the accuracy required. Plot geology directly onto the map as the traverse leg is walked. Distinguish geological fact from inference by showing a solid traverse line where a formation is well exposed, and a broken line where a rock can only be inferred. Overlay the lines in the appropriate coloured pencil for the rock type seen or inferred.

Before starting a traverse, examine the ground ahead, with binoculars if necessary, so that the best route can be chosen, both in terms of geology and accessibility. Aerial photographs can help you to plan your route too. Mark the end of each leg in case you need to return to check geology or correct a mistake in measurement. Use a stone, blazed tree, stake, or even a small cairn and number it with a felt-tipped pen or timber crayon.

Much emphasis has been placed here on traversing. This is intentional. Only too often geologists wander aimlessly from rock to rock, keeping little track of their movements. Every time they stop to make an observation they must relocate themselves from scratch—some, possibly, just making a guess. Traversing ensures you do cover the ground properly with the least wastage of energy and time by not having to continually search your map to find out where you are.

4.1.1 *Controlling traverses*

Unless traverses are strictly controlled, survey errors accumulate to an unacceptable level. Wherever possible, make your traverses from known point to known point. If a traverse consists of a number of legs controlled by compass bearings, start at one known point on the map and finish at another: alternatively, make a complete loop and finish back at your starting point. Invariably, you will find that the last bearing and distance plotted does not fall exactly where it should owing to the accumulation of minor errors due to the limitations of the measuring methods used. This *closure error* must be corrected by distributing it over the whole traverse: a convenient method is described in Appendix II.

Because a compass traverse always needs to be corrected, do not record geology directly on to the uncorrected traverse on your field map. Plot the traverse lines, from turning point to turning point, on your map, but record the details of the geology in your notebook as a sketch on an exaggerated scale. If your notebook is a surveyor's 'chain book' with a double red line down the centre of the page, then borrow the surveyor's technique. Use this column as if it were your traverse line. Record the distance of each observation from the start of a leg within this column and show the geology to either side of it (Fig. 4.1). This keeps distances measured along the traverse line and the details of geology separate.

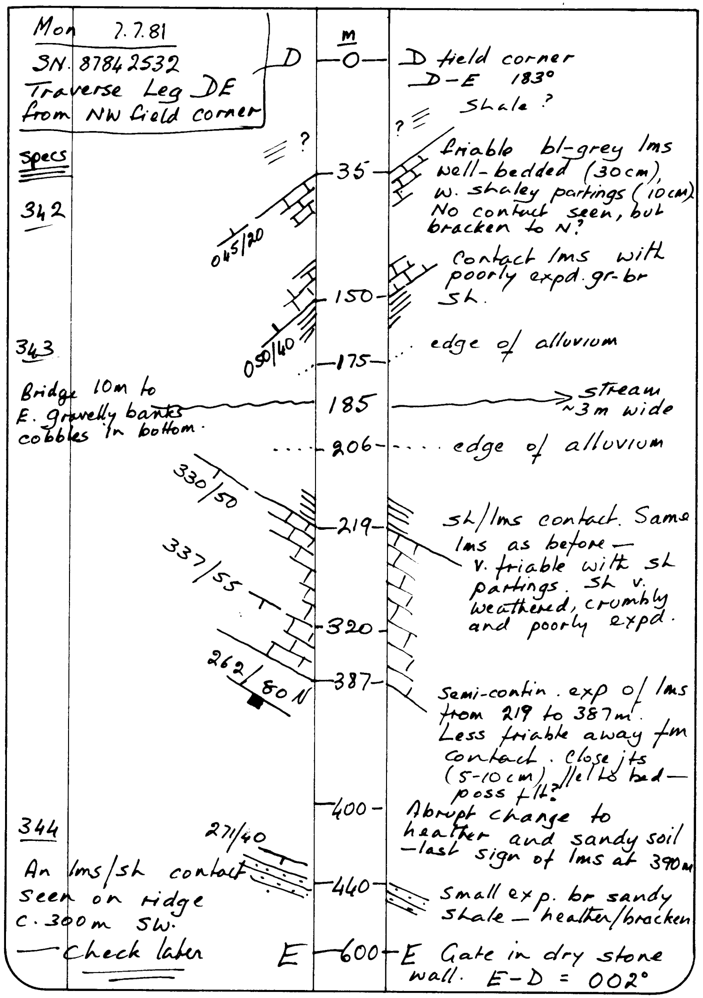


Fig. 4.1 Recording a traverse in a surveyor's chain book. The double column down the centre of the page (often printed in red) represents the traverse or 'chain' line. It has no actual width on the ground: it is used merely for recording the distance from the start of the traverse leg.

Wherever possible, correct your closure error in the field. When corrected, plot the geology on the map.

4.1.2 *Cross-section traverses*

Where succession is doubtful or structure complex, traverse across the geological grain, plotting a cross-section as you go. Draw it on squared paper kept for the purpose in your map case, or in your field notebook, but plot the traverse legs 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 can be mapped by traversing them alone. Much reconnaissance work is based on stream traversing. Position finding on streams is often relatively easy from the shape and direction of bends, and the position of islands and other features and, if the surrounding country is open, compass bearings can be taken on distant points. In dense mountain rain forests, streams and rivers may, in fact, be the only places where you can locate yourself on your map or photographs because no other features can be seen through the canopy of trees.

Ridges, and the spurs which lead off them, may also 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 from them. Exposures are usually good. Most ridges are there because they are erosion-resistant, and in sedimentary rocks tend to follow the strike. Side traverses, down spurs, provide information on the rocks which lie stratigraphically above and below those of the crest; alternatively, stream traverses may provide better information.

4.1.4 *Road traverses*

A rapid reconnaissance of an unmapped area can often be made by mapping the geology along tracks and roads and by following paths between them. Roads in mountainous regions, in particular, usually exhibit excellent and sometimes almost continuous exposures in cuttings. In some places the roads zigzag down mountainsides to repeat exposures at 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 formations and show where they occur on a map. One way of doing this is to find a contact and to follow it 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. Following contacts is probably the easiest method of mapping but it is not al-

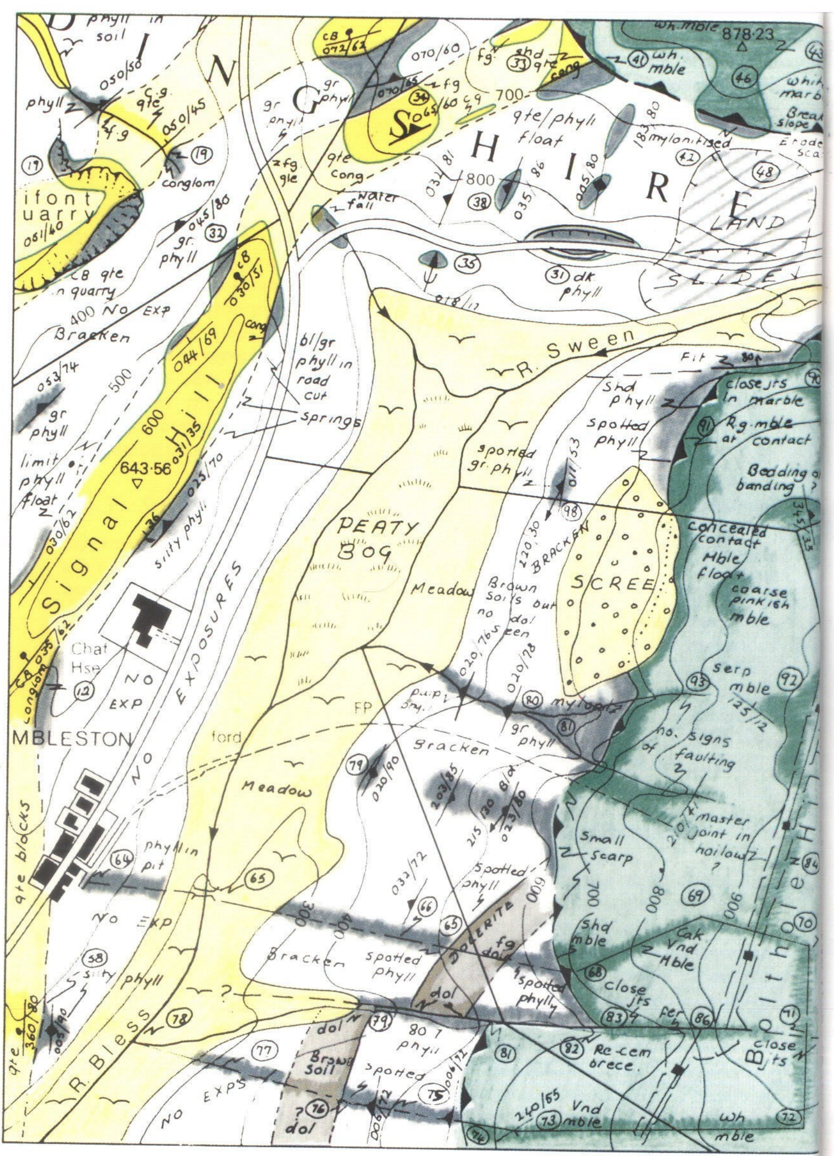


Plate 4.1 Portion of an inked-in field slip showing: green-line mapping in the north; exposure mapping without the green-line in the centre; and a closed traverse (points 64–78) and a stream traverse (points 78–84) in the south. Unexposed ground has been coloured in to distinguish ground already covered from that yet to be mapped.

ways the most rewarding. Areas where it can be used as the main mapping technique are usually structurally uninteresting. Sometimes contacts identified on the ground can be followed more easily—and more accurately—on aerial photographs under a stereoscope. The photographs show small changes in topography and vegetation which cannot be detected on the ground, but which indicate the position of the contact even where it is concealed by colluvium or other drift. Once traced on the photograph, the contact should be checked 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 with the coloured pencils appropriate to those rocks. Where contacts are inferred, show the boundary with a dashed line. Where a contact is concealed—for instance where it passes beneath alluvium—show it as a dotted line.

4.3 'Exposure' and '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 it in with the appropriate coloured pencil for that formation. Some geologists go further and mark the limits of 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 around your exposures is a matter of choice, but if a map is used in the field over long periods, exposures become blurred as pencil shading fades, or is worn off. If boundaries are inked, colouring can be touched up when needed; if not, exposure edges become vague and accurate recolouring difficult. 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 made of it in your notebook. Do not be too fastidious in plotting accurate outlines; an approximate shape is all that is required. On the other hand, unless some care is taken, the natural optimism of human nature nearly always results in exposures being shown larger than they really are: remember that an exposure 10 m square is a mere 1 mm² on a 1:10,000 map; one the size of a football pitch is only 10 × 5 mm. Show groups of exposures which are obviously part of the same outcrop thinly covered with drift, 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 and quantity of the evidence it is based on. Plate 4.1 illustrates the general principles.

4.3.1 *Descriptive map symbols*

There are some types of geological terrain 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 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 you 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 to decide your 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-mubi gn*, where *M*, stands for microcline porphyroblast and *m* for microcline in the groundmass, etc. Devise your own code. These codes give *field-names* (Section 6.2.1), not to be confused with the *formation names* and letters (Sections 6.2.2 and 8.5) used to designate recognized formations. Try to keep them more concise than the extreme example quoted above. 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.

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. 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 also sometimes be found where trees have been uprooted by storms and in the spoil from holes dug for fenceposts or wells, in road and railway cuttings, and from many other man-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 expected. Sandy soils are obviously derived from rocks containing quartz, 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. 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.

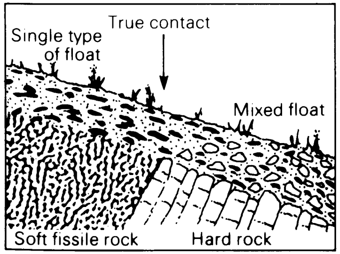
4.4.2 Topography and vegetation as a guide

Both topography and vegetation reflect geology and should be noted during mapping. Springs, seepage lines, lines of more luxuriant vegetation, and changes of vegetation, may indicate contacts, joints and faults, or a change of rock below. Some plants thrive on soils formed from certain rocks, but do not grow on others; take notes for future reference where plants and rocks can be correlated. Add topographic symbols to field slips to indicate minor features which are not already printed on them, but which might reflect underlying geology or structure. Breaks of slope, or small scarps and ridges which are too low to be reflected in the contours, are typical examples.

4.4.3 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 (Fig. 4.2). Care must obviously be taken in glaciated regions that the hill-slope soils, or colluvium, have not been transported.

Fig. 4.2 Float in hillslope colluvium as an indicator of a contact. The contact is where the first signs of hard rock float appear in soil.



4.4.4 Pitting, trenching, augering and loaming

When it is essential to examine rock beneath the soil in a poorly exposed region, pits and trenches may have to be dug. A pit can be sunk quite rapidly as long as the digger does not become too ambitious over the size of the hole. The most economical pits, widely used for prospecting in Africa, are about 85 cm in diameter, excavated with a short-handled hoe. Contacts are best located by trenches (*costeans*).

In many cases, identifiable fragments of weathered rock can be recovered from shallow hand-auger holes. A 'post hole' auger can rapidly sink a 10–20 cm diameter hole to 60 cm. Mechanized augers are obviously quicker.

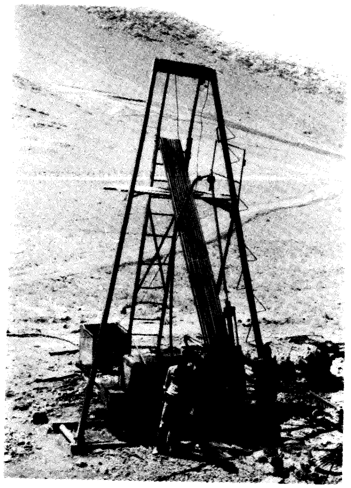
Loaming is a method of mapping in poorly exposed, deeply weathered, regions. Soils, collected from beneath the humus layer in pits and auger holes, are washed in a gold pan (Section 5.11) and the concentrates compared with 'heavy mineral suites' collected from soils lying above known formations. Large areas of Venezuela, and smaller, laterite-covered parts of Africa, have been mapped in this way.

4.5 Drilling

Every 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 types of drill: percussion ('churn') and rotary. Percussion rigs drill by repeatedly raising a heavy drill bit attached to a wire cable and dropping it to just touch the base of the hole. Rock is *crushed* and *chipped* away and the debris is bailed from the hole at intervals for examination. Rotary drills, on the other hand, rotate a drill bit attached to the end of a tubular drill pipe: 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 can be broken off and recovered as a sample of solid rock. Percussion rigs can drill only vertical holes: they yield chippings without core 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 from about 4 to 60 cm in diameter, with the larger holes drilled by 'tricone bits' consisting of three conical cutting wheels. The sludge of ground-up rock flour formed by rotary drilling is continually removed from the hole by circulating drilling fluid and collected from the hole as sample material, whether core is taken or not (Fig. 4.3).

Fig. 4.3 A diamond drill drilling an inclined hole.



4.6 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 appropriate help when needed. Most geophysical methods need 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 organizations and two are described below.

4.6.1 *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 serpentine and the surrounding sedimentary rocks or locate unexposed dolerite (diabase) dykes. Less portable, but more sensitive, are *proton precession* instruments.

4.6.2 *Radiometry*

Acid igneous rocks, rich in potash 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.

4.7 Superficial deposits

Only too often, unconsolidated deposits are mapped poorly, if at all. Superficial deposits, or 'drift', must be indicated on field maps. Laterites, sand dunes, boulder clay, and river and beach deposits represent important events in the later geological history of a region. Peat and areas of bog and swamp may indicate recently past climates, or that drainage has been disturbed, perhaps by tilting or other causes. Unconsolidated materials of lesser extent, such as scree, landslide debris and hillside colluvium should be noted too. Nor should soils be ignored. All, apart from any other consideration, obscure the solid geology and their presence—or absence—contributes to the reliability of your interpretation. Much superficial material is clearly visible on aerial photographs and can be plotted on to your field map directly from them.

Not all this information need be transferred to your fair copy map. Soil and colluvium, for instance, justify your interpretation to those who refer to your field map later but add nothing to the understanding of the geology of the region. Scree need be transferred only if it is extensive or covers important contacts so that interpretation beneath it is speculative. Much depends on the map scale. Scale particularly affects the mapping of alluvium: at small scales it can be generalized but on more detailed maps individual terraces may be shown. Dunes, laterite and boulder clay, however, are part of the stratigraphic succession and must always be shown.

4.7.1. *Landslides*

Landslides are a special case. They are a geological hazard and far more common than most geological maps would suggest. To ignore them is geological negligence. If not recognized, much time can be wasted in trying to make structural sense from the diverse strikes and dips that sliding produces. That an apparent rock outcrop is the size of a house is no guarantee that it is in place. Evidence of sliding is important to both environmentalists and engineers who may use your map for planning. Builders of dams, roads, railways and housing estates also, not unnaturally, wish to know of unstable areas.

Landslides can be recognized by the scar where the slide starts, and by the material that has slid (Fig. 4.4). If the slide is old the scar may be eroded and overgrown. The debris, however, may show several recognizable features. Its average gradient is gentler than the rest of the hillside and its surface different. There may be small parallel ridges or hummocks

Fig. 4.4 A major landslide near Livingstone, Montana, USA. Note the hummocky nature of the slipped ground in front of the stable slopes forming the hills on the sky-line.

caused by 'earth flow'. Drainage is small scale, often dendritic, and there may be small ponds and pools. In heavily-wooded areas the slide may support only scrubby bush, or dead trees with new growth between them. Where sliding is imminent, trees may be 'kneed'. Some slides are indicated by massive unweathered blocks poking through the hillside colluvium and they can cover huge areas. Map a slide as a distinctive geological unit, indicating both the scar and the spread of the debris.

4.8 Large-scale maps of limited areas

From time to time there is the need to map specific aspects of the geology on a far larger scale than that being used for your main map. In Britain, it may be possible to use 1:1250 or 1:2500 OS plans, or prints from an OS *copy-card*. More satisfactory for those able to do it, is to use a planetable. 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 wherever 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 and a basic knowledge of surveying are assets. Keep sheets of squared paper in your map case in case you need them.

4.8.1 Compass and tape traverse

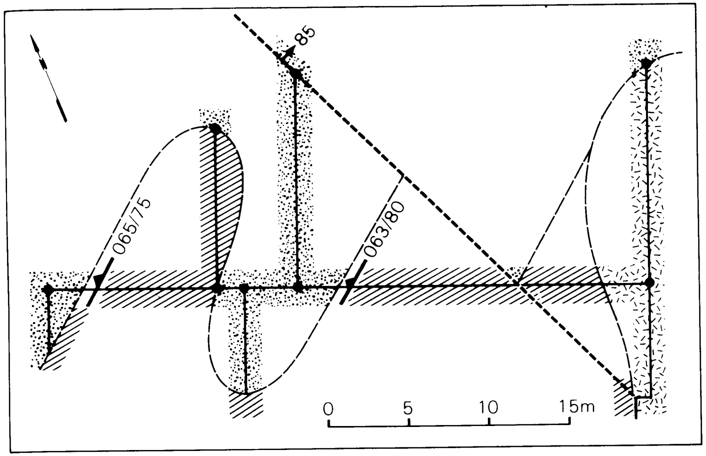


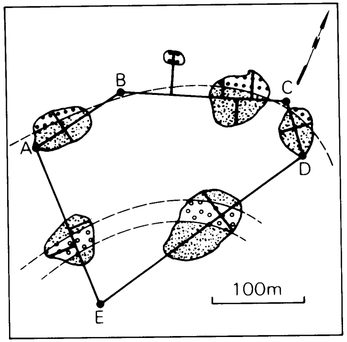
Fig. 4.5 Simple compass and tape traverse to plot in large-scale geological detail.

The simplest method of plotting geological detail is by taking offsets from a 'chain line' or traverse, as described at Section 3.4.3. A single traverse may even suffice (Fig. 4.5). The same method can be used as a 'mini traverse' to map a single exposure in detail.

4.8.2 Traverses with offsets

Where a number of exposures are spread over an area of more or less level ground, but scattered too far apart to be mapped by a single traverse line, geology can be mapped rapidly by running a series of traverse legs in a loop. Detail is mapped by offsets from the legs (Fig. 4.6). For small areas, measure the bearings and lengths of the legs first, marking the turning points so they can easily be found again. Plot the traverse and correct the closure error, then plot the geological detail. An 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 the detail.

Fig. 4.6 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 area of 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); and then measure traverses at right angles from it, with stones again marking 10 m intervals. The effect is to build up a grid to guide your sketch map (Fig. 4.7). Where a great deal of field sketching of exposures 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 Fig. 4.8 was constructed by pegging out an area 16 m × 20 m, with pegs every 4 m along the sides. Three-ply nylon cord was used to make a net with a 4 m mesh. Detail is plotted by estimation on squared, water-resistant paper, with measurements by steel tape when necessary. Compass bearings are measured by assuming one side of the net is 'grid north' and correcting your compass to read accordingly. Fig. 4.9 shows structure mapped in the deformed 'Scourie' dyke shown in Fig. 4.8.

Remember that other methods not described here may be used by other people. Use the methods that suit you and the geology best but ensure that those you do use give acceptable results in terms of accuracy. 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.

Fig. 4.7 Mapping a large exposed area by building up a rough grid.

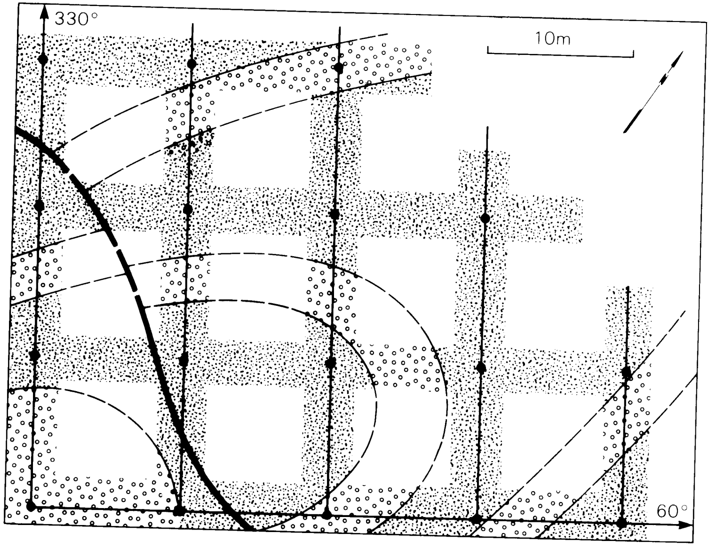


Fig. 4.8 A 4 m mesh cord grid to aid sketch mapping laid over an exposure in NW Scotland (see Fig. 4.9). (The cord in the photograph has been retouched for clarity.)

4.9 Photogeology

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

4.9.1 Use of 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. At night, review your map and photographs together. You may well find that you can trace contacts and faults on your photographs which you could not trace on the ground. This is because the vertical exaggeration of the 3-D image seen under the stereoscope 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 that you have seen on the photographs whose geological cause was not obvious. Their geological significance may now become apparent. Often, photograhs 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 confirm. This does not mean that they do not exist: show

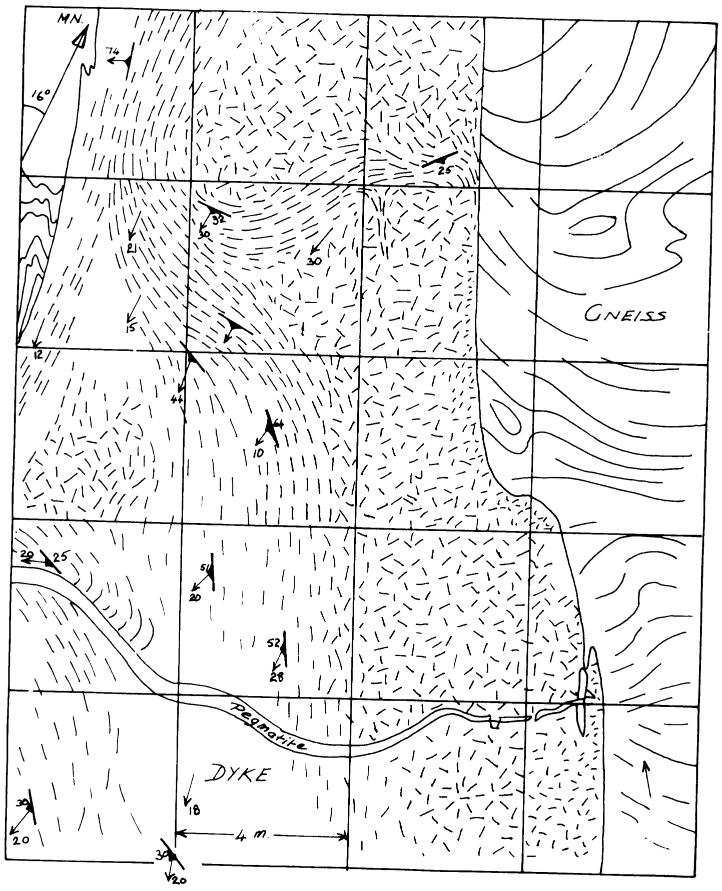


Fig. 4.9 Structures in a deformed 'Scourian' dyke at Badcoll in NW Scotland mapped using the 4 m mesh net shown in Fig. 4.8 (courtesy of R.H. Graham).

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.*

4.9.2 *Photogeological features*

Only a few indications of what may be inferred from photograhs can be given here. Refer to Ray (1960), Allum (1966), and Lillesand and Kiefer (1979) for further information; but experience is the best teacher.

Tone results from ground reflectivity. It varies with changing light conditions. Sudden changes in tone on a single photograph may indicate a change of 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 recognizable by a 'micro-drainage' pattern.

Lineaments are any straight, acurate, or regularly sinuous linear features of geologically uncertain significance seen on photographs. They may show in the drainage, as vegetational changes, as ridges, or even as thin lines of lusher vegetation in arid bushland. They may result from faults, master joints, contacts, or for other geological reasons. The cause of some lineaments is never discovered.

Vegetation is an excellent guide to geology and changes can usually be seen more easily 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 of calculating the amount of dip where large dip slopes are exposed.

4.9.3 *Systematic analysis*

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

1. Tape an overlay of *Permatrace* or *Mylar* to one photograph of a stereopair: mark the *pp* and *cj's* on it (Section 3.7.1). (Fig. 4.10a).
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 pointing down the dip slopes—the steeper the slope, the more the barbs (Fig 4.10b).
4. Draw (in purple) known marker beds or beds which can be easily traced. Indicate their dip by 'ticks'—the steeper the dip, the more the ticks (Fig. 4.10b).
5. Show obvious faults in red.
6. Plot as lineaments all linear and arcuate features whose cause is uncertain. Show as purple lines broken at invervals by three dots.
7. Draw contacts in purple as *dotted* lines.
8. Identify rocks and label formations.

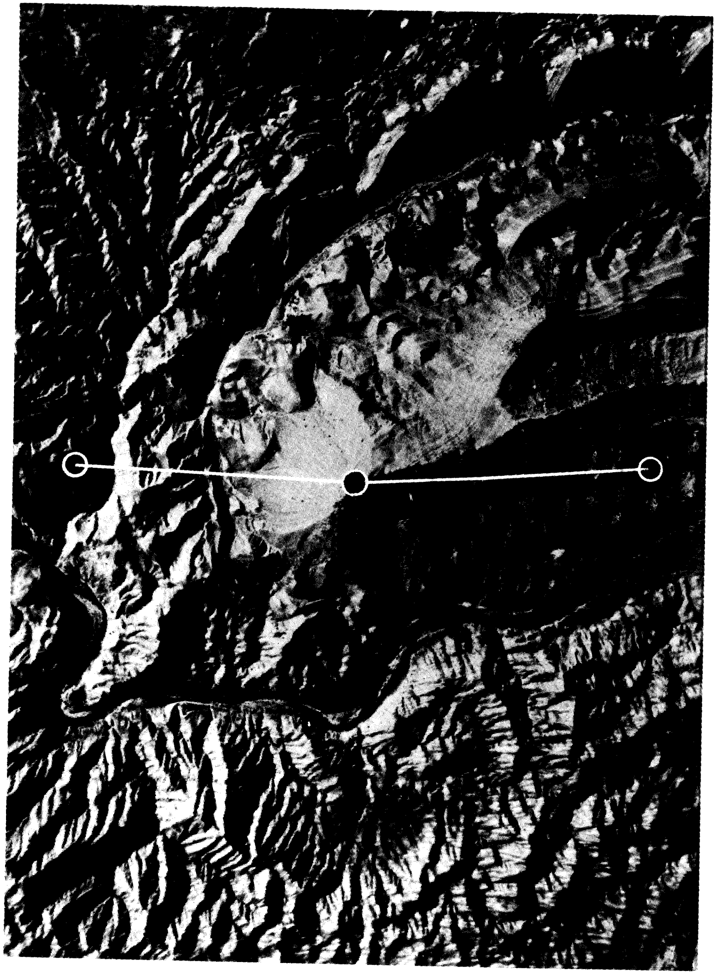
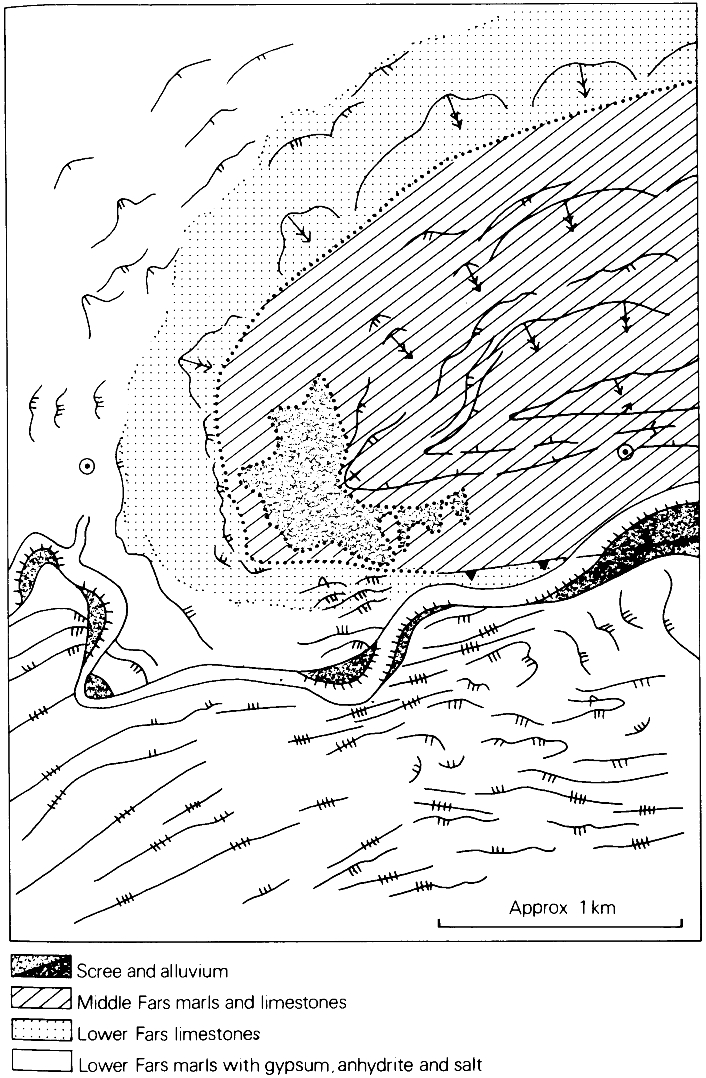


Fig. 4.10 (a and b) Comparison of an aerial photograph (courtesy of British Petroleum Ltd) with its photogeological interpretation.



Check your interpretation on the ground and against your field map. Amend as necessary and transfer your information to the field map in the appropriate colours to distinguish photogeological from other information. If you are mapping directly onto 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 4.10a and 4.10b show an aerial photograph from Iran compared with its photogeological interpretation. Note that the symbols used are different from those on ordinary geological maps.

5

Field measurements and techniques

One object of geological mapping is to elucidate the structural history of the region studied. This can only be done if measurements are made of the attitude of planar structures such as bedding and foliation, and of linear features, such as the trends of minor folds. It is assumed that the reader already knows what these structures are, but many geologists do not 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. Other structures must also be investigated, specimens collected, photographs taken and, possibly, even soils panned to determine heavy mineral suites where no rocks are exposed. These are all part of mapping technique.

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 about 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.

Strikes and dips can be measured in a number of ways, some better than others. Suit your method to the type of exposure. Limestone for instance, often has uneven bedding planes and a method which allows you to measure strike and dip over a wide area of dip surface will give more representative values than one where only a point on the plane is measured. Metamorphic rocks offer additional problems. Measurements of cleavage often have to be made on very small surfaces, sometimes 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 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 measuring them. One point must be emphasized: 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 your map without adding to a direct understanding of structure. Record joint directions in your notebook and plot them on to map overlays later, or treat them statistically. An exception to the rule of immediate plotting of structural measurements is where structures are locally complex: then you may draw an enlarged sketch map in your notebook and log the measurements with it. Several different methods of measuring strike and dip are described below. Modify them as occasion demands. Apparent dips can be used to calculate true dip when true dip cannot be measured directly (Sect. 9.2.2).

5.1.1 *Method 1*

This, the *contact method*, is commonest of all. Use it where the surface to be measured is smooth and even. If there are *small* irregularities, lay your map case on the rock and make your measurements on that. Sometimes, such a small area of bedding or cleavage is exposed that this is the only method which can be used. Place the edge of your compass on the surface, hold it horizontally, align it parallel to strike and read the bearing (Fig. 5.1). Some compasses are provided with a level bubble, so 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 down your scale. With practice you can usually estimate strike with sufficient accuracy, but where surfaces are nearly horizontal, strike may be more difficult to determine. Then it may be easier to determine the direction of maximum dip and scratch a strike line at right angles to it. Alternatively, 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 strike (Fig. 5.2).

Fig. 5.1 Measuring strike by contact (Method 1) using a map case to smooth the surface.

5.1.2 *Method 2*

On large uneven planes of relatively low dip, estimate a strike line 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 to it at waist height. In stream sections or on lake shores nature may help, for a water line makes an excellent strike line to measure. The same method can be used for measuring the strike of foliation or of veinlets exposed on flat surfaces (Fig. 5.3). Because you measure a greater strike length, 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 exposures, because there may be no dip surface exposed. The *end-on* method must then be used; sometimes you may even have to lie down to do it. 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 the sight line is horizontal and *in the strike of the plane measured.* Figure 5.4 shows a typical exposure suitable for 'end-on' dip measurements.

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 limestone 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 (Fig. 5.5). To measure dip, move back so that you can see as much dip surface as possible, then take an 'end-on' reading (Fig. 5.6). Compasses with built-in hand-levels, such as the Brunton, are ideal to establish the strike line for this type of measurement.

Fig. 5.2 Measuring dip by contact.

5.2 Plotting strike and dip

Plot strike and dip immediately you have measured them. The quickest way to plot a bearing is by P.O.P. (pencil-on-point method) devised by Edgar H. Bailey of the US Geological Survey. It takes only a few seconds, as follows:

1. Place your pencil on the point on the map where the observation was made (Fig. 5.7a).

Fig. 5.3 Method 2 used to measure strike of veinlet on horizontal surface.

2. Use your pencil as a fulcrum and slide your protractor along it until the origin of the protractor lies on the nearest north–south grid line; then, still keeping the protractor origin on the grid, slide and rotate the protractor around your pencil still further, until it reads the correct bearing (Fig. 5.7b).
3. Draw the strike line through the observation point along the edge of the protractor (Fig. 5.7c).

The larger the protractor, the better: 15 cm diameter is recommended. If necessary draw extra grid lines if they are spaced too far apart on your field map. Some bearings, such as those lying between 330° and 30°, are easier to plot from the east–west grid lines

The Silva compass has the advantage that, if used according to the directions enclosed with it, you can use the compass itself as a protractor. Make your reading, then without disturbing the setting of the rotating graduated ring, align the N-arrow inscribed on the transparent base of the compass case with a grid line and slide it into position (Fig. 5.8).

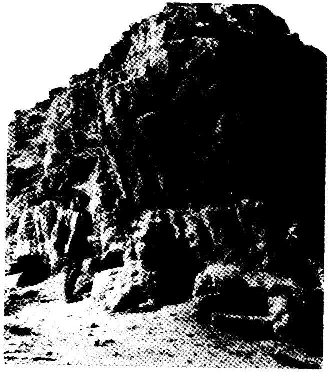


Fig. 5.4 An ideal exposure for *end-on* measurement of dip.

5.3 Recording strike and dip

It is usually unnecessary and time wasting to enter strike and dip readings in your notebook. It takes little extra time, however, to record the bearing of the strike, in addition to the amount of dip, against the symbol on your field map. This is particularly convenient when mapping on aerial photographs when you must later replot your field information on to a base map of a different scale.

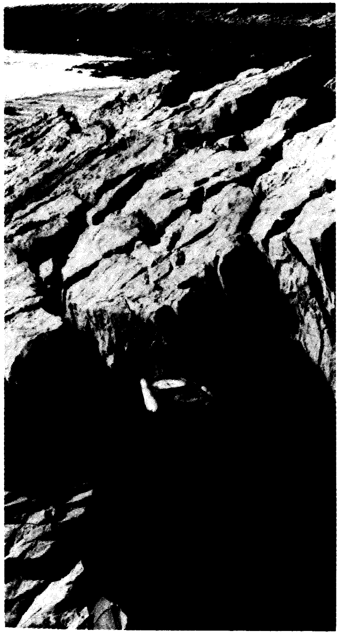


Fig. 5.5 Measurement of strike of uneven surface with a prismatic compass (Method 3).

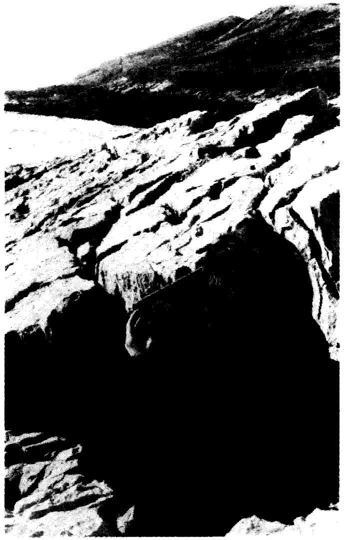


Fig. 5.6 Measurement of dip of uneven surface by Method 3.

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 the quadrant it points to, viz. 223/45NW. The right-hand rule is simpler: always record strike in the direction your right index finger points when your thumb points down the dip (Fig. 5.9). The quadrant letters can now be omitted

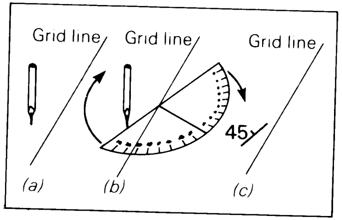


Fig. 5.7 Plotting a bearing by P.O.P. (pencil-on-point).

and the reading of 223/45NW now becomes 043/45. All types of planar information can be written in this form. If you use this method, note the fact in front of your notebook to inform future readers.

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 feature, whether resulting from glaciation, currents associated with sedimentation, or flowage in igneous intrusions.

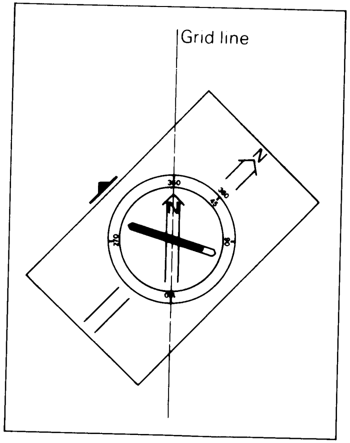
5.4.1 Trend, plunge and pitch (or rake)

A lineation is defined in space by its *trend*—the bearing of an imaginary vertical plane passing through it—and by its inclination of *plunge* in that plane (Fig. 5.10). Some lineations appear as lines on an inclined surface, such 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 (Fig. 5.11a). Providing strike and dip of the surface has been measured, trend and plunge can then be calculated on a stereographic net. Always log the angle of pitch in your notebook by its clockwise angle so that there is no ambiguity over its direction on the surface (Fig. 5.11b). Pitch can be measured with a common transparent protractor, the bigger the better, a Dr Dollar clinometer or a Silva-type compass.

5.4.2 Measuring lineations

Although some lineations can be measured by their pitch, most must be measured directly with a compass. Sometimes this is simple, as in the case of the stretched conglomerate pebbles shown in Fig. 5.12. All that needs to be done is to stand above the exposure and measure the trend, vertically below. Plunge is then measured by 'contact' or 'end-on' methods. Direct measurement of trend and plunge can also be made for lineations on gently to moderately dipping surfaces but, as surfaces become steeper, it is increasingly 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 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 accurately and easily by the Japanese compass illustrated in Figs. 2.3e and 2.6.

Fig. 5.8 Plotting a bearing with a *Silva* compass.



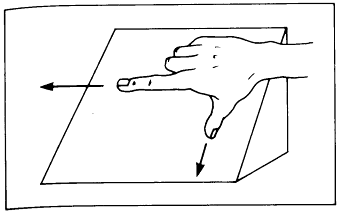
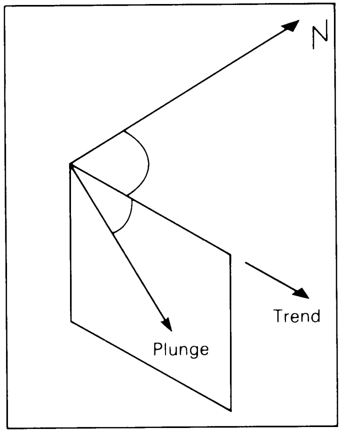


Fig. 5.9 The *right-hand rule* for recording strike and dip.

Some lineations are most difficult to measure, especially those related to minor folds. Considerable ingenuity may be needed. Folds in gneisses may often, at first sight, appear to show up beautifully, but on closer examination, it may be found that no crest or hinge lines are properly exposed (Fig. 5.14). It is these crest or hinge lines that you normally measure. Figure 5.15 indicates some of the considerations which must be kept in mind. If the axial plane of a fold is vertical, then the crest and hinge lines are coincident and the trace of the axial plane indicates its strike, whether the fold plunges or not (Fig. 5.15a). If, however, the fold is overturned, the axial plane is no longer vertical and the hinge line now becomes a lineation formed by the intersection of two surfaces—the inclined axial plane, and the vertical plane in which the trend of the hinge is measured (Fig. 5.15b). In practice, what you can usually measure are: the trace of the axial plane on the rock surface, the trend and plunge of the hinge, or the trend and plunge of the crest line. Only too often, the plunge itself cannot be measured at all. You may be able to estimate it, but sometimes you can do little more than indicate its direction, and whether it is gentle, moderate or steep.

Fig. 5.10 Geometry of trend and plunge.



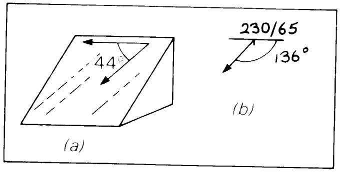


Fig. 5.11 (a) Geometry of pitch on a lineated dip slope. (b) Record pitch in your notebook by a diagram: record also strike and dip.

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 shape and style, and their cleavage indicates the attitude of the axial planes, of the major folds. Also, their vergencies indicate where the closures of the major folds lie and the attitudes of their axes and axial planes: for example, the 'Z' fold shown in Figure 5.16 indicates that the major antiformal fold closure is to the right of the picture, the synformal to the left. It also indicates overturning of the axial plane. Minor folds, such as this, are too small to show in outcrop on your geological map except as a symbol selected from the list of symbols printed inside the front flap.

The terminology of folds is complex; it is also often ambiguous 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 sketches.

Fleuty (ibid.) gives numerical values for terms defining the attitudes of folds, etc., open, close, tight, etc. In the field, *make measurements* wherever 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. Much of the difficulty you will encounter is in recognizing structures in the field when you see them for the first time: they seldom resemble those idealized diagrams in textbooks.

Fig. 5.12 Stretched conglomerate pebbles in East Africa: trend and plunge can be measured directly.

Fig. 5.13 Measuring lineation on a steep surface with a hinged-lid compass (see text).

Fig. 5.14 Minor folds in Precambrian granite gneiss in East Africa.

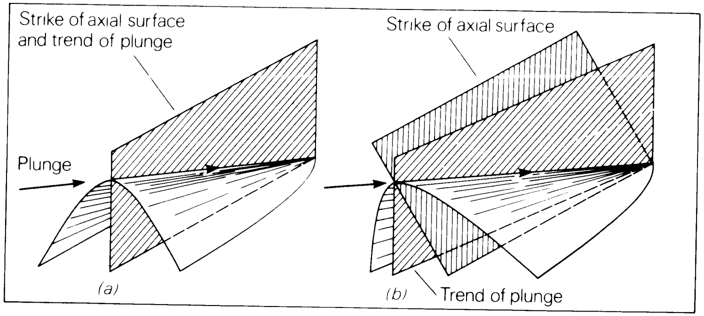


Fig. 5.15 (a) Axial surface in an upright plunging fold. (b) Overturned plunging fold: note that now the *trend* of the hinge-line is no longer parallel to the *strike* of the axial surface.

5.6 Faults

Most faults are never 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 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. 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 joint spacing decreases suddenly to a few centimetres, and rocks become flaggy. Topography is often a good guide. Faults may result in boggy hollows, seepages, or, in semi-arid countries, even a line of taller, greener trees surrounded by lower flat-topped acacia. Most fault zones erode a little faster than the adjacent rocks to form longitudinal depressions, but beware, 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 the stereoscope accentuates those minor linear features called *lineaments*— features often difficult to find on the ground.

The sense of displacement of a fault, that is, distinguishing the downthrown side, may become evident only by noting the difference in stratigraphy or lithology on each side of a fault. In textbooks much is made of slickensides and, if they are seen, they should be measured. But do not put too much faith in them—they merely reflect the last phase of movement, and most faults have several phases, not always all in the same direction. Note also that faults have a thickness which may be wide enough to plot on large-scale maps, particularly on sketch maps. They may also be gouge-filled or breccia-filled, or they may be mineralized, and their outcrops are seldom as straight as shown on maps. Record all such observations in your notebook.

5.7 Thrusts and unconformities

Thrusts and unconformities are treated together because one can easily be mistaken for the other. Large thrusts are often obvious, with older rocks overlying younger; 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 lower 'plates' may both show angular unconformity with its assumed position, or the surface may show complete disregard for the stratigraphy of the upper plate. If the surface is exposed, the situation should be clearer. The lower part of the upper plate should not show any of the sedimentary features expected in a stratigraphic unconformity; there may be shearing along the surface, or mylonites. Where mylonite does occur it may be thick enough to map as a formation in itself and form a useful marker.

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 larger thrusts, as in the Scottish *Moine*. 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. The rocks just above an unconformity should also

Fig. 5.16 Minor fold in Precambrian sedimentary rocks in East Africa. The major antiform closes to the right.

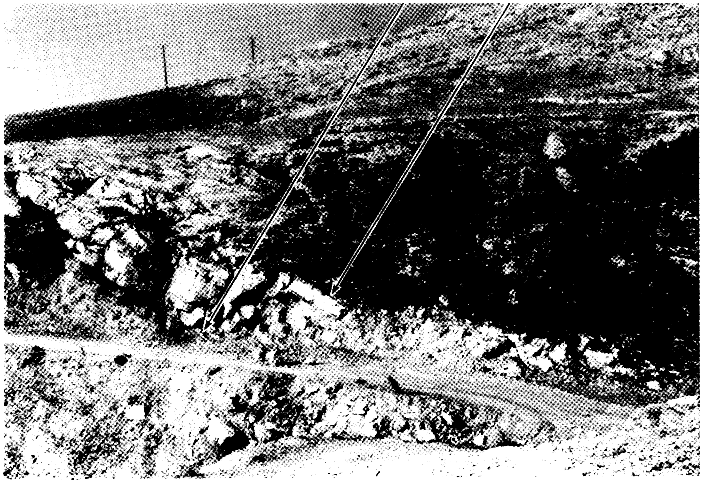
show features which indicate original deposition on an eroded surface. Unfortunately, this relationship is not always as clear as textbooks suggest, especially where rocks have been metamorphosed. Sometimes, to confuse matters, there is angular unconformity on both sides of the break if the later rocks have been deposited on a sloping surface (Fig. 5.17). A *disconformity* may be even more difficult to recognize. 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. Record joints, but do not clutter your map with them. Enter them into your notebook and replot them on to 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 may 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, however, keep joints off your maps.

Measure the strike and dip of joints in the same way as bedding. Often surfaces are uneven and contact methods unsuitable. Book readings in your notebook, using the *right-hand rule*, together with estimates of their lengths. Note also the spacing between 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 by lines of sink-holes. Joint patterns seen on photographs can sometimes be used to distinguish one formation from another.

Fig. 5.17 Unconformable Neogene conglomerates lying on Palaeozoic limestone and phyllite in Turkey. Left-hand arrow indicates limestone/phyllite contact. Right-hand arrow indicates conglomerate/limestone unconformity.



5.9 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 of the region to prove that it does not. Some variations in composition may not, of course, be obvious in hand specimen and 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 see what he needs for thin-sectioning. Whenever possible, collect material which shows both weathered and fresh surfaces and, if necessary, take two samples to show both. 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 represent 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: break them off, and then fit them back to where they were broken off and mark a direction and 'dip' on the surface so that they can be oriented in space when thin sections are cut from them. Whenever possible orient specimens before breaking them off.

5.9.1 *Marking specimens*

Rock specimens are best marked with a waterproof felt-tipped pen or, for dark rocks, a yellow timber crayon or a numbered piece of surgical 'sticking plaster'. Wrap specimens in newspaper to protect them from bruising and to spare your rucksack. In camp, scrub your specimens, dry them and then add a spot of white paint: later number the spot with black paint. Re-wrap your specimens in newspaper and number the packets on the outside with a felt-tipped pen so that they can be easily identified should you want to examine any of them again in camp.

5.9.2 *Fossils*

Some fossils are easy to remove from their parent rock, others are not. Many are embedded with only a small portion showing: scrape away enough rock with a knife to see whether the specimen is worth collecting, and then cut out the piece of rock containing it. Many other 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 the 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 are found and do not collect more material than you need.

Pack delicate specimens in boxes or tins and pad them with cotton wool, tissue or newspaper, or use expanded polystyrene ceiling tiles cut to fit the boxes. Carry a selection of containers, from matchboxes upwards in size. Wrap non-fragile specimens in newspaper and treat in the same way as rock specimens.

5.9.3 *Booking specimens*

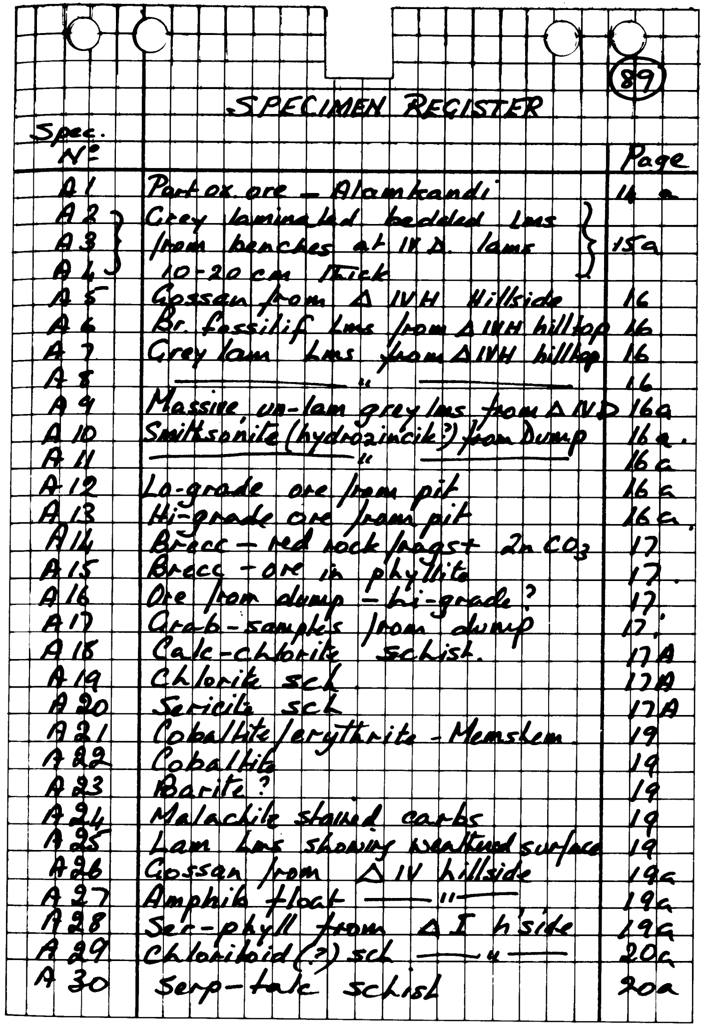
Log specimens in your notebook immediatley you have collected them. Preferably write their number in the left-hand margin, so that their details can be easily relocated. If specimen numbers are written in red pencil, they can be distinguished from observation numbers listed in the same column. Alternatively, if you are collecting large numbers of specimens, add a column to your notebook specially for this purpose. In addition to logging specimens on the working pages of your notebook, register them in the back of the book too. This avoids finding yourself with two almost identical specimens with the same number and no way of telling which is which. A register also helps you ensure that you have collected specimens of everything you should collect, and if you show the page numbers where they are more fully described in your notebook, it acts as a handy ready-reference (Fig. 5.18).

5.9.4 *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, can go much more quickly by passenger transport. A box about 25 × 30 × 25 cm made of +1 cm timber, battened, and banded with steel tape, is acceptable by T.I.R., railway passenger services, and airlines. Mark your name and address on the top and sides, and add ROCK SPECIMENS FOR SCIENTIFIC RESEARCH. Never write 'ore specimens' or 'mineral specimens' on boxes. Most countries do not appear to have export regulations controlling *rocks*, but do for *minerals* and *ores*. 'Rocks', an honest declaration for any geological material, avoids bureaucratic delays and gets your rocks back to your laboratory more quickly.

5.10 Field photography

A camera is an asset in the field and a 35 mm model is the most versatile. The only important specification is that it should not have a fixed focus lens. The selection of lenses depends on your pocket. A 50 mm lens is probably the most useful; a wide-angle lens is probably the next choice if you can afford more than one. Always use an ultraviolet filter when using colour on a shore or in mountains over 2000 m. It is virtually colourless and can be kept on the camera at all times so that it is not forgotten. When photographing exposures in black and white, a dark yellow filter helps to bring out detail. 'Instant' cameras have the advantage that an exposure may be photographed and annotated with a fibre-tipped pen on the spot.



(89)

SPECIMEN REGISTER

Spec. Nº		Page
A 1	Part ox. ore – Alamkandi	14 a
A 2	Grey laminated bedded Lms	15a
A 3	from benches at IV D. lams	
A 4	10-20 cm thick	
A 5	Gossan from △ IVH Hillside	16
A 6	Br. fossilif Lms from △ IVH hilltop	16
A 7	Grey lam Lms from △ IVH hilltop	16
A 8	—————— " ——————	16
A 9	Massive, un-lam grey lms from △ IV D	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 fragst $ZnCO_3$	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 – Memskem	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 △ IV hillside	19a
A 27	Amphib float —— " ——	19a
A 28	Ser-phyll from △ I h'side	19a
A 29	Chloritoid (?) sch —— " ——	20a
A 30	Serp-talc schist	20a

Fig. 5.18 Specimen register in a field notebook.

Whenever you take a picture, make a sketch of the scene in your notebook to show what to look for in the photograhic print. This is particularly important for photographs of rock exposures for you may not see the prints until you have returned from the field. It may then be difficult to identify photographs, particularly where you have taken several of similar rock exposures. Log every picture taken and number it in the same way as you record specimens, entering the number in blue pencil in the left-hand column of your notebook, or in the 'specimen' column. Keep a photograph register, as for specimens. To keep track of photographs of exposures, make a device from two strips of perspex taped together between which you can slip large numbers cut from a trade calendar, as in Fig. 5.12. Whatever method you use to photograph outcrops, you must include some object to give it a scale.

Photographs can be taken in black and white; or in colour, either as prints or transparencies. The choice depends on what you intend to use your photographs for. Colour prints are effective for scenery but can be disappointing for close-ups of outcrops. For general geological work, black and white photography is probably adequate, especially if you intend to publish the photographs in reports or papers.

There is no need to mark on your map where you have taken photographs of exposures: they will be already logged against an observation number in your notebook. It is, however, helpful to indicate the direction in which you took a scenic photograph by an arrow on your field map, so that you can identify topographic points more easily later.

Finally, having taken photographs in the field, file your negatives so that they can be easily found again.

5.11 Panning

Every geologist should be able to use a gold pan. It needs little practice. Gold and cassiterite can be 'panned' for, 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 4.4.4).

Fig. 5.19 Panning in the River Euphrates.

Unlike gold, garnet and epidote, etc., are only a little more dense than the sand and rock debris accompanying them (S.G. 3.2–4.3 compared with ±2.7) and more skill is required to concentrate them. A 30 cm diameter pan is sufficient for purely geological purposes. Keep it spotless and free from rust and grease. Collect *stream gravel* from the coarsest material you can find, for that is where the heavier minerals concentrate. 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 vigorously under water, in a stream, or even in a tin bath. The finer heavies will pass down through the lighter coarse material, a process known to the mineral dresser as *jigging*. Larger pebbles can be scraped off the top and thrown away. Continue shaking and removing pebbles until only sand size material is left. Then, tilt the pan away from you, dip it into the water and swirl the water around the pan so that it just washes off the lighter sands. Give an occasional shake to ensure that the heavier minerals can work their way down into the angle between the bottom and the side of the pan. When little is left except dark and coloured minerals, alternate shaking from side to side with letting water flow over the concentrate to wash away any remaining lighter sands (Fig. 5.19). Finally, let in a little water and give a single swirl around the pan sides to produce a 'tail' of minerals graded in order of their density. Examine the tail with a handlens under a shallow cover of water. Identify any minerals you can, then collect the concentrate in a phial for future examination. Panning is like fishing: you do not actually have to catch 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 recognize the 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, describe it fully and systematically in your notebook. Rock descriptions are essential when you come to write your report. A rock description made from memory 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 covering it, its topography, 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 turtle-backs, pavements, tors or ridges, jagged or rounded. Comment on joint spacing, bedding and lamination (see **Appendix III.**), structures and textures, cleavage and foliation. Support your observations with measurements. Describe the colour of the rock on both weathered and freshly broken surfaces. Weathering often emphasizes textures; note its effect, such as the honeycomb of quartz left on the surface of some granites after feldspars have been leached away, which immediately distinguishes silicic from less silicic varieties. Finally, describe features seen in hand-specimen, both with and without a handlens. Note texture, grain-size and the relationship between grains. Identify the minerals and estimate their relative quantities. Name the rock. Where appropriate, prepare a sedimentary section and/or log (Sections 6.3.2, 6.3.3). A *formation letter(s)* will eventually be assigned to every mappable rock unit, but that is something to be done later. Remember you can take a specimen home with you, but not an outcrop. Ensure that you 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 name*

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, identify the minerals, and estimate their relative abundances in most rocks, under a handlens. He should be able to distinguish orthoclase from plagioclase, 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 in this manner.

A field name should indicate structure, texture, grains-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 full field names and 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 your laboratory later. This is the coward's way out. If you are really stuck for a name, and with 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, you have a type specimen of every rock named. Sometimes, you may even find it helps to carry small chips around with you in the field, for comparison.

6.2.2 *Formation names*

Consider the *formation* as your basic mappable unit—the one you show with a specific colour or pattern on your map. Some formations may consist of a number of different *members*, each of which has to be identified and given a field name although they cannot be mapped in separate colours. The formation must be given an identifying name. This may be purely descriptive of its geological position, such as the *Boundary Quartzite* which forms the base of a system in Africa, or it may have a locality name, such as the *Igara Schist*, which lies unconformably below it, or the *Chitwe Granite*, which intrudes both. Both the Igara Schists and the Chitwe Granite contain several different rock types, but each is distinguished on the map by only one colour. Formation names may have to be modified later, as further work is done at larger scales. Some formations, usually igneous rocks, can be distinguished only by a rock name, such as *dolerite, elvan, quartz-diorite.* Others may be named after a locality or the group they commonly intrude, such as the *Karroo Dolerites.*

6.3 Naming and describing sedimentary rocks

Formal rules are laid down for naming sedimentary sequences. Any description of a succession should be accompanied by a *stratigraphic sec-*

tion to define the sequence and, in detailed work, a *sedimentary* or *graphic* log to illustrate the variations in sedimentation.

6.3.1 *Sedimentary formations and members*

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 mappable unit. 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 loose terms, such as the *White Limestone* or *Brachiopod Bed.* Establish a type section for every named formation for reference or comparison in case problems arise. The Geological Society of London has issued a guide on the subject (Geol. Soc., 1972) and the US Geological Survey offers similar advice (Cohee, 1962).

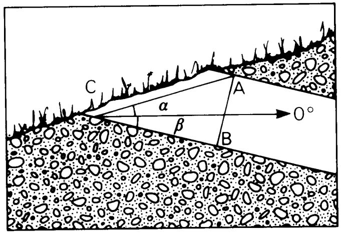
6.3.2 *Stratigraphic sections*

Stratigraphic sections show the sequence of rocks, distinguishing and naming the formations and members that comprise them. They show the thickness of units, the relationships between them, any unconformities and 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 section 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 select a suitable place with good exposure. Make measurements of the true thickness 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 on squared paper, or trigonometrically (Fig. 6.1). Compton (1966) illustrates various methods of measuring true thickness directly.

Indicate on the stratigraphic section the name and extent of every lithological unit, together with the rock types which comprise it. Take specimens of everything logged. Mark and note the position and names of any fossils found. Collect specimens, where necessary, for later identification. Indicate the position of the section on your field map. Redraw the section from your notebook on squared paper in camp. Later the formation may be simplified and combined with sections from other parts of your mapping area as *columnar sections* or *fence* diagrams (Sections 9.3 and 9.4.4). Stratigraphic sections may also contain igneous and metamorphic rocks.

Fig. 6.1 Correcting for the true thickness of a bed. The stratigraphic thickness $AB = AC\ \mathrm{Sin}\ \alpha + \beta$.



6.3.3 *Sedimentary (graphic) logs*

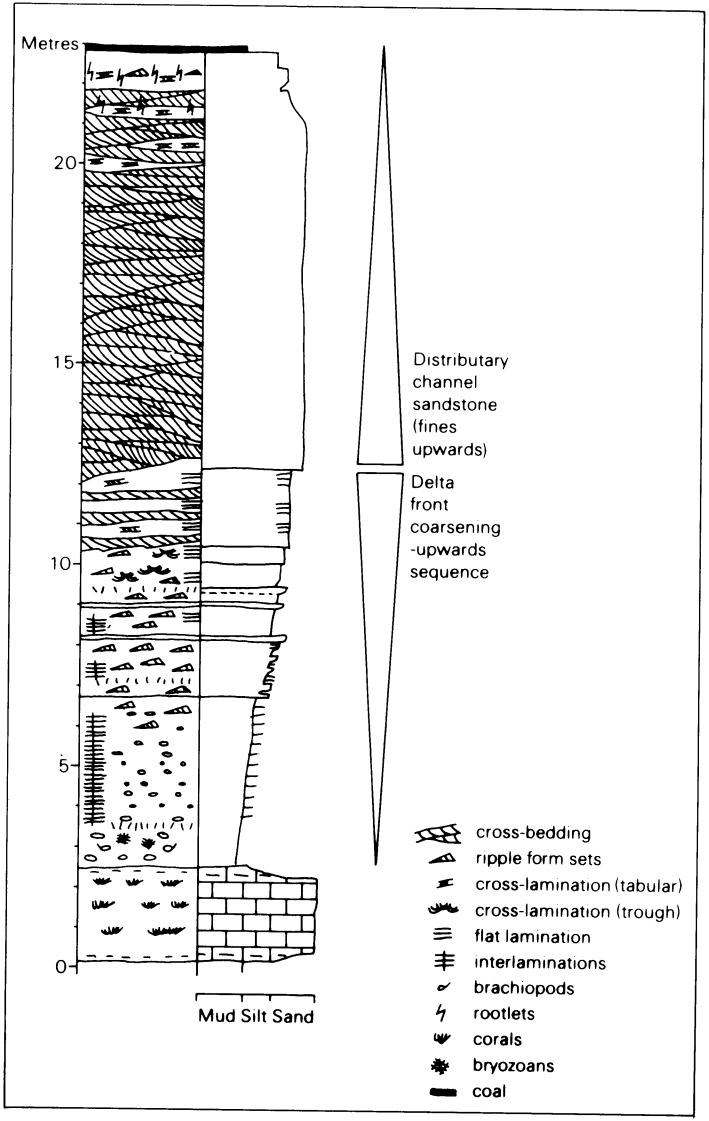
Although there are similarities, sedimentary logs and stratigraphic sections differ in their purposes. Sedimentary logs are detailed graphic displays of the lithologies, sedimentary structures, and fauna in a succession. The succession is broken down into homogeneous units—termed *sedimentary facies*—which 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 associations. 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 (Fig. 6.2). Symbols are used to indicate a wide variety of sedimentary features, such as different forms 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 your logs 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 nature of boundaries between units, whether they are erosive, sharp or gradational and see whether there are any lateral variations. Tucker (1982) 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, despite often abundant evidence. There are three main 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 on its own is not always reliable. Look at a number of different ones before making a decision.

A most important *structural* guide to way-up is the angle between bedding and cleavage. If bedding dips more steeply than cleavage the fold limb has been overturned (Fig. 6.3). This can be used in rocks devoid of fossils or sedimentological features, even in rocks such as quarzites. In structurally-disturbed areas where it is often difficult to tell which way up beds are, mark the 'overturned' symbol for dip and strike on your map where overturning is confirmed; where the beds are known to be right-way-up, add a dot to the pointer of the usual symbol (see list of geological symbols inside front flap); 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. That is part of your field evidence.

6.3.5 *Grain-sizes*

The vast majority of sedimentary rocks are classified by their grain-size. Anything greater than 2 mm is ***gravel***, anything less than 4 microns is called ***mud***; what lies between is ***sand*** or ***silt***. Each of these groups is subdivided into coarse, medium and fine, etc. (Appendix III, Table III.2 inside back cover). Measure larger grains in the field with a transparent plastic scale placed over a freshly broken surface. Use a handlens with the scale for finer sizes. Generally, if a piece of the rock is gritty between your teeth, 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 rocks are sandy rocks which contain clay. Breathe on the rock and note whether it returns a clayey smell. This is not infallible, for if the rock is 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.

6.3.7 *Hardness*

Always test a fine-grained rock first by scraping your hammer over it. If it scratches, it is probably a sedimentary rock; if it does not, it may be a chert or a hornfels, or an igneous or pyroclasitc rock. Some compact cream, white and grey rocks can be scratched with your finger nail. They are probably gypsum or anhydrite, or possibly rock salt: one lick can settle that!

6.3.8 *Acid*

Every geologist should carry a bottle of 10% hydrochloric acid with him. To use it, break off a fresh piece of rock, blow off any dust, and add *one* drop of acid. If reaction is vigorous, the rock is *limestone*. If it does not fizz, scrape up a small heap of powder on the surface with your knife and add another drop of acid. Gentle reaction indicates *dolomite*. Many carbonate rocks contain both calcite and dolomite, so collect specimens for staining when you return to base. Remember, however, some other, if rarer, carbonates react to acid too.

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 a fossil itself. Note the abundance of the fossils in each fossiliferous horizon of the locality: are they widespread or clustered into 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 which can be traced over considerable dis-

Fig. 6.2 A graphic sedimentary log. The horizontal scale is a measure of grainsize. Divisions are unequal because the Ø-scale range for silt is only 4/5ths that for sand (see Appendix III). The vertical triangles to the right indicate coarsening and fining in the sequence. (From N. Wales, courtesy of A.R. Gardiner.)

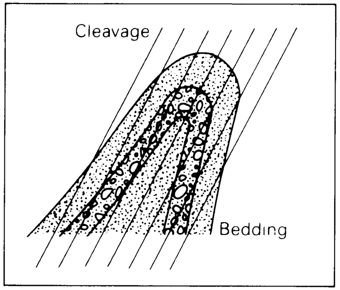


Fig. 6.3 Relationship between cleavage and bedding in an overturned fold.

tances, indicating a changing environment. There may also be vertical changes 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 with sketches if necessary. Probably you will see only a small part of the fossil, perhaps because only a small part of it is exposed, or because only 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 remove a specimen in the field. If you find a whole fossil, one specimen of that species is probably enough; leave the rest for others. Usually, however, you will only be able to collect incomplete fossils. 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 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 whereabouts in that bed you are. It can even tell you the displacement where both sides of a fault are of the same rock type.

Mark good fossil localities on the field map with a symbol, so that you can find them again, but you need not show them all on your fair copy. Mark only the more important localities people may want to visit.

6.5 Phaneritic igneous rocks

Phaneritic igneous rocks are easily recognized and acid to intermediate varieties can usually be readily named. Dark coloured (melanocratic) phanerites are 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 rocks you expect to encounter, taken, if possible, 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 grain	+5 mm
Medium grain	1–5 mm
Fine grain	−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, remember to quote the size of the phenocrysts, too; a phenocryst 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 (**Appendix III**) **inside the back flap**. Without a chart, you will almost certainly overestimate the quantity of dark minerals by a factor of up to two. Look at a *selection* of grains of every mineral present. identify each mineral in turn, using your handlens. Note the relationships between them. Rotate the specimen in the light to catch reflections from polysynthetic twinning in plagioclases—it is remarkable how many geologists have never seen this except under a microscope. Dark minerals are the most difficult to identify in 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 cleavage in amphibole is much better than in pyroxene, epidote has only one cleavage, and tourmaline virtually none. Refer to Dietrich and Skinner (1979) to name these rocks.

6.6 Aphanitic igneous rocks

Aphanitic igneous rocks are difficult to name. 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 (Dietrich and Skinner 1979). Table 6.1 shows how the groups divide.

Table 6.1

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

Adapted from Dietrich and Skinner (1979)

Careful examination of aphanites under a handlens usually gives some pointers to identity and many contain phenocrysts. Basalt is by far the commonest of all black aphanites. In the field, revert to 'spotted black rock' type of terminology if all else fails.

6.7 Quartz veins and pegmatites

Quartz veins are very 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. Some show 'ghosts' of the replaced rock with structures still parallel to those in the walls. Some veins are clearly emplaced on faults; some enclose breccia fragments. Some veins contain barite and fluorspar in addition to quartz, and may even be sulphide-bearing: all veins should be looked at carefully for traces of ore minerals. However, not all veins are quartz veins. Some contain calcite, dolomite, ankerite or siderite, or mixtures of them, and may be mineralized too. Veins by no means always 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 a metre. '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, and rarely, hornblende. Complex pegmatites can be huge with several zones of different composition around a core of massive quartz. They may be mineralized.

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. Note any alteration and *measure* its extent: a 'narrow' chill zone means 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 aluminosilicates. 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 calc-silicate minerals. Search skarns with special care for ore minerals, for they are very susceptible to mineralization. Examine contacts between lavas, and the rocks both above and below them, closely, and do not forget the contacts between individual flows.

Few intrusions are homogeneous, yet many maps give that impression because intrusions are so often shown in only one pattern or colour. Map the interior zones of intrusions with the same care you would give to an equivalent area of sedimentary rock. Boundaries between phases may be irregular, gradational, and seldom exposed, but differences in mineral composition and texture, and very often flow banding, can be seen if looked for. Map them. Map also all dykes and veins in intrusions, and record joint patterns.

6.9 Pyroclastic rocks

Treat pyroclastics as sedimentary rocks and apply the same rules when mapping them. They are important markers in geological sequences because they may be deposited over wide areas during relatively short periods of time. Pyroclastic materials are essentiallly glassy ashes. Unconsolidated, they are called *tephra*, when consolidated, *tuff*. *Agglomerates* contain fragments larger than 64 mm, *lapilli tuff* 2–64 mm, and *ashy tuff* anything less than 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 lava, e.g., *andesite tuff*, or *ashy andesite tuff*, but many finer-grained varieties are difficult to identify and non-committal names are justified. Some are so glassy, some even 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*.

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 metamorphic rocks: 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 recrystallize to gneisses 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 recognizable minerals, e.g., *pyritic black slate* or *green chiastolite slate*. *Phyllites* cleave more readily than slates, leaving lustrous faces shining with sericite scales.

Geologists will seldom agree where to put the 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 weather easily and are often poorly exposed.

Gneisses are medium to coarse-grained foliated rocks in which bands and lenses of different mineral composition alternate. Some gneisses split roughly parallel to 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. As with 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'. These 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 except 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.

6.10.2 *Contacts*

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

6.10.3 *Foliation*

Where structure is fairly regular, map 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 must be mapped in metamorphic rocks. These include the trend and plunge 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 intersection of planar features, such as bedding/cleavage, cleavage/cleavage, etc.; or mineral alignments, rodding, mullions and stretched conglomerate pebbles (Fig. 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.

6.11 Economic geology

Any geologist worth his salt should at least be able to recognize the principal economic minerals and rocks, for it is his duty to consider the economic, as well as the purely scientific, aspects of any area he maps. To ignore them, or consider them beneath one's scientific dignity—as some do and freely admit—is intellectual snobbery. Before going into the field, review any literature concerning minerals in the region you are to map, both metalliferous and industrial. Note records of quarries and mines. Find out what ores were mined and, particularly, whether they were associated with sulphides, for those 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 recognizable form. Some are just rock in which metallic minerals are disseminated; 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—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 metallic minerals glinting in the sun. Sulphides, especially, are often extensively altered above the water-table by oxidation. Some oxidize to a highly soluble state—copper, zinc and silver ores are examples—and the metals are leached downwards to redeposit near the water table as a zone of *supergene enrichment*, leaving the upper part of the body depleted (Fig. 6.4). The insoluble iron oxides remaining are left to accumulate at the surface during erosion as outcrops of hard cellular limonite called *gossans*, or as iron-stained soils spread over a wide area.

Rocks near outcrops of ore may be stained by the brightly-coloured basic copper carbonates *malachite* and *azurite*, or coated with the tiny green crystals of the lead chloro-phosphate *pyromorphite*, which are easily mistaken for moss. Blue, green, yellow, red and orange stains should always be looked at carefully.

6.11.3 *Structural control*

Particular attention must be paid to the fracture pattern in any mineral-bearing area, for ore deposition is often controlled by faults and joints. But 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 irregular masses grading into their host-rocks; 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 *Grades and economics*

Before going into the field, study the economics of the rocks and ores you may encounter. For instance, what now constitutes a useful slate? What is a cement limestone? What is a good brick, china or ball clay? What is viable iron ore? Examine specimens of any ores you may expect to see and their oxidized products before you leave for the field. Remember, too, that in the field ores are iron-stained and covered with dirt and may not resemble those scrubbed, and often unrepresentative, specimens seen in collections.

6.11.5 *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 search for water is geological common sense. Note its occurrence in any area you map and learn from it.

6.11.6 *Industrial minerals*

Many of the materials you map have a use. That includes many clays, sands and gravels, fluxing materials, even aggregates, roadstones, ballasts and crushed rocks. The variety is immense. Build up your background knowledge of industrial minerals. Bates (1969) and Robertson (1961) are excellent guides.

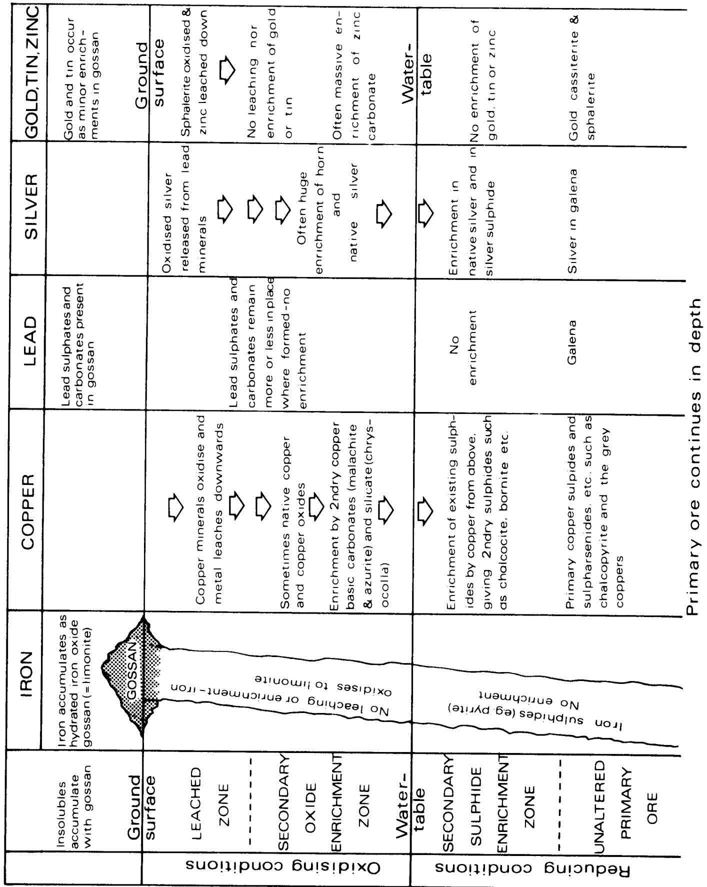


Fig. 6.4 The oxidation of deposits containing iron, copper, lead, silver, gold, tin and zinc. (First published in *Subterranean Britain* (ed. Crawford) by A. & C. Black (Publishers) Ltd.)

7

Field maps and field notebooks

Field maps and notebooks are valuable documents which constitute part of the record of the 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 employer wishes to reinvestigate an area you mapped, then it will be necessary to refer back to the original field 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, but all contacts should be plotted on it in the field, though some may have to be inferred from minor indirect evidence or sometimes merely by your judgement of where they most probably occur. 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 later wish to refer to. 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 informatin to be recorded on a field map is:

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 notebook 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 positions of seeps and spring lines are examples.

8. All major contacts, including faults, both certain and inferred.
9. River terraces, beach terraces, and similar features.
10. Alluvium, scree, boulder-clay and any superficial materials, including landslide debris.
11. Cuttings, quarries and other man-made excavations exposing geology eg. pits and boreholes.
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 open in the rain.

7.1.2 *Preparation*

Before using a new map sheet, cut it into a number of sections or 'field slips' which will fit into your map case without having to be folded. Folding ruins a map: it is difficult to plot any information close to the folded edges (especially if folded over twice) and any information which is plotted there is soon smeared and eventually worn off. Every field slip should be titled, have a scale, and carry a full explanation of the colours used unless they follow the strict conventions of the organization you are working for. Any non-standard or unusual symbols used should also be shown, together with a diagram of how the several field slips which make up the whole sheet are numbered and relate to each other. The number of the notebook which refers to the slip should also be included, together with the name of the author of the map and the dates of starting and completing it. Write this information on the reverse of the field slip, (Fig. 7.1). On the face-side of the map the north direction from which structural measurements have been plotted should be shown; true, grid, or magnetic north as the case may be.

Do not stick your field slips together with adhesive tape when fieldwork is complete. It makes them awkward to use again in the field if new information has to be added, and most self-adhesive tapes shrink with time, dry out, or come adrift leaving a dirty stain.

7.1.3 *How and what to plot*

A field map is a record of field observations of the type listed at 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 (for fine-grained), lam (laminated), shd (sheared). Refer also to Section 4.3.1. Many exposures need no more than an outline drawn to show their limits, shaded with the appropriate coloured pencil. Exposures which are so small that they can only be shown by a coloured 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 the location on the map must be linked to the notebook record (see Section 7.1.5). Structural observations are shown by the appropriate symbols, drawn large enough to enable them to be traced off accurately on to the fair copy on a light-table: 6–7 mm is a suitable length for strike symbols. Print the numerical value of dip or plunge legibly in such a position that there is no ambiguity as to which symbol the figures refer to. Even better, record both dip and strike by using the 'right hand rule' (Fig. 7.2). It is unnecessary to enter every dip and strike, trend and plunge, in your notebook, providing you draw your symbols large enough on the map itself and record strike/dip etc. in figures beside them. Booking unnecessary information merely consumes time better spent on mapping.

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 contacts 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 in front flap). Inferred contacts are shown by broken lines and different types of inferred contacts can be distinguished by the frequency of the breaks. Keep the 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 on printed maps: a tooth every 1–2 cm is quite adequate for a field map, and if you do make a mistake, is far easier to erase after inking-in (Fig. 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

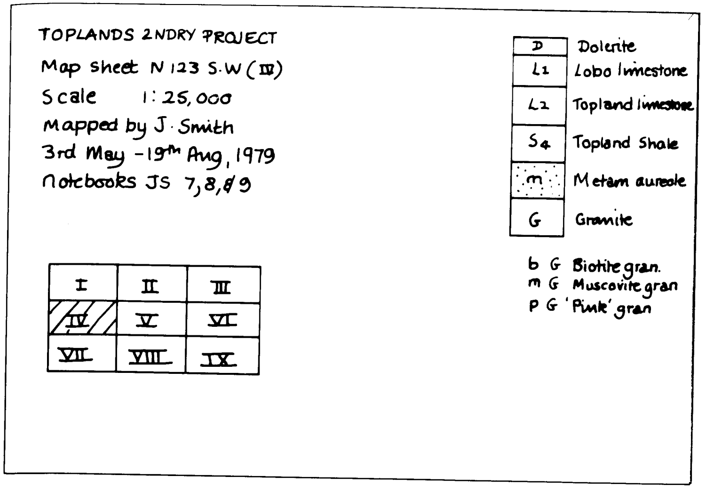


Fig. 7.1 Reverse side of a field slip with the information it should carry. Note the index showing how this slip relates to the others which make up the whole field sheet.

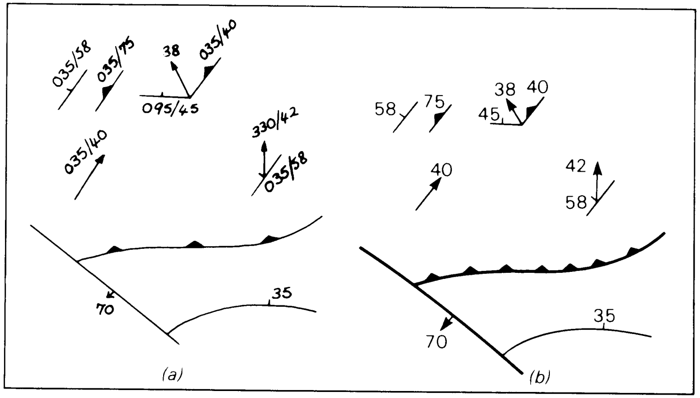


Fig. 7.2 Symbols for field (a) and fair copy (b) maps compared. Strike and trend, dip and plunge, are shown on the field map, but only dip and plunge on the fair copy.

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 owing to 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 the base map should be added to it. These include breaks 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 the 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 its scale. 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 extremes. The face of the map should contain all relevant *basic* geological information: the notebook should expand it and provide details of features which are too small to show on the map. The complexity of the geology and its degree of exposure also, of course, determines how much can be shown. Sometimes a small scale may be deliberately chosen to restrict the amount of detail in reconnaissance surveys when a larger scale might tempt the geologist to spend too much time on details.

On the other hand, if the main object of the work is to solve specific geological problems, then the scale must be large enough to show, without crowding, the type of detail that must be mapped to solve those problems; and if maps of a suitable scale are not available, then they may have to be made. Often, however, complexity of geology and degree of exposure vary from one part of a region to another so that very large-scale maps need only be made over limited areas, with 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 recognized and unmineralized 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, 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.

7.1.4 Neatness

Information written on the map 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 plot or write legibly on your map. If you use only one pencil, you will be continually sharpening it between notetaking and plotting. Write on your map in a fine, clear *printed* script. Do not use a miniature cursive running handwriting; this is far less legible, especially when written 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 made 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 any field geologist: if he cannot draw neatly, he cannot map accurately. Much of the skill needed can be acquired by effort and practice.

7.1.5 Linkage of map localities to notebooks

The most practical permanent way to link map localities to notes in your notebook 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 the simple consecutive numbering of observations. This works well, providing 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 within those squares. Whatever you do, always enclose observation numbers on the map by a circle to avoid confusing them with dip readings. Notebook entries are numbered A1, A2 ... A23, or 8746/1 ... 8746/2 (Fig. 3.1), etc., and there is seldom any difficulty in rapidly 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 lose the field map the notebook becomes virtually useless.

Map localities can also be identified by notebook page number. If several notes are made on the same page, designate them a, b, c. When more than one book 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.

7.1.6 *Inking and colouring field slips*

Observations made on field slips during the day should be inked-in at 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 line in Indian ink. After inking, recolour each exposure with the appropriate coloured pencil. Ink traverse lines with a continuous line where geology is certain and a broken line where inferred, then overlay the line—continuous or broken—with a coloured pencil line.

Inked contacts can be distinguished by lines of different thickness drawn with stylus-type pens, 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 normal.

Ink all structural symbols and rewrite the amounts of strike/dip etc. Rewrite notes in fine neat script so that they cover no geological features and align them so that all, as far as 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 day whose positions are still uncertain: leave them uninked until you are quite certain of their validity, even it it means repencilling their traces each evening to avoid losing them. Add any information from air-photographs to your map in waterproof ink —purple for general geology, red for faults—to distinguish it from information mapped on the ground. This discrimination in no way diminishes the validity of photogeological information; but it does distinguish your sources of information and also shows you where features can be confirmed on the ground.

Having inked in your map and reviewed your day's work, then, if you must, *lightly* shade or cross-hatch in colour those areas which you now infer are underlain by specific rock types. DO NOT colour in your map heavily, as if it were a 'fair copy' map. DO, however, re-colour 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 finished geological map. A field map is an 'evidence' map. It is not a rougher version of a fair copy, and should not look like one. Make sure that fact can be distinguished from inference on it.

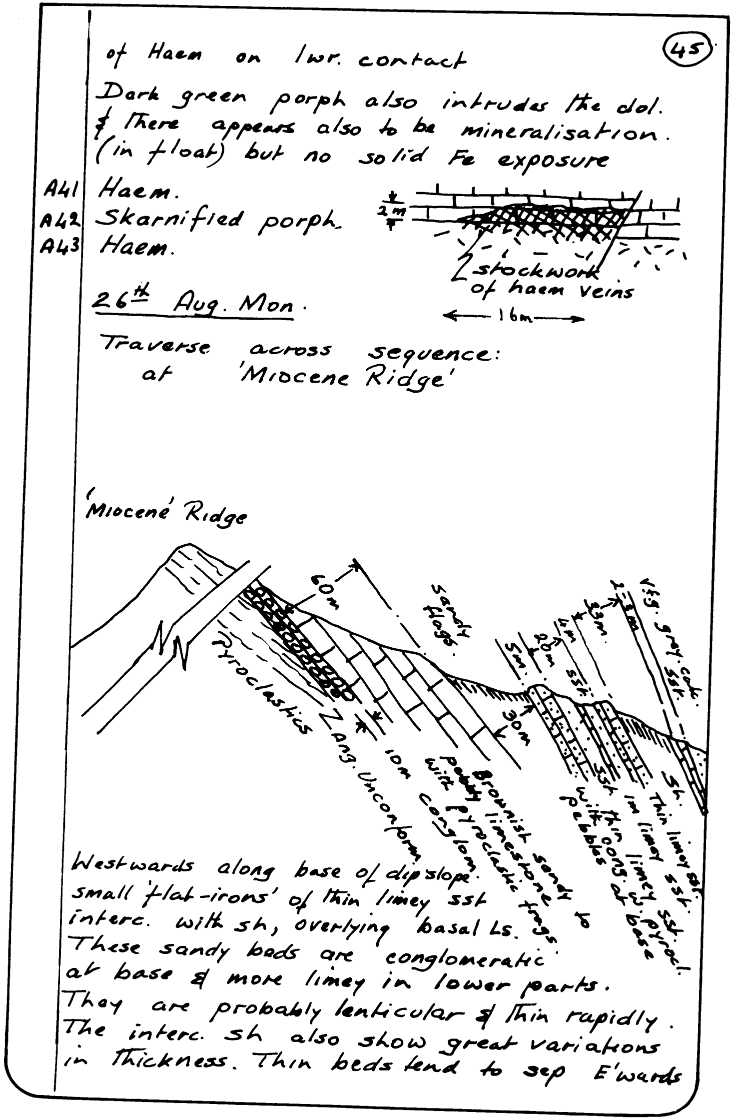
7.2 Field notebooks

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 workers who reinvestigate the area it concerns at least as often as 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 want further details of specific exposures or lithological sections to discover why you drew the conclusions you did, or your notebooks may provide information which is no longer available: exposures may be built on or dug away, pits and quarries may be filled, or records 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 their notebooks are written only 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, such as of expenses, also have to be kept. Where better than in your field notebook? Use your notebook as a diary and even if no work is done on a particular day, such as a Sunday, record the fact. Even visits to cinema or pub can be noted, as social events can often help you to remember more geological occurrences that you saw on the same day. Do remember, however, that others may read your notebook later! Only too often notebooks suffer the fate of diaries. Copious neat notes are written on the first day, fewer, rougher ones on the second. 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 because the loss of a notebook can be disastrous. If necessary, repeat the information in the language 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 a list of contents and their page numbers. This helps not only others who may have to use your notebook, but also you yourself when you come to look up information for your report from notes made months, perhaps even a year or more, before. Remember that



of Haem on lwr. contact (45)
Dark green porph also intrudes the dol.
& There appears also to be mineralisation.
(in float) but no solid Fe exposure
A41 Haem.
A42 Skarnified porph.
A43 Haem.

26th Aug. Mon.
Traverse across sequence:
at 'Miocene Ridge'

'Miocene' Ridge

Westwards along base of dip slope.
small 'flat-irons' of thin limey ssk
interc. with sh, overlying basal Ls.
These sandy beds are conglomeratic
at base & more limey in lower parts.
They are probably lenticular & thin rapidly.
The interc. sh also show great variations
in thickness. Thin beds tend to sep E'wards

Fig. 7.3 Page from a field notebook. The column on the left shows the registered number of specimens collected. The observation number referring to the locality 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, provided section lines are shown on your field slips.

you keep a notebook to refer to, so make it easy to find things in it. Ask yourself 'What use would this notebook be to me if I had to refer to it a year, two years, or even five years from now?'. If you doubt that you could understand it yourself, no one else will be able to.

Add also to your notebook, registers of rock specimens, fossil specimens and photographs. Tape on to the last few pages xeroxed tables of pace lengths and charts such as the **'percentage area' chart given in Appendix III and fasten a piece of fine sandpaper into 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 your notebook 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 note, specimen and photograph numbers. Write note numbers in pencil, specimen and photo numbers in red and blue 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 on your field map, not to duplicate it. For instance, normally there is little point in writing down the numerical values of dips and strikes plotted on the map unless weather conditions are so bad that you cannot plot them in the field. If for any reason dips and strikes have to be recorded—joints are an 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, providing you do not lose the sense of meaning. Use abbreviations where appropriate: there are many all geologists understand, such as ls for limestone, sst for sandstone, and sch for schist, or flt for fault and jts for joints. Tabulate in the front of the book any non-standard abbreviations you use unless their meaning is obvious. Use any short cuts in the field which save time without loss of information.

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, especially those which carry fine lines, lettering and dimensions, to avoid loss of details. The practice of inking-in notebook notes in general, however, is quite unnecessary. A specimen page from an actual notebook is shown in Fig. 7.3.

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 to anybody reviewing the geology of the region later and show the validity of a structural interpretation far better than those beautifully drawn and coloured cross-sections which accompany redrawn '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' manuscript (i.e., hand-drawn) map from your field maps, notes, and your later laboratory work, to accompany your report. The fair copy is not merely a redrawn version of the field map: geological formations are now shown as continuous units instead of disconnected outcrops. It is also a selective map and it may well be that some formations distinguished on the field slips are not differentiated when boundaries are transferred to the fair copy. This may be because the distinctions made in the field were found to be geologically less important than first thought, or because some units were so discontinuous that they could only be traced over very short distances. Alluvium, swamp, peat and bog are shown on the fair copy, as also are 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 to omit those which do not.

Much of the information gathered during field work is not transferred to the fair copy. For instance, the notes made on the face of the map are not normally shown although generalized comments may be made, such as 'cordierite schist' if this zone is not indicated by a specific symbol of its own, or 'red soils' to justify the continuation of an unexposed dolerite dyke. More specific notes, such as 'malachite stains' may occasionally be needed, but otherwise notes are used only to emphasize specific or unusual details, or justify the geology. Specimen locality numbers should not appear on the fair copy, either, although ore mineral and fossil localities may be marked where their presence is geologically or economically significant. The criterion for what to transfer is really a matter of common sense. The finished fair copy map should show the geology of the region in such a manner that the geological formations can be clearly distinguished one from another, 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 so 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 part of your geological interpretation. It is essentially an index map 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 fair copy map is usually drawn on a new copy of the original topographic base map used in the field. If the fair copy has to be made on tracing paper or film, then sufficient topography must be traced off the field map to make the geology understandable. This is tedious, but it is necessary. In very mountainous districts sufficient relief may sometimes be shown by tracing every second, or even fifth, contour. Draw contours in brown unless 'dye line' (ozalid) copies are to be made. In that case, as brown ink reproduces patchily, show them in black as broken lines or with a thickness that can be clearly distinguished from geological boundaries. Sometimes, fair copies have to be drawn on tracing paper or film because the printed base map is so cluttered with coloured geographic detail that the geology would be lost if plotted on top of it. This is particularly so on maps of some of the more mountainous parts of the world. Some maps drawn on tracing film are made from aerial photographs. In this case trace off main drainage and mark hilltops, at the very least.

8.3 Transferring geology

Usually, when preparing a fair copy map, information has to be transferred from field slips on to a clean, new opaque paper base map. There are several ways of doing it. The first is to copy information purely by inspection. This can only be done if there is sufficient printed detail on the map to serve as reference points. If there is not, then pencil a grid in on both field slips and base map and transfer the information square by square. In either case, strike symbols must be replotted from the original data. A better way is to use a *light-table* so that detail can be traced from field slips directly onto the base map. If the printed geographic detail on the well-used field slips does not exactly fit that on the brand new fair copy base sheet owing to scale changes caused by weathering, you must constantly adjust each field slip beneath the fair copy to maintain as good a fit as possible as detail is traced off it. A light-table is not difficult to make. Sink a window of opalescent perspex, 20–30 cm square, into a large piece of plywood mounted on a well-ventilated box. Light the window from below by two short fluorescent tubes. To use, move the working area of the map over the window as required.

8.4 Lettering and symbols

Bad printing can ruin an otherwise well-drawn map while good lettering can improve even a poorly drafted one. 'Transfer lettering' is one solution but is expensive and better kept for titles and subtitles. Stencils cannot produce such a fine result as transfers, but can be used over and over again. Mistakes, however, are more difficult to remedy. For small-sized printing, such as descriptions of rock units in the map explanation, for notes and formation letters on the face of the map, and for ancillary explanatory notes, stencils are probably quicker and easier too.

Despite such aids as transfer lettering and stencils, 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 a field map is a good way to get practice. *Italic* letters are easier to print than upright, and always use parallel guide lines except for the smallest sizes. 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. Print figures for dip (bearing of strike is omitted now) *either* parallel to the symbol or parallel to the bottom edge of the map, but not in both directions on the same map (Fig. 7.2). The symbols printed inside the front flap conform to those generally accepted around the world. A much more extensive list compiled by staff of the Australian Bureau of Mineral Resources is given in the *Field Geologists' Manual* (Berkman, 1976, p. 146–64).

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, **Mld** 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 letter of the unit wherever possible, as this acts as a mnemonic, and 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, the formation letters should be repeated several times, but where an area is too small to contain them, print the letters beside it with a 'leader'(Ƶ) pointing to the area.

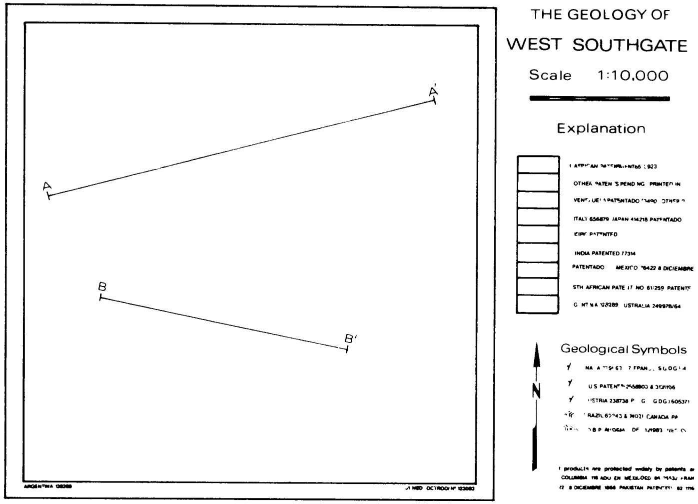
8.6 Layout

A fair copy map should be properly laid out. It should have a proper title, a scale, north points and an 'explanation' of the symbols used, together with a record of the authorship of the map and accreditation of any other sources used, including the source of the base map itself. It should also show the date of the fieldwork and the date of its 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 that the sheet looks properly balanced. If the map is stuck down to a larger sheet of good quality thin paper, the ancillary information can be arranged around it, or at one side of it, as in Fig. 8.1. Express the scale of the map in both figures, as a 'representative fraction' (i.e., 1:10,000), and graphically, as a 'bar scale' (Fig. 8.2). North points should be as plain as possible so that they are quite unambiguous. Show the differences between true, grid and magnetic norths at exaggerated angles so that there can be no mistake in their relative positions. Print the amounts of the deviations in words and figures beside them, and do not forget the annual rate of magnetic change. In the explanation draw the symbols at exactly the same size as those used on the face of the map: this is not always done.

8.7 Colouring

A manuscript fair copy map is normally hand-coloured by its author before being presented. 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. Water colours probably give a more finished look to a map but they are very difficult to apply over large areas, especially if those areas have intricate boundaries: irregular drying marks mar the result. Coloured pencils give excellent results with a minimum of practice. Lay on colour gently and with care and, if not dark enough, then 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'. Some coloured pencils react better if the swab is first damped with water, petrol or other solvents. Coloured pencils will give patterned effects if a textured surface, such as sandpaper or a 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; or darker textured colour can be overlaid on a plain colour. Alternatively, coloured dots can be added to a base colour with a felt-tipped pen. Dots can even cross geological boundaries to indicate, for instance, a thermal aureole.

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



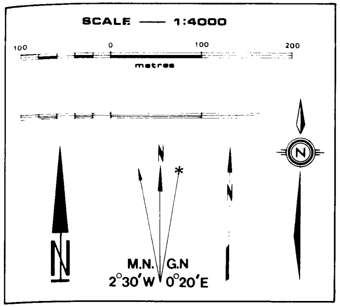


Fig. 8.2 Scales and northpoints for fair-copy maps. Two examples of 'bar scale' are shown and a selection of northpoints. Avoid the 'arty' N-point on the left. The two on the right are printed transfers. A composite northpoint is shown in the centre.

Choose colours with care and with due consideration for tradition. In general, use pale colours for rock units which cover wide areas and strong colours for rocks with limited outcrop, such as thin beds and narrow dykes. Always keep your reader in mind. Try to follow a system which does not force him to keep looking back to your map's explanation to find out what things mean. Relate your colours to rock mineralogy. For instance, if a hornblende schist is shown in pale green, or overlain with green dots, and a biotite schist is shown in brown, or is overlain with brown dots, then your reader will probably find your map easier to follow than if these formations were shown in purple or blue. Note, however, the use of colour does not obviate the need for formation letters.

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 on separate sheets, draw all on the same sheet so that they can be easily compared. Show the positions of all sections presented with the fair copy map by lines drawn on the face of the map with each end of each section clearly indicated, as in Figure 8.1; and always draw cross-sections so that their northern and eastern ends are at the right-hand side of the sheet.

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 of geology 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 that 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 over-crowd a fair copy map with specialized 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: folding axes; sub-surface contours on specific beds determined from drill holes; 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 map and overlay are of different materials which distort differently, draw 'register' marks to fit the grid intersections on the fair copy.

Title the overlay and give it a simplified bar scale, a north point, and an explanation of the symbols used. Add a subtitle to indicate which map the overlay refers to and the source of any information which does not originate from the authors.

8.10 Text illustrations

Text illustrations are needed in nearly all geological reports. The simplest are merely outline diagrams to explain a single point. Figure 5.9, which shows the 'right-hand rule', is an example. Field sketches redrawn from a notebook are often included in reports. Keep them 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 reproduce every detail faithfully. 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 Fig. 5.15.

9

Cross-sections and three-dimensional illustration

No geological map can be considered complete until at least one cross-section has been drawn to show the geology in 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 as simplified 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 these variations in three dimensions. Refinements in three-dimensional illustration 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'.

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.

9.1.1 Trial cross-sections

Draw a cross-section whenever a problem of interpretation arises. Do it when possible while still at 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 being 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 in the same tints, for it is to all intents and purposes a part of that map. Present it on a separate sheet, with all other sections of the same map, or draw it in the map margins.

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 page, and the northern, north-eastern and eastern ends, on the right. 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 at a few well-separated points to keep it nearly perpendicular to strike. 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.

9.1.4 *Text figures*

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

9.2 Plotting and drawing cross-sections

9.2.1 *Construction*

Poorly-drawn sections are so often encountered in professional life that a résumé of the process is given below:

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 (Fig. 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 tracing paper on which to 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 (Fig. 9.1a).
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 line cuts a contour line on the map (Fig. 9.1a). 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 (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) (Fig. 9.1b).
8. Project, in its direction of strike until it meets the section line on the map, any strike symbol lying close to the cross-section line, but not actually crossed by 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 (Fig. 9.1b).
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.

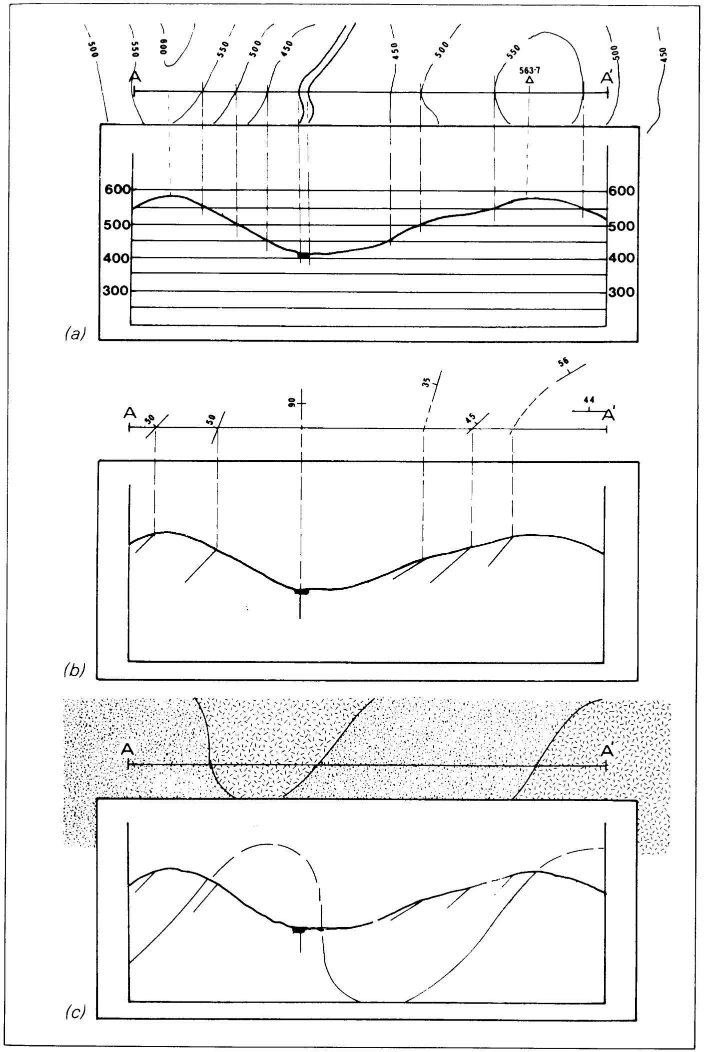


Fig. 9.1 Drawing cross-sections (see text).

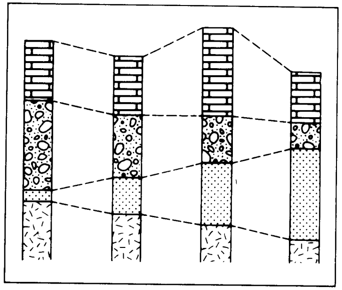
10. Lightly sketch in the structure, extending the 'dip lines' and drawing contacts parallel to them. Then modify the interpretation to allow for thickening and thinning of beds, and for any other suspected change in straightforward folding or tilting. Do not interpret geology to improbable depths beneath the surface. Test your interpretation by continuing the structure above the topographic surface: you have just as much evidence there as you have for below the surface (Fig. 9.1c). Finally, ink-in your interpretation, including, where appropriate, a dashed line to indicate structure now eroded away.

The task is made easier if a 'T-square' or a drafting machine is available. Badgley (1959) describes various ways of drawing cross-sections in many types of structural settings, including geometric constructions such as the Busk method.

9.2.2 *Calculating apparent dips*

Unless a cross-section line cuts the strike of a bed at right angles, the angle of dip must be modified in the cross-section because the *apparent dip* in the plane of section will always be less than the true dip. Apparent dip can be determined by graphical methods, trigonometrical methods, or more easily, by conversion tables or charts (Badgley 1959; Berkman 1976; Compton 1962). The *Wulff* stereonet—the geologist's 'slide rule'—can also be used (Phillips 1971).

Fig. 9.2 Columnar section.



9.3 Columnar sections

Columnar sections consist of a number of simplified stratigraphical columns shown side by side to illustrate how stratigraphy or lithology changes from place to place (Fig. 9.2). They are prepared from surface outcrops and drillhole logs.

9.4 Three-dimensional illustration

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

9.4.1 *Isometric projection*

Isometric projection has no vanishing points: all parallel lines remain parallel in the diagram. The two horizontal coordinates are inclined at 30° to the E–W baseline. The viewer sees the faces of a cube, for instance, as three equal-sided parallelograms (Fig. 9.3a). Geological information drawn on the faces of an isometric block must be distorted to fit them. Grid your geological information—map or cross-section—and also the faces of the block and then transfer information by eye, grid square by grid square, or by rectangular coordinates. You can also use isometric projection as a framework for illustrations. Fig. 9.3b shows the principle, Fig. 5.15 a typical result.

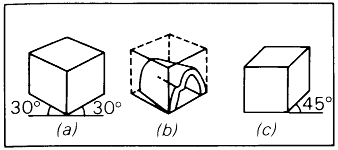
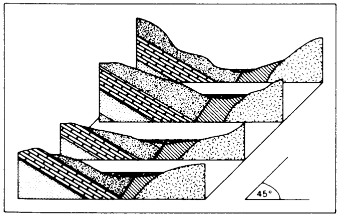


Fig. 9.3 (a) shows an *isometric* cube; (b) a fold drawn by using the cube as a guide; and (c) an *oblique* projection of the same cube.

9.4.2 *Oblique projection*

In oblique projection the front face of the basic cube remains a square and lies in the plane of the paper (Fig. 9.3c). The side and top faces, however, are parallelograms inclined at 45° to the E–W base-line, with distances receding from the viewer foreshortened by one-third to prevent the cube appearing rectangular. Oblique projection is ideal as a framework for showing serial cross-sections, for each section can be drawn true and undistorted (Fig. 9.4).

Fig. 9.4 Oblique projection of serial cross-sections. Each section is a true cross-section, but the distance between them is foreshortened by one-third.



9.4.3 *Block diagrams*

Block diagrams show the solid geology of a rectangular block of ground. Either isometric or oblique projection can be used and 'cut-aways' made to bring out structural details (Fig. 9.5).

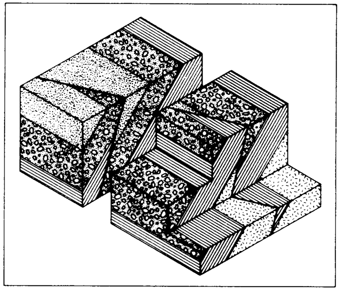
9.4.4 *Fence (panel) diagrams*

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 may be used (Fig. 9.6). They are often constructed from borehole logs.

9.5 Models

Geological problems can sometimes be solved by constructing three-dimensional models which can be

Fig. 9.5 Simple block diagram, split with the two halves separated, and with steps.



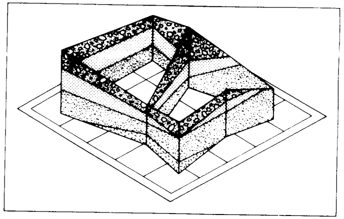


Fig. 9.6 Fence or panel diagram illustrating stratigraphic variations in a region. It gives a better spatial impression than a columnar section (see Fig. 9.2).

viewed from every direction. They need no embellishments if used only as interpretative aids.

9.5.1 *'Egg-crate' models*

An egg-crate model is constructed from a series of intersecting cross-sections. Draw the sections on bristol board or heavy cartridge paper; then cut them out and slot them together by cutting slits where they intersect. Egg-crate models are particularly useful in mountainous regions where the geology has been complicated by *nappes* and overthrusting (Fig. 9.7).

9.5.2 *Glass-sheet models*

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

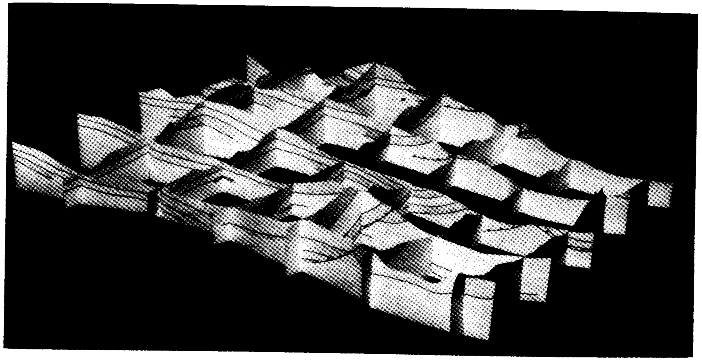


Fig. 9.7 Photograph of an 'egg-crate' model (courtesy of S.J. Matthews).

Appendix I
Safety in the field

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

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 always in company. Use proper lighting, headgear and clothing and ensure that someone knows where you are, when you went underground, and when you are expected back. Report your return so that people do not arrange unnecessary search parties.
4. Always work in pairs or in close association in rugged mountains. Wear easily seen clothing.
5. Always wear a safety helmet in quarries, under steep cliffs and scree slopes, and underground, and wear goggles when hammering rocks. These are legal requirements in Britain under the Health and Safety at Work Act.
6. Never use one hammer as a chisel and hit it with another. Hammers 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. Report them to an official if you do see them. Do not pull at pieces of fuse or wire protruding from a rock pile: they may have unexploded charges at the other end.

Whenever possible note weather forecasts in mountainous country and if you are going into a remote part of an area leave your route map and the time you expect to return with a responsible person. 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. 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 be careful of sudden drops on mountain streams. Forest tracks can be difficult; one looks much like another. 'Blaze' your trail if necessary, and learn to recognize your own footprints; they often help you to recognize the path you came in by.

I.1 Emergency kit

All geologists should take a course in first aid and keep a first aid kit and manual in camp with them. In very remote areas, Eastman's *First Aid Afloat* (1977) is recommended. Carry a small emergency kit in your rucksack, including dressings for blisters, a whistle and a flashlight for signalling (and a mirror if your compass does not have one). Include, also, matches sealed in a waterproof plastic bag, and an aluminized foil 'space blanket' (it weighs almost nothing). In hot climates, carry a water bottle and a packet of effervescent water sterilizing tablets. Always carry some form of emergency ration in case you have to spend a night on a hillside in mist or snow. One of the very bitter forms of 'sportsmen's' chocolate is best as it will deter you from eating it until really necessary. With sugar, it can be made into cocoa if you carry a metal cup. Take glucose tablets or similar 'pick-me-ups' with you too, to give that extra bit of energy towards the end of a long hard day.

I.2 Distress signals

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

I.3 Exposure

All geologists working in temperate or cold 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 the winter months: sudden drops in temperature can occur at any time of the year on any high ground. Geologists are particularly at risk because they work in weather in which other people stay indoors. Learn to recognize the symptoms of exposure in both yourself and your companions and know how to treat it.

Prevention is largely a matter of proper field clothing. Too often, students short of money economize 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 meal. Warm waterproof clothing, good boots and adequate food, all contribute to keeping warm. Do not forget a hat, for heat is lost through your scalp more quickly than from any other part of your body. It is not, however, only cold weather that causes exposure. Wind increases the effects of cold: at 0°C a wind speed of 16 km/hr produces an effective temperature of –8°C, or –14°C (7°F) at twice that speed. Wet clothing intensifies the problem, chilling by evaporation at even 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 a person lags behind, resents attempts to hurry him, constantly stumbles, slurs his speech and shows a lack of interest in everything, take shelter. Get out of the wind. Get dry clothes on him if possible, if not, cover him with windproof materials, such as a space blanket. Get him into a sleeping bag or an 'emergency bivouac' if you have one: even get in with him. If possible give him a hot sugary or glucose drink but *do not give him alcohol*—it can *kill* him. Alcohol dilates the smaller blood vessels so that blood flows to the extremities more rapidly and accelerates heat loss.

If the victim is in a state of total collapse, get help quickly for if his temperature drops below 31°C (88°F) only medical treatment can save him. If you carry him on a stretcher, keep his head lower than his feet. Back at base, put him fully dressed (to reduce shock) into a bath at 45°C (113°F) for 20 minutes, *providing* his temperature is not below 31°C. If his temperature is under 31°C, get him to a hospital but, if all else fails, allow him to warm *slowly* in a warm room.

I.4 Health in warm climates

If you intend to work in a warm climate, whether tropical or not, familiarize yourself with the elementary rules of tropical hygiene and ensure that you have all the vaccinations and inoculations required by the country you are going to. If you are going to a malarial area, obtain medical advice so that you can start taking antimalarial drugs at least a week before departure. Typhoid-paratyphoid and antitetanus inoculations are highly desirable if you are to live under field conditions. Your doctor may advise inoculation against cholera and hepatitis too. Also ask him to prescribe 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. When travelling, drink only tea, coffee, or well-accredited bottled soft drinks: it works out cheaper in the long run. *The Preservation of Personal Health in Warm Climates* is an excellent pocket guide which can be bought from the Ross Institute of Tropical Hygiene, Keppel Street, London WC1. It covers a wide range of topics including the treatment of bites from snakes, scorpions and other pests.

I.5 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 or clothing suitable for the conditions of the excursion, or who wilfully disobeys safety instructions. Otherwise, he could be deemed negligent in the case 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 place to keep a comprehensive first aid kit, packed in a clearly-labelled plastic bag. It should include a mountain stretcher, an 'emergency bivouac' (a large plastic bag sold by sports shops), a flashlight and a first aid manual.

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 and 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.

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Appendix II

Adjustment of a closed compass traverse

A compass traverse seldom closes without error, e.g., a traverse started at A, passed through turning points B, C, D, E and F, and finished back at the starting point A again (Fig. II.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 traverse distance = 3600 m

Correction factor per traverse metre $= \frac{110}{3600} = 0.03$ metres

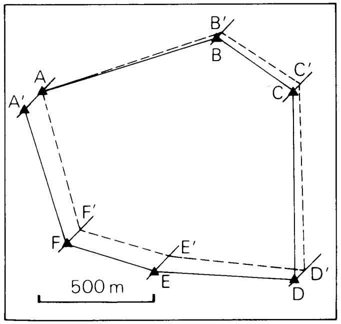

Fig. II.1 Adjustment of a closed traverse.

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Appendix III

Table III.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 III.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	0	1
	Coarse sand	1	0.5 (½ mm)
	Medium sand	2	0.25 (¼ mm)
	Fine sand	3	0.125 (⅛ mm)
	Very find sand	4	0.063 (1/16 mm)
Silt	Coarse silt	5	32 µm
	Medium to very fine silts	8	4 µm
Clay	Clay	14	

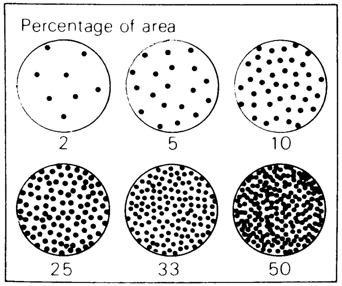

Fig. III.1. Percentage area chart

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