University of Diyala
College of Science
Department of Petroleum Geology and Minerals

Lectures in Field Geology

Prepared by:

Prof. Dr. Mundher A. Taha

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FIELD EQUIPMENT

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

2.1 Hammers and Chisels

Any geologist going into the field needs at least one hammer with which to break rock. Generally, a hammer weighing less than about **3/ 4 kg** is of little use except for very soft rocks; **1 kg** is probably the most useful weight. The commonest pattern still used in Europe has *one square faced end and one chisel end*. Many geologists now prefer a ‘prospecting pick’; it has a long pick-like end which can be inserted into cracks for levering out loose rock, and can also be used for digging in soil in search of float. Most hammers can be bought with either wooden or fibreglass handles or with a steel shaft encased in a rubber grip (Figure 2.1). If a wooden handle is chosen (it does have some advantages: it is more springy), buy some spare handles and some iron wedges to fix them on with.

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

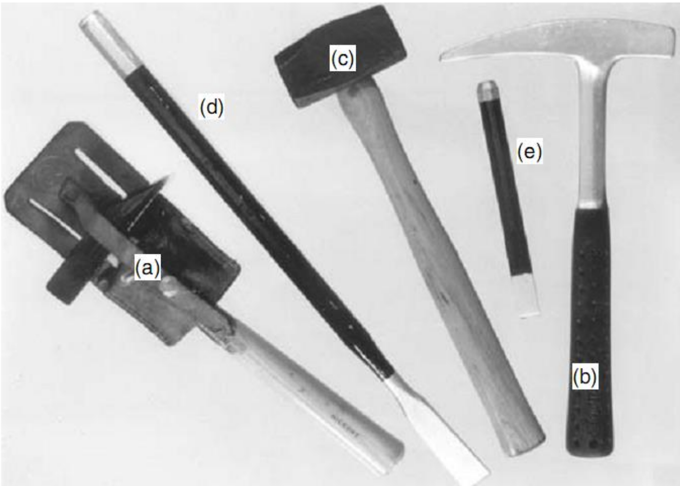


Figure 2.1 *Tools for the field: (a) traditional geologist's hammer in leather belt 'frog'; (b) steel-shafted 'prospecting pick'; (c) bricklayer's 'club' hammer with a replaced longer shaft; (d) 45 cm chisel with 2.5 cm edge; (e) 18 cm chisel with 2 cm cutting edge*

Sometimes a cold chisel is needed to break out a specific piece of rock or fossil. Its size depends on the work to be done. A **5** mm chisel may be ideal to delicately chip a small fossil free from shale, but to break out large pieces of harder rock a **20–25** mm chisel is required (Figure 2.1).

2.2 Compasses and Clinometers

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

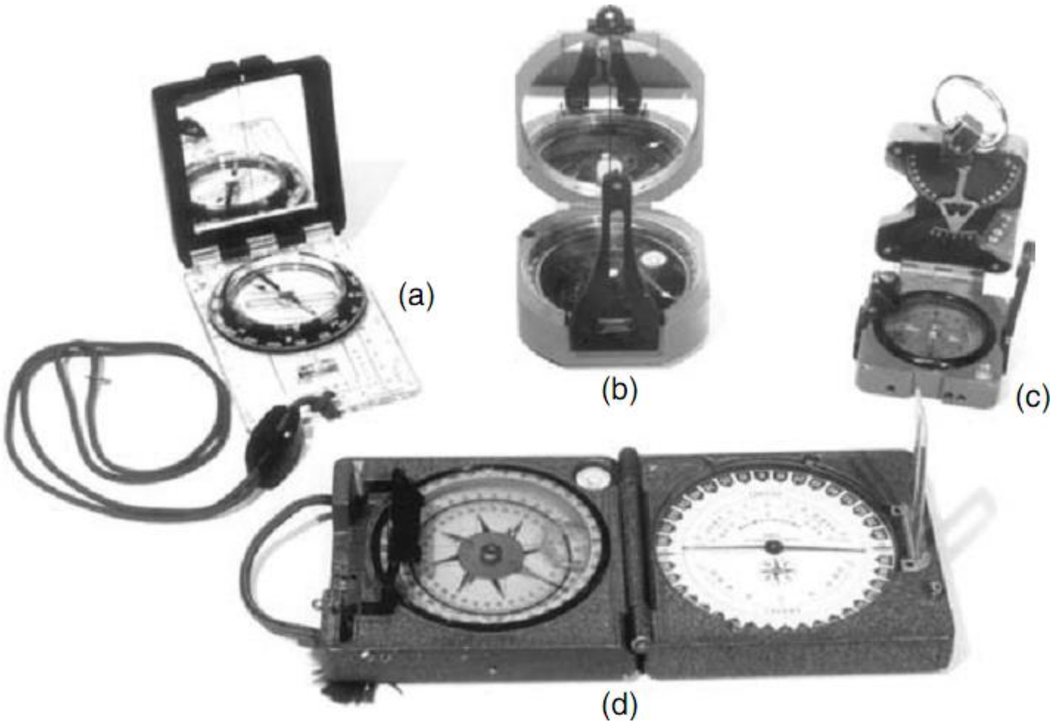


Figure 2.2 *Compasses designed for the geologist: (a) Finnish Suunto compass, similar to the Swedish Silva Ranger 15 TDCL; (b) American Brunton 'pocket transit'; (c) Swiss Meridian compass; (d) French Chaix-Universelle. The Brunton and Meridian can also be used as hand-levels*

2.2.2 Using compasses

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

Table 2.1

Quadrant bearing	Azimuth bearing
N36 E	036
N36W	324
S36 E	144
S36W	216

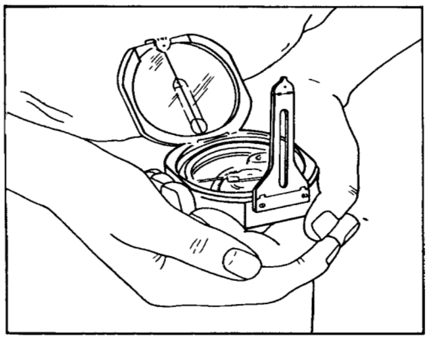


Figure 2.5 *The recommended way to use a Brunton compass when taking a bearing on a distant point (reproduced by courtesy of the Brunton company, Riverton, Wyoming)*

The Brunton Company recommends that the compass is held at waist height and the distant point aligned with the front sight so that both are reflected in the mirror and are bisected by the hairline on the mirror (Figure 2.5).

2.2.3 **Clinometers**

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

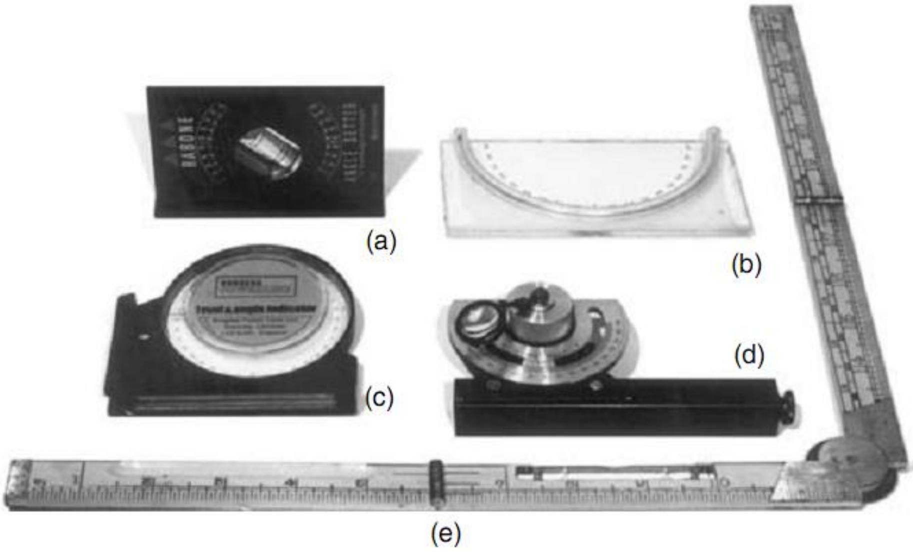


Figure 2.7 *A selection of clinometers: (a) Rabone adjustable spirit level; (b) Home-made clinometer (see Figure 2.6); (c) Burgess 'level and angle indicator'; very cheap, if you can find one in a DIY shop (may be sold under other names); (d) Abney hand-level; can also be used as a clinometer; (e) builder's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

2.3 Handlenses

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

2.4 Tapes

A short 'roll-up' **steel tape** has many uses. A **3** m tape takes up no more room than a 1 m tape and is much more useful. You can use it to measure everything from **grain size** to **bed thickness**, and if the tape has black numbering on a white background, you can use it as a **scale** when taking close-up photographs of rock surfaces or fossils. A geologist also occasionally needs a **10** m or **30** m 'linen' tape for small surveys.

2.5 Map Cases

A map case is obviously essential where work may have to be done in the **rain** or **mist**; but even in **warmer climes**, protection from both the **sun** and **sweaty hands** is still needed. A map case must have a **rigid base** so that you can plot and write on the map easily; it must **protect** the map; and it must **open** easily.

2.6 Field Notebooks

Do not economise on your field notebook. It should have **good** quality '**rainproof'** paper, a **strong hard cover** and good **binding**. It will have to put up with hard usage, often in **wet** and **windy** conditions. Nothing is more discouraging than to see pages of field notes torn out of your notebook by a **gust** of **wind** and **blowing** across the landscape. **Loose-leaf** books are especially **vulnerable**. A **hard cover** is necessary to give a good surface for **writing** and **sketching**. A notebook should fit into your **pocket** so that it is always available, but big enough to write on in your hand. A good size is **12** cm × **20** cm so make sure you have a pocket or belt-pouch to fit it. Try to buy a book with **squared**, preferably **metric** squared paper; it makes sketching so much easier. **Half-centimetre** squares are quite small enough. A surveyor's *chaining book* is the next best choice: the paper is rainproof, it is a convenient size.

2.7 Scales

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

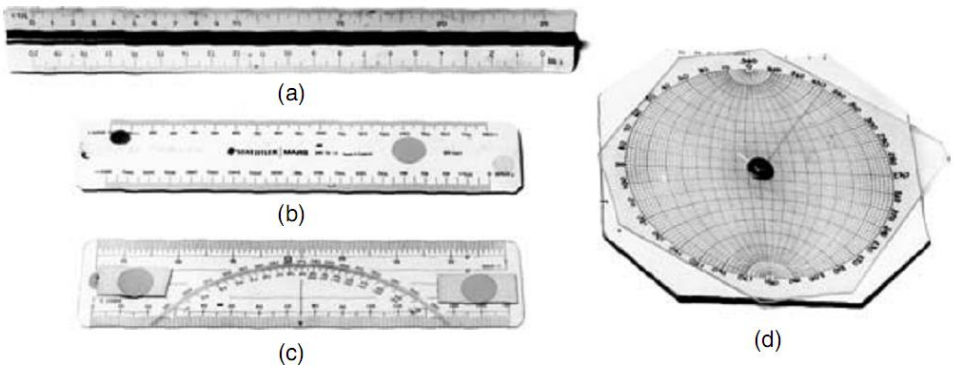


Figure 2.10 *A selection of scales: (a) a triangular map scale which is not recommended for field use, but excellent in the office; (b) a plastic scale with different graduations on both edges and both sides; (c) a transparent combination of map scale and protractor – cheap with a wide choice of scales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

Scales are not expensive for the amount of use they get. Many are thinly oval in section and engraved on both sides to give four different graduations. The most convenient combination is probably **1:50 000**, **1:25 000**, **1:12 500** and **1:10 000**. In the USA scales with 1:62 500 and 1:24 000 are needed. Colour code scale edges by painting each with a different coloured waterproof ink or coloured adhesive tape, even nail varnish, so that the scale you are currently using is instantly recognisable. (Figure 2.10).

2.8 Protractors
They are easily obtainable and relatively cheap. For ease of plotting they should be **15–20** cm in diameter and semi-circular; **circular** protractors are no use for plotting with in the field. **Transparent** protractors (and scales) are difficult to see when dropped in the field but are easier to find if marked with an **orange** fluorescent spot.

2.9 Pencils and Erasers
At least **three** pencils are needed for mapping in the field: a **hard pencil** (**4H** or **6H**) for plotting **bearings**; a **softer** pencil (**2H or 4H**) for plotting **strikes** and **writing notes** on the map; and another pencil **(2H, HB or F**) kept only for writing in your notebook. The **harder** alternatives are **for warmer climates**, the **softer** for **cold**. Do not be tempted into using **soft** pencils, they **smudge** and they need frequent sharpening. A **soft** pencil is quite incapable of making the **fineness** of line needed on a geological map with sufficient permanency to last a full day's mapping in rigorous conditions, and keep a separate pencil for your notebook to avoid frequent sharpening.

2.10 Acid Bottles
Always carry an acid bottle in your **rucksack**. It should contain a *small* amount of **10% hydrochloric** acid. **Five** millilitres (5 ml) is usually ample for a full day's work even in limestone country, providing only a *drop* is used at a time, and one drop should be enough. Those tiny plastic dropping bottles in which some proprietary ear-drops and eye-drops are supplied make excellent field acid bottles.

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

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

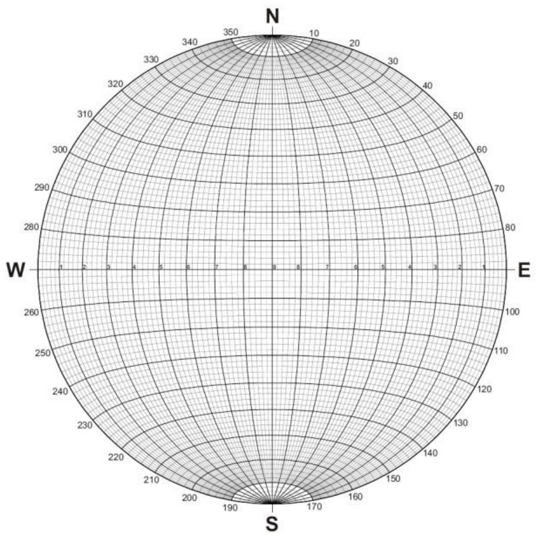
2.12 Other Instruments

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

2.12.1 **Stereonets**

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

Flächentreue, stereographische Projektion (Schmidt´sches Netz)



2.12.2 Stereoscopes

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

2.12.3 Pedometers

A pedometer is mostly useful in **reconnaissance** mapping, or at scales of **1:100 000** or smaller. It does not actually **measure** distance directly: it **counts** paces and

expresses them in terms of distance after it has been set with your own pace length. Make allowances for your shorter paces on slopes, both **up** and **downhill**.

2.12.4 Altimeters

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

2.13 Field Clothing

To work efficiently a geologist must be properly clothed and you cannot work efficiently if soaking wet or frozen stiff. In **warm** or **hot** climates, bad **sunburn** will not lead to full concentration on your work, nor will be covered in insect **bites**. Note that in summer, **arctic** regions frequently swarm with **mosquitos** on lower ground and biting black-fly on hillsides; **long sleeves** and sometimes even a **face net** are needed.
In **temperate** and **colder climates**, wear loose-fitting trousers: **tight jeans** are not as warm, especially if they get wet, and geologists often do get wet. Even when the weather appears warm, carry a sweater in your rucksack in hilly country, and when buying an **anorak**, choose **bright oranges** or **yellows**: they are more easily **seen** by search parties.

GEOLOGICAL MAPS AND BASE MAPS

To make a geological map you need a **topographic base map** on which to plot your geological observations in the field. You will also need a **second map** on which to replot your interpretation of the geology as a ‘fair copy map’ to submit to your employer or supervisor, when your work is complete.

2.1 Types of Geological Map

Geological maps fall into **four** main groups. These are: 1-reconnaissance maps; 2-maps made of regional geology; 3-large-scale maps of limited areas; 4- and maps made for special purposes. Small-scale maps covering very large regions are usually compiled from information selected from one or more of these groups.

2.1.1 Geological reconnaissance maps

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

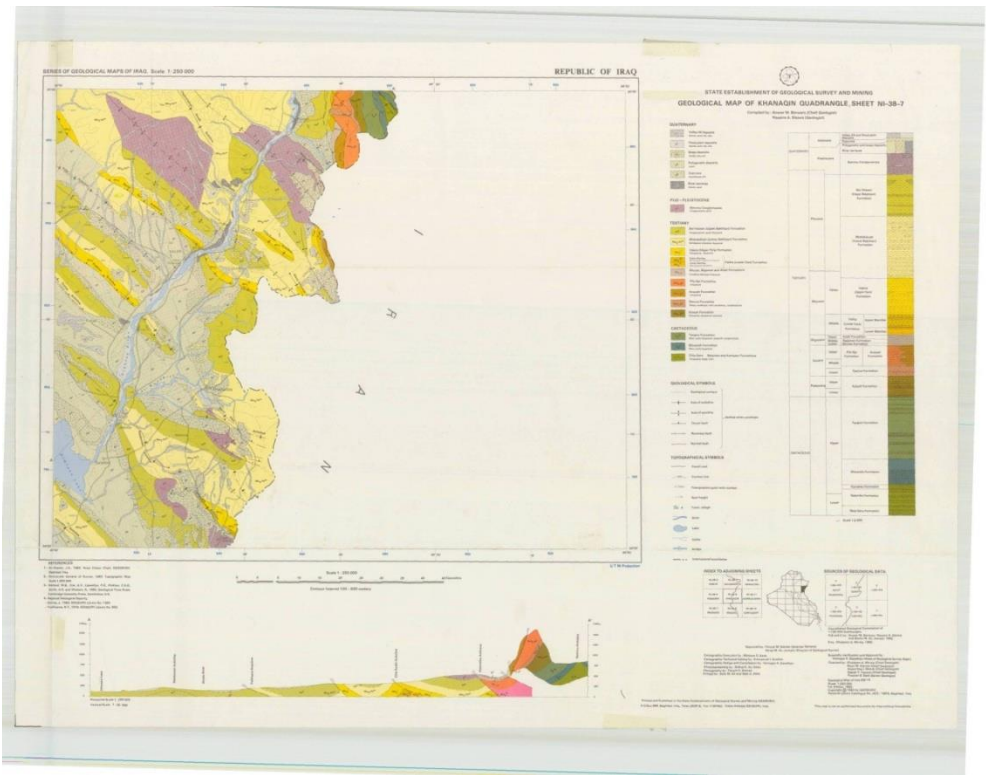


Fig. 2-1Geologic Map of Khanaqin-Iraq, scale 250,000

2.1.2 Regional geological maps

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

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

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

2.1.3 Detailed geological maps

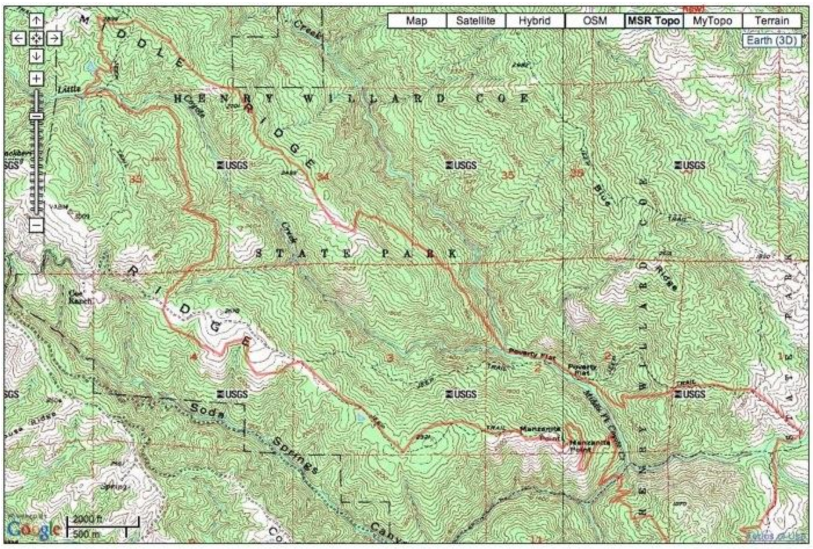
Scales for detailed geological maps may be anything from **1:10 000** and larger. Such maps are made to investigate **specific problems** which have arisen during smaller-scale mapping, or from discoveries made during **mineral** exploration, or perhaps for the **preliminary** investigation of a **dam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

2.1.4 Specialised maps

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

2.2 Topographic Base Maps

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



2.2.1 Great Britain

They are held on the National Topographic Database (NTD) and digitised so that they can be printed on demand. The scales are:
1-Urban areas 1:1250 printed as **500 m** squares, 2**- Rural areas** 1:2500 printed as **1 or 2 square km** areas, 3-**Uncultivated areas** and **moorland** 1:10 000 (also covers above areas).

2.2.2 Other countries

It is difficult to particularise the availability of maps in other countries.

2.3 Geographic Coordinates and Metric Grids

2.3.1 Geographic coordinates

Geographic coordinates represent the **lines of latitude and longitude** which sub-divide the terrestrial globe. To make a map, part of the curved surface of the globe is projected on to a flat surface. This may result in one or both sets of coordinates being shown as curved lines, depending on the type of projection being used. In Transverse Mercator's projection, however, the one most commonly used for the large-scale maps on which geologists work, latitude and longitude appear as intersecting sets of straight parallel lines. This results in some distortion because, of course, in reality lines of longitude converge towards the poles, but on any single map-sheet the distortion is negligible.

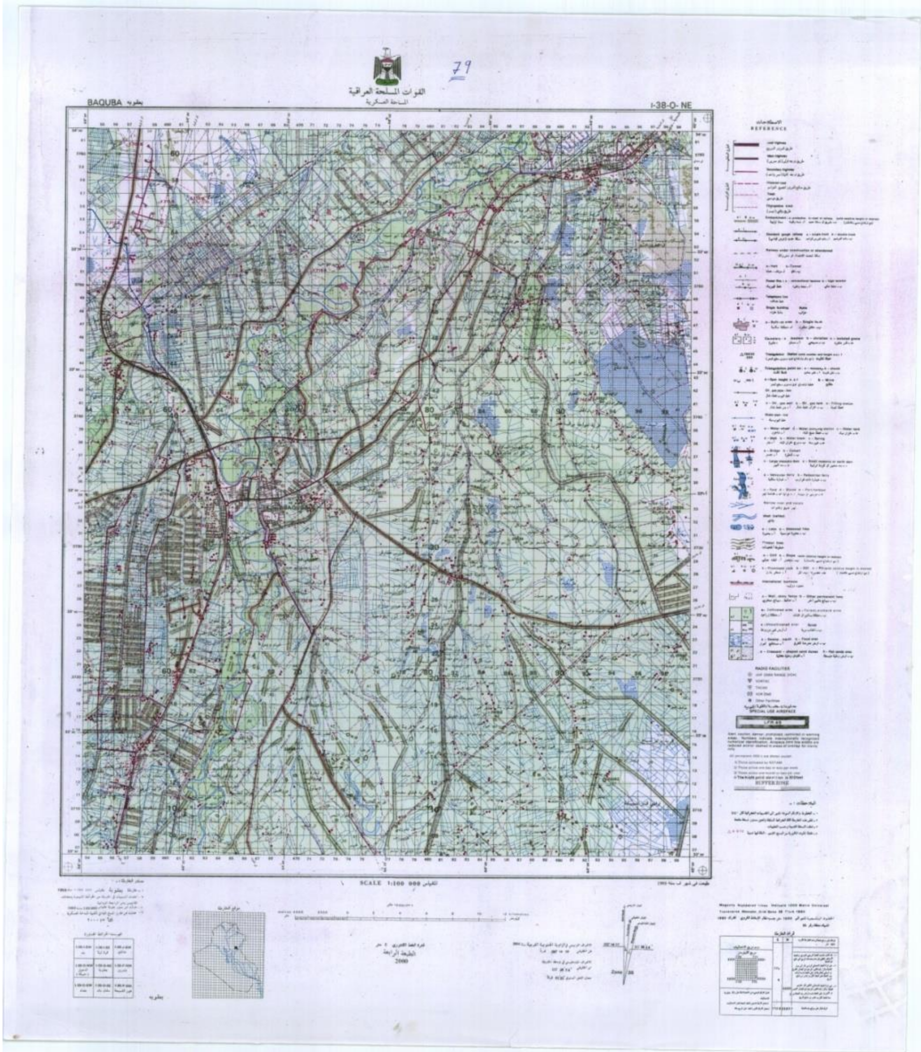


Fig. (2-2)

2.3.2 Metric grids

The metric grid printed on maps is a **geometric** not a geodetic device. The grid is superimposed on the **flat map projection** and has (almost) no relationship to the **surface of the globe**: it is merely a system of **rectangular coordinates**, usually printed as **1 km squares** on maps from 1:10 000 to 1:50 000 and **10 km squares** on maps of smaller scales. The whole grid is divided into **100 km square** blocks, each designated by two reference letters.

The metric grid is a useful device for describing a point on a map. In Britain, a full map reference is given by first quoting the reference letters of the 100 km square block in which the point lies, e.g. SN if in southwest Wales. This is followed by the ***easting***, i.e. the distance in kilometres from the **western margin** of square SN and then the ***northing***, the distance from the **southern margin** of the square. The complete reference is written as a single group of letters and figures, **easting always before northing**. This figure will give the position of the point to the nearest kilometre. For instance, SN 8747 means that Llanwrtyd Wells is 87 km east and 47 km north of the margins of square SN. This is good enough to indicate the general area of the town. SN87724615, however, is more specific and locates the position of the road **(Fig. 2.3).**

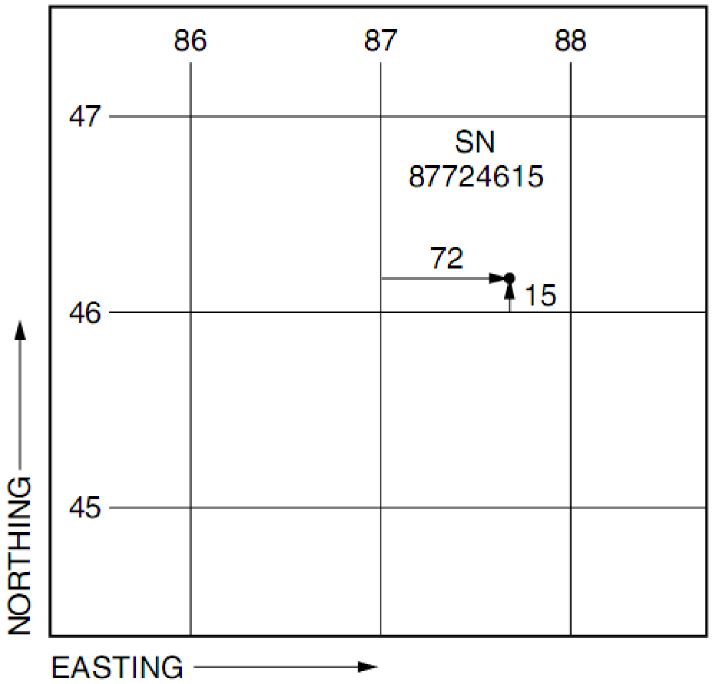


Figure 2.3 *Finding a map reference. The figure shows coordinates of a portion of 100 km square SN of the British National Grid. The point referred to lies 0.72 km east of the 87 km coordinate and 0.15 km north of the 46 km coordinate (eastings are always quoted before northings). The map reference of the point is therefore SN87724615*

2.4 Position Finding on Maps

In the field a geologist should be able to position himself to better than 1 mm of his correct position on the map, whatever scale he is using; i.e. to within 10 m on the ground or better on a 1:10 000 map, and to within 25 m on a 1:25 000 sheet. On British 1:10 000 maps a point may often be fixed purely by inspection, or by pacing along a compass bearing from a field corner, building or stream junction printed on the map, or by resecting from known points. In any case, a geologist should know **how to find out where he is without one**.

2.4.1 Pacing

Every geologist should know his pace length. With practice he should be able to pace with an error of less than **3 m in 100** m even over moderately **rough** ground. This means that when using a 1:10 000 map he should be able to pace 300 m and still remain within the 1 mm allowable accuracy, and over half a kilometer if using a 1:25 000 map. However, pacing **long distances** is not to be recommended unless it is essential. Pace the distance **twice in each direction** counting *double* paces, for they are less likely to be miscounted when pacing long distances.

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

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

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

2.4.2 Location by pacing and compass

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

2.4.3 Offsets

Offsetting is a simple method of plotting **detail** on a map. It is particularly useful where a **large number of points** are to be plotted in one small area. Take a compass bearing from a **known** position to any convenient point in the general direction of the exposures you wish to locate on your map, for instance a **tree**. Pace along this line until you are **opposite** the first exposure to be examined. Drop your rucksack and then pace to the exposure at **right angles** to your main bearing line: this line is an offset. Plot the exposure and return to your rucksack and **resume** pacing towards the tree until opposite the next exposure. Carry on until you have completed plotting all the exposures (Figure 2.4). This method is comparatively fast, for once the direction of the traverse (or 'chain line' in surveyor's parlance) has been determined, there is no real need to use your compass again; providing the offsets are short, you should be able to estimate the right angle of the offset from the chain line for short lengths, but check with a compass for longer offsets.

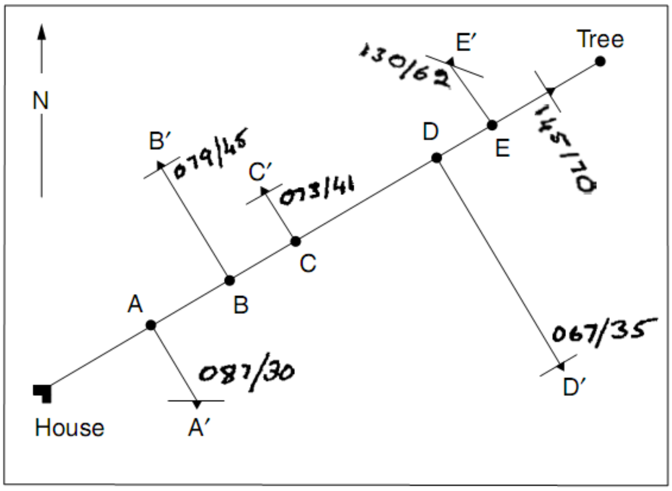


Figure 2.4 *Locating a point by offsets. A traverse (bearing 62) is paced from the house, using the tree as an aiming point, until you reach point A, directly opposite an exposure at A. Mark A with your rucksack and then pace the offset A–A at right angles to the traverse line. Plot the position of A;make your observations of the exposure at A; and return to your rucksack. Resume pacing and repeat the process for points B, C,etc*.

2.4.4 Compass intersections

Your position on any **lengthy feature** shown on a map, such as a **road**, **footpath**, **fence**, **river or stream** can be found by taking a compass bearing on any point which can be identified on the map. Plot the **back-bearing** from this point to intersect the road, river, etc. and that is your position. Where possible, check with a second bearing from another point. Choose your points so that the back-bearings cut the fence or other linear feature at an angle of between 60˚or 90˚for the **best results** (Figure 2.5).

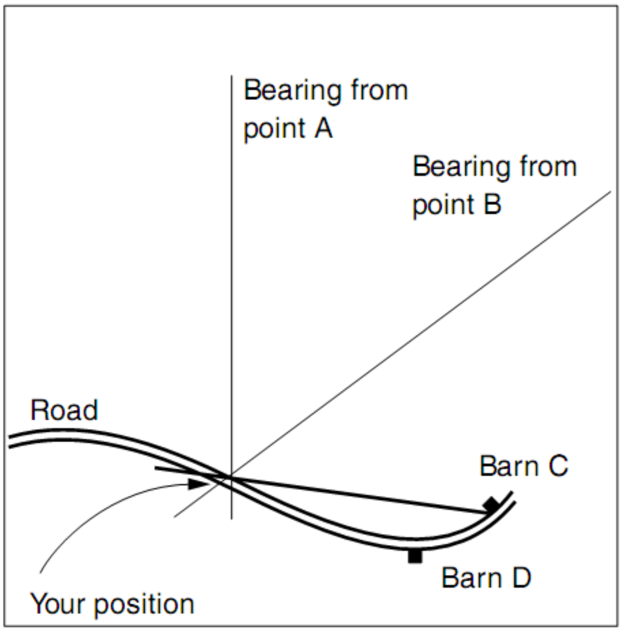


Figure 2.5 *Locating yourself on a road or similar longitudinal feature. Sight points which give good intersections with the road: a bearing to barn D, for instance, is not satisfactory*.

2.4.5 Compass resection

Compass resection is used where the ground is too **rough**, too **steep**, too **boggy** or the distances too **long** to pace. Compass bearings are taken from the unknown point to

three easily recognisable **features** on the map, chosen so that **back-bearings** from them will intersect one another at angles between 60˚and 90˚wherever possible. Ideal intersections are, unfortunately, seldom possible, but every attempt should be made to approximate to them (Figure 2.6). Features on which bearings may be taken include **field corners**, **farm houses**, **sheep pens**, **path or stream intersections**, **'trig' points**, or even a cairn that you yourself have erected on a prominent point for this very purpose.
All too frequently bearings do not intersect at a point but form a *triangle of error*. If the triangle is less than 1 mm across, take its centre as the correct position. If larger, check your bearings and your plotting.

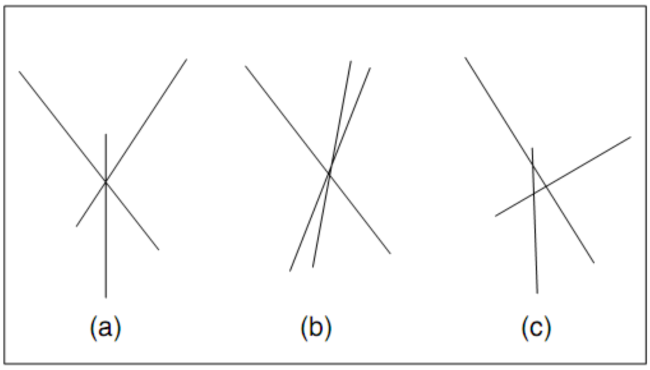


Figure 2.6 *Intersection of bearings: (a) relatively good; (b) poor; (c) shows a triangle of error*.

2.4.9 Global positioning system (GPS)

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

2.5 Magnetic Declination

At most places on the surface of the earth there is a **difference** between the direction of **true north** and the **north shown by a magnetic compass**. This is called *magnetic declination* or *magnetic variation* and it changes by a **small amount** every year. Magnetic declination and its annual change vary from place to place, and these values, together with the difference between true and grid north (which is of course constant), are shown as part of marginal information on map sheets. In Britain, the change is about 1˚every 15 years. Magnetic declination must be allowed for when plotting compass bearings.
As in most instances bearings will be plotted on a map from a metric grid coordinate, the correction used must be taken as the **difference** between **magnetic** and **grid north**, **not** between magnetic and true north. On many needle compasses, such as the Silva, Suunto and Brunton, this correction can be compensated for by rotating the graduated ring by means of a small screw.

2.6 Plane table Mapping

Plane tabling is a method of **constructing** a **topographic map** for which little training is needed. It is excellent for making a **geological map** when no topographic base is available. In the first instance the map, both topographic and geological, is made in the field at one and the same time. The contours are drawn with the ground in front of you, so you can show all those subtle changes in topography which often have a geological significance. Plane tabling makes you wholly independent of base maps of dubious quality or of the assistance of topographic surveyors, who are not always available.

2.7 Aerial Photographs

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

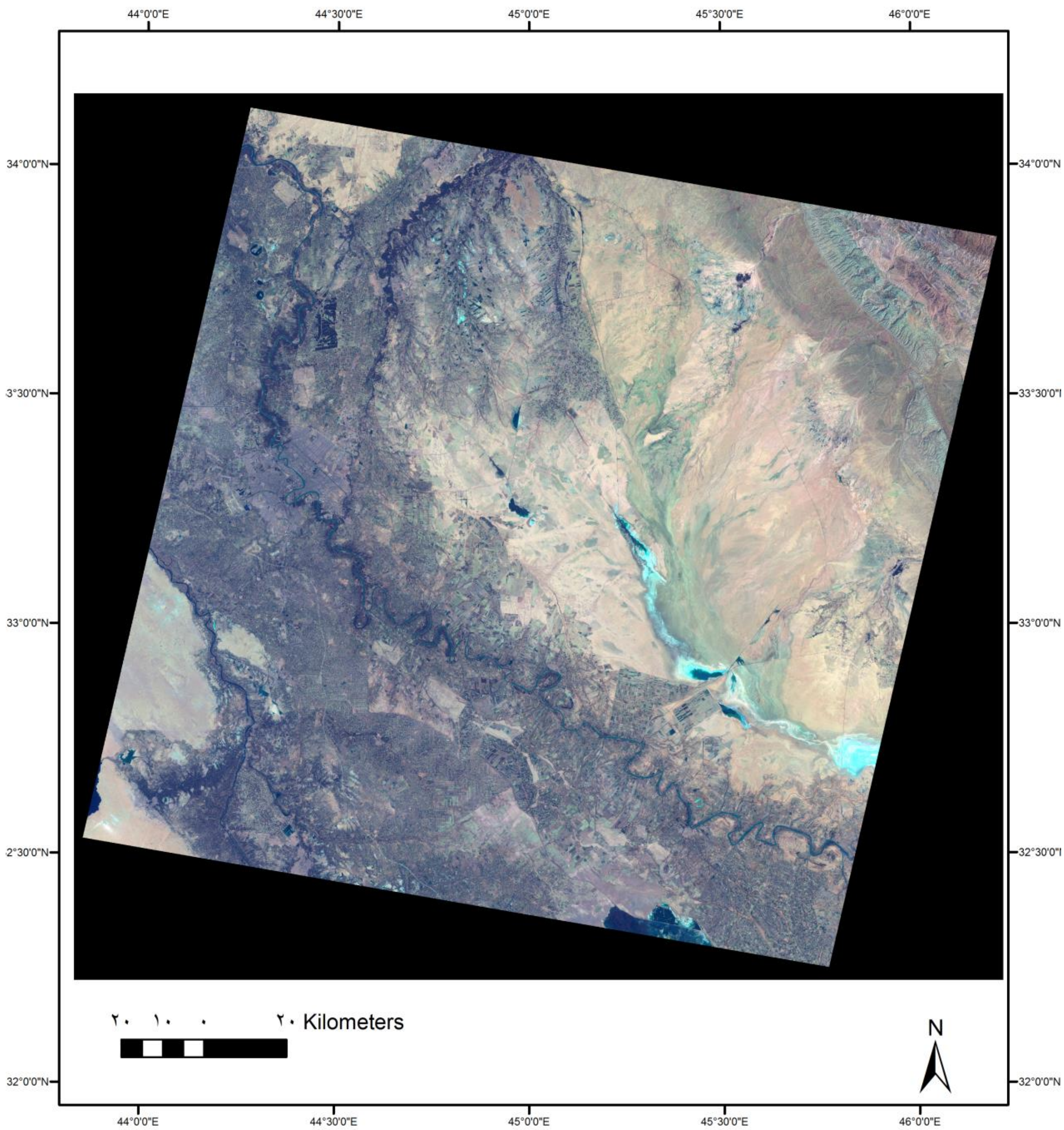
Figure 2.7 *A block of three runs of aerial photographs, A, B and C. Photographs in each run overlap each other by 60% so that the position on the ground of the principal point (a) of photograph A-1 can also be found on photograph A-2. Similarly the pp on photo A-2 is found on both photos A-1 and A-3. Adjacent runs overlap by about 30% so that a feature $d_1$seen on photo B-1, can not only be found on photo B-2 and B-3, but also on photos C-1, C-2 and C-3 of the adjacent run*

a photograph varies from place to place; a hilltop is closer to the camera than a valley bottom, and the centre of the photograph closer than a corner. These differences cause distortions .

2.8 Satellite Imagery

Satellite images (do not call them photographs) can be useful aids but are in general of too **small a scale** for anything but small-scale mapping although they may show **gross regional features**. They are generally either in **colour** or **'false-colour'**, that is where part of the non-visible spectrum (i.e. infrared) is shown, usually in red, to express certain features such as the condition of vegetation. The natural colours are then shifted in the spectrum so that anything in visible red appears as green, anything green as blue. Much of what is available in satellite images is from NASA (www.nasa.gov.satimages), but the French also produce images from their own SPOT (Satellite Probatoire pour l'Observation de la Terre). SPOT has the advantage that the system produces stereopairs. In general satellite imagery is expensive to produce and therefore expensive to buy.

مرئية لوسط وجنوب ديالى TM1990



FIELD MEASUREMENTS AND TECHNIQUES

One **object** of geological mapping is to elucidate the **structure** and **structural history** of the region studied. This can only be done if measurements are made of:

1- The attitude of planar structures such as the bedding , foliation and faults ; 2- linear features including the intersection of bedding and cleavage; 3-the trends of minor folds; and 4- the directions of overturning. Measurements once made must be **plotted** and **recorded**, and there are several ways of doing this too, some easier than others. **Structures must also be investigated**, **specimens collected**, **photographs taken**, and **possibly even soils panned to determine heavy mineral suits where no rocks are exposed.**

5.1 Measuring Strike and Dip

Measurements of strike and dip of **bedding**, **fault**, **cleavage**, **foliation** and **jointing** are fundamental. Without them, a geological map means **little**. A useful rule of thumb is to take readings to give an average density of about **one** for every **$5cm^2$**or **1 $inch^2$** of map surface regardless of the scale of mapping. Strikes and dips can be measured in a **number** of different ways. **Suit** your method to the type of **exposure**. Limestones, for instance, often have **uneven bedding** surfaces and a method which **allows** you to measure strike and dip over a **wide area** of surface will give more representative values than one where **only a point** on the surface is measured. Metamorphic rocks **offer** additional problems. Measurements of **cleavage** often have to be made on **very small parts** of a surface, sometimes even overhanging ones.

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

5.1.1 Method 1

This, the ***contact method***, is commonest of all. Use it where the surface is **smooth** and **even**. If there are *small* irregularities, **lay** your map case on the rock surface and make your measurements on that, but sometimes such a small area of bedding or cleavage is exposed that direct contact is the only method that can be used. Place the **edge of your compass** on the surface, hold it horizontally, align it parallel to strike and read the bearing (Figure 5.1).

Some compasses are provided with **a level bubble** so that there is no difficulty in establishing strike. With others, you may first have to determine strike with your clinometer, as follows: **rotate the clinometer** on the rock until it reads zero dip and, if necessary**, scratch** a line parallel to it with your hammer or lay your scale down beside it. With **practice** you can usually **estimate** strike with sufficient accuracy, but where surfaces are close to horizontal, strike may be more **difficult** to estimate. Then it may be **easier** to determine the direction of **maximum dip**, or if you have water to spare, let a **little run over** the surface to determine the dip direction. Measure dip with your clinometer at **right angles** to the strike (Figure 5.2).

Figure 5.1 *Measuring strike by the contact method*, ***Figure 5.2*** *Using a 'Dollar' type clinometer to measure dip*

5.1.2 Method 2

On **large uneven planes** of relatively **low dip**, estimate a **strike line** of a meter or more long (if necessary, mark it with a **couple of pebbles**), then stand over it with your compass opened out and **held** parallel with it at **waist height** (Figure 5.3). In a **stream** or on a **lake shore** nature may help, for the **water line** makes an excellent strike line to measure. The same method can be used to measure the strike of **foliation on turtlebacks**, or of **veinlets** on flat surfaces. Because you measure a **greater strike length** with this method, it gives **more accurate** readings **than** the **contact method**, and it is particularly useful where foliation is indistinct and seen better in the rock as a whole. **Dip** is often difficult to measure in some **pavement exposures**, because there may be little dip exposed. The *end-on* method must then be used; sometimes you may even have to lie down to do it. Move back a few metres, hold your clinometer at arm's length in front of you and align it with the trace of foliation seen in the end of the exposure, ensuring that your sight line is horizontal and *in the strike of the plane measured*. Figure 5.4 shows an excellent exposure suitable for end-on dip measurement, but it can be used on far poorer exposures of dip than that.

Figure 5.3 *Measuring the strike of a veinlet on a rough horizontal surface by Method 2,* ***Figure 5.4*** *An ideal exposure for the end-on measurement of dip*

5.1.3 Method 3

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

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

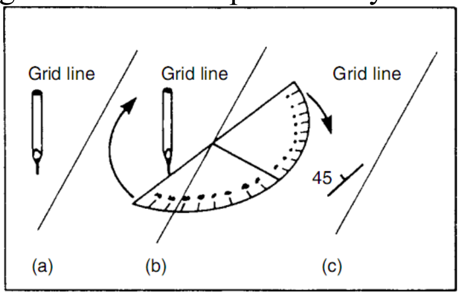
Figure 5.6 *Measuring the dip of an uneven surface by Method 3*

5.2 Plotting Strike and Dip

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

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

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



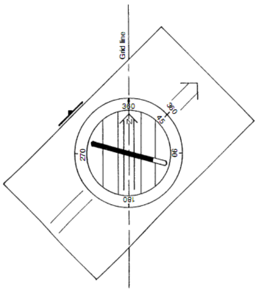


Figure 5.7 Plotting a bearing by POP (pencil-on-point), Figure 5.8 Plotting a bearing with a Silva type compass.

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

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

5.3 Recording Strike and Dip

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

5.3.1 Right-hand rule left

Strikes and dips must be recorded in a manner where there can be no possible confusion over the direction of dip; the recording of dip 180˚in error is a common mistake. Many geologists write the bearing of the strike, followed by a stroke and then the amount of dip, and then the quadrant it points to: 223/45NW (or S43W/45NW if your compass is graduated in quadrants). *The right-hand rule* is simple if applied as follows, when only a contortionist can get it wrong: always record strike in the direction that your right-hand index finger points when your thumb points down the dip (Figure 5.9). **Quadrant letters can now be omitted** and the reading of 223/45NW now becomes 043/45. In this method the dip direction was always toward the left side.

All types of planar information can be noted in this form. There are other versions of this notation with which it can be confused, so note the method used in the front of your notebook.

5.3.2 Right-hand rule right

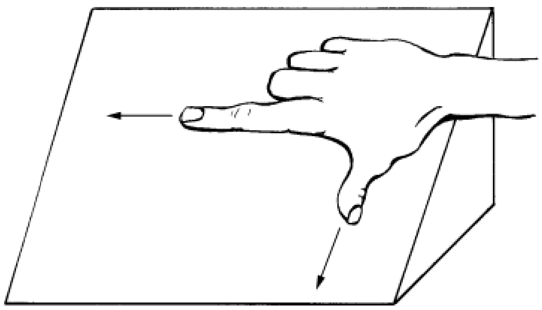
The fingers of your Right hand point down the dip, then your Thumb points in the direction of strike.

Working with an outcrop (in the field):

1. **Place your right hand on the surface and point your fingers towards the dip.**
   2. Now extend your thumb on the same plane. The direction which your thumb is pointing to is the direction of the strike.

In this method the dip direction was always toward the right side.

The example above which gave the strike and dip as 223/45NW or S43W/45NW in the method Right-hand rule right becomes 223/45



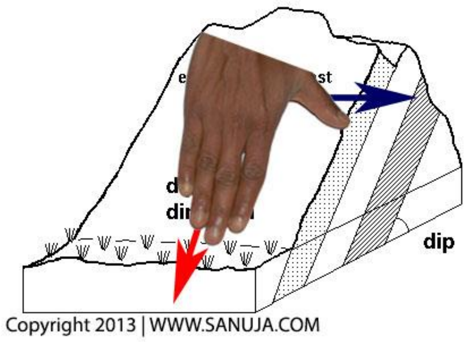


Figure 5.9 *The right-hand rule left method for measuring and recording dip and strike*. ***Figure 5.10*** *The righ-hand rule right*

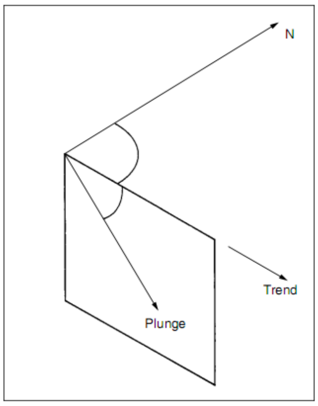
Whatever method you decide to use to record strike and dip on your field map, it is *your* field map and *you* will be replotting the information on your fair copy map at a later date. It is up to you to choose the methods which suit you best. However, remember that although the fair copy map is the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

5.4 Measuring Linear Features

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

5.4.1 Trend, plunge and pitch (or rake)

A lineation is defined in space by its ***trend*** (the bearing of an imaginary vertical plane passing through it) and by its inclination or ***plunge*** in that plane (Figure 5.11). 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** (Figure 5.12(a)). Provided the strike and dip of the surface have been measured, trend and plunge can then be calculated on a stereographic net. Log the angle of pitch in your notebook by the clockwise angle so that there is no ambiguity over its direction on the surface (Figure 5.12(b)). Pitch can be measured with a common **transparent protractor**, the bigger the better.



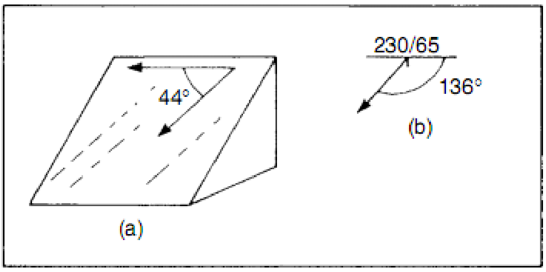


Figure 5.11 *The geometry of trend and plunge .*

Figure 5.12 *(a) Geometry of pitch on a lineated dip slope. (b) Record pitch in your notebook by a diagram; record its angle together with the strike and dip of the surface it lies on*

5.4.2 Measuring lineations

Although some lineations can be measured by their pitch on a surface, many must be measured directly with a compass. Sometimes this is simple, as in the case of the stretched conglomerate pebbles shown in Figure 5.13. All that needs to be done is to **stand above** the exposure and measure the trend vertically below. Plunge can then be measured by contact or by end-on methods. Direct measurements of trend and plunge can also be made for lineations on moderately dipping surfaces but, as surfaces become **steeper**, it is increasingly more **difficult** to measure trend accurately. Figure 5.14 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.

Figure 5.13 *Stretched conglomerate pebbles in SW Uganda; trend and plunge can be measured directly*

Figure 5.14 *Measuring lineation on a steep surface using a compass with a hinged lid*

5.5 Folds

Minor folds are quite **frequently seen** in outcrop; major folds seldom are except in the more arid countries. Minor folds can, however, often provide the key to the major folds they are related to. They reflect the same shape and **style**, **the direction in**

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

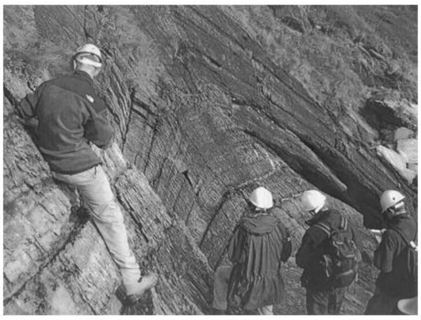


Figure 5.15 *A minor fold in Precambrian (Karagwe-Ankolean) sedimentary rocks in SW Uganda. The major antiform closes to the NE (to the right of the photograph).*
Figure 5.16 *Axial-plane cleavage in Devonikan slates at Combe Martin, North Devon. North is to the left of the photo*

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

Fleuty (1964) gives numerical values for terms defining the attitudes of folds; **1- Gentle greater than 120** ,2- **open (70-120)**, 3-**closed (30-70)**,4- **tight less than 30** and5**- isoclinals 0**.

5.5.1 Folds with axial plane cleavage

Cleavages and other foliations formed during the folding of rocks usually adopt a special orientation in relation to the associated folds. **Cleavage** has an orientation **approximately parallel** to the axial plane of the fold and this is a useful tool when mapping fold structures; it uses the relative orientations of bedding and cleavage (Figure 5.16). At outcrops where both bedding and cleavage can be seen, 1-make a field notebook sketch of their dips (Figure 5.17). 2-Hold the notebook up to the outcrop and rotate it until the cleavage appears to be vertical. 3-When this is done, the dip direction of the bedding in the rotated drawing indicates the direction in which the nearest synform is to be found. For example, if the rotated bedding dips to the east, the nearest synform is located to the east of the exposure. If such observations are made repeatedly across an area and recorded on the map, large-scale antiforms and synforms can be mapped out.

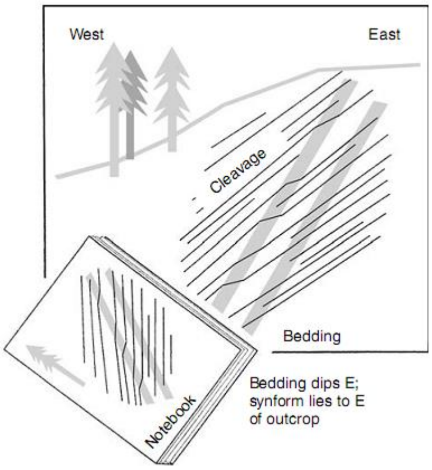


***Figure 5.17** Mapping out fold structures from cleavage and bedding; make a notebook sketch of the dip, hold it up to the outcrop and rotate until the cleavage appears to be vertical; the dip direction of the bedding now indicates the direction of the nearest synform.*

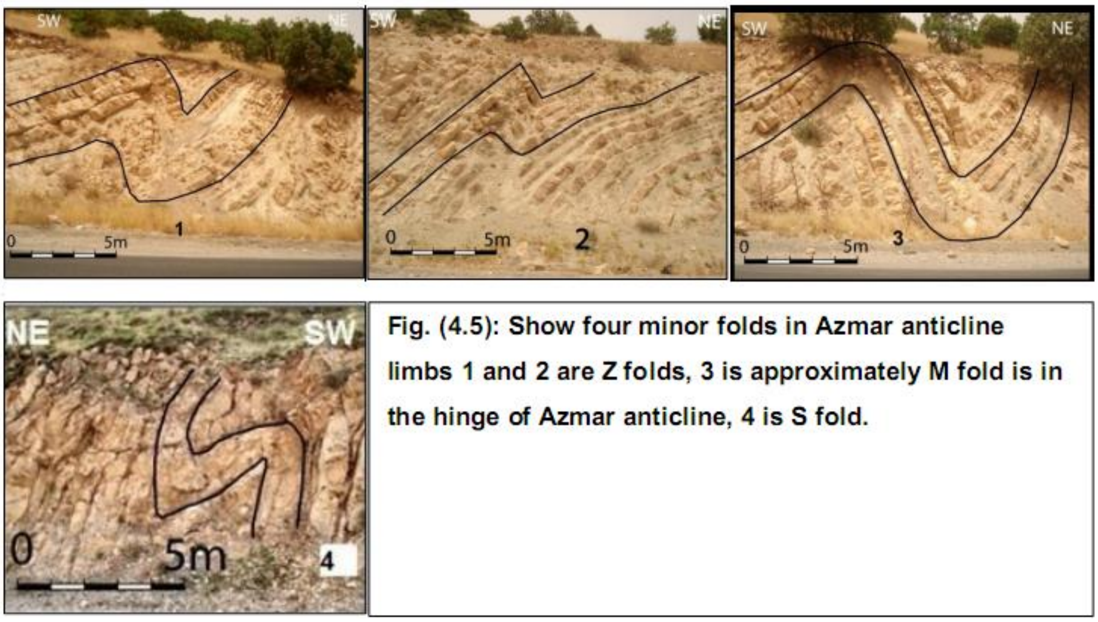
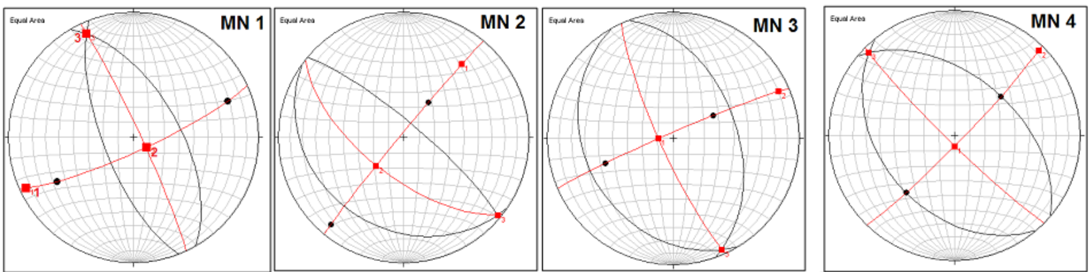


Fig. 5.18Shows four minor folds in Azmar anticline



Minor fold (1)
Formation: Balambo
Major fold: Azmar
Fold axis: Trend 336° Plunge 10°
Axial plane: 336°/86°
First limb attitude: 330°/60°
Second limb attitude: 159°/70°
Interlimb angle: 50°
Fleuty: Close
Ramsay: ----------------
Relation with Major fold: [illegible]

Minor fold (2)
Formation: Balambo
Major fold: Azmar
Fold axis: Trend 130° , Plunge 02 °
Axial plane: 128°/64°
First limb attitude: 125°/28°
Second limb attitude: 310°/80°
Interlimb angle: 72°
Fleuty: Open
Ramsay: Class (1. B).
Relation with major fold: Sub congruous

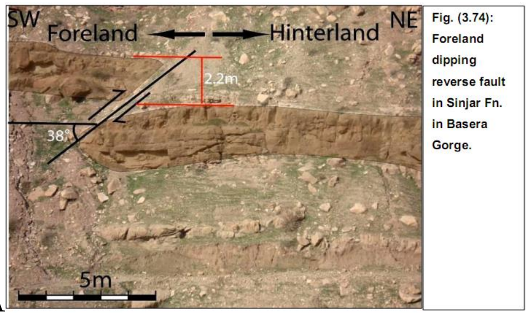
Minor Fold (3)
Formation: Balambo
Major fold: Azmar
Fold axis: Trend 157° , Plunge 04°
Axial plane: 156°/81°
First limb attitude: 150°/30°
Second limb attitude: 340°/48°
Interlimb angle: 102°
Fleuty: Open
Ramsay: Class: 1B
Relation with major fold: congruous

Minor fold (4)
Formation: Balambo
Major fold: Azmar
Fold axis: Trend 314° , Plunge 05°
Axial plane: 135°/85°
First limb attitude: 310°/50°
Second limb attitude: 140°/40°
Interlimb angle: 90°
Fleuty: Open
Ramsay: Class (1.B)
Relation with Major fold: Subcongruous

Fig.19.*Shows the projections of the fourth minor folds, **Right-hand rule right** method have been used.*

5.6 Faults

Most smaller faults never get mapped because they are never seen. Many have such small displacements that it matters little if they are individually missed, but record those you do see in your notebook to help you to establish a fracture pattern. Major faults are more likely to be found, but even those with displacements of tens of metres may be missed where exposures are poor. Compare the multiplicity of faults on a coal field geological map with a map from a non-coalbearing area. The ground is probably just as faulted on both maps, but in the coal field the faults have been detected underground and projected to the surface. Many faults have to be mapped by inference. **Suspect a fault**: 1-where there are unaccountable changes in lithology; 2-where sequences are repeated; 3-where strikes of specific beds cannot be projected to the next exposure; 4- where rocks suddenly become flaggy with joint spacing suddenly decreasing to a few centimetres. Topography is often a good guide. Faults may result in **1- spring lines, 2-boggy hollows, 3-seepages, in semi-arid countries 4- a line of taller greener trees**, flanked by lower flat-topped acacia. However, beware; although most fault zones erode a little faster than the adjacent rocks, to form longitudinal depressions, some faults in limestones may form low ridges owing to slight silicification which helps to resist erosion. Faults are most easily traced on aerial photographs, where the vertical exaggeration of topography seen under a stereoscope accentuates those minor linear features called *lineaments*, features often difficult to find on the ground; many of them are probably faults.

A


B


Fig.5.20. *ShowsA- reverse fault in Sinjar Formation, B, normal fault*

The **sense of displacement** of a fault, that is, distinguishing the downthrown side, may become evident only by noting the **different stratigraphy** on each side of a fault, in addition to the **flexure of strata** which indicate normal displacement, Fig.5.20A, B, &C. In textbooks much is made of **slickensides**, and if they are seen they should be noted, but do not put too much faith in them, they merely reflect the **last phase** of movement Fig.5.21A and B. Most faults have moved **several times**, although not always in the same direction. Note also that faults may have a thickness wide enough to show on your map. Faults may also be **breccia or gouge filled**, or even **mineralised**, perhaps with **calcite** or even **fluorite**. Note such facts in your notebook.

Fig.5.20.C shows the flexure of the beds at normal fault plane.

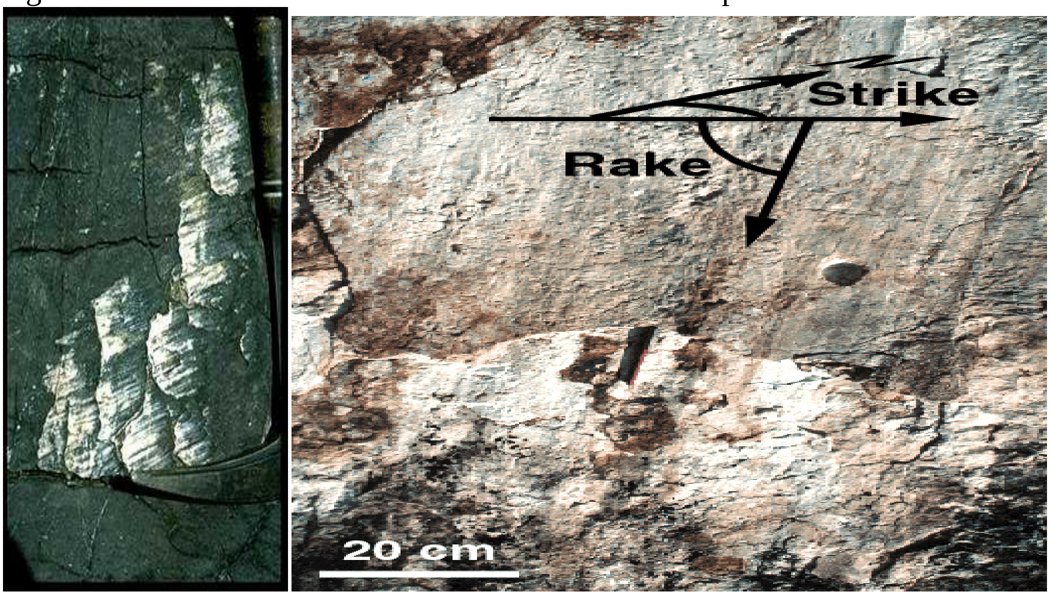


Fig. 5.21 A *Slickenside on fault plane show dextral normal displacement.**B .**Show the strike of the fault and the rake*

A

B

C

Fig. 5.20 shows fault surfaces, A, crushing surface in normal fault, B, mineral slicken side surface, C horizontal striation in strike slip fault.

5.7 Thrusts and Unconformities

Thrusts and unconformities are treated here together because one can easily be mistaken for the other. **Large thrusts** are usually obvious, with older rocks overlying younger ones; but not all thrusts show such a clear relationship. Sometimes thrusting may be discovered only by unexpected changes in stratigraphy. If the thrust surface is not properly exposed, the upper and the lower ‘plates’ may show no angular conformity with their expected positions, or the thrust surface may show complete disregard for the stratigraphy of the upper plate. If the surface is exposed, the position should be clearer. The lower part of the upper plate should not show any of the sedimentary features you would expect in a stratigraphic unconformity Fig.5.22: there may be **shearing along the surface**, or there may be **mylonite**. Where mylonite does occur it may be thick enough to map as a formation in itself and form a useful **marker**. However not all thrusts are major thrusts. Some are merely reverse faults, others may form **imbricate zones**, consisting of numerous small **sub-parallel thrusts** associated with major thrusts, as in the Scottish Moine thrust zone. Such zones are marked by multiple repetitions of partial sequences which, if poorly exposed, are impossible to map completely. Sometimes the spacing between individual thrusts may be only a few metres, sometimes tens of metres Fig.5.23.

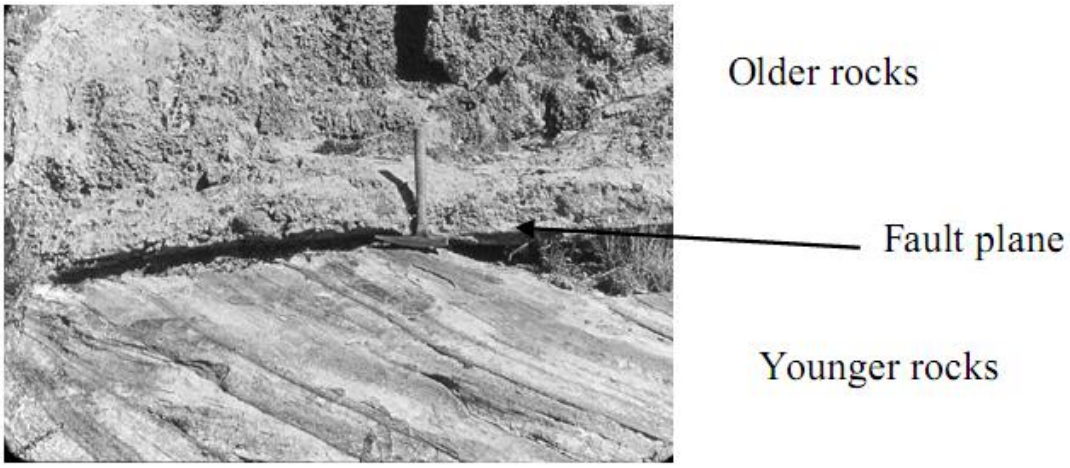


Fig.5.22.*Shows thrust fault*

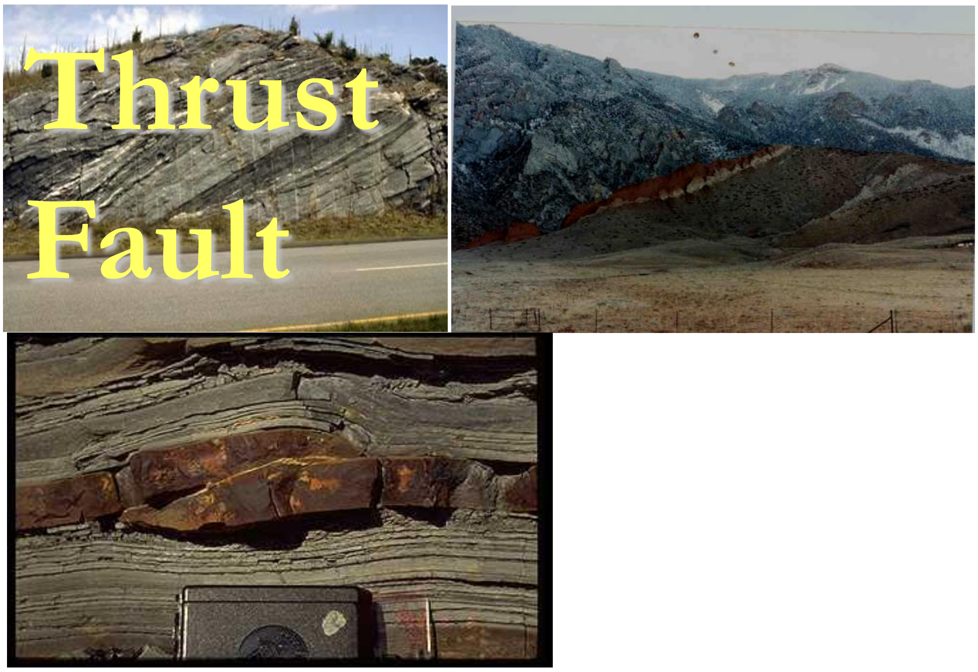


Fig5.23. *Shows thrust faults*

Stratigraphic unconformities show younger rocks lying on older rocks below, usually with angular unconformity between them (Figure 5.24). The rocks just above an unconformity should show features indicating that they were deposited on an already eroded surface, Unfortunately, this relationship is not always as clear as textbooks suggest, especially where rocks have been metamorphosed. Sometimes, to confuse matters, there is angular unconformity on both sides of the break if the later rocks were deposited on a sloping surface.

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

A  B 

Figure 5.24,*A,* *An unconformity at Sully Island, Glamorgan, South Wales; Triassic mudstones lie unconformably on Carboniferous Limestone, B, angular unconformity in Dokan Area North Iraq.*

5.8 Joints

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

Measure the strike and dip of joints in much the same way as bedding. Often their surfaces are uneven and contact methods unsuitable. Book readings in your notebook using the right-hand rule, or whatever your chosen notation is, and estimate where possible, the length and the spacing of joints in each set, and what formations each set penetrates. Master joints may show up well on aerial photographs, especially in limestone regions where they may be indicated by *karst* patterns and lines of sinkholes (*dolines*). Joint patterns on photographs can sometimes be used to distinguish one formation from another Fig.5.25.

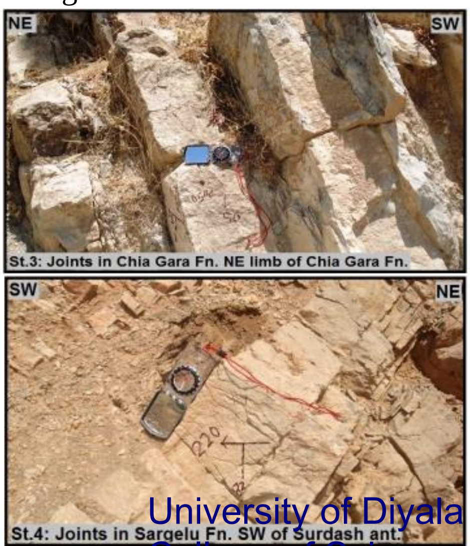
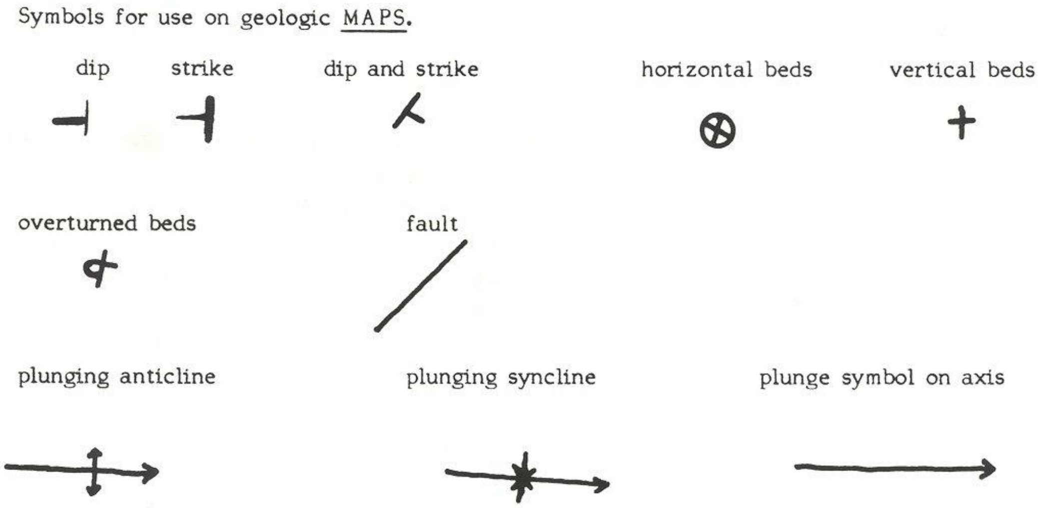


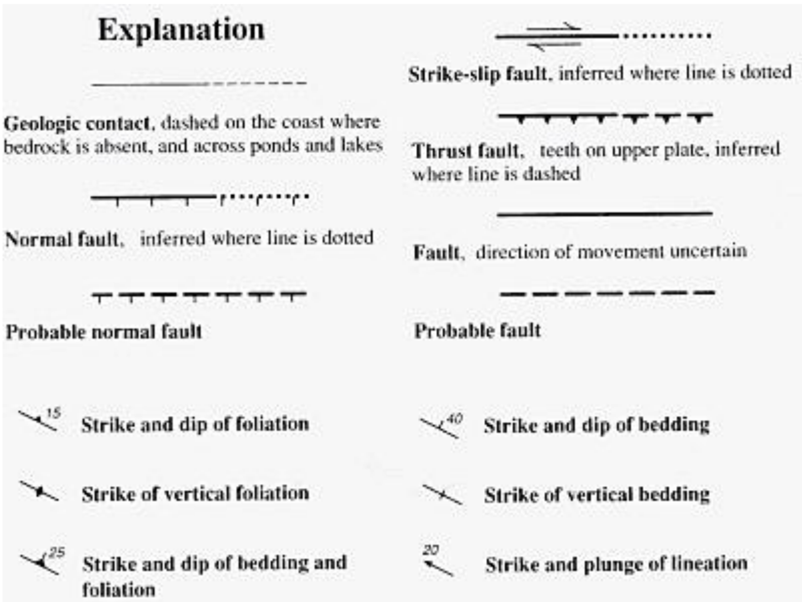
Fig.5.25. *Shows set of systematic joints*

5.9 Map Symbols

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

Note, a **strike line** is drawn on a map with its *centre* at the point where the reading was taken. **The point of a lineation arrow head** is the point where that reading was made. The exception is where several readings are made at one point: in that case the symbols radiate from the observation point Fig.5.26.





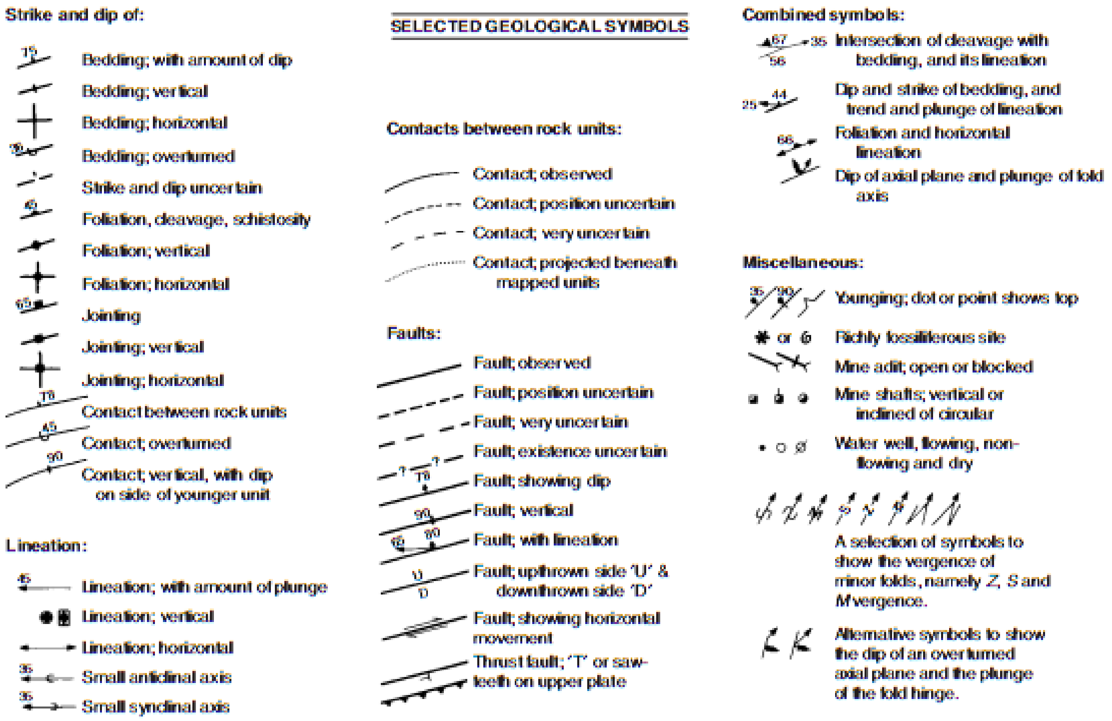


Fig. 5.26 *Shows map symbols*

5.10 Specimen Collecting

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

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

5.10.1 Marking specimens

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

5.10.2 Fossils

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

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

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

5.10.3 Booking specimens

Log specimens in your notebook **immediately** after you have collected them. Preferably, write the specimen numbers in the **left-hand margin** of the page so that their details can be relocated easily. If their numbers are written with **red** pencil, they can be even more easily distinguished from field observation numbers listed in the same column. Alternatively, if you are collecting large numbers of specimens, add a column to your notebook specifically for specimen numbers. In addition to logging specimens on the working pages of your notebook, register them with a brief description in a specific index at the back of your notebook too.

This avoids finding yourself with two almost identical specimens from different places with the same number, and no way to tell which is which. A register also helps you to ensure that you have collected specimens of everything you should have collected, and if you give it the notebook page numbers where they are more fully described, it acts as a handy ready-reference (Figure 5.27).

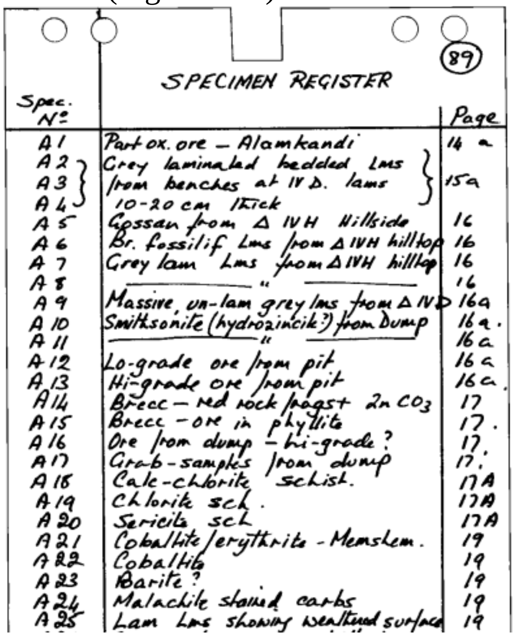


Figure 5.27 *A specimen register in a field notebook*

5.10.4 Shipping specimens

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

5.11 Field Photography

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

Whenever you take a photo, roughly sketch the scene in your notebook to show what to look for on the print, and the general direction in which the photo was taken, so that you can identify topographic features again later. Also mark each side of the notebook sketch with its direction, e.g. NW and SE, or WSW and ENE, etc. If there is room on your field slip, add an arrow pointing in the direction it was taken. When photographing rock exposures, provide a scale: for a large exposure, include a human; for a smaller exposure, include a hammer, compass, or any familiar object; for a close-up, use a scale. Do not use coins; they vary from country to country. Log in your notebook every picture taken and give it a number, and keep a register of photos in the back of your notebook (as for specimens) and for the same reason. Log photo numbers in coloured pencil, as with specimens, but of course in another colour. To keep track of photographs of exposures, make a device from two strips of perspex taped together, between which you can slip large-sized numbers (cut from a calendar) mounted on thin card, as in Figure 5.13. Add a scale to it; it also gives you a point to focus on, not always easy when photographing some rock surfaces. Use an ultra-violet filter with colour film when photographing at over 1500 m, or over sea and other large bodies of water, to eliminate the blue cast which such conditions cause. As a UV filter is virtually colourless, it can be left on all the time, wherever you are. If you are using black and white film for B/W photos to illustrate a report, a yellow filter gives better contrast in close-ups of granitoid rocks. Also remember that in some areas you may not see the prints of your photos for several weeks, or sometimes even months, so do keep good notes otherwise you may end scratching your head and wondering why on earth you ever took some photographs.

5.11.1 Digital cameras

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

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

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

5.12 Panning

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

Because of its density, native gold (SG 16.6–19.3 depending on purity) is easy to concentrate in a pan, but garnet and epidote (SG 3.2–4.3) are only a little denser than sand and rock debris (SG 2.7) and more skill is needed to concentrate them. A 30 cm diameter pan is sufficient for purely geological purposes. Keep it spotless and free from rust and grease, so do not use it as a camp frying pan. Collect *stream gravel* from the coarsest material you can find, for that is where the heavier minerals concentrate (Figure 5.28). Dig for it with a trowel or entrenching tool and get down to bedrock if possible. Collect *soils* from below the humus. Heap the pan full of material, then shake it vigorously underwater in a stream, or even in a tin bath. The finer heavies will pass down through the coarser light material, a process known to the mineral dresser as *jigging* (and this is what, with the constant movement of stream gravels, helps to concentrate the 'heavies' on bedrock). Larger pebbles can be scraped off the top and discarded. Gradually wash off the finer, lighter materials by: tilting the pan, dipping it into the water; lifting it out, swirling it around; dipping again; until only a small amount of usually darker and sand-size material is left. Then, using only a small amount of water, give a final careful swirl with the pan at an angle of about 30 to form a *tail* of sediment, graded with the 'heavies' at one end in order of their densities, leaving the lighter material at the other end (Figure 5.29). Now, under a cover of a little water, identify any minerals you can, using your hand lens. Wash the concentrates into a phial for future examination, using a plastic funnel and a camel-hair brush. Label it. Decant the surplus water back in camp. Panning is like fishing: you do not have to find anything to enjoy it.

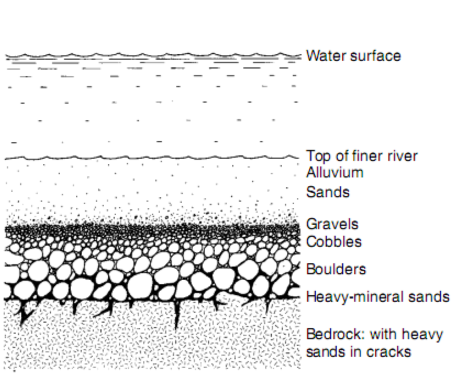


Figure 5.28 *A simplified profile through stream gravels; the heavy-mineral sands accumulate at the base of the coarser material and may even penetrate cracks in the bed rock. Note that the sands and gravels of the stream are in constant movement which allows the 'heavies' to pass downwards through them*
Figure 5.29 *A geologist panning in the Euphrates valley*

ROCKS, FOSSILS AND ORES

6.1 Rock Descriptions

When you have mapped a rock unit for long enough to be familiar with it and its variations, describe it fully and systematically in your notebook.

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

6.2 Identifying and Naming Rocks in the Field

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

6.2.1 Field names

A field name should be descriptive. It should say succinctly what the rock is, but you cannot name a rock until you have identified it. A field geologist should be able to determine the **texture**, **the relationship between minerals**, and **estimate their relative abundances in most rocks under a hand lens**. He should be able to distinguish **plagioclase** from **orthoclase**, and **augite** from **hornblende** in all but the finer-grained rocks. He should be able to give some sort of field name to any rock.

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

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

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

Broad scheme for the study of sedimentary rocks in the field.

1. Record details of the locality and succession by means of notes and sketches in the field notebook, and photos; if appropriate, make a graphic log; if rocks are folded, check way-up of strata.
2. Identify lithology by establishing mineralogy/composition of the rock.
3. Examine texture of the rock: grain-size, shape and roundness, sorting, fabric and colour.
4. Look for sedimentary structures on bedding planes and bed undersurfaces, and within beds.
5. Record the geometry of the sedimentary beds and units; determine the relationships between them and any packaging of beds/units or broad vertical grain-size/lithological/bed thickness changes; is the succession cyclic.
6. Search for fossils and note types present, modes of occurrence and preservation.
7. Measure all structures giving palaeocurrent directions.
8. Consider, perhaps at a later date, the lithofacies, cycles, sequences, depositional processes, environmental interpretations and palaeogeography.
9. Undertake laboratory work to confirm and extend field observations on rock composition/mineralogy, texture, structures, fossils, etc.; pursue other lines of enquiry such as the biostratigraphy, diagenesis and geochemistry of the sediments, and read the relevant literature, e.g. sedimentology/sedimentary petrology textbooks and appropriate journals.

6.3 Litho-stratigraphy and Sedimentary Rocks

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

supergroup
group
formation
member
bed

6.3.1 Sedimentary formations

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

A formation may consist of several *members*, which may not be continuous but have a distinct lithological character. The smallest division of a formation is a *bed*, which is a unit with a well-marked difference from the strata both above and below it. A *group* consists of two or more naturally related formations. A *supergroup* consists of two or more associated groups. Groups do not have to be collected into supergroups.

6.3.2 Stratigraphic sections

Stratigraphic sections *show the sequence of rocks in a mapped region, distinguishing and naming the formations and members that comprise them*.

They show the 1-thickness of the units, 2-the relationships between them, 3-any unconformities or breaks in succession, and 4-the fossils found. It is impossible to find one continuous exposure that will exhibit the complete succession of a region (even in the Grand Canyon) and a complete succession is built up from a number of overlapping partial sections. There may even be gaps where formations are incompletely exposed.

Sections can be measured in a number of different ways and some guidelines are given here. The **first task** is to find a suitable place with good exposure. Make measurements of the *true thicknesses* of the beds, starting at the *base* of the sequence, and log them in your notebook as a vertical column.

In measuring thickness, corrections must be made for the dip of the beds and the slope of the surface on which they crop out. This can be done graphically or trignometrically (Figure 6.1).

Indicate on the stratigraphical section the name and extent of every lithological unit, together with the rock types within it. Take specimens of everything logged. Mark and note the names of any fossils found; collect specimens for later identification where necessary. Note the position of every section on your field map. Redraw to scale in camp the sections from your notebook on squared paper. Later the section may be simplified and combined with sections from other parts of your mapping area as a columnar section or a fence diagram. Stratigraphic sections may also include igneous and metamorphic rocks.

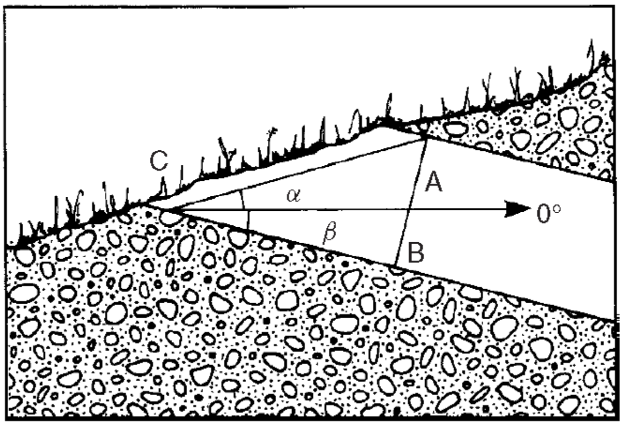


Figure 6.1 *Correcting for the true thickness of a bed. The stratigraphic thickness AB* = *AC* sin (α + β)

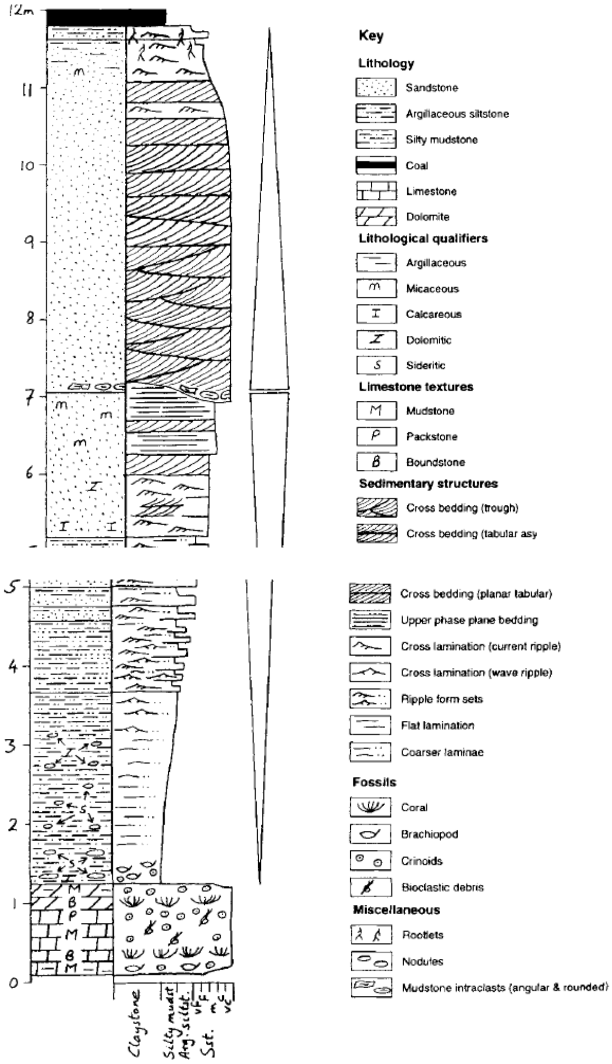


Figure 6.2 *A graphic sedimentary log. The horizontal scale is a measure of grain-size. Divisions are unequal because the* φ-*scale range for silt is only four fifths that for sand (see Appendix V). The vertical triangles to the right indicate coarsening and* fining in the sequence (from North Wales,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

6.3.3 Sedimentary (graphic) logs

Although there are similarities, sedimentary logs and stratigraphic sections differ in their purposes. Sedimentary logs are detailed graphic displays of the lithologies, sedimentary structures, and the fauna of a succession. The succession is broken down into homogeneous units termed *sedimentary facies* which contain distinctive combinations of features. The manner of deposition of a unit can be inferred from its facies, and the overall environment of deposition from its vertical and lateral variations. There are a number of conventions in recording logs. As with stratigraphic sections, the thickness of beds is shown to scale in a vertical column. However, in a sedimentary log there is also a horizontal scale: the width of the column is a measure of the grain size of each rock unit portrayed (Figure 6.2). Symbols are used to indicate a wide variety of sedimentary features, such as different forms of ripples, cross-bedding, rootlets and mud-flakes. So far no convention of symbols has been universally accepted. Devise your own in a form which makes them easy to understand.

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

6.3.4 Way-up of beds

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

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

Wherever there is evidence of way-up in such areas, note what it is, such as *c.b*, for cross-bedding, *r.m.* for ripple marks, *t.p.* for trumpet pipes, etc. That is all part of your field evidence Fig(6-3).

Fig.6-3 Sedimentary structures.

6.3.5 Grain sizes

Many sedimentary rocks can be classified by their grain size. Anything greater than 2 mm is gravel; anything less than 4 microns is mud; what lies between is sand or silt. Each of these groups is sub-divided into coarse, medium and fine, etc. (Table 4.2). Measure larger grains in the field with a transparent plastic scale placed over a freshly broken surface; use a handlens with the scale for the finer sizes. Generally, if a piece of rock is gritty between your teeth (no need to bite!), then silt is present, and if grains lodge between your teeth there is fine sand, but that should be visible under your handlense.

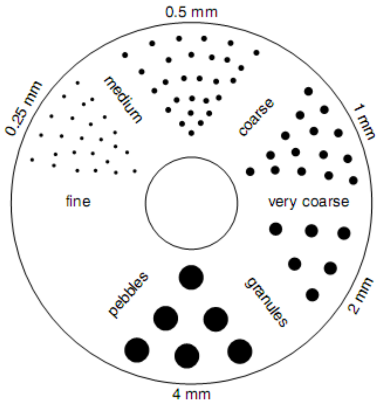


Table 4.2 Terms for grain-size classes (after J.A. Udden and C.K. Wentworth) and siliciclastic rock types. For sand–silt–clay mixtures and gravel–sand–mud mixtures see Fig. 3.1.

Size	Class	Rock type
	boulders	conglomerates (rounded clasts)
256 mm	cobbles	and
64	pebbles	breccias (angular clasts)
4	granules	
2 mm	v. coarse	SANDSTONE
1	coarse	
500 µm	SAND medium	
250	fine	
125	v. fine	
63 microns	v. coarse	MUDROCKS types: mudstone shale marl slate
32	coarse	
16	SILT SILTSTONE	
	medium	
8	fine	
4 microns	CLAY CLAYSTONE	

***Figure 6.1** Chart for estimating grain-size of sands: medium sand is 0.25 to 0.5 mm in diameter, coarse sand is 0.5 to 1 mm in diameter, etc. Place a small piece of the rock or some grains scraped off the rock in the central circle and use a hand-lens to compare and deduce the size.*

6.3.6 Smell

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

6.3.7 Hardness

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

6.3.8 Acid

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

6.4 Fossils

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

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

6.5 Phaneritic Igneous Rocks

Are igneous rocks with large, visible crystals because the rock formed slowly in an underground magma chamber.

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

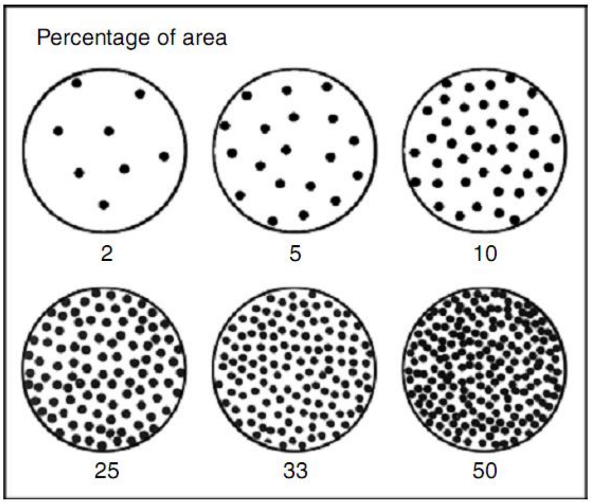
6.5.1 Grain-size in phaneritic rocks

Grain-size terminology in igneous rocks differs from that used for sediments, namely:
Coarse-grained >5mm, Medium-grained 1–5 mm, Fine-grained <1mm

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

6.5.2 Igneous mineralogy

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



6.6 Aphanitic Igneous Rocks

Are igneous rocks that form on the earth surface and have very fine-grained texture because the crystals are too small to see without magnification.

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

Table 6.1

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

6.7 Veins and Pegmatites

Quartz veins are common and should give no trouble in identification. Some are deposited by **hydrothermal solutions** along fractures and may show coarsely zoned structures and, sometimes, crystal lined vughs. Others have been formed by replacement of rock and may even show ‘ghosts’ of the replaced rock with structures still parallel to those in the walls. Some veins are clearly emplaced on faults and may enclose breccia fragments; some may contain barite and fluorspar and even sulphides. If pyrite is present, check for ore minerals (but see Figure 6.3). However, not all veins are quartz veins. Some contain calcite, dolomite, ankerite or siderite, or mixtures of them, and they may be mineralised too. Note, however, that veins do not necessarily have igneous associations.

Pegmatites always have igneous associations. They are usually, but not exclusively, of granitoid composition. Grain size may be from 10 mm upwards to over meter size (Figure 6.3). ‘Granite pegmatites’ fall into two main groups, *simple* and *complex*. Simple pegmatites are usually vein-like bodies consisting of coarse-textured quartz, microcline, albite, muscovite, sometimes biotite and, rarely, hornblende. Complex pegmatites can be huge, some may be tens of metres long, and often podlike in shape with several distinct zones of different composition around a core of massive quartz. They may be mineralised, with beryl, spodumene, large crystals of commercial muscovite, and various other micas, including zinnwaldite and lepidolite. They may also contain ore minerals such as cassiterite and sometimes rarer ore minerals, including columbite (niobite) and tantalite.

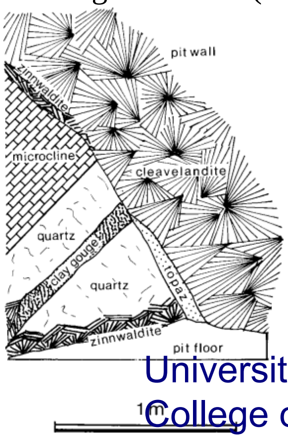


Figure 6.3 Part of a complex pegmatite in Buganda Province, Uganda, redrawn from a notebook sketch of the wall of a prospecting pit. Note the large radiating sheaves of 'cleavelandite' albite; the massive microcline; the granular topaz (not gem form); and large books of zinnwaldite, a lithium-bearing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

6.9 Pyroclastic Rocks

Are igneous rocks formed from consolidated fragments of cooling magma blown out of a volcano come in various shapes.

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

6.10 Metamorphic Rocks

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

6.10.1 Naming metamorphic rocks

Sedimentary rocks change with increasing metamorphism, first to1- slates, then to 2-phyllites, 3-schists and 4-gneisses. Igneous rocks deform and recrystallise to genisses or schists and many basic igneous rocks, including volcanics, become *amphibolites*.

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

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

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

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

Migmatites are, literally, mixed rocks. They contain mixtures of schistose, gneissose and igneous-looking material. Treat them in the same way as other gneisses: name them for composition, texture and structure. For all these rocks, measure the dips and strikes of foliation and the direction and amount of plunge of any minor folds .