ROYAL HOLLOWAY UNIVERSITY OF LONDON

Department of Earth Sciences

Fieldwork Techniques Handbook

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FIELDWORK TECHNIQUES HANDBOOK

CONTENTS

INTRODUCTION

Fieldwork is the best part of Geology and is an essential part of your training. It tests your motivation and initiative as well as the knowledge and skills you have learned in lectures and practical classes. Depending on your degree programme you can expect to spend up to about a hundred days in the field, culminating in a period of independent geological mapping. The intention of this handbook is to bring together instruction hand-out sheets from various field courses. **The Fieldwork Techniques Handbook should be taken on every field course** as some part of it is sure to be relevant.

The main skills of the geologist in the field are systematic observation and accurate recording of field data. Though fieldwork is undertaken for a variety of purposes, and the appropriate techniques may be different, the advice is the same — collect as much information as you can while you are in the field and record it as clearly and as neatly as possible. Remember that you may not know, when you are collecting field data, which observations will be critical to your interpretation or report so collect a lot of data. Since you will have to use your field observations your record has to be clear and since an important part of the marking of your fieldwork is assessment of your field records they have to be intelligible to someone else.

Attendance. As fieldwork is an essential part of your training **you must attend all the required field courses**. Exemption is normally only permitted for medical or compassionate reasons. Absence from fieldwork may affect your completion of individual courses.

Equipment The equipment needed to undertake fieldwork comes under three headings. **The items which you must carry for your safety or for use in an emergency are listed both in the section on Safety in this handbook (page 3)** and in the Department of Earth Sciences Student Safety Handbook. What you should wear so that you can undertake fieldwork safely and in comfort is also covered in this handbook (page 6). The following items are the basic 'tools of the trade' for the geology student and should be taken on every field course, unless directed otherwise:

Yellow field notebook

hand lens	**hammer**
compass-clinometer	**hard-backed notebook**
indian-ink mapping pen	**coloured pencils**

pencils (preferably including a propelling pencil with a 0.5mm HB lead)
a map case or other means of keeping your notebook and field-sheets dry and accessible

Health Fieldwork can be quite strenuous and weather conditions may be a little less than ideal at times so you should be properly equipped and reasonably fit. If you have any medical condition or disability which may affect your participation or special requirements such as diet you must tell the Departmental Office so that due consideration can be taken or alternative arrangements made. All information given will be kept strictly confidential.

Standards of behaviour While you are doing fieldwork you are a representative for Geology in general and of the College in particular. Your conduct can affect not only your ability to carry out the fieldwork but may influence how geologists are regarded for years to come in the field area. A good standard of behaviour is therefore expected in the field, in the accommodation and during your social activities. Any problems with behaviour on field courses are dealt with under the College Disciplinary Code and the course leaders have the authority of the College to dismiss a student from the course.

In the field you should obey the countryside code
e.g. http://www.countrysideaccess.gov.uk/

Get permission for access to enclosed land, use gates and stiles rather than climbing over fences or walls, do no more hammering than you have to and avoid spreading rock chips round the site, and try to leave no trace of your visit. Take only field information, leave only footprints!

Your accommodation may range from hostels through to hotels and you are likely to have to share with others. Be very careful not to cause any damage as your hammer and any rock specimens are hard and will easily scratch furniture. Your wet field kit can dirty bedding and carpets. Boots must not be worn indoors. Use the nearest bin for your rubbish and do not allow this to build up in bedrooms. Act with consideration for others who may be staying in the same place, both your fellow students and other residents. The main problem is likely to be noise so keep things quiet when near sleeping accommodation, especially if there are likely to be children asleep. Spontaneous, late-night, 'get-togethers' in bedrooms can easily cause disturbance and resentment, and should be avoided. As a general rule you should be quiet after midnight unless you are in specific places designated for socialising. You can expect to pay for any damage you cause.

In your leisure time it is very easy to get carried away as part of a crowd. So act responsibly as an individual regardless of what the crowd is doing. By all means drink, but do not get drunk as this may make you lose control of yourself. Remember being drunk is no excuse for your conduct. Avoid any sort of disagreement or conflict with local residents who may feel you are infringing on their territory, especially when abroad.

Jürgen Adam
Head of Department of Earth Sciences

SAFETY IN THE FIELD

Geological fieldwork is an activity involving some inherent risks, because it is often undertaken in remote areas or rugged terrains, or in quarries or mines. In addition, severe weather conditions are likely to be encountered in all seasons. However, by taking reasonable precautions it is possible to reduce the risks to an acceptable level.

It is the statutory duty of the Department to ensure that fieldwork and any visits are undertaken in a safe manner. Thus staff leaders of field trips will outline the likely hazards associated with a particular field trip, and any necessary precautions you should take. It is imperative that individuals cooperate by following these guidelines, and act responsibly during fieldwork in order to minimise the risk of accidents. **Because of the legal implications it is important to stress that any individual not conforming with the instructions given by staff members will be barred from a field trip**.

There are some particularly important points regarding safety in the field that need to be stressed. Further detailed advice is given in the **Department of Earth Sciences Student Safety Handbook,** which every student should read.

1. You **must** possess your own **whistle, safety helmet, safety glasses, first aid kit,** and **emergency blanket,** and these should be carried **at all times**. Helmets, preferably with a chinstrap, must be worn whenever there is a danger of falling objects/rocks, and when instructed to do so by someone in authority. Glasses must be worn when hammering rocks. **Never** use a hammer as a chisel, and do not hammer near others.

2. Always stay with the party and obey all instructions. Do not climb any rock faces or enter any workings unless properly supervised. Never roll rocks down steep slopes or try to slide down slopes.

3. Report any injury, illness, or harassment immediately. Do not try to achieve more than you can physically manage.

4. Wear adequate clothing, bearing in mind the possibility of changing weather conditions (see below). Boots must be adequate, with good tread. Note that they also provide protection from snake bites, especially to ankles.

5. Although the College may be legally liable in cases of negligence, you and your belongings are not automatically insured on field trips.

A briefing meeting will be held before each major field course at which you will be informed of the potential hazards, e.g. the terrain, weather conditions and other dangers, in addition to other arrangements for the field course. Attention will be drawn to special equipment or precautions that will have to be taken. Notice of the times of such briefings will be posted on the notice board and **all participants <u>must</u> attend.**

In cases of ***independent fieldwork*** it is imperative that careful consideration is given to safety matters well before the work is started. A **risk assessment** must be completed with the supervising staff member. Plan the work carefully and make arrangements for possible emergencies. In remote or rugged areas try to carry out the work in the company of a colleague. Pay particular attention to the terrain covered, weather conditions, and tides.

A useful first aid book is the **Outward Bound Wilderness First Aid Handbook** published by Ward Lock, London. This book is intended for those taking part in outdoor pursuits and gives advice on coping with accidents when help may be far away.

CONSERVATION OF GEOLOGICAL SITES

Fieldwork is one of the most enjoyable parts of Geology, although it may not seem that way on a chilly, wet afternoon when you are tired, hungry and cold. To get the best out of fieldwork you need to find the best exposures, examine them carefully and record your observations so that you (and others!) can understand and interpret the notes subsequently.

There has been increasing pressure on many of the best and most interesting exposures and areas both in the United Kingdom and elsewhere in Europe. In short, too many geologists are visiting the best areas and exposures and causing too much damage. As a result an increasing number of landowners are reluctant to allow geologists onto their land and formerly good exposures have been spoiled. It is essential that your behaviour in the field conserves the best exposures and maintains access to classic areas for future students and geologists.

Considerate behaviour in the field

Access to the rocks is the first essential for successful fieldwork, whether you are in an organised party or on your own doing your independent mapping. Access to private land is a privilege so it is vital not to antagonise local landowners or farmers.

Permission must always be sought before you go onto private land. It is usually best to chat to the landowner, explain where you are from, what you are trying to do and why you need to get onto each particular piece of land. If you are allowed on to ground, but restrictions such as ‘no hammering’ or ‘stay out of this or that field’ are imposed, accept and observe them rigorously. Do not ignore the conditions as soon as you are out of sight of the farm; it is quite probable that they will keep an eye on you. If you are refused access you have no option but to accept the refusal with good grace and remember that the landowner is completely within his rights. Remaining polite may get you or other geologists access at some future date.

Once allowed onto land act considerately and obey the Countryside Code.

Don’t touch any farm machinery.

Leave no litter.

Keep to footpaths where possible, particularly if you are in a large group, as it easy to trample a broad swathe across grazing or crops. Walk round fields with crops growing and if you have to visit exposures surrounded by crops use the shortest route.

Do not climb walls or fences but use gates or stiles and remember to close all gates after you.

Avoid any unnecessary disturbance to wildlife and wild flowers and do not try to attract the attention of livestock. Mooing at a few inoffensive cows might bring you to the attention of a jealous and hostile bull!

Conservation of exposures

Observe all local byelaws or other restrictions with regard to collecting and hammering and under no circumstances should you damage protected sites.

Hammering is hazardous, both to yourself and to your companions. Many exposures will show traces of previous activity by geologists so there are likely to be fresh surfaces available for observation. Hammer only if you cannot examine the rock properly or have a genuine need to collect material.

Keep collecting of *in situ* rocks, minerals and fossils to a minimum, particularly if you are in a large party. There is usually sufficient broken material, fallen blocks or scree from which you may add to your collection. While you are mapping you have to document as many exposures as possible in your area, identify the rock types and minerals and find fossils if they are present. All this makes hammering more necessary, but do it judiciously.

If possible hammer inconspicuous parts of an exposure as a large area of fresh rock on a well-weathered exposure can look unsightly. Any hammering, whether of exposures or loose blocks, leaves sharp fragments of rock that can be hazardous both to livestock and to subsequent visitors. Tidy up after yourself by gathering the broken rock and leaving fragments where they will cause no harm. Collecting material for geochemical analysis often requires the breaking of considerable quantities of rock to yield a sample unaffected by weathering, so clearing up afterwards is all the more important.

Never collect material from walls or buildings, however good the specimen seems to be, or from places where such structures may be undermined.

Even when you are exercising iron self-control it is quite likely that you will collect more rocks than you need. This becomes more apparent when you are walking back as your rucksack feels heavier and heavier. At the end of a day in the field or at the end of the field trip you may wish to reconsider your collection and discard rock fragments or specimens dispose of them carefully. Do not drop them indiscriminately in fields or on roads where they may harm livestock or road users.

Do not disfigure exposures either by painting symbols to show location of critical spots or with any graffiti. Strangely enough most people do not want to read who has been here. Which institution such vandals attend may be of more interest to the reader, but does not reflect very well on the College.

The Geologists' Association has prepared a detailed **Geological Fieldwork Code** that covers appropriate conduct in a range of geological fieldwork activities.
http://www.geolsoc.org.uk/page2542.html

CLOTHING AND FOOTWEAR FOR FIELDWORK

For your safety and comfort in the field it is essential that you are properly equipped with clothing which will ensure that you remain dry and warm in wet and cold weather, and have footwear which will give you support and a good grip and stay comfortable all day as well as day after day.

Such gear is expensive and you should look to build up your equipment during your course at Royal Holloway. You will need:

Boots A good, waterproof pair of boots that are properly broken in. These should give your ankles support and be comfortable to wear. Leather or Goretex boots are suitable but must be well maintained. Wearing two pairs of socks helps to reduce the danger of blisters. Make sure your boots have adequate tread on the sole to prevent slipping on surfaces such as wet grass.
Snakes: Note that unless you are mapping in Ireland or the Arctic, geologists are at risk from snakes. Boots are your first and best protection, as snakes are very likely to strike at your ankles or unprotected feet.

Trousers Avoid wearing jeans unless dry weather is assured as they give no insulation and become heavy when soaked. In addition they dry very slowly. Thin cotton trousers give little insulation when wet, but dry quickly. For cold conditions, thicker wool/synthetic fibre trousers are better. In tick-infested areas wear pale-coloured trousers so that ticks can be spotted and removed before they attach to skin.

Shirts A thick working shirt, with pockets, can be worn over a T-shirt and sweat shirt.

Sweaters A thick woollen jersey should be kept in reserve in a polythene bag in your rucksack as well as any sweater you need to wear.

Jacket A waterproof anorak made of Goretex or similar fabric is ideal but expensive. A fleece jacket that can be used with a waterproof cagoule is cheaper. In very cold conditions a fleece will be necessary underneath your anorak.

Hat A warm, woolly hat is valuable as much heat is lost from the head in cold weather. For fieldwork in hot areas a sunhat is needed.

Waterproofs In addition to a waterproof anorak or cagoule you are likely to need waterproof trousers (if you are wearing jeans, waterproof trousers are **essential**) and/or waterproof gaiters. Waterproof gloves or mitts are essential as warm hands make you feel better and allow you to continue making notes in the cold.

Rucksack A field rucksack is essential. This should be big enough (around 30 litres) to hold the emergency equipment, which you must carry at all times in the field as well as your reserve clothing, field equipment and food and drink. If it is not waterproof the items carried should be in polythene bags.

Safety It is essential that you are properly equipped and clothed during fieldwork. Inadequate clothing or equipment compromises the safety of yourself and the field party and you may be forbidden to undertake fieldwork if you are not adequately equipped. Although this list concentrates on clothing required for cold weather to prevent hypothermia, fieldwork in hot areas brings other problems. Light clothing is necessary and it is essential to avoid excessive exposure causing painful sunburn or sunstroke. Sufficient water must be carried and sunbathing avoided. In addition, high altitude areas are often very warm when the sun is shining but, during and after rain, can be cold particularly if you are wet. So in areas like the Provencal Alps and Spain you must still carry waterproofs and warm clothing ALL THE TIME.

KEEPING A FIELD NOTEBOOK

Layout

An essential part of your field record is your notebook. The data will be used as the basis for interpretation. Your notebook needs to record what you did each day, recorded at the time, and include all your observations.

There is no absolute in recording field data. The aim is to produce a record of your observations that will be legible, understandable and useful to you and to others long after you return from the field. You will forget things that may seem obvious in the field if you do not record them. You need to be able to provide the evidence upon which your later interpretations are based.

Although there is no definite right and wrong, and you will need to adapt to different conditions, the notes below provide guidance. You will not be penalised if you produce a good field record in a different, clear and organised way but consider this advice seriously before disregarding it. Another geologist should be able to take your field notebooks and maps, see where and what you have been working on and be able to reproduce your observations.

The department advises you to follow these guidelines:

Use a hard-backed notebook with high visibility cover (eg. those available from the online store).

You should make a considerable effort to maintain a neat record. The notebook should be clearly organised and arranged.

Number all the pages. Put your name and contact details on the front leaf!

Rule off a column, about 1 cm wide, at the left hand edge of each page in which you can record your locality numbers.

Rule off a column, about 2 cm wide, at the right hand edge of each page in which information such as strikes and dips, photograph numbers or sample numbers can be recorded.

Start each new day in the field on a new page with the day and date. Give a few sentences to indicate your targets and working area for the day.

Information that cannot be plotted on the field-slips must be recorded in your field notebook and a reference number put on the field-slip.

Exposures described in your notebook must have a grid reference to indicate where to find it on the field-slip. You do not need to give grid reference for each outcrop, but there need to be enough grid references for each day so that another person can follow your route. For mapping there should be a grid reference for each location in your notebook.

Do not waste time re-writing or inking over notes made earlier. You should choose a medium that is durable, such as indian ink or pencil, and be prepared for mistakes to be made. 01 or 02 Pilot Drawing pens are waterproof, cheap and ideal. Avoid ballpoint or felt-tip pens.

The notebook can be used for detailed sketch-maps, for sketches of features and scenery as well as for written notes (if you take photographs, always make a sketch of the thing photographed with essential information such as co-ordinates, direction of view and scale in your notebook — it is very easy to forget where and why photographs were taken).

Don't be afraid to think into your notebook and sketch out, for example, alternative interpretations, or summarise the information that might distinguish between different explanations of an observation. These records will be useful when you come to write your report. Make sure that you indicate clearly what is observation and what is interpretation.

Review your progress most evenings, and certainly every few days, in your notebook. Such reviews are very helpful when you come to write reports but they are also invaluable aids to identifying what you know and what you need to find out.

You may have some information that is not recorded in your notebooks and on your maps. This could include such things as stereo-plots, logged sections, and sketch cross-sections. Look after these and hand them in with your notebooks.

Additional information that you collect may include:

- completed logged sections of as many of your mapping units as possible
- palaeontological information
- palaeocurrent information
- additional structural information (e.g. orientation of minor fold axes, faults, etc).

It is difficult to decide which data will be critical to your interpretation of the geology of your area while you are in the field so collect as much information as you possibly can.

Checklist for recording information in your field notebook

1. Location An eight figure grid reference should be recorded. A description of the position of the exposure and a sketch map may be needed.

2. Lithology
Colour What is the colour of the rock? Is there a difference between the colours of the weathered and fresh surfaces?
Grain sizes Record the range of sizes present.
Minerals present Identify the main minerals present in the rock.
Texture Record the texture of the rock – interlocking grains, mineral alignment.
Rock type Identify the rock type or types present. If a sample is collected it should be numbered and the number recorded in the field notebook. Describe any peculiarities or characteristics of the rocks.

3. Sedimentary structures
Record the dip and strike of the bedding at least once
Bedding Are the bedding planes evenly spaced or not. Is the rock thinly or thickly bedded? Are the bedding surfaces planar or undulating or irregular?
Other sedimentary structures Describe any other sedimentary structures, e.g. cross-bedding, channels, ripples, sole-markings, concretions, etc., which may be present. Sketch these features. Record the dips and strikes of cross-bedding and the trends and plunges of linear structures.

4. Tectonic structures
Foliation Record the dip and strike of planar fabrics such as schistosity or banding of gneiss or mylonite. Describe the foliation, e.g. composition, thickness.
Cleavage Record the dip and strike of slaty or fracture cleavage. Note whether it is present in specific lithologies, and how pervasive it is. Relationship to known folds?

Joints & Fractures Record the dips and strikes. Annotate directly on a sketch if necessary. Try to classify fracture sets in the field, and record intersection relations.
Faults Record dip and strike and direction and amount of movement. Sketch the fault and record any associated fault rocks, folds, and damage zone.
Folds Sketch the folding and record the trend and plunge of fold axes and the strike and dip of the fold axial surface. Describe the geometry of the fold. Remember that outcrop-scale folds give clues about the geometry and orientation of large-scale folds
Lineation Record the trend and plunge of lineations such as cleavage– bedding intersections,preferred orientation of elongate minerals or mylonitic lineations.
Other minor structures Note the presence of any other structures such as tension gashes, slickensides, etc., and the direction of movement implied.

5. Junctions Many exposures have more than one rock type present. Note the distribution of the rock types in the exposure and the nature and orientation of the junctions.

6. Fossils Note whether they are abundant or rare; one species or many; body or trace fossils. Make a preliminary identification if possible. Sketch and collect numbered specimens for further laboratory investigations.

7. Other Note any other obvious features, e.g. mineralisation, relationships of different rock types to each other, etc. Note any reason why your observations may have been compromised – for example, heavy rain, low sun, rising tide.

8. Sketches As well as sketching individual features larger scale sketches illustrating the structure of the rocks or relating the geology to topography are necessary. All sketches must have a scale and be fully labelled. Note the subject of the sketch in case visual representation is unclear. Landscape sketches should have the direction of viewing. Photographs also can be used. The subject of each photograph should be noted in the field notebook with the direction of viewing and a rough sketch may be made to assist annotation of the photo later. Make quick sketch maps and cross sections at all scales whilst on the outcrop to help understand structural relationships.

Until you have developed a routine of examining rocks in the field you should copy this list into your field notebook as a reminder of features to look for and measure.

FINDING YOUR POSITION

You should be able to locate your position on a map or plan to within 1mm, whatever the scale being used. This means that when mapping on the scale of 1:10,000 you should be able to fix your position to within 10m on the ground or when trying to find localities visited during a field course, using a 1:50,000 map, to within 50m. The more accurately you can find your position the more reliable will be the field sheet and map you produce so it is vital to develop the necessary skills.

Base maps vary considerably in quality. Where they are very poor the geologist may have to spend time surveying the position of prominent points to work from. Other base maps may have been enlarged from 1:50,000 or 1:25,000 maps and may therefore lack detail. British Ordnance Survey 1:10,000 maps are generally reliable but even here there may be the odd error. Aerial photographs may be used for mapping both to complement base maps and also where published maps are not available.

The two major techniques available to you are measurement of direction using the compass and measurement of distance by pacing.

Pacing

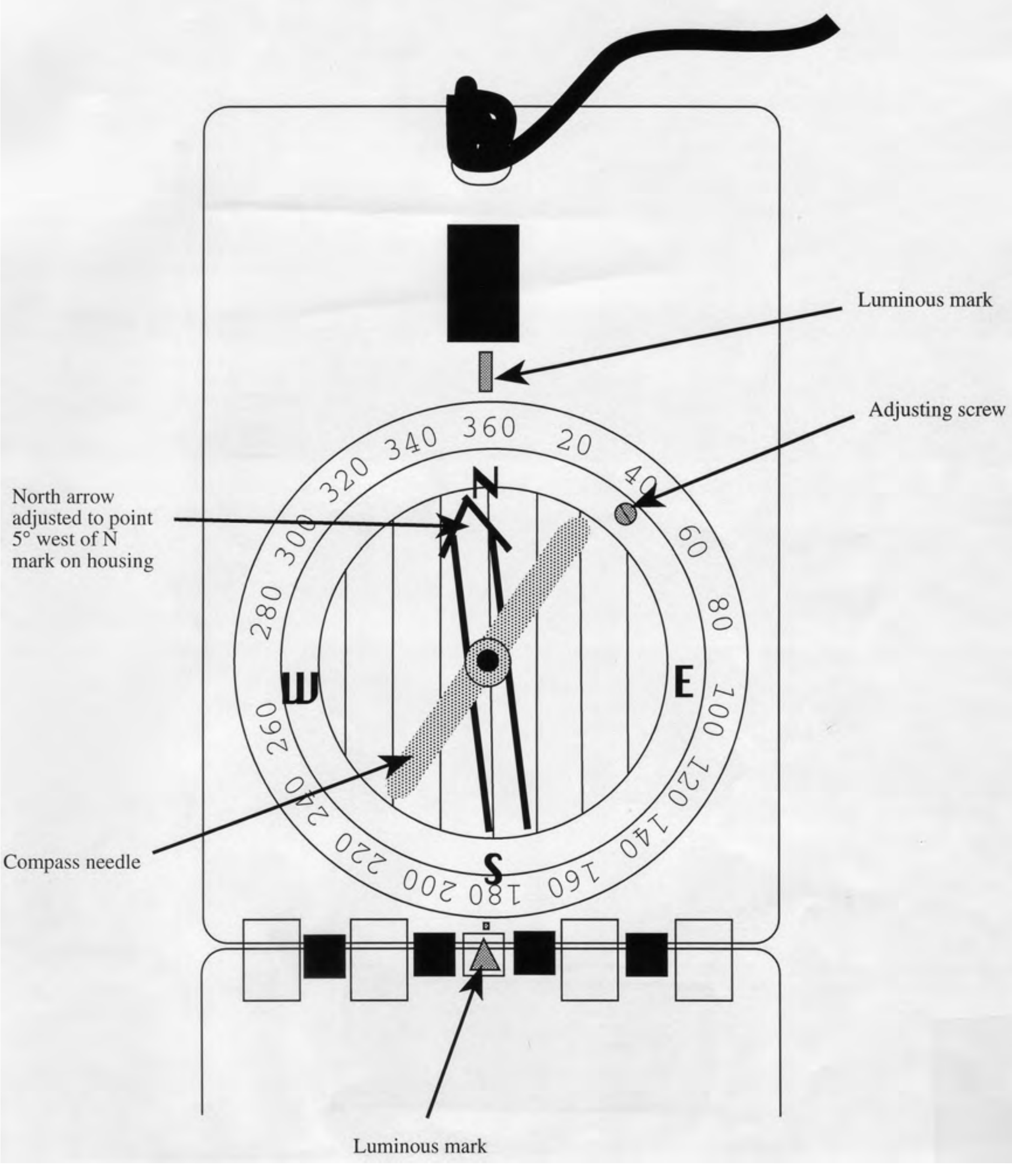
You should know the length of your pace over a variety of surfaces and gradients and with practice you should be able to estimate distances by pacing with an error <3%. So on a 1:10,000 map you should be able to pace a maximum of 300m and still remain within the 1mm on the map.
Pace length will shorten over rough ground and on a gradient so it should be checked on typical ground in the field area. Either tape out a 200m course or find a traverse between mapped points 100 - 300m apart and pace the distance twice in each direction and count double paces as this will reduce the risk of miscounting. Use a comfortable pace — not too short, nor too long — and do not try to pace whole numbers of metres. Calculate the length of your pace and a conversion table can be prepared for use in the field, avoiding the need for field mental arithmetic.

Using the compass

You will use a Silva compass-clinometer for your fieldwork. The Silva compass is light, easy to use, reasonably accurate, fairly cheap and it can be adjusted so that bearings you take can be plotted directly onto your map. A diagram of the Silva compass is shown on the following page.
Adjusting the compass for magnetic variation: the compass needle indicates magnetic north, which lies in northern Canada with its exact location changing slightly from year to year. In order to plot bearings directly onto your map using your compass it has to be adjusted for the difference between **magnetic north** and the **grid north** on your base map. Information on the magnetic variation is often printed on the map sheet so if you are using photo-copies for field sheet you may have to check the original map. The local 1:50,000 map of the Egham area gives magnetic north as 5½º west of Grid North in 1990 decreasing by ½º in 3 years. For this area your compass should be adjusted using the adjusting screw with the 'screwdriver' provided so that the north arrow within the compass housing lies 5º to the west of the north mark on the rim of the compass housing. The declination must be reset when you go to another area. Declination information for any locality can be obtained from http://gsc.nrcan.gc.ca/geomag/index_e.php

Taking a bearing: involves holding the compass at eye level and adjusting the cover of the compass so that the mirror reflects the compass dial. Orient the compass so that the two luminous index marks, the sighting line on the mirror, the notch of the sight and the object on which you wish to take a bearing are seen lined up with your sighting eye. Take care to keep the compass level so that the needle can swing freely. Then observing the compass in the mirror, rotate the compass housing so that the

THE SILVA COMPASS



orienting arrow marked within is aligned exactly with the compass needle and the red (magnetic north) end of the needle is between the luminous spots. The bearing can be read from the scale on the outside of the compass housing. To take the bearing of a strike, trend or other structural feature involves laying the compass with the long side of the base plate along the direction to be measured and rotating the compass housing, etc, as above.

Plotting the bearing should be carried out immediately by putting the compass on the map and rotating it so that the north-south lines within the compass housing are parallel with the north-south grid lines. The long side of the compass base plate is now correctly oriented for the bearing and it can be drawn directly onto the map. If you are measuring a strike etc, your location must be known and the line drawn must pass through that point. If you have taken a bearing on a mapped point, such as the corner of a house, the intersection of two walls etc, in order to find where you are move the compass up or down the grid line till the long side of the base plate passes through that point, then draw the back-bearing along the edge of the compass from the point to where you think you are.

Fixing your position

With your base map, measurement of distance and your compass you should be able to find where you are and plot the location accurately.

Mapped features: you may be present at a distinctive point which you can find actually plotted on your map, e.g. road junction, where a stream crosses a path, a sharp bend in a wall etc. Take care to plot location exactly such as which side of the road or wall the exposure actually is.

Estimating distance along a mapped feature: your position on a path or beside a wall or a stream shown on your map can be found by pacing from a distinctive point. It is often a good idea to keep some count of your paces as you walk along a path, starting again from zero when you pass another mapped point, so that if you reach an exposure you can plot its position immediately by measurement along the mapped feature. Alternatively you can use your compass bearing to get an intersection. Take a compass bearing onto a point which can be identified on the map and plot the back-bearing from that point. Your position is where the back-bearing intersects the path etc and it can be checked by taking and plotting a second bearing on another point. Ideally the points used should give bearings that intersect the trend of the feature nearly at right angles.

Pacing along a compass bearing: is necessary if your location is uncertain but you are close to a feature marked on your map. Take a compass bearing on the feature and plot the back-bearing on your field sheet. Then pace to the feature, convert the number of paces to metres and measure the appropriate distance along the back-bearing using the scale on the side of the compass to fix your position. Exposures close to the traverse you are pacing can be located by finding the point on the traverse directly opposite the exposure and pacing the distance to it at right angles to the traverse. The length of the offset can be measured and plotted on your map.

A compass resection (triangulation) is used when pacing is difficult or likely to be inaccurate due to the roughness of the ground, steep gradients, ponds or boggy ground or just that the distances are too great. Take compass bearings on three easily recognised mapped features and plot the back-bearings on your field sheet. Ideally the features should be selected so that the back-bearings intersect each other at about 60^{o}, and ideally the three back-bearings should intersect at a point, indicating your position. More commonly the back-bearings intersect giving a triangle of uncertainty. If the triangle is small, up to 1mm, your position can be taken at the centre. If the triangle is large, over 1mm, then check your bearings and plotting. If the large triangle persists check that the features you are using are in fact those marked on the map and check the setting of your compass. If it still persists you may be standing near magnetite deposit!

In areas where there are few mapped features you may need to take time to fix the position of visible objects like trees and plot them on your map so that you can use them for compass resections when you find exposures.

The map below shows six points the locations of which have been found by the range of techniques you might be expected to use.

Location A lies close to a distinctive mapped feature, in the south bank of the stream on the west of the road, within 5m of the bridge.

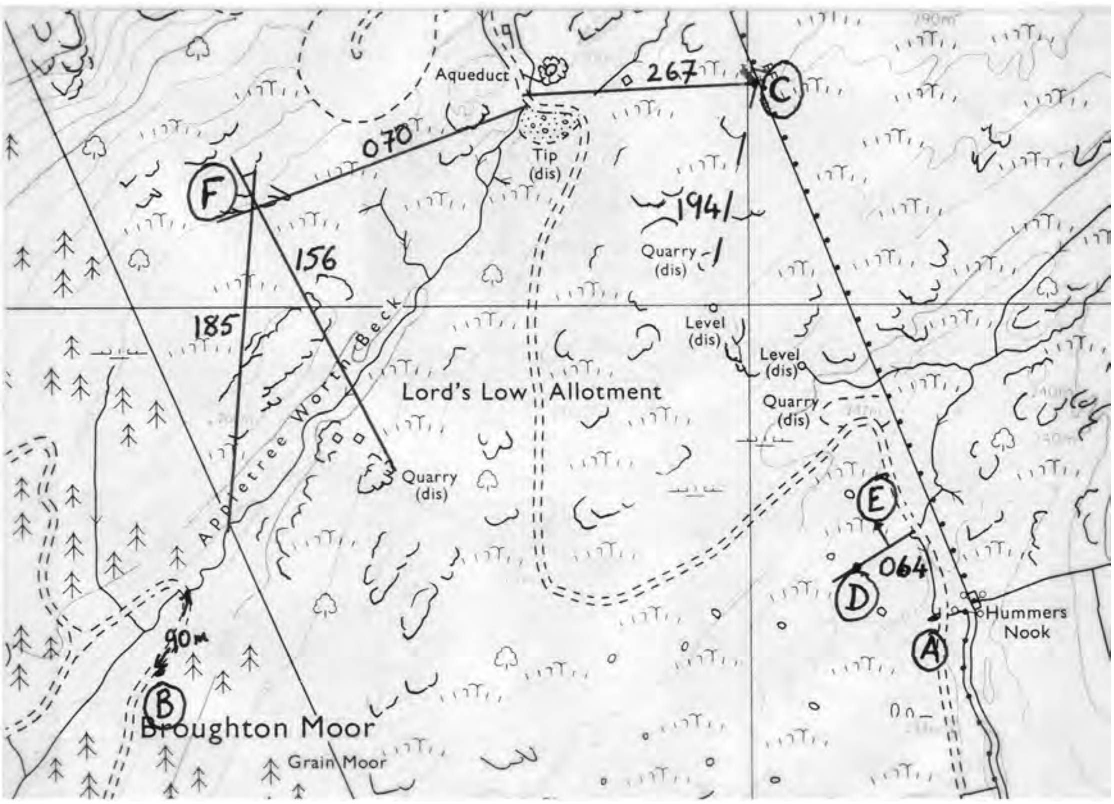
Location B lies in the south side of a mapped track through woods. Visibility is restricted and so the compass cannot be used. The location is fixed by pacing up the track from where it crosses the stream. Fifty-six double paces at 1.6m per double pace gives 90m, which is measured as 9mm on the 1:10,000 map.

Location C lies close to the west side of the mapped wall. Its position is fixed by taking a bearing on where the quarry road crosses the stream, **267**, and plotting it on the map. The position can be checked by plotting the bearing, **194**, taken on the eastern edge of the quarry which is just visible.

Location D is located by taking a bearing, **064**, on a mapped feature, where the quarry road crosses a stream, and pacing there. The bearing is plotted on the map and the distance, 44 double paces = **70m**, i.e. 7mm on the map, is measured.

Location E was found lying close to the traverse for location D. Pacing back **30m** from the quarry road bridge brought E perpendicular to the line of the traverse and its position was found by pacing the **25m** offset NNW from the traverse.

Location F lies on the edge of some small crags and its position was fixed by compass resection. The bearings were taken and plotted: **070** onto where the quarry road crosses the stream, **185** onto where the same stream is crossed by the wall and **153** onto the eastern edge of the small quarry. The three bearings give a small triangle of uncertainty.



GPS
Hand-held GPS receivers are increasingly common, cheap and useful. They are a valuable tool. If you use GPS positioning you need to know your map datum and coordinate system. You should be aware of the errors in GPS positions and use the instrument as an additional tool, not a substitute for your compass. Write GPS position immediately in your notebook. Do not store them until the evening.

SKETCHING IN THE FIELD

You don't have to be an artist. By following a number of rules and avoiding over-elaboration everyone can produce sketches that will convey information about the rocks that were being investigated.

1. Title Sketches are done for a variety of reasons: panoramas of the landscape to show aspects of the regional geology, hillsides or cliffs showing the boundaries between different rocks or large structures, detailed depiction of an exposure or a plan of a small area with many exposures. So it is essential that each sketch has a title to indicate why you drew it and what you intended to show.
2. Location A grid reference is necessary to indicate the site being sketched or the point from which a panorama has been drawn.
3. Orientation You should say what was the general direction in which you were looking while you were drawing. This can take the form of a compass bearing or a direction — 'looking SW'. On the sketch you should show the orientation e.g. by putting SE and NW at either end of the diagram.
4. Scale You must convey an impression of the size of what you are drawing so put a scale bar showing an appropriate length in centimetres or metres.
5. Labelling Although your sketch should have visual impact it is essential that as much information as possible is conveyed. Label all the rocks present, give the dip and strike of planar structures and the orientation of other structures as well as depict them. Mark structural measurements directly onto the sketch to show where they were taken. Show where fossils were found and where any other points of interest were located.

Now for the sketch itself.
Give yourself plenty of room — Some sketches can be small and concise, just to show a particular feature – most outcrops will require one. For more substantial sketches where there is a lot of information, don't try to squeeze your drawing into a spare corner of a crowded page, use the next clean page. Top-bound notebooks are ideal for panoramic sketches as you can draw across two pages.
Draw a reasonably accurate outline of the sky-line or the boundaries or the exposure as this gives you a frame for the detail of you sketch.
Outline major features of the landscape, hillsides, spurs, river valleys etc, or the main irregularities of the rock face.
Do not overdo insignificant detail — you don't need to draw every tree, bush or other bits of vegetation or every last indentation of the rock face as all these will reduce the clarity of the features you want to show.

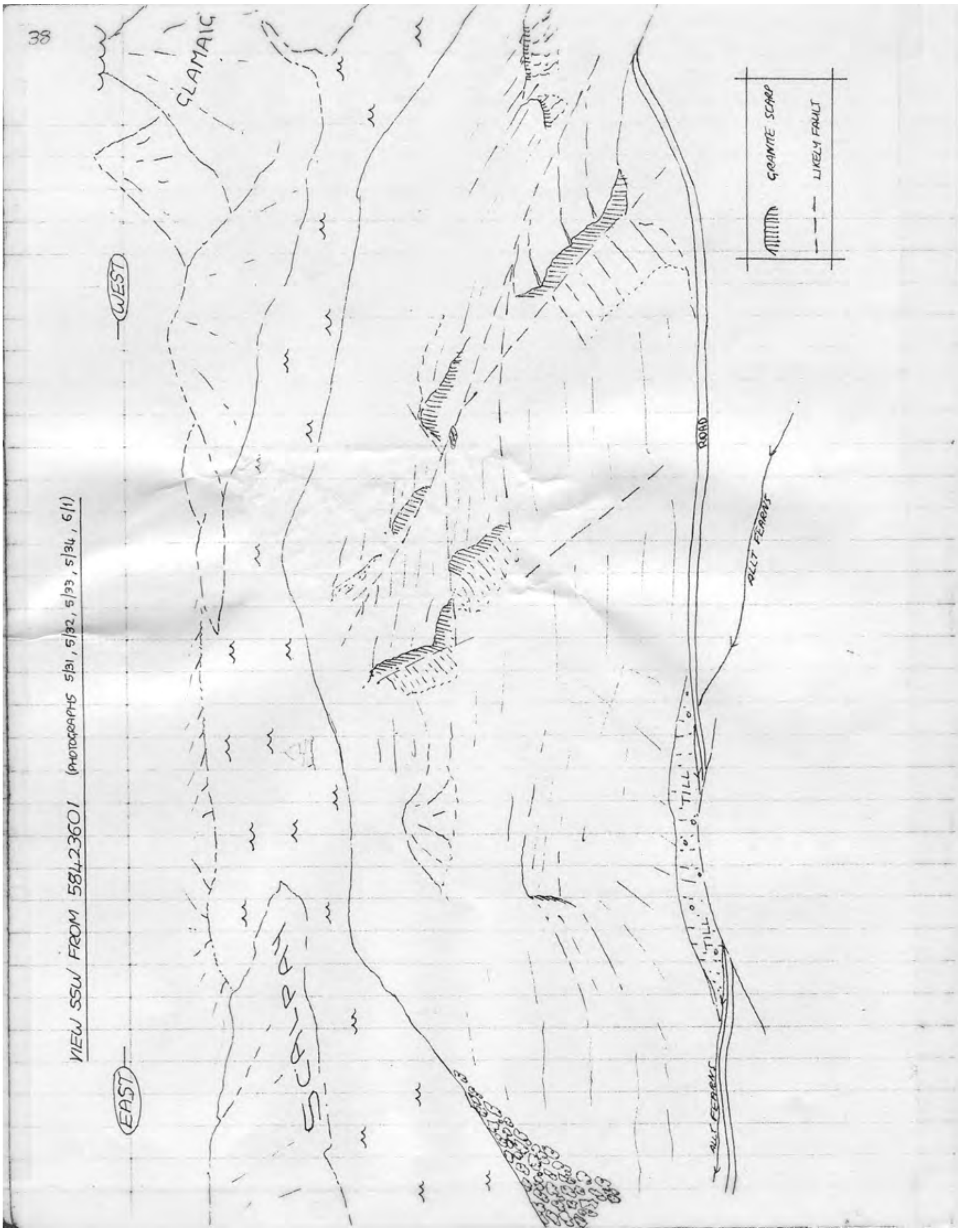
SHOW CLEARLY AND SIMPLY THE GEOLOGICAL FEATURES.

Emphasise the boundaries between rocks in the exposure, the orientation of bedding and give an indication of the fracture patterns in each of the beds.

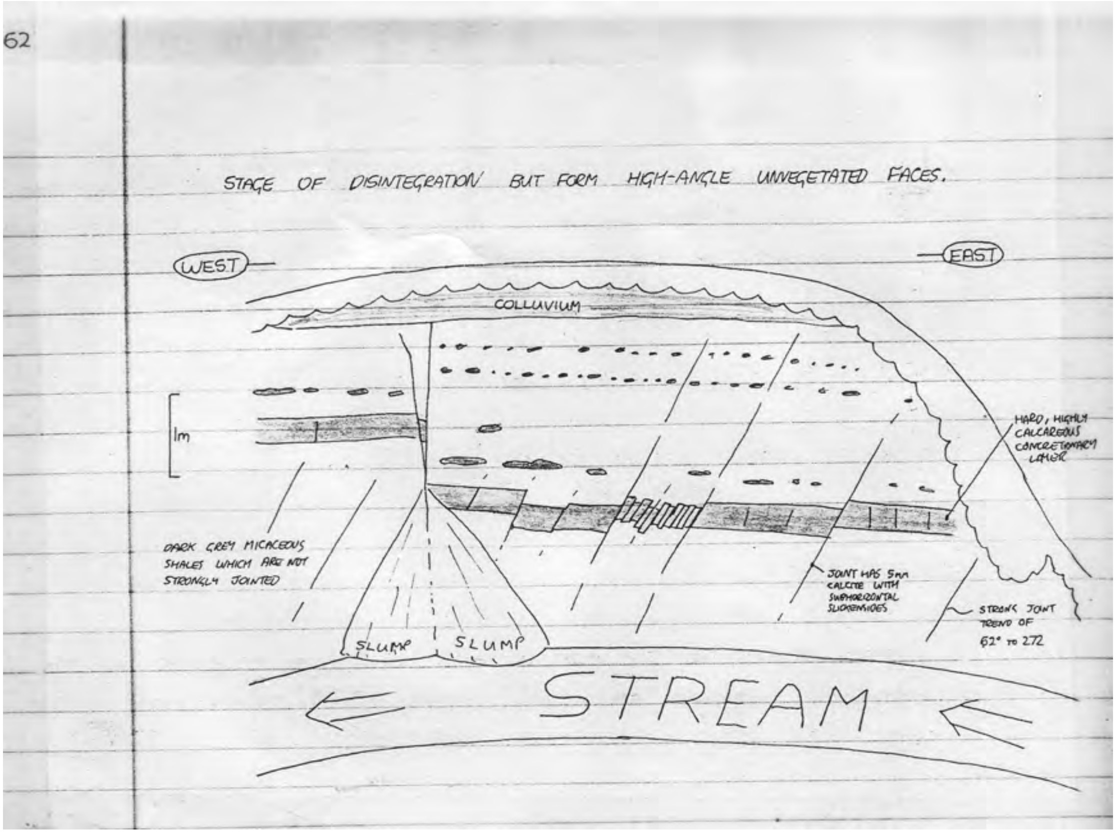
Show the presence of faulting and other structures, indicate their orientations clearly and interpret directions of displacement.

The presentation of sketches and diagrams can be considerably improved by checking them over back at base in the evening. Obvious deficiencies in labelling, scale, etc. can be rectified by reference to your field notes and sketches done in pencil can be tidied up. Colour can be added for different rock types.

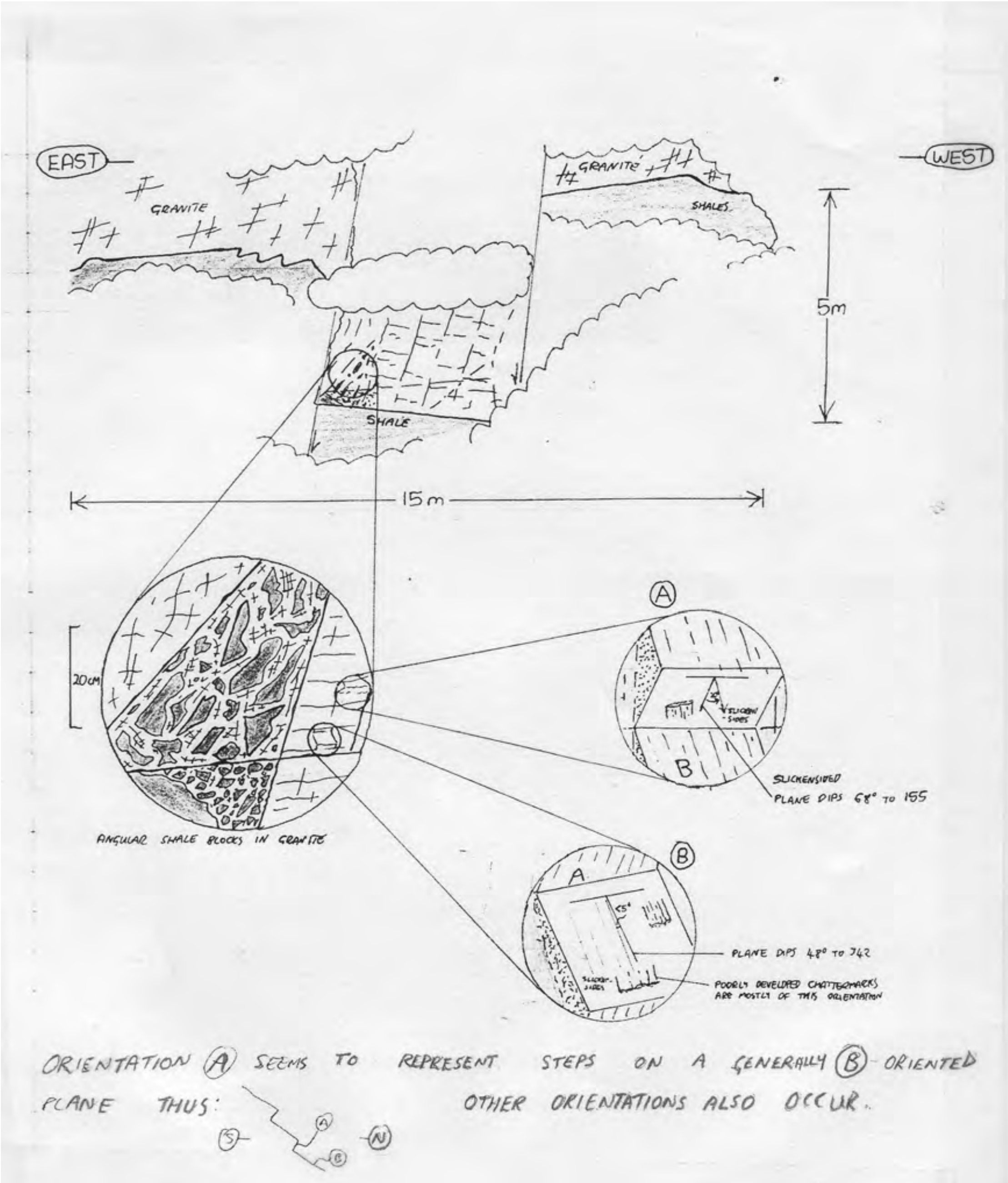
Sketch 1 shows a depiction of southern Raasay drawn to locate some possible faults in a mapping area. As a general view it shows the main features of the landscape and would provide a good skeleton for showing the regional geology of southern Raasay and the adjacent areas of Skye. Where it was drawn from and the direction of view are given clearly.



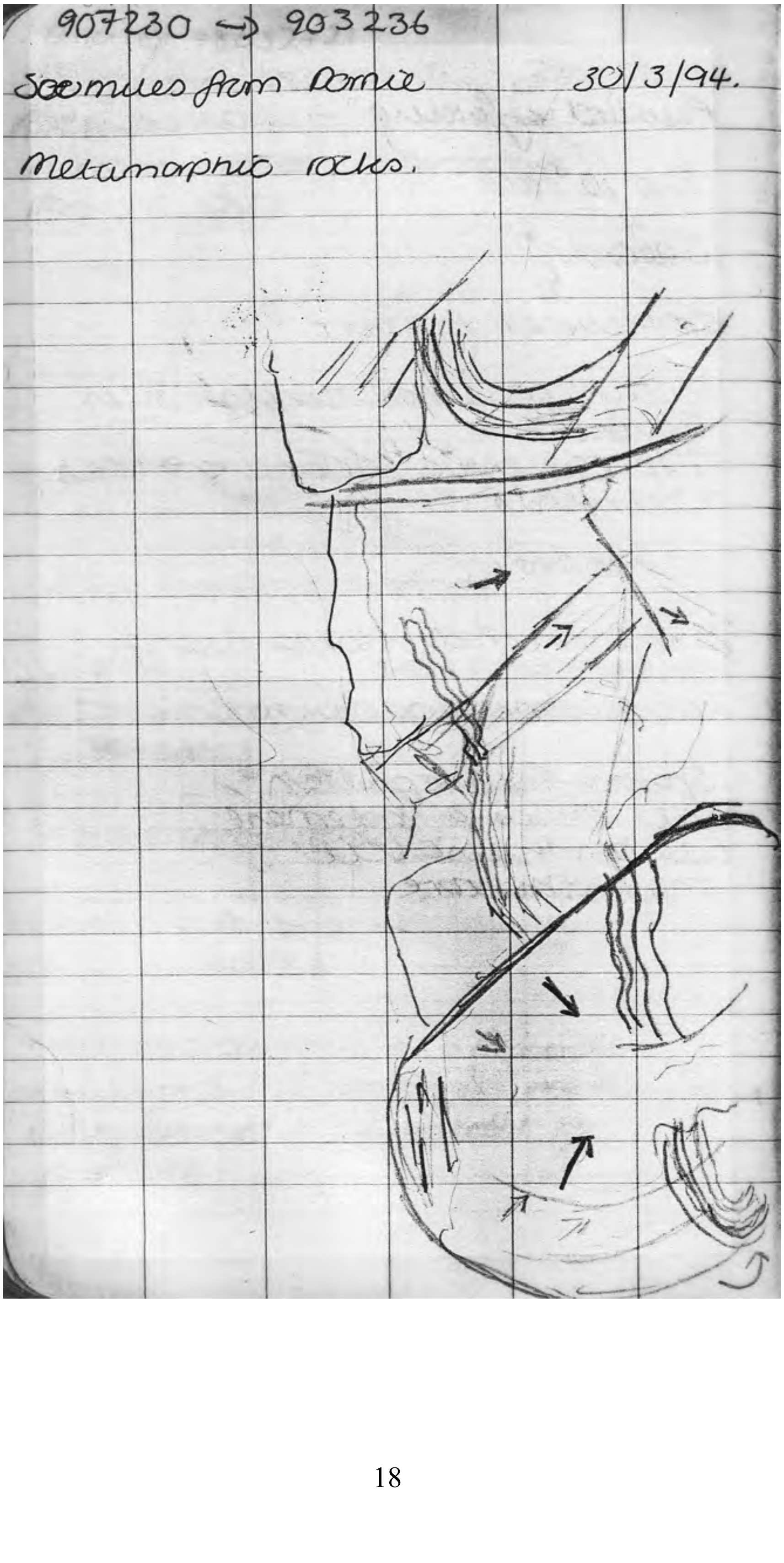
Sketch 2 is part of a description of a small cliff beside a stream with the location given on the previous page of the field notebook. The direction of view and the scale are indicated and the main features of the geology are clearly and simply shown.



Sketch 3 again is part of the description of a small crag whose location is given on the previous page and shows the junction between granite and shale clearly. Structure is interpreted and particular features are shown in enlarged sketches with their locations clearly shown.



Sketch 4 may well have been drawn by a better artist, but though the location of the section is shown by the six-figure grid references the sketch lacks just about everything else! There is no indication of direction of view and scale. Although the structures are emphasised and arrows are added the features are not labelled nor are the different rocks described, and what are the arrows anyway?



LOGGING SEDIMENTARY SEQUENCES

Graphic sedimentary logs are normally the most appropriate way of collecting and recording field data for sedimentary rocks. They are concise, convenient and give a visual impression of the sedimentary sequence. There is no standardised format for sedimentary logs and the most appropriate format for a log can vary depending on the type and amount of information required. The following is a set of guidelines for the collection and representation of data about a sedimentary sequence in the form of a graphic log.

Recording data in the field

It is normal practice to use logging sheets prepared with columns and scale already marked on, but under some circumstances a field notebook can be used. Logs drawn in a field notebook may be drawn to scale or a 'sketch log' may be drawn. All the appropriate information should be shown on a sketch log, but it is not precisely drawn to scale. Use a sharp pencil, eraser and ruler; it is important that your log is neat, clear and tidy.

Ideally a sedimentary log should be recorded along a continuous line perpendicular to bedding. In practice the nature of the exposure may make it necessary to offset the log along the beds in places; if the offset is significant this should be recorded. If vegetation covers part of the sequence measure the distance obscured and record it as 'no exposure'.

Start from the bottom and work upwards; this is logical because you will then be working through the sequence in the order in which things happened.

Drawing the log

Scale: this depends on the detail required. For precise work 1:10 (1cm on the log = 10cm of rock) is used, but if the beds are relatively thick and there is a long sequence to be logged 1:50, (2cm = 1m), 1:100 (1cm = 1m) or even 1:200 (0.5cm = 1m) will be adequate. Spend time looking at the sequence before you start logging to decide on the scale.

Identification of beds: where the bedding planes are clear and the lithology changes between beds this is straightforward. However in some cases it is appropriate to group thin beds together as a single unit. Under these circumstances record the character and range of thickness of the thin beds that make up the unit on the log.

Bed thickness: measure with a tape measure perpendicular to the bedding plane.

Bed contacts: note whether the contact between beds is sharp, gradational or erosional (scoured). Care needs to be taken where contacts are gradational as beds can be difficult to define.

Lithology: this is recorded in a column on the log using appropriate ornamentation. The symbols shown are those commonly used, but other ornaments may be used in some circumstances and a key should be given.

Texture (grain size): a horizontal scale on the right-hand side of the lithology column is used to show the grain size from fine on the left to coarse on the right. Changes in grain size (normal or reverse grading) are indicated by tapering the right edge.

Sedimentary structures: these can usually be indicated by symbols within the textures column, although they may also be drawn on the side to make the features clearer. Symbols used should be a simple graphical representation of the feature to make the log easy to understand If the features cannot be satisfactorily shown by symbols, make a note in the description column.

Cross bedding: the angle of the foreset, the shape of the cross-strata (tangential or tabular, planar or trough), the thickness of the set of cross-strata and the thickness of the individual laminae should be recorded in the description column. The direction of dip of the foreset should be recorded and entered in the palaeocurrent column.

Fossils: symbols for fossils found in the beds should be placed within or alongside the texture column. Use symbols that can be recognised easily. If the fossils are broken, a diagonal line may be drawn through the symbol. The size and orientation of the fossils should be noted. Trace fossils (burrows and trails etc) are important so record the shape, size, orientation and abundance of trace fossils.

Description: any features that cannot be adequately represented in the symbols should be noted in this column. The composition of the rock should be recorded where this can be determined in the field. Record the colour of the rock (fresh and weathered surfaces if different). Make a note of the numbers of any samples collected, photographs taken or if there is additional information in the field notebook on that part of the sequence.

Presentation of the log

The log can be drawn up neatly and accurately in the same style when you return from the field. Two columns should be added to present your interpretations.

Process interpretation: what do the features recorded indicate about the processes of deposition?

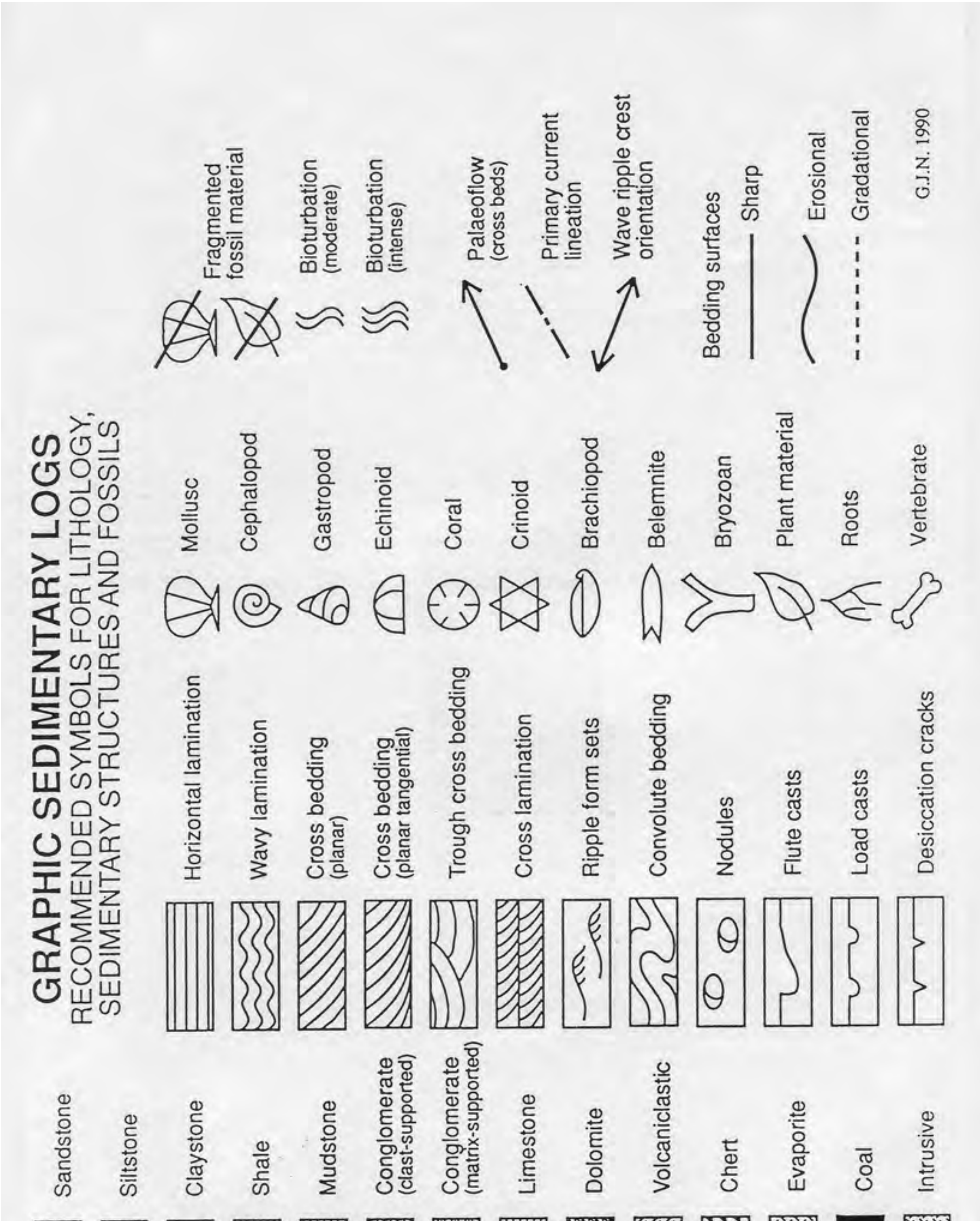
Environment interpretation: what environment does this association of depositional processes suggest?

Computer Presentation of the log

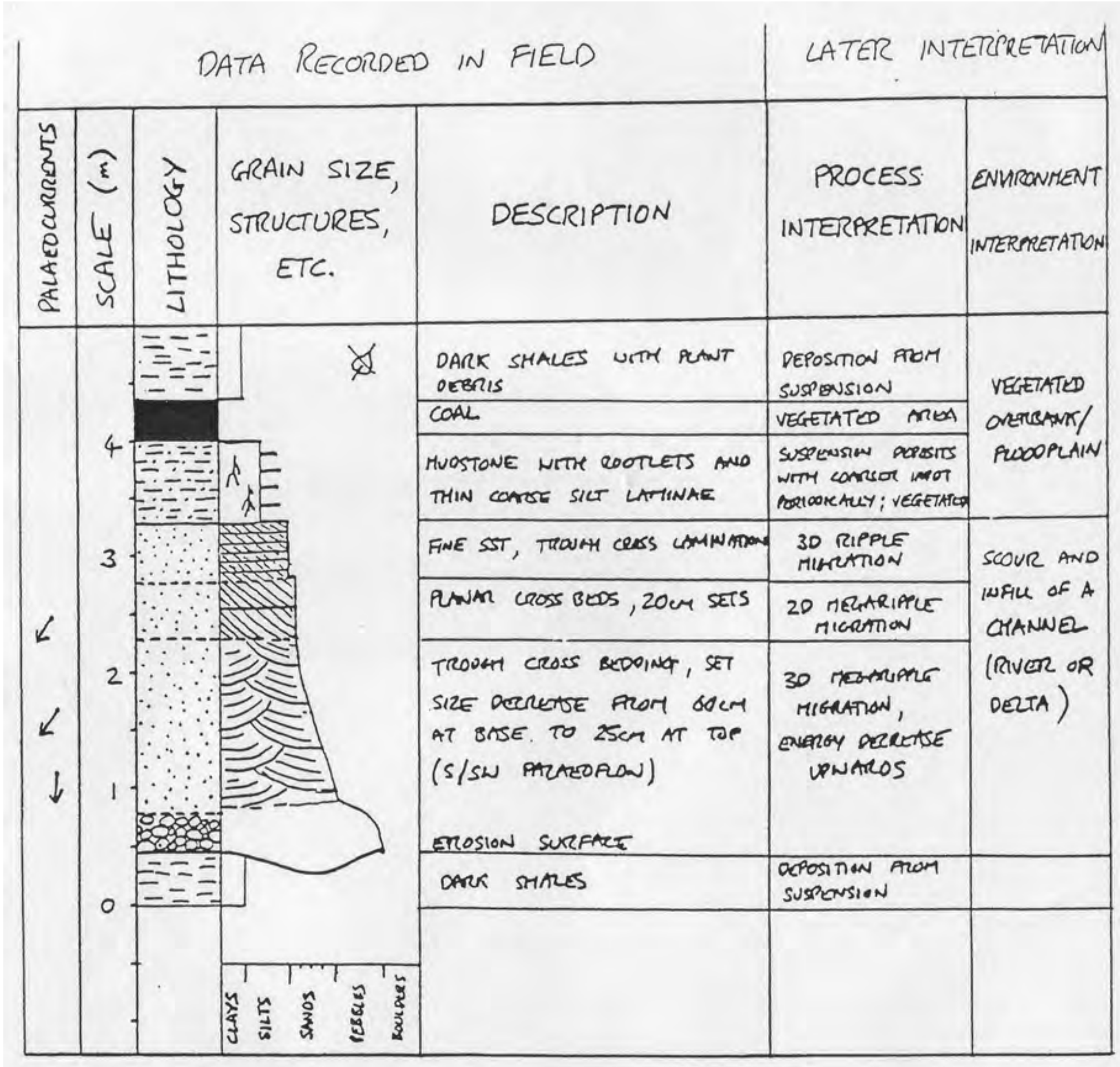
The log can also be drawn up using a computer program called SedLog, produced at Royal Holloway by the SE Asia Research Group. The program is free and will run on a PC or Mac. It can be obtained from

http://www.sedlog.com/

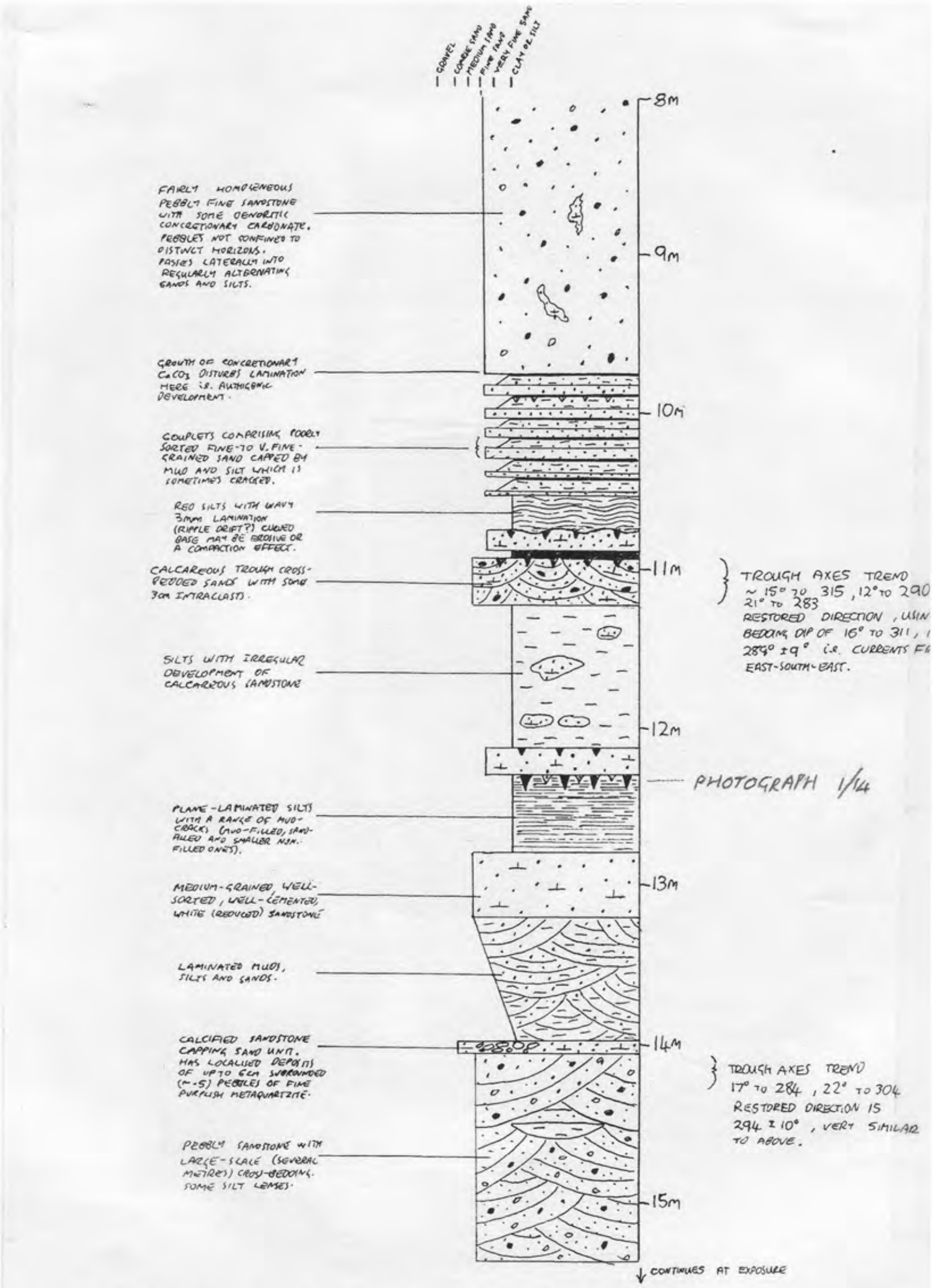
This program is not suitable for drawing of stratigraphic columns.



GRAPHIC SEDIMENTARY LOGS
RECOMMENDED SYMBOLS FOR LITHOLOGY, SEDIMENTARY STRUCTURES AND FOSSILS
Sandstone
Siltstone
Claystone
Shale
Mudstone
Conglomerate (clast-supported)
Conglomerate (matrix-supported)
Limestone
Dolomite
Volcaniclastic
Chert
Evaporite
Coal
Intrusive
Horizontal lamination
Wavy lamination
Cross bedding (planar)
Cross bedding (planar tangential)
Trough cross bedding
Cross lamination
Ripple form sets
Convolute bedding
Nodules
Flute casts
Load casts
Desiccation cracks
Mollusc
Cephalopod
Gastropod
Echinoid
Coral
Crinoid
Brachiopod
Belemnite
Bryozoan
Plant material
Roots
Vertebrate
Fragmented fossil material
Bioturbation (moderate)
Bioturbation (intense)
Palaeoflow (cross beds)
Primary current lineation
Wave ripple crest orientation
Bedding surfaces
Sharp
Erosional
Gradational
G.J.N. 1990


DATA RECORDED IN FIELD
LATER INTERPRETATION
PALAEOCURRENTS
SCALE (m)
LITHOLOGY
GRAIN SIZE, STRUCTURES, ETC.
DESCRIPTION
PROCESS INTERPRETATION
ENVIRONMENT INTERPRETATION
DARK SHALES WITH PLANT DEBRIS
DEPOSITION FROM SUSPENSION
COAL
VEGETATED AREA
VEGETATED OVERBANK/ FLOODPLAIN
MUDSTONE WITH ROOTLETS AND THIN COARSE SILT LAMINAE
SUSPENSION DEPOSITS WITH CONTACT INPUT PERIODICALLY; VEGETATED
FINE SST, TROUGH CROSS LAMINATION
3D RIPPLE MIGRATION
SCOUR AND INFILL OF A CHANNEL (RIVER OR DELTA)
PLANAR CROSS BEDS, 20cm SETS
2D MEGARIPPLE MIGRATION
TROUGH CROSS BEDDING, SET SIZE DECREASE FROM 60cm AT BASE TO 25cm AT TOP (S/SW PALAEOFLOW)
3D MEGARIPPLE MIGRATION, ENERGY DECREASE UPWARDS
EROSION SURFACE
DARK SHALES
DEPOSITION FROM SUSPENSION
4
3
2
1
0
CLAYS
SILTS
SANDS
PEBBLES
BOULDERS

This graphic log was sketched in a student's field notebook and has only been inked in and tidied up. Nice example but should be drawn facing to the right.



COMPOSITE GRAPHIC LOG LOGGED DOWN FROM THE CLIFF-TOP.

GENERAL CHARACTER OF CONTINENTAL

	AEOLIAN FACIES	FLUVIATILE FACIES	LACUSTRINE FACIES
DEPOSITION:	Wind blown sand typical of deserts, also along shorelines.	(a) Meandering streams with well developed floodplains — lateral channel migration, overbank sedimentation and crevasse splays (b) Braided streams — channel processes and bar formation (c) Alluvial fans — sheet floods, debris flows.	Lakes vary in size, shape, depth and salinity; subject to a strong climatic control; waves and storm currents in shallow water; turbidity currents (and river underflows) in deeper water, biochemical & chemical precipitation.
LITHOLOGY:	Mature, matrix-free sandstones (usually quartz).	Conglomerates, sandstones, mudrocks; intraformational conglomerates common; sandstones often immature (lithic, feldspathic).	Diverse — conglomerates, sandstones, mudrocks, limestones, marls, evaporites, cherts, oil shales and coats.
TEXTURES:	Well-sorted, well-rounded sand grains; often stained with haematite; pebbles wind-faceted and sand grains abraded.	Conglomerates — pebble supported with imbrication (stream deposits) or matrix supported (debris flows). Sandstones — moderately sorted, angular to rounded grains.	
STRUCTURES:	Large-scale cross-bedding (set heights metres to tens of metres); cross-beds dip up to 35°.	Fluvial sandstones — cross-bedded, flat-bedded with primary current lineations, channels and scoured surfaces; finer sandstones show ripple and cross-lamination. Conglomerates — lenticular with crude cross-bedding. Mudrocks — massive with rootlets and soil horizons.	Wave-ripples, desiccation cracks common on lake shorelines; rhythmic laminations and turbidity current graded deposits in deeper water.
FOSSILS:	Rare — occasional vertebrate footprints and bones.	Plants, plus rare fish and freshwater molluscs.	Non-marine bivalves, gastropods and vertebrates (footprints, bones); plants (algae).
PALAEOCURRENTS:		Unidirectional, dispersion depends on stream type.	
GEOMETRY:		Sand and/or gravel bodies (ribbons, sheets and fans) sometimes enclosed in mudrocks.	
FACIES SEQUENCES & ASSOCIATIONS:	Playa lake mudrocks and evaporites, water-lain sandstones and conglomerates (debris flows).	(a) Meandering streams — fining-up, cross-bedded sandstone up to several metres thick with lateral accretion surfaces; interbedded with mudrocks. (b) Braided streams — lenticular cross-bedded sandstones with few mudrock interbeds. (c) Alluvial fans — overall coarsening-up or fining-up trends.	Sequences often reflect changes in water level (climatic /tectonic controls). Fluvial and aeolian sediments often associated; soil horizons

AND MARINE CLASTIC FACIES

DELTAIC FACIES	SHALLOW MARINE SILICICLASTIC FACIES	DEEP MARINE SILICICLASTIC FACIES	GLACIAL FACIES
River, tidal and wave processes in varying degrees of importance. Sub-environments include distributary channels and levees, swamps and lakes, mouth bars, distal bars, interdistributary bays, prodelta slope.	Tides, waves and storm currents important processes; environments include tidal flat, beach, barrier island, lagoon, nearshore shelf, offshore shelf.	Submarine slopes, submarine fans, particularly by turbidity currents, debris flows and from suspension.	Various: beneath glaciers, lakes, outwash plains and shelves by moving/melting glaciers, meltwater and icebergs.
Sandstones, mudrocks, coal seams and ironstones.	Sandstones, mudrocks, rare thin conglomerates.	Sandstones, mudrocks and conglomerates.	Polymict conglomerates (tillites), sandstones, muddy poorly sorted sediments.
Variable — not diagnostic.	Not diagnostic, but some sandstones well-sorted, well-rounded.	Not diagnostic, sandstones often immature, conglomerates matrix-supported	Conglomerates poorly sorted, matrix-supported, striations on clasts, some preferred orientation.
Sandstones — cross-bedding of various types and scales, flat-bedding; channels common; flaser and wavy bedding in finer sediments, rootlets in mudrocks; nodules of siderite common.	Sandstones — cross-bedding with herring-bone character, reactivation surfaces, low angle and flat bedding, wave/current ripples, cross-lamination, flaser & lenticular bedding, desiccation cracks, thin graded sandstones (storm deposits); pyrite nodules in mudrocks; bioturbation common.	Sandstones show turbidite features (graded bedding, 'Bouma Sequences', sole marks, slumps) or are massive Mudrocks finely laminated.	Massive tillites, laminated (varved) muddy sediments, fluvio-glacial sandstones cross-bedded, laminated, scoured & channelled.
Plants common; marine fossils in some mudrocks and sandstones; non-marine fossils (bivalves) in some sediments.	Marine fossils with diversity dependent on salinity, level of turbulence, etc; trace fossils.	Pelagic in muds or derived shallow fauna in turbidites.	Absent except in glacio-marine sediments.
Mainly directed offshore; also shore-parallel (marine reworking).	Variable, parallel or normal to shoreline, unimodal, bimodal or polymodal.	Variable, downslope or along basin axis.	
Sand bodies may be ribbons, sheets or both, depending on the delta type.	Linear sand bodies if barrier or beach; sheets if extensive shallow shelf sea.		Laterally extensive tillites.
Delta progradation leads to coarsening-up units from pro-delta mudrocks to (channel) sandstones capped with seat-earth/coal. Many variations possible.	Sequences variable depending on environment and rising/ falling of sea level; both fining-up and coarsening-up units occur. Limestones, ironstones, phosphates occur in shallow marine environments.	Turbidites may show thinning & fining-up or thickening & coarsening-up sequences.	No typical sequences.

PALAEOCURRENT MEASUREMENTS

Palaeocurrent data give vital evidence of the interaction between the sedimentological and structural evolution of a sedimentary basin as they show how the source and distribution of sediment changes through time as the basin evolves. However the beds in which palaeocurrent indicators are found have often been deformed. Where the rocks have been simply tilted it is necessary to restore the bed to a horizontal position so that the true palaeocurrent direction can be determined. In folded rocks it is also necessary to correct for the plunge of the axis about which the beds have been folded. These corrections are carried out using a stereonet.

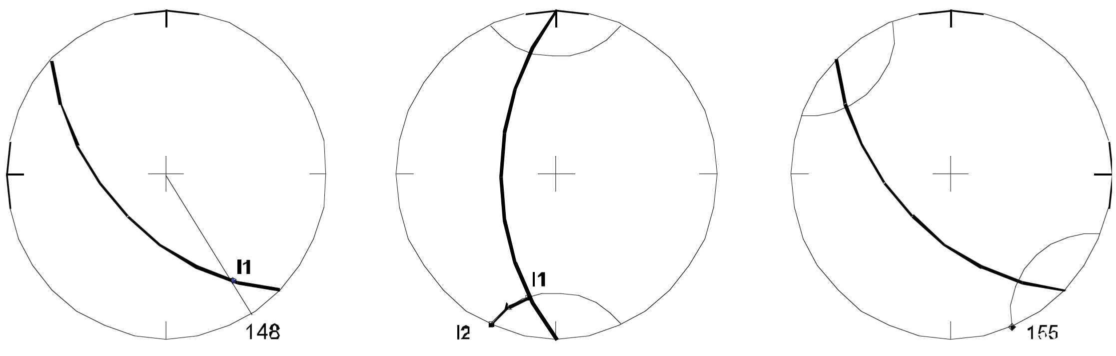
Field measurements

In the field you need to collect the following data:
- sufficient palaeocurrent measurements to give you an accurate mean palaeocurrent measurement (preferably about 20, or as many as you can find in a single exposure).
- the dip and strike of cross beds and either the pitch or the dip and direction of dip of linear features such as grooves.
- the dip and strike of the bed from which the palaeocurrent data were collected.
- the orientation of any fold axes that are visible.
- in the absence of visible fold axes, sufficient bedding measurements to determine the fold axis orientation using a stereonet.

Reconstructing palaeocurrent data using a stereonet

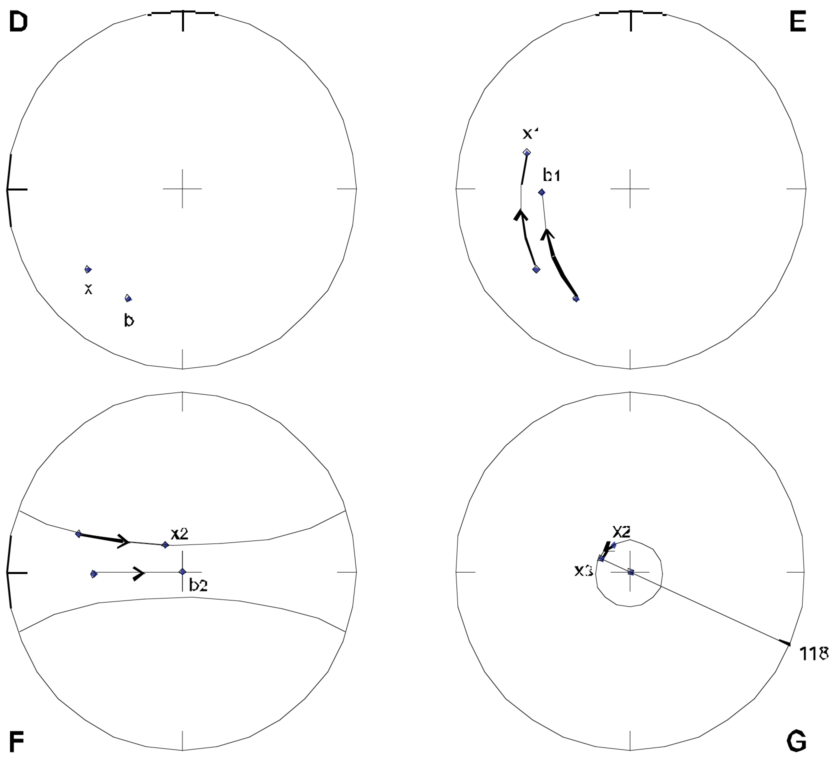
Each evening you should reconstruct your palaeocurrent data using the following techniques:

Where fold axes are horizontal
Linear data: plot the bedding plane (135/50 SW) and the linear feature (16° to 148) ***(l1)*** on the stereonet **(A).** Orient the bed so that it lies on a great circle on the stereonet and restore the structure to the horizontal by moving the point to the edge of the stereonet ***(l2)*** along the **small circle** on which it lies **(B).** Rotate the overlay back to the N-S orientation **(C)** and read off the original azimuth (155°).



A B C

Planar data: plot the poles to both the bed ***(b)*** and the cross bed ***(x)*** shown in **(D)**. Rotate the overlay **(E)** so that the pole to bedding lies on the east-west cross line ***(b1)***. Restore the bed **(F)** to the horizontal by moving the pole to the centre of the stereonet ***(b2)***. Rotate the pole to cross bedding by a similar amount along the **small circle** on which it now lies ***(x1 to x2)***. Rotate the overlay back to its original position **(G)** where the original palaeocurrent direction is given by the azimuth in the opposite quadrant to the restored pole ***(x3)*** is 118.

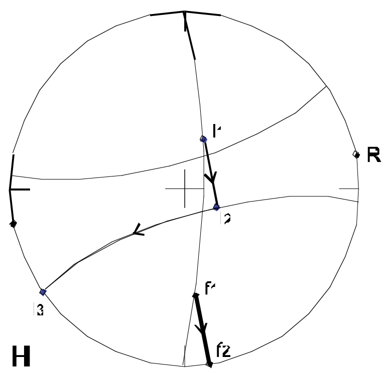


Where fold axes are inclined

Plot the linear feature ***(l1)*** or the poles to bedding and cross bedding and the fold axis ***(f1)*** on the stereonet. Firstly, the fold axis is restored to the horizontal by rotating it about a horizontal axis ***(R),*** which is at 90^{o} to the direction of plunge of the fold axis. Mark this point on your overlay and rotate it so that it lies over either the **north** or **south** point of the net.

Restore the fold axis to the horizontal by rotating it along the **small circle** to the edge of the net ***(f2)*** and then rotate the lineations or bedding and cross bedding poles through the same angular distance along the **small circles** on which they lie ***(l2)***. The newly orientated linear feature is restored to the horizontal by aligning the horizontal fold axis with either the **north** or **south** point and rotating it along its **small circle** to the edge of the stereonet. ***(l3)*** Rotate the overlay back to a N-S orientation and read off the original azimuth.

For the newly orientated bedding and cross bedding poles treat as described for planar data with horizontal fold axes.



FOSSILS IN THE FIELD

Fossils are an important component of many sedimentary rocks. They have two primary uses:
1. For biostratigraphy: to determine the age of the rock sequence by correlation with standard and other sequences elsewhere.
2. For palaeoenvironmental analysis: to determine factors such as depth of deposition, level of turbulence, salinity and sedimentation rate etc.

Field identification of fossils to species or even generic level is seldom easy, although for a few formations in Britain and for some of the most common fossils there are published faunal and/or floral guides available. If you cannot collect fossils for laboratory identification with the aid of a specialist, or at least specialist literature, you should draw them carefully for later identification from the drawings. (A scale is essential!)

Even where you cannot identify the fossils to species or generic level they may still provide you with useful information, especially for palaeoenvironmental analysis. For this purpose it is useful to systematically record field observations on the distribution, associations and preservation of the fossils, their relations to the sediment and the presence of unusual forms. A list of the features worth looking for and recording is given below (slightly modified from **Ager, 1963)**.

You should answer these questions as far as you can for each separate rock unit.

A. Distribution of fossils

1. Are the fossils evenly distributed throughout the rock unit?
2. Do they occur in pockets, lenses, bands or nodules?
3. Are they more abundant at any particular level in the unit?
4. Do they occur in reefs or shell banks?
5. Are the different fossils distributed in the same way?
6. Are the fossils the same as are seen in the same bed elsewhere?
7. Are any of the species present rare here but more common elswhere?
8. Approximately how many species are present?

B. Associations of the fossils

1. What, very roughly, is the relative abundance of the different groups of fossils present?
2. Are there any obvious close associations, such as crinoids with wood fragments?
3. Are there any obvious absentees, e.g. no ammonoids in a Cretaceous marine shale?
4. Are there any obvious derived fossils?
5. Are all growth stages present for each species and if not which stages are present for which species?
6. Are any of the fossils encrusted or bored and if so how and by what, e.g. bryozoans inside or outside bivalve shells?
7. Are any of the fossils attached to one another in any way?
8. Is there any evidence of the mixing of organisms from different environments, such as land plants and echinoderms?

C. Preservation

1. Are there any unusual features about the preservation, such as colour banding on nautiloids?
2. Are all the fossils preserved in the same way?
3. Are there any traces of 'soft parts'?
4. Are any delicate structures preserved, such as spines on productoids?
5. Are the fossils worn or broken and are some species more so than others?
6. Are the valves of bivalves separated and if so are both valves present in equal numbers?
7. If the valves are still joined together, are they tightly closed, partly open, or wide open?
8. Are the ossicles of crinoid or other pelmatozoan stems present in long lengths, short lengths or separated?
9. If higher-plant remains are present, which parts of the plant are found? Are roots, stems, leaves or fruits present?

D. Relation of the fossils to sediment

1. What is the nature of the enclosing sediment?
2. Are there any sedimentary structures, such as cross-bedding, slumps, ripple marks or scour marks?
3. Is there any obvious relationship between the fossils and the nature and/or grade of the sediment, such as larger forams in coarser grained sands?
4. Are there any of the fossils obviously out of place in the sediment, such as reef corals in a shale?
5. If fossils are found in nodules, are they preserved in the same way as those in the surrounding sediments?
6. What is the nature of the infilling of any closed shells?
7. Are there any signs of a general disturbance of the sediment by organisms?
8. Are any of the fossils in the 'life position' and if so what is the percentage of each species?
9. Are any of the other fossils oriented in a particular way, such as parallel alignment of belemnite guards?

E. Form

1. Are there any noteworthy growth forms, such as delicately branched corals?
2. Are there any obvious peculiarities of adaptation, for example the expanded glabella on trilobites?
3. Are there any obviously pathological specimens or any that have been damaged during life?
4. Are there any cemented forms, like oysters, or other forms needing a firm substrate for anchorage?
5. Are there any borings, burrows, tracks or trails?
6. Are there any other signs of organic activity, such as coprolites?
7. Are the fossils highly ornamented or smooth or is there a mixture of the two?
8. Are there any signs of stunting or gigantism?
9. Are there any signs of unusual shell thickness or excessive ornamentation?
10. Are there any signs of seasonal growth or of general change in growth rate or direction during life?

Further Reading

Ager, D.V. 1963. *Principles of Paleoecology*. McGraw Hill.
Goldring, R. 1991. *Fossils in the field: information, potential and analysis*. Longman.
Tucker, M.E. 2003. *The Field Description of Sedimentary Rocks*. John Wiley & Sons.

RECORDING STRUCTURAL DATA IN THE FIELD

Aims

The study of geological structures is a key component in unravelling the geological evolution of any area. By identifying and carefully describing structures it is possible to determine the sequence in which they evolved **(kinematic analysis)** and the forces and stresses which were responsible for their formation **(dynamic analysis).** However such data should not be treated in isolation, but must be integrated with lithological, sedimentological, petrological and palaeontological information to show how structural evolution has interacted with other aspects of the geology to provide a complete analysis of the geological evolution.

Field observations

Field observations are the primary source of structural data. You should carefully record the following information in your field notebooks.

Field sketches: Large scale sketches made from a distance are invaluable for showing the relationships between different structures, and between structures and other elements of the geology. The very act of drawing a sketch can often help you to work out the details of structural relationships that may not be apparent from simply observing a large exposure. However, large-scale sketches should always be supplemented by more detailed observations to make sure that the observations made from a distance are consistent with what you observe close up!
Small-scale sketches should also accompany your description of individual exposures and show the relationships between the different structures that you are describing and measuring (e.g. bedding and cleavage or minor folds).

Description: supplement and annotate your sketches with careful description of the lithologies and of the structural features that are present.

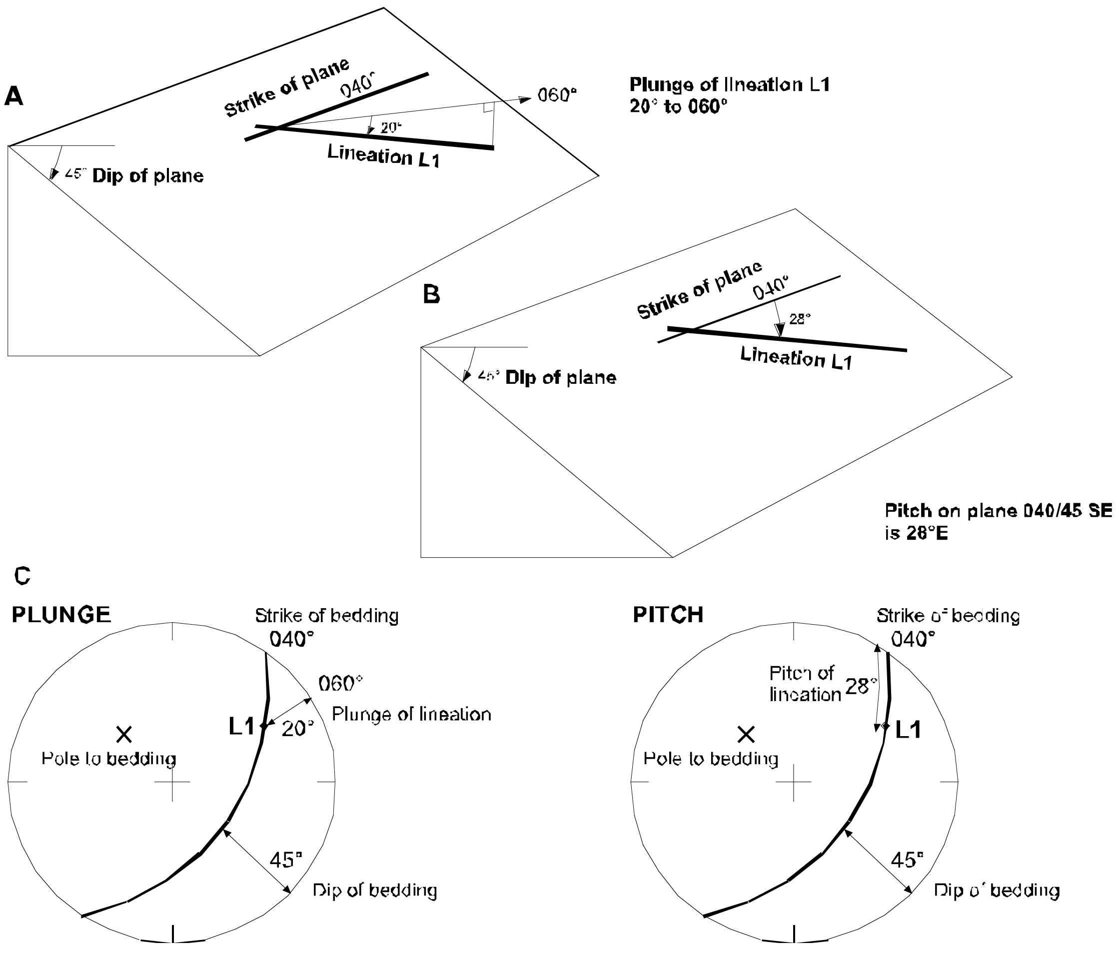
Measurements: it is always important to make careful measurements of the structures you observe so that you can analyse them later using techniques such as stereographic projection to work out the relationships between the different structures.
Planar features (bedding, cleavage planes, fault planes, joints) are recorded as a **dip** and a **strike.**
Linear features (fold axes, slickensides, bedding/cleavage intersections, mineral lineations) are recorded as a **plunge** and **trend** (i.e. a dip of the lineation and the direction in which it dips - see diagram) or as a **pitch** on a measured plane (i.e. the angle between the strike of the plane and the linear feature as shown on the diagram). Remember you need to record the dip and strike of the plane that shows the lineation as well as the pitch.

Checklist for structural measurements: you should copy this list into your field notebook as a reminder of the structures to look for and measure if present.

1. **Bedding plane dip and strike.**
2. **Bedding way-up.**
3. **Type of tectonic foliation, e.g. cleavage, schistosity or gneissose banding.**
4. **Foliation dip and strike.**
5. **Mineral and stretching lineation orientations.**
6. **Major and minor fold axes (phases of folding if more than one).**
7. **Fault plane orientations, type of faulting and amount of displacement.**
8. **Joint planes dips and strikes.**
9. **Dyke orientations.**
10. **Vein types and orientations.**
11. **Shear zone orientation and sense of shear.**
12. **Relation of faults, lineations, veins etc to folds.**
13. **Geomorphological features indicating structures, e.g. eroded fault scarps, anticlinal ridges etc.**

Analysis
It is important to remember while you are making observations and collecting data in the field that you will need to analyse it later. As you cannot go back to an exposure, you must make sure that you have collected all the data you will need while you are there and that you will be able to understand what you have measured once you are back at base in the evening. If you have enough data it may be possible each evening to plot your observations on a stereonet or you may have to draw on several days' fieldwork for your structural analysis. Plotting fold axes and fault planes on the stereonet may show the relationships between different generations of structures. Bedding plane measurements and bedding/cleavage relationships can be used to determine the orientation of fold axes. Plotting mineral lineations from fault planes will show how consistent the sense of movement is on particular generations of faults, or how the sense of movement changes from one generation of faults to another. With the information you have gathered you should be able to produce a cross section that is consistent with all your observations and which shows the essential structural, stratigraphic and sedimentological relationships. You should also be able to work out a geological history.

Measuring linear features (from McClay 1987)



(a) Measurement of a plunge of a lineation L_1 20° to 060 within the bedding plane. The angle 20° is measured in the vertical plane (azimuth 060°) containing the lineation L_1.
(b) The pitch of a lineation L_1 is measured as 28° E from a line striking 040° in the bedding plane. The pitch of the lineation would be recorded as 28° to the NE on the bedding plane.
(c) Lower hemisphere stereographic projections of plunge and pitch of the lineation L_1.

STRATIGRAPHIC PRACTICE AND MAPPING

Introduction

An understanding of lithostratigraphy is fundamental to your mapping. The lines on your map and the units of rock that you map will be lithostratigraphic boundaries and units. In practice this means that you are mapping different rock types that are recognised by their different petrological, mineralogical and palaeontological characters. The boundaries between units may be sharp or interbedded and gradational, but you must erect your own criteria in the field for recognising the upper and lower boundaries of the units you are mapping.

Lithostratigraphic units:

Formations The basic mapping unit is the **formation**. This should have distinctive lithological features that enable you to separate it from other local units and for you to place a boundaries on your map at a scale of 1:10,000. This therefore is the basic unit of mapping. It must be defined by a **type section** in your mapping area where it is best exposed.

Members A formation may have local variations in its lithological character, e.g. a sandstone lens within a formation otherwise made up of mudstone, and if it is thick enough it can be mapped and named as a **member**. A formation may be completely divided up into members but it does not have to be, in which case it may have no subdivisions.

Beds Individual lithological horizons or beds that are important enough to be represented on your map may be formally defined as a **bed**. Beds may be lithologically distinctive, such as a single tuff layer in a thick sandstone formation or a pebble layer within a mudstone formation, or give indications of age or environment, e.g. a fossiliferous layer in an otherwise unfossiliferous sequence or a layer with distinctive sedimentary structures. A bed must be described in a type section.

Groups Formations that are lithologically similar may be formally brought together as a **Group.** Examples of groups could include a number of limestone formations overlain by a number of volcanic or siliciclastic formations or a number of sandstone, siltstone and mudstone formations. Formations do not have to be gathered into Groups. Finally groups may be gathered together into **Supergroups**, but this is unlikely to be possible within the confines of a single mapping area.

Naming Stratigraphic Units:

Each stratigraphic unit you recognise and define must also be named. The name you give should contain the geographical location where the unit is best exposed in your area (i.e. the type section) together with a descriptor of the dominant lithology that is essential for Beds and Members. Examples could include the ‘Egham Mudstone Member’, ‘Leckhampton Limestone Formation’, ‘Borrowdale Volcanic Group’ and the ‘Windermere Group’.

The Stratigraphic Column

Having divided up your stratigraphy into lithostratigraphic units you will have to establish the order of succession, from the oldest to the youngest, of the units from sedimentological (way-up) or palaeontological criteria within the rocks. This will enable you to erect a stratigraphic column that should also include the thicknesses (and the lateral variation in thicknesses) within your area and any stratigraphic breaks or unconformities.

Biostratigraphy

As a separate exercise you will also have to try to establish the age of the rocks you have mapped. For your mapping this will be carried out using the principles of biostratigraphy. These are quite different from and have nothing to do with lithostratigraphy. Any age-diagnostic fossil must be recorded, together with the formation from which it has been collected, and identified as precisely as possible. When this has been carried out you may be able to assign geological ages to the groups, formations and members you have mapped. Depending on the nature and identification of the fossil you may be able to assign particular formations to the internationally agreed zones (e.g. *Cardioceras cordatum)*, stages (e.g. Albian), epochs (e.g. Miocene) or periods (e.g. Cretaceous). You can find these in Harland *et al.* (1990)

Common Pitfalls in Stratigraphic Practice

Do not confuse **biostratigraphy**, which is concerned with time, with **lithostratigraphy,** which is concerned with rock units.

Remember that rock units can transgress geological time surfaces.

Rock units can be informally subdivided into **upper, middle** and **lower** portions, e.g. the lower Kimmeridge Clay Formation, whereas biostratigraphic units should be informally subdivided into **early, middle** or **late** events (e.g. the early Turonian of the late Cretaceous). Do not confuse spatial with temporal adjectives.

Always remember **you are mapping rock units** (formations or members) and **never** what you interpret to be (or even worse! what others have interpreted to be) the age of the rocks such as the 'Oxfordian limestones' or 'Ordovician sandstones'.

General References:

Haile, N. S. 1987. Time and age in geology: the use of Upper/Lower, late/early in stratigraphic nomenclature. *Marine and Petroleum Geology* **4**, 255-257.

Harland, W. B. *et al.* 1990. *A Geological Time Scale 1989*. Cambridge University Press.

Rawson, P. F. *et al*. 2002. A guide to stratigraphical procedure. Geological Society of London, Professional Handbook.

Whittaker, A. *et al*. 1991. A guide to stratigraphic procedure. *Journal of the Geological Society, London*, **148**, pp. 813-824.

RECORDING INFORMATION ON A FIELD SHEET

Your field sheet is a very important scientific document. In conjunction with your field notebook it is the complete record of your field observations and is thus the data upon which the interpretation of the geology of your mapping area as shown by your report and fair copy map, cross sections and stratigraphic column is based. The field sheet is not just a scruffy version of a geological map like those purveyed by the British Geological Survey.

The most important information is given by rocks exposed at the surface and so as many exposures as possible must be found and recorded on your field sheet.

The first step is being able to plot your position accurately on the base map. The usual scale of the base map is 1:10,000, so 1mm on the map represents 10m on the ground. By using a combination of position-fixing techniques such as pacing along mapped features, pacing along bearings from a mapped point and using compass resections you should be able to plot to within 1mm on the base map.

The amount of exposure in an area should be easily seen by glancing at the field sheet (and backed up by remote sensing evidence). Some variability in the way in which this is conveyed will be necessary in different areas. In many areas of the UK each exposure should be plotted to scale and outlined faintly with dots. Some exaggeration of size may be necessary, but should be kept to a minimum. Very small exposures may be plotted as a spot. In areas of very good exposure it is better to demarcate the unexposed areas. The use of colour signifying lithology enhances the prominence of the exposures if the actual outlined exposure is coloured using heavier shading than the background level of colouring. A small halo of heavier shading around a small exposure may be used as well. Background shading should be kept very light otherwise the contrast between exposed and unexposed areas will not be obvious.

The main lithologies can be represented by different colours, e.g. sandstones by shades of orange and yellow, limestones by blues and greens, conglomerate and course sands by browns, argillaceous rocks by purples or greys, and igneous rocks by varieties of reds and dark green. You should have sufficient coloured pencils to allow for variations of each lithology. Twelve colours are an absolute minimum and more than twenty are desirable.

A key must be provided on the field sheet for the colours and any symbols used.

While colour on the map indicates the basic lithology, more information can be put on the field sheet as notes, e.g. the colour and other distinguishing features of the rocks. This should be written adjacent to the exposure - where it will not obscure another exposure - using small but clearly legible printing. Contractions of words are likely to be necessary and should be as obvious and unambiguous as possible. Generally single letter contractions should be avoided, e.g. ‘g’ could be grey or green so ‘gy’ and ‘gn’ would be better.

It is essential to put a complete list of abbreviations used (and their meaning) on the field sheet key.

Where adjacent exposures are composed of the same rock unit a single note on the field sheet is sufficient. In addition you should not keep on repeating the same information *ad nauseam.* If there is no variation in lithology single notes will be adequate for several exposures. Where there is a dominant lithology with minor variations colour can be used to indicate the lithology and the variations can be described in the notes.

Structural data are important information and should be clearly visible. Dip and strike of planar structures, e.g. bedding and cleavage, and plunge and direction of plunge of lineations, fold axes etc. should be plotted clearly. The position of the symbol should indicate exactly where the structures were measured. Strike lines should be plotted in the appropriate orientations as should lineation arrows with the angle of dip or plunge. Bedding, cleavage and other structural symbols should be inked onto your field-sheet using your compass-clinometer while you are in the field.

The lithological units that emerge from the mapping need to be defined and named. If a unit is sufficiently distinctive to be delineated by two lines on the 1:25,000 or 1:10,000 scales it qualifies as a ***formation.*** Most formations are hundreds of metres thick, though thickness is not definitive. A name should be chosen from a topographic feature at or near the point where the formation is best exposed, and preferably on it. Incorporation of a rock term in the name is optional. So 'Egham Hill Formation' or 'Egham Hill Sandstone Formation' are equally acceptable. If the latter is chosen as the formal name it can be shortened in any descriptive text to 'Egham Hill Sandstone'.

A ***member*** is a less important, though still mappable rock unit, generally tens rather than hundreds of metres thick. Formations may be completely subdivided into several members but more often contain only one. For example, a prominent sequence of sandstone beds in a formation otherwise made up of shale might well be classed as a member. Members, like formations, must have their own names taken from suitably close topographic features. If there are no such features a member can be referred to informally, e.g. as 'the sandstone member'.

Boundaries between formations, members or other lithological units must be mapped in the field and inked up using an indian ink-pen (0.3mm or less). Black ink should be used for all geological contacts.

Some parts of your area may be poorly exposed. If the area has been properly mapped nothing plotted should be sufficient to indicate lack of exposure. During mapping writing 'no exposure' in pencil in fields or areas that have been searched may be useful but these should ultimately be erased. Significant areas of drift deposits, e.g. alluvium, river terraces, peat, boulder clay, blown sand etc., should be mapped where they occur, especially in areas of poor exposure of the 'solid' geology.

Feature mapping can be used in areas where exposures are sparse, as indications of variations in lithology, possible boundaries and faults, may be inferred from landscape features such as ridges, breaks in slope, gullies and springs.

Ridges trending parallel with bedding may be due to harder beds, e.g. sandstones or limestones, whereas shales may not outcrop at all in depressions between such ridges. The breaks in slope, where the gradient becomes more or less steep, are particularly significant and are plotted as linear features. The breaks in slope on each side of ridges should be plotted. Discontinuous or offset ridges may indicate faulting. Linear valleys or gullies often follow the line of faults and should be plotted on the field sheet.

Not all geomorphological features reflect the underlying geology but plotting as many features as possible in areas of poor exposure often allows geological boundaries and faults to be inferred rather than just guessed. Geomorphological features should be marked using thin continuous lines with ornamentation and should not dominate the field sheet. Thus the inferred boundary and the feature on which it is based can be seen. The geologically insignificant features should not confuse the field sheet.

RECORDING INFORMATION IN YOUR FIELD NOTEBOOK

Your field sheet must be used in conjunction with your field notebook as much more information can be recorded there than can be depicted and noted on your field sheet. To indicate that there is further detail in the notebook a location number should be put on the field sheet close to the relevant exposure. The numbers should not be encircled and must not be confused with structural figures.

Use your notebook to record full descriptions of each of the lithological units in the mapping area with additional information about variations when they are encountered. Details of lithology, sedimentary structures, fossils found etc. together with field sketches, record of photographs taken (and what they were meant to show!) and samples collected should all be recorded. Dips and strikes and all other structural readings should be recorded in your notebook as well as plotted on your field sheet. Many structural measurements may be taken in well-exposed areas and, while only a few can be plotted on the field sheet, all should be recorded in your field notebook.

As a supplement to your field sheet, small areas with many exposures can be sketch mapped on a larger scale in your notebook. This includes detailed maps of wave-cut platforms, stream sections or other extensive rock surfaces as well as interesting or complex parts of your mapping area.

Each lithological unit mapped requires a definitive section to be selected and described. This **type section** should be well-exposed, reasonably accessible and as far as possible representative of the unit as a whole. It should be chosen to show the lower contact of the unit that can be accurately mapped. In the notebook the locality should be given an eight-figure grid reference and the contact zone should be logged on a scale of 1:100 or larger so that the position of the actual contact can be defined within a few centimetres. Ideally the type section should traverse the entire unit, though in practice this rarely occurs due to lack of exposure, and should be logged as this will enhance your stratigraphic column by adding detail and provide material for the descriptions of the various mapped lithological units in your report. The thickness of the lithological unit should be determined at the type section and, if it varies across the mapping area, determined at other places as well.

Finally your notebook should be used to test your evolving ideas about the geology of your area. Sketch possible configurations of the rocks in plans and cross sections.

As your notebook must be used in conjunction with your field sheets it is necessary define each location sufficiently so that the site can be found easily on the map. An eight-figure grid reference is needed to indicate the location for each note. You may need to draw and number additional grid lines on your field sheet. Additional ways of depicting positions are often necessary, such as using sketch maps.

EACH EVENING you must work through your day's observations. Observations on the field sheet, made in pencil to allow for erasure in case of error, must be inked in so that they are not smudged during subsequent days' mapping and appropriate colouring done.

The field notebook must also be worked on — you can show which part of your area you worked in by a sketch map. You can draw conclusions from your day's work about the geology, structure and correlation of the rocks as well as tidying up field sketches, graphic logs etc. In addition you can also plan your next day's mapping.

Try to keep your field sheets flat by avoiding unnecessary folding and crumpling. Ideally glue them to sheets of thick card before you go to the field. A wet field sheet disintegrates rapidly so **keep it dry at all costs.** Even if waterproof field sheets are used a soaking may blur or wash off your observations.

DRAWING CROSS-SECTIONS

This is an important task as it forms part of second and third year field courses and is an integral component of the mapping project. The final versions will be completed after you return from the field, but it is wise to decide where your lines of cross section will be (normally perpendicular to strike). Construct a preliminary section before the end of the field course to see if all makes sense and, if necessary and time permits, try to gather more structural information along the line of section.

If you are not happy with your ability to construct cross-sections then ask your tutor to go through the procedure with you before you go mapping, or consult references 1 or 2 listed below.

REMOTE SENSING

Before and after field mapping it is wise to consult aerial photos, Google Earth or similar remotely sensed images of your area to gain a better understanding of topography, drainage, vegetation, outcrop extent and colour and accessibility. This will greatly assist the mapping process and the subsequent inference of formation boundaries.

Recommended Further Reading

1) Shows the correct way to go about mapping and produce a map, cross-sections and sedimentary logs
Geological Field Techniques Angela L. Coe (Editor), Paperback: 336 pages, Wiley-Blackwell (8 Oct 2010).

2) Provides good practice for drawing cross sections and understanding basic structures
An Introduction to Geological Structures and Maps (A Hodder Education Publication) George M. Bennison, Paul A. Olver, Keith A. Moseley**,** Paperback: 184 pages, Hodder Education; 8 edition (25 Mar 2011).

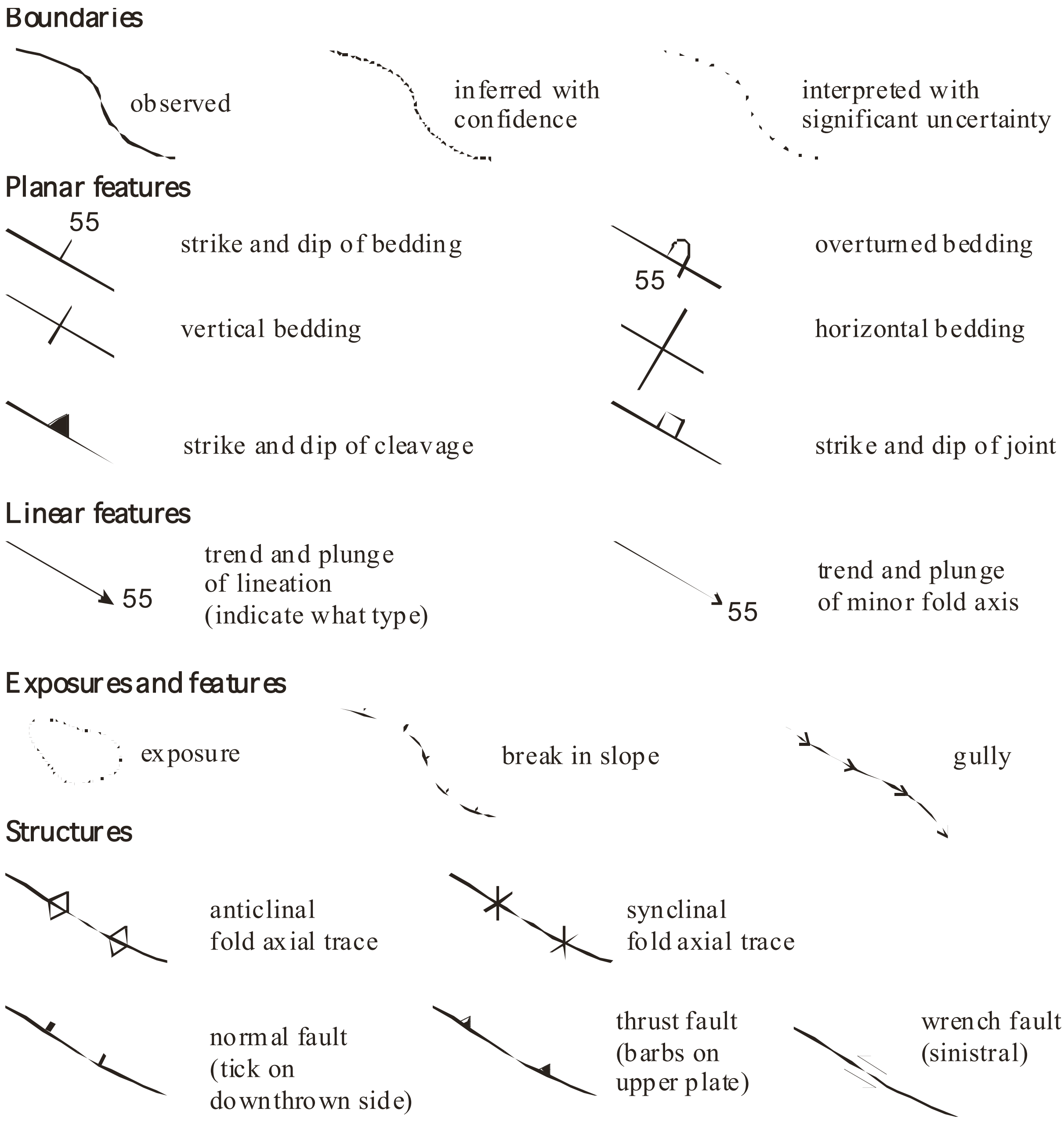
3) Small enough to take into the field and provide assistance
Basic Geological Mapping (Geological Field Guide) Richard J. Lisle, Peter Brabham, Paperback: 240 pages, Wiley-Blackwell; 5th edition (26 Aug 2011).

4) The Geological Society of London, Handbook Series, John Wiley & Sons.

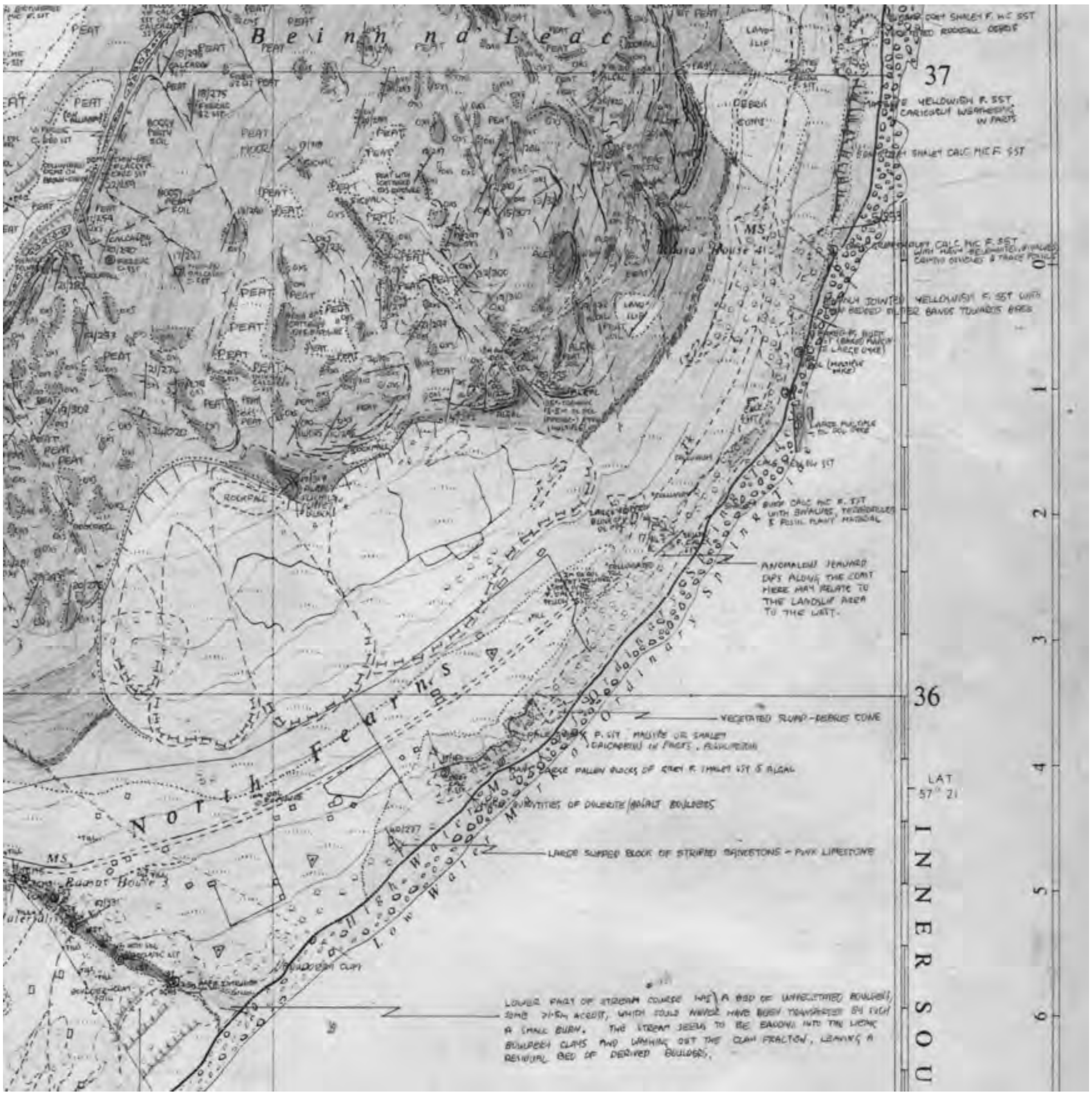
K. McClay	**The Mapping of Geological Structures**
N. Fry	**The Field Description of Metamorphic Rocks**
R.S. Thorpe & G.C. Brown	**The Field Description of Igneous Rocks**
M.E. Tucker	**The Field Description of Sedimentary Rocks**

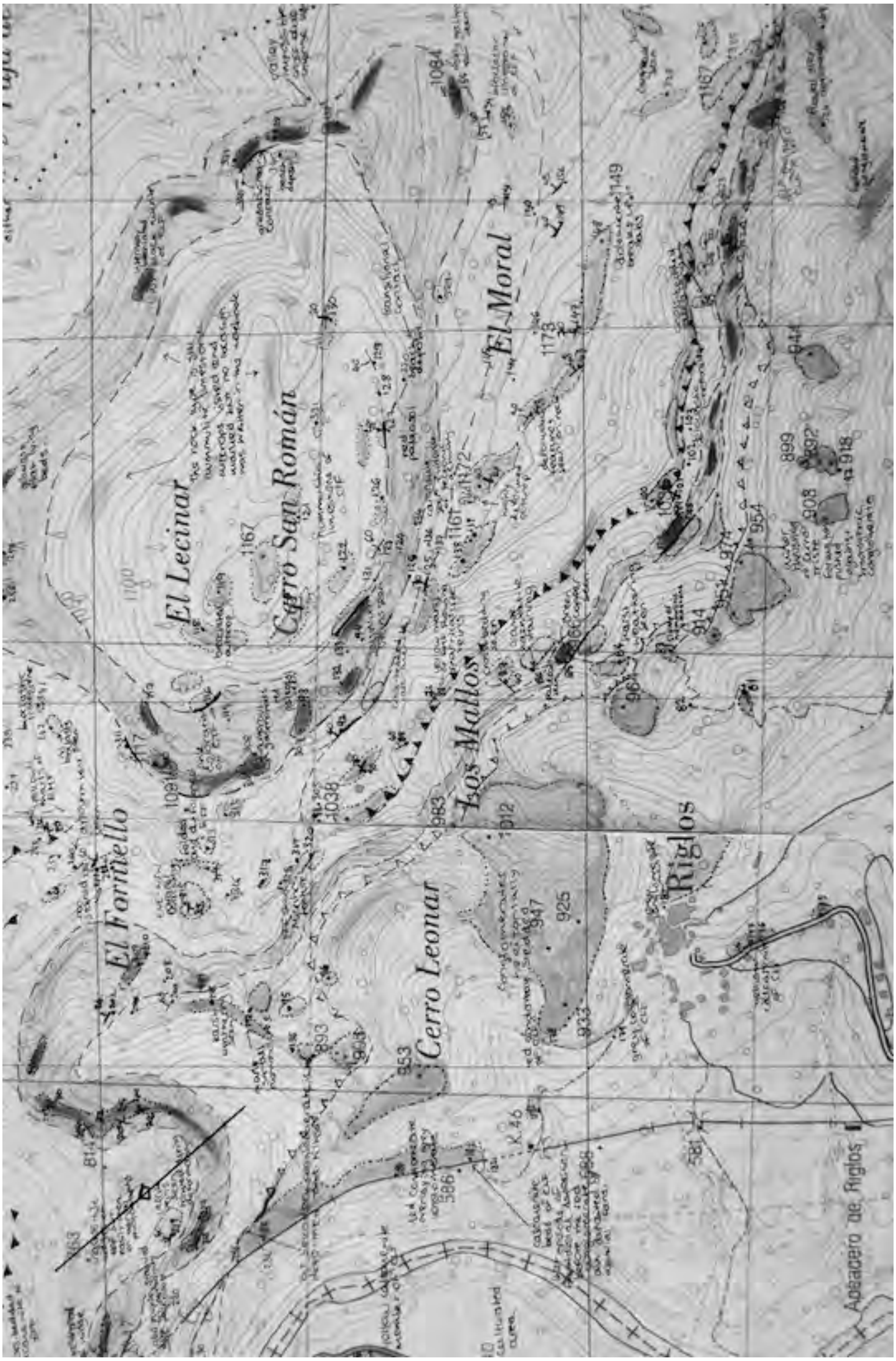
Symbols

There is no single agreed convention for the symbols used on geological field sheets so it is essential to provide a detailed key on your field sheets. These symbols are suggested for general geological mapping. More specialised mapping may use different conventions.



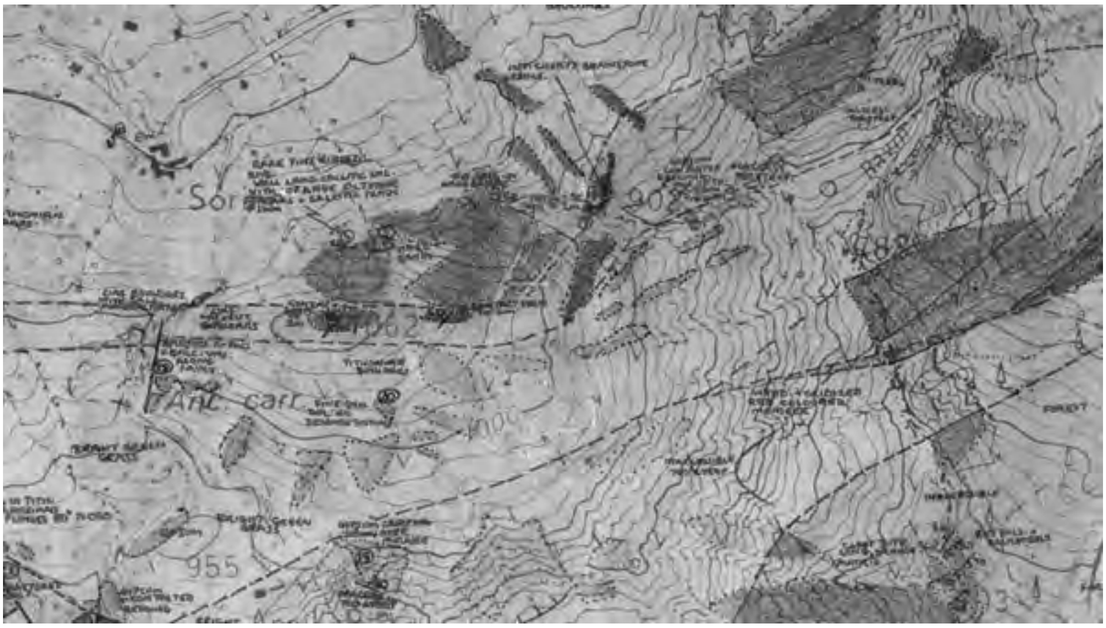
Part of a student's field sheet showing good coverage of the area. Though the differences shown by the use of colour on the original do not come over well in black and white the heavier shading shows clearly where the rocks are exposed. The writing on the original is small, neat and legible, with reasonable use made of the margins and sea space for writing fuller notes.

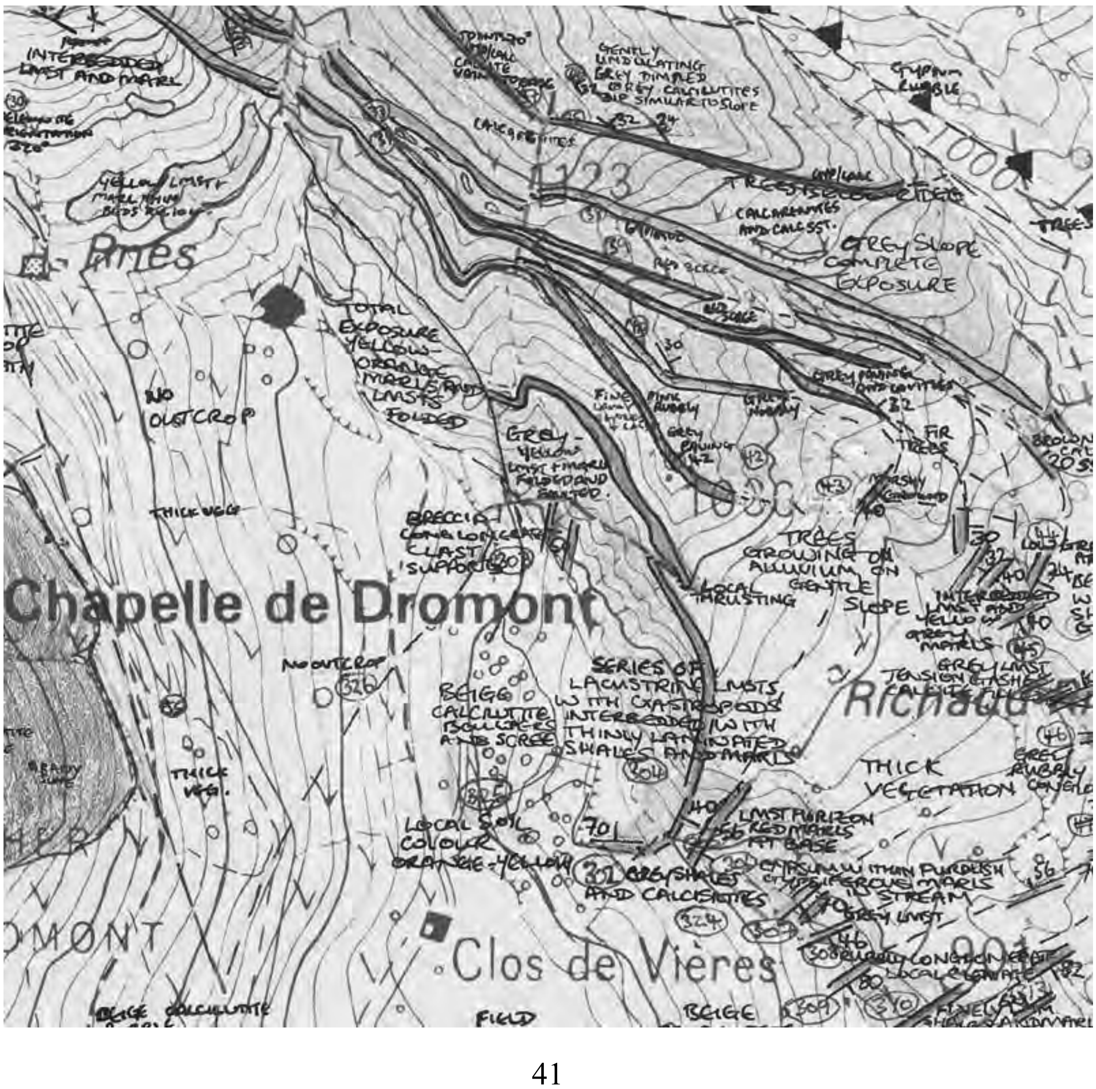




Example of field slip with correctly displayed locations, outcrop extent and inferred boundaries, with a good amount of useful annotation.

Details of small areas of field sheets. Both maps show outcrops clearly. The upper map would benefit from more annotation, and structural information, the lower from having dotted rather than solid outcrop lines and the removal of circles from around the location numbers, and not having annotation cutting outcrop.





Written by Rab Colvine, David Alderton, Gary Nichols, Chris Elders, Ted Rose, Dan Bosence, Martin Menzies and Robert Hall, with help from Ian Davison and Ken McClay, and compiled by Rab Colvine and Robert Hall. Updated by Dave Lowry