Chapter 2
Geological Mapping in Exploration

2.1 General Considerations

2.1.1 Why Make a Map?

A geological map is a graphical presentation of geological observations and interpretations on a horizontal plane.[1] A geological section is identical in nature to a map except that data are recorded and interpreted on a vertical rather than a horizontal surface. Maps and sections are essential tools in visualizing spatial, three-dimensional, geological relationships. They allow theories on ore deposit controls to be applied and lead (hopefully) to predictions being made on the location, size, shape and grade of potential ore bodies. They are the essential tool to aid in developing 3-dimentional concepts about geology and mineralisation at all scales. As John Proffett – widely regarded as one of the most skilled geological mappers in the exploration industry of recent decades – has written (Proffett, 2004):

> Because geological mapping is a method of recording and organising observations, much of its power in targeting lies in providing conceptual insight of value. Conceptual tools can then help in the interpretation of isolated outcrops and drill hole intercepts that might be available in and adjacent to covered areas.

Making, or otherwise acquiring, a geological map is invariably the first step in any mineral exploration programme, and it remains an important control document for all subsequent stages of exploration and mining, including drilling, geochemistry, geophysics, geostatistics and mine planning. In an operating mine, geological mapping records the limits to visible ore in mine openings, and provides the essential data and ideas to enable projection of assay information beyond the sample points.

Making a geological map is thus a fundamental skill for any exploration or mine geologist.

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[1] The ground surface is, of course, not always horizontal and, although this can usually be ignored in small-scale maps, it can have profound effects on the outcrop patterns of large-scale maps.

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2.1.2 The Nature of a Geological Map

A geological map is a human artefact constructed according to the theories of geology and the intellectual abilities of its author. It presents a selection of field observations and is useful to the extent that it permits prediction of those things which cannot be observed.

There are different kinds of geological map. With large-scale[2] maps, the geologist generally aims to visit and outline every significant rock outcrop in the area of the map. For that reason these are often called "fact" maps, although "observation" or simply "outcrop" map is a much better term. In a small-scale map, visiting every outcrop would be impossible; generally only a selection of outcrops are examined in the field and interpolations have to be made between the observation points. Such interpolations may be made by simple projection of data or by making use of features seen in remote sensed images of the area, such as satellite or radar imagery, air photographs, aeromagnetic maps and so on. Small-scale maps thus generally have a much larger interpretational element than large-scale maps.

The difference between the two map types is, however, one of degree only. Every map, even at the most detailed of scales, can only present a small selection of the available geological observations and no observation is ever entirely free from interpretational bias. Even what is considered to represent an outcrop for mapping purposes is very much scale dependent. In practice, what the map-maker does is to make and record a certain number of observations, selected from the almost infinite number of observations that could be made, depending on what he regards as important given the purpose in constructing the map. These decisions by the geologist are necessarily subjective and will never be made with an unbiased mind. It is often thought that being biased is a weakness, to be avoided at all costs – but bias is the technique used by every scientist who seeks to separate a meaningful signal from noise. If we were not biased, the sheer volume of possible observations that could be made in the field would overwhelm us. An explorationist has a bias which leads her to find and record on her map features that are relevant to mineralisation. This will not be to the exclusion of other types of geological observation, but there is no doubt that her map will (or at any rate, should) be different from a map of the same area made by, say, a stratigrapher, or a palaeontologist. However, you can only use your bias to advantage if you are aware it of and acknowledge it – otherwise you risk fooling yourself.

A geological map is thus different from other types of map data that the explorationist might use. Although typical geochemical or geophysical maps can contain interpretational elements and bias, they in general aim to provide exact presentations of reproducible quantitative point data. The data on such maps can often be collected

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[2] By convention, large-scale refers to maps with a small scale ratio (that is, a large fraction) – e.g. 1:1,000 scale or 1:2,500 scale. Small-scale refers to large scale ratios (a small fraction) such as 1:100,000 or 1:250,000. Generally, anything over 1:5,000 should be considered small-scale, but the terms are relative.

by non-professionals and the map can be compiled and plotted by computer according to pre-set formulae. A geological map, on the other hand, is not contoured point data but an analog presentation of ideas; ideas backed up by detailed, careful observation and rational theory but, nevertheless, ideas. To be a successful geological map-maker, it is necessary to keep this concept firmly in mind, and throw out any idea of the geological map-maker as an objective collector of "ground truth"[3] data. After all, one geologist's "ground truth" may be another geologist's irrelevant noise.

2.1.3 Intelligent Mapping

Producing a geological map is a process of problem solving. One of the best ways to approach problem solving is known as the system of multiple working hypotheses.[4] In practice this means that the geologist does not start the field work with a completely blank mind, but armed with ideas about the geology which has to be mapped. These ideas are developed from looking at published maps, from interpreting air photos, satellite images or aeromagnetic data or even by following an intuitive hunch. From these ideas or hypotheses, predictions are made: areas are then selected and observations are made which will most effectively test these predictions. Sometimes this will involve walking selected traverses across strike, sometimes following a marker horizon or contact, sometimes a more irregular search pattern. The mapping sequence depends on the postulated geology: strong linear strike continuity usually indicates that across-strike traversing is the best approach; complex folding or faulting is best resolved by following marker horizons, and so on. In any case, the early working hypotheses will certainly contain several alternative scenarios and may not be precisely formulated; to check them out a very wide range of field observations will have to be made and a mix of different search patterns may need to be followed. The geologist at this stage must be open to all possible ideas, hypotheses and observations. If the observations do not fit the hypotheses, then new hypotheses must be constructed or old ones modified to accommodate the observations. These new hypotheses are then tested in their turn, and so the process is repeated.

With each step in the process the predictions become more precise and the search pattern more focused on to the key areas of interest. These are the usually areas where significant boundary conditions can be defined in the outcrop. Most of the time of the intelligent mapper is thus spent in the areas of "fertile" outcrop where there is most to be learned, and less time is spent in those areas where the rocks are uniform – in the latter areas a lower density of observation will serve (Fig. 2.1).

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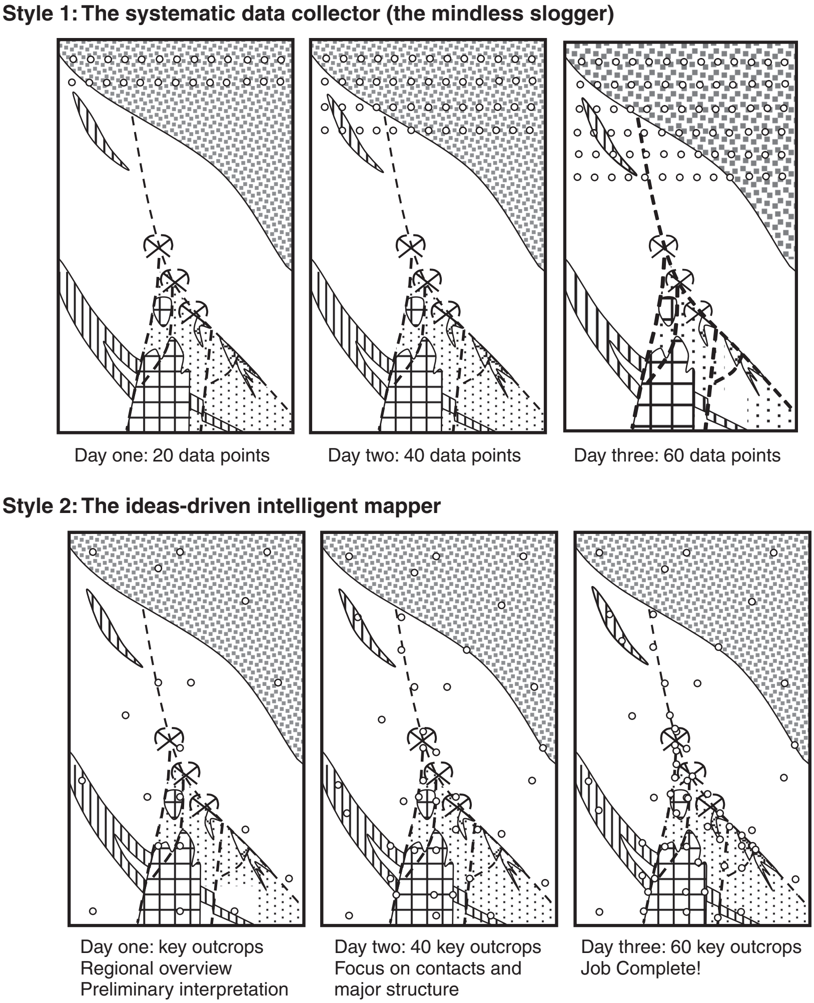
[3] "Truth" and "fact" are slippery concepts that are often employed to claim authority and stifle debate. They are best not used in scientific contexts.

[4] The concept of multiple working hypotheses, now widely acknowledged as a basic part of the scientific method, was first enunciated by geologist Thomas Chrowder Chamberlin (1897).



Style 1: The systematic data collector (the mindless slogger)

Day one: 20 data points

Day two: 40 data points

Day three: 60 data points

Style 2: The ideas-driven intelligent mapper

Day one: key outcrops
Regional overview
Preliminary interpretation

Day two: 40 key outcrops
Focus on contacts and
major structure

Day three: 60 key outcrops
Job Complete!

Fig. 2.1 Comparison of geological mapping styles. In the first case, the "systematic data collector", driven by a pre-determined inflexible strategy rather than ideas, regularly traverses the ground. The task will eventually be completed, but this is not the most efficient procedure. The intelligent mapper on the other hand continuously assesses the significance of each outcrop against evolving ideas about geology, and then determines strategy in the search for the next significant outcrop. The job is completed more quickly, and better too

Many small structural features can be observed in individual outcrop or hand specimens that allow predictions to be made about large structures occurring at the scale of a map. Most useful of such observations are the predictable geometrical relationships that occur between bedding, cleavages, lineations and folds, as well as movement indicators that can be used to deduce the sense of movement on brittle faults and ductile shear zones. Where such structures as these occur, they are a boon to the field mapper, and he should learn to recognize and make use of them. A detailed description of these structures is beyond the scope of this book but they are treated in many standard geology texts. Some useful references will be found in Appendix F.

Another aspect of rocks is the way the features and relationships seen in hand specimen or outcrop often exactly mirror features occurring at map scale. This has been informally called "Pumpelly's Rule" after Raphael Pumpelly, the nineteenth century USGS geologist who first described it.[5] Once again the intelligent mapper will be on the look out for such potential relationships in outcrop as a means of developing ideas as to the map scale geological patterns.

With geochemistry having a major role in most modern exploration programmes, the geological map will usually play a large part in the planning and understanding the results of surface geochemical sampling programmes. In order to fulfil this role, exploration geological mapping in most cases will need to carefully show the distribution of superficial and weathered rock units (the regolith), as well as bedrock features.

Observations are thus not made randomly, nor are they collected on a regular grid or according to a fixed search pattern; rather they are selected to most effectively prove[6] or disprove the current ideas. Geological mapping is a scientific process and when carried out properly corresponds to the classic scientific method: theorizing, making predictions from the theories, and designing experiments (planning the required field observations) to test the predictions.[7]

An aspect of this technique is that thinking and theorizing are constantly being done while field work proceeds. In other words, data collection is not a separate and earlier phase from data interpretation; these two aspects are inextricably linked and must proceed together. Above all, observation and interpretation should never come to be regarded as "field work" and "office work".[8]

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[5] Today we recognize that geological processes are essentially chaotic (i.e. non-linear). Such systems typically exhibit what is called "scale-invariance", meaning there is a repetition of characteristic patterns at different scales – the example often quoted being the comparison in shape between a rock pool and the coastline of which it is an element. Pumpelly's Rule is an early recognition of this type of relationship (see Pumpelly et al., 1894).

[6] Actually, as pointed out by the philosopher of science Karl Popper (1934), an experiment either falsifies a hypothesis or expands the range of conditions under which it can be said to hold good: it can never prove it.

[7] All theories in science, and that includes ideas on geology, must be formulated in such a way that they are capable of being falsified. For example, for field mapping purposes it is not very useful to postulate that "these outcrops constitute a metamorphic core complex" because there is unlikely to be a simple observation which can falsify that statement. Rather postulate "this outcrop is felsic gneiss, that outcrop is sandstone, this contact is a mylonite" – if these turn out to be false then the hypothesis may need revision.

[8] In our society from the earliest training we are unfortunately conditioned to think indoors, and to enjoy less cerebral pursuits outdoors. It is a syndrome that the field geologist must learn to break.

2.1.4 Choosing the Best Technique

The mapping technique used depends upon the availability of suitable map bases on which to record the field observations. A summary of the different techniques is given in Table 2.1.

The ideal base is an air photograph or high resolution satellite image, as these offer the advantages of precise positioning on landscape/cultural/vegetation features combined with an aerial view of large geological structures that cannot be seen from the ground. For small-scale maps (say 1:5,000–1:100,000) remote sensed images are virtually the only really suitable mapping base, although if good topographic maps are available at these scales they can be used as a second-choice substitute. In Third World countries, where there is often no aerial photography available at any suitable scale, satellite imagery can provide a suitable base for regional geological mapping. Radar imagery, whether derived from satellite systems or special aircraft surveys, can also be used as a geological mapping base in much the same way as aerial photography.

In the special case of mine mapping, the mapping base is usually a survey plan of the mine opening prepared by the mine surveyor and supplemented by accurately established survey points from which distances can be taped. In open-cut mines, most available rock surfaces are vertical or near-vertical; observations are thus best recorded onto sections and afterwards transferred to the standard level plans, a composite open-cut plan or mine sections. In underground mines, observations can be made on the walls, roofs and advancing faces of openings, and are then recorded and compiled onto a section or plan. These mapping techniques are detailed in subsequent sections.

For surface mapping, suitable photography is often not available or is only available at too small a scale to permit photo enlargement for detailed mapping purposes. In many cases also, air photographs are difficult to use for precise field location because of vegetation cover or simply because of a lack of recognizable surface features. In areas of very high relief, photos can also be difficult to use because of extreme scale distortions. In these cases, alternative techniques are available to provide the control for detailed mapping. In order of decreasing accuracy (and increasing speed of execution) these mapping techniques are: plane table mapping, mapping on a pegged grid, tape and compass mapping, and pace and compass mapping.

Plane table mapping is seldom done nowadays because it is slow and the alternative use of pegged grid control can provide all the surveying accuracy that is normally required for a geological map. Further disadvantages of the plane table technique are the requirement for an assistant and the fact that geological observation and map-making usually have to be carried out as two separate processes. However, plane tabling provides great survey accuracy and is an invaluable technique where precision is needed in mapping small areas of complex geology. Such situations often arise in detailed prospect mapping or in open-cut mine mapping. The plane table technique is also indicated where a pegged grid cannot readily be

Table 2.1 Comparison of mapping techniques

Mapping technique	Ideal scales	Indications	Advantages	Disadvantages
Pace and compass	1:100–1:1,000	Rough prospect map. Infill between survey points	Quick. No assistance and minimal equipment needed	Poor survey accuracy, especially on uneven ground
Tape and compass	1:100–1:1,000	Detailed prospect maps. Linear traverse maps. Mine mapping	Quick. Good accuracy. No preparation needed	May need assistance. Slow for large equidimentional areas
Pegged grid	1:500–1:2,500	Detailed maps of established prospects	Fair survey accuracy. Relatively quick. Same grid controls/correlates all exploration stages	Expensive. Requires advance preparation. Poor survey control in dense scrub or hilly terrain
Plane table	1:50–1:1,000	Detailed prospect mapping in areas of complex geology. Open cuts	High survey accuracy. No ground preparation required	Slow. Requires assistance. Geological mapping and surveying are separate steps
GPS and DGPS	1:5,000–1:25,000	Regional and semi-regional mapping. First pass prospect mapping	Quick, easy downloadable digital survey data. Good backup for other techniques at similar scales	Encourages geological mapping as collection of point data
Topographic map sheet	1:2,500–1:100,000	Regional mapping and reconnaissance. Areas of steep topography. Mine mapping. Base for plotting GPS observations	Accurate georeferenced map base. Height contours	Difficulty in exact location. Irrelevant map detail obscures geology. Not generally available in large scales
Remote sensed reflectance imagery	1:500–1:100,000	Preferred choice. Ideal geological mapping base at all scales	Geological Interpretation directly from image. Stereo viewing. Easy feature location	Scale distortion (air photos). Expensive if new survey needs to be acquired

used, for example, mapping a disused quarry or open cut. Plane table mapping is therefore a useful skill for a field geologist to acquire.

Pegged grids are used for outcrop mapping at scales of 1:500–1:2,500 and are a commonly used survey control for making detailed maps. The technique relies on placing a close network of survey pegs into the ground at regular stations on a Cartesian coordinate system (see Sect. 10.5.2). The coordinates are marked onto the pegs that are then placed in the ground to provide control for all stages of exploration over the area. The disadvantages of using a pegged grid lies in its expense, and the danger that geologists often come to regard the grid as a series of predetermined geological traverse lines, rather than a pre-positioned network of points for survey control.

A measuring tape and compass or Hip-Chain™ and compass survey allows for quick production of detailed prospect maps, or maps to provide a base for location of sample points in areas where the geologist cannot spend long on site. With this technique it is possible to produce a high-quality, detailed geological map without needing any advance preparation (provided there is a tape or hip-chain available[9]).

If there is no measuring tape available then pacing distances can still allow a rough map to be constructed. Pacing is better than estimation and has the advantage of being quick. Pacing can even be reasonably accurate for short distances over open flat ground. Explorationists should be aware of their normal pace length by laying out a 100 m tape along flat even ground and checking pace length by walking back and forward many times (using a normal, easy stride) and taking an average. Every time a pegged grid line is walked, the pace length over different types of terrain should be checked.

2.1.5 Choosing the Best Scale

The scale chosen for mapping controls the type of data which can be recorded and hence the type of observations which are made in the field (see Fig. 2.2). The choice of appropriate scale depends on the purpose in making the map.

A small-scale map – say at 1:25,000 or smaller – shows broad regional patterns of rock distribution and major structures. From an exploration point of view this is the scale at which the prospectivity of a basin, fold belt, tectonic unit or other large geological subdivision might be determined. It is a scale appropriate for developing ideas for new project generation. Explorationists do not often make maps at these small scales. There are two reasons for this: firstly, this is the type of mapping undertaken by Geological Surveys and can often be bought off the shelf; secondly,

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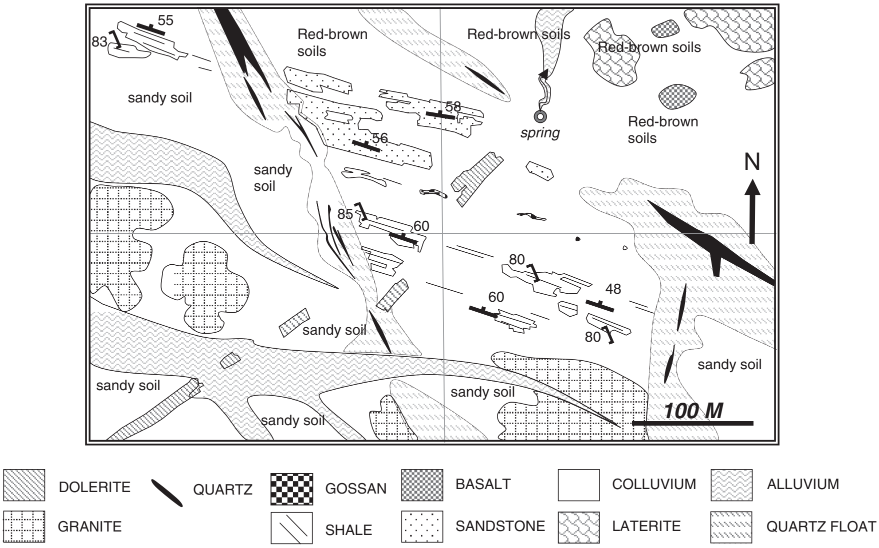
[9] Hip-Chain™ is a reel of disposable, biodegradable cotton thread. As it reels from its spool, a meter records the length wound off, and hence the distance travelled. The thread is then simply broken and left on the ground. Other brand names for similar measuring instruments are Fieldranger™, Chainman™ and Topofil™.

WOLLOMAI PROSPECT 1:1000 SCALE - OUTCROP MAPPING



WOLLOMAI PROSPECT 1: 5000 SCALE - DETAILED REGIONAL MAPPING

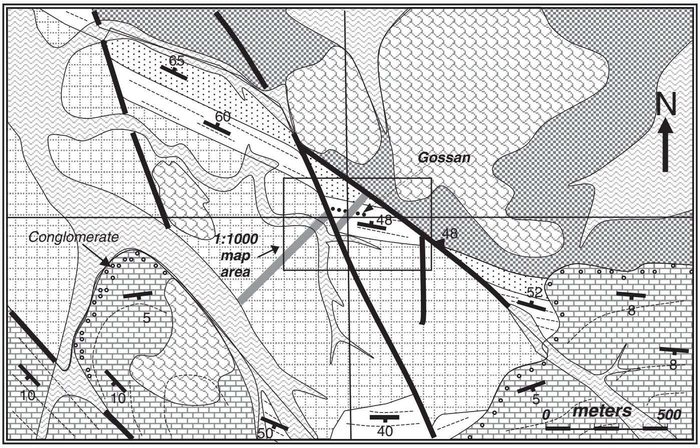


Fig. 2.2 How the scale chosen affects the style and content of geological maps of the same area. Generalisation is required at all scales. There is no such thing as a "fact" map. However, the component of field observation is greatest in large-scale maps

explorationists in most cases cannot obtain a sufficiently large tenement holding to make this kind of mapping worth while.

Maps with intermediate-range scales between 1:25,000 and 1:5,000 can be described as detailed regional maps. These are appropriate scales for the first-pass mapping of large tenement holdings. They are also ideal scales to use when combining geological mapping with regional prospecting or regional geochemistry (such as stream sediment sampling). At scales in this range, some of the larger features which might have had an effect on the localization of ore are capable of being shown, although the outline of an ore deposit itself could not generally be shown. The intermediate range of map scales is therefore suitable for the control and development of new prospect generation.

On maps at scales more detailed than 1:5,000, individual outcrops or outcrop areas and the surface expression of significant areas of mineralization can be shown. These scales are appropriate for showing the features that directly control and localize ore. Maps at these scales are often called outcrop maps and the need to make them generally arises after a prospect has been defined. The purpose of such maps is to identify the size, shape and other characteristics of the potential ore body. The map is then used to help specify, control and evaluate all subsequent programmes of detailed prospect exploration including geophysics, geochemistry and drilling.

2.1.6 Measuring and Recording Structures

To fully define and understand the attitude of a planar surface such as a bedding plane, cleavage, joint, vein etc., a geologist needs to know its strike, its dip and the direction of the dip towards one of the principal compass quadrants. Of these measurements, the strike is usually the most important, because it is that which defines the potential continuity of the surface in the horizontal plane of a geological map, or between the adjacent sections of a drilling program. When measurements are recorded digitally (as opposed to analog recording as a strike and dip symbol on a map) the most common traditional way has been in the form of *xxx/yy/A*, where *xxx* (the strike) is a 3-digit compass bearing (000–360°), *yy* (the dip) a two digit number representing the angle from the horizontal (00–90°) and A is the direction of dip towards a principal compass direction or quadrant (i.e. *N, NE, E, SE, S, SW, W* or *NW*). As an example: *042/23 NW* is a surface with strike of 42° that dips at 23° to the northwest. Because this method requires three data fields (strike, dip and dip direction) the advent of computer-based databases has lead to a variety of other ways, utilising only two data fields, being employed for digital recording of the measured attitude of planes. These involve recording attitude as dip and dip direction, or as a simple strike and dip with the dip direction qualifier recorded by means of a convention in the way the strike number is expressed. The most common of these conventions is the so-called “right-hand rule”. This rule can be explained thus: imagine grasping a strike/dip map symbol with the right hand, palm down and fingers pointing in the direction of dip. The thumb then indicates the strike direction to be recorded. For example: an east-west strike (090–270°) with a 60° dip to the north would be recorded as 270/60. A record of 090/60 would indicate the same strike but a dip of 60° to the south.

These different methods of recording the attitude of planes are described and discussed in detail in Vearncombe and Vearncombe (1998).

The attitude of linear structure is measured and recorded as its trend and plunge (see Fig. E.4). Trend is defined as the horizontal direction or strike of a vertical plane passing through the lineation, measured in the direction of plunge. It is recorded as a compass bearing between 000 and 360°. Plunge is the angle that the lineation makes with the horizontal, measured in the vertical plane. A measurement of 76/067 represents a plunge of 76° towards 067°. If a lineation lies in a plane, then it can be measured as its pitch on that plane. A pitch is the angle that a lineation makes with the horizontal, measured in the plane that contains the lineation. If the attitude of the plane is also known, then knowing the pitch enables the trend and plunge to be calculated. The simplest way to do this is by means of a stereonet (Fig. D.2).

Any computer software used should be capable of accepting and presenting data in all the above formats.

2.1.7 Using Satellite Navigation (GPS)

Small, battery-operated, man-portable instruments have been available since the late 1980s to make use of the satellite-based global positioning system GPS).[10] They are a boon to many aspects of field geology. Since the GPS provides location data based on latitude/longitude or regional metric grid coordinates, it is of most value for fixing position or navigating on a published map sheet on which these coordinates are marked.[11] This makes GPS ideal for regional geological mapping onto published map bases or for regional prospecting and regional and detailed geochemical and geophysical data collection. Observations and sample locations can be quickly recorded against location coordinates and the position of each data point readily found again should that become necessary. In addition, the explorationist can roam around the country on foot, by vehicle or plane, following outcrop, evolving ideas or hunches, confident that anything interesting found can be easily located again, and, at the end of the day, the GPS instrument will provide a direct route back to base camp.

Some limitations in the operation of GPS instruments should be noted however:

- For the most accurate location signal, GPS devices need an unobstructed line of sight to the satellites. At least four widely spaced satellites must be "seen" for an accurate triangulated fix to be computed. This means that GPS will not work well in heavily wooded or forested areas except where large clearings can be found.[12]

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[10] GPS is operated by the US Department of Defence and is available free to all civilian users. At the time of writing (2010) it is currently the only commercially-available available GPS system. From 2013, on current estimates, the European Galileo satellites will provide an alternate coverage.

[11] The most commonly used grid is Universal Transverse Mercator metric grid (UTM). A description of coordinate systems will be found in Sect. 10.5.

[12] However, in forested areas, GPS is a boon for airplane or helicopter operations. The geologist dropped off in a clearing in the rain forest to collect a stream sediment sample need never again fear that the helicopter pilot will not be able to find that particular hole in the canopy again.

The presence of adjacent cliffs or rock faces (such as might be encountered in a mine open cut) can also seriously degrade the satellite signal and lead to lower levels of accuracy, or even a complete absence of signal.

- At the time of writing (2010) the GPS system only provides a maximum consistent accuracy from small hand-held units of 10–15 m in the horizontal direction. Maximum potential errors in altitude are generally slightly greater. That means that a GPS position plotted onto a map could lie anywhere within a circle of 20–30 m diameter. This provides a practical limit to the scales at which hand-held GPS-controlled mapping can be employed. A position error of 30 m at 10,000 scale is 3 mm. This might be acceptable, but at 1,000 scale the equivalent potential 30 mm error in plotting a point on a map would not.

  Better GPS accuracy can be provided by averaging a number of fixes over a period (some GPS units can do this automatically) but this process takes time. High accuracies of the order of ±3 m can be achieved by the use of two time-coordinated GPS units, the location of one of which is fixed. This is known as differential GPS (DGPS). For it to provide fixes in real time there has to be a short-wave radio link between the mobile and fixed GPS units. Alternatively, data from the two units can be subsequently downloaded to computer, and an accurate position calculated. The highest GPS accuracies (maximum errors around 1 m) are obtainable by making use of special GPS correction radio signals. These systems make use of signals from geostationary satellites to calculate a correction map for their area of coverage. DGPS equipped receivers can then make use of this data to correct their position fix. However, at the time of writing, these signals are only available in some areas of the developed world. In the United States the system is called the WAAS system (Wide Area Augmentation Service), in Europe as EGNOS (Euro Geostationary Navigation Overlay Service) and in Japan as MSAS (Multifunctional Satellite Augmentation System). High accuracy DGPS systems are normally employed for accurate surveying applications (such as for aircraft navigation systems, accurate land surveying (i.e. claim boundaries) or levelling gravity stations), but at present have limited application for a geologist trying to create a large scale geological map in the field.
- Relying exclusively on GPS for navigation can create problems (potentially serious) should the unit become inoperative. Never rely on GPS to the point where, if the instrument stops working for whatever reason, you cannot find your way safely back to base.
- GPS cannot be used to provide accurate positioning on air photographs since these lack coordinates and contain scale and angle distortions. However, it is still useful to approximately locate oneself on a photo by using the GPS to provide a distance and bearing to a known feature of the photo scene. That feature has been previously entered as a waypoint in the GPS instrument's memory. In most cases, knowing an approximate position on an air photo will enable an exact fix to be quickly obtained by means of feature matching. Ground-located photo features for entering as waypoints should ideally be located in the central two-thirds of the photo scene, where distortion of the image is minimal.

- Plotting latitude and longitude coordinates in the field is difficult. Metric grid coordinates such as UTM (Universal Transverse Mercator, for a detailed description see Sect. 10.5) are much easier to use. Make sure your GPS unit can provide a fix in latitude/longitude and regional metric grid coordinates.
- In many parts of the Third World where explorationists operate, available published maps are often based on poor-quality photogrammetry with little or no ground checking. Such maps can be highly inaccurate. Even where photogrammetry-based maps have been made with care, in heavily forested country the map-maker has often been unable to accurately position smaller streams, roads or villages because of the obscuring tree canopy. In these areas, the GPS fix, being more accurate than the map, can be very misleading when it comes to trying to locate a particular feature.

2.2 Mapping Using Reflectance Imagery as a Map Base

2.2.1 General

Light from the sun reflects from the earth's surface and radiates in all directions, including (provided it is not blocked by clouds) back into space. Any system which can record the intensity and wavelengths of the reflected light and reproduce the data as an image, is known as reflectance imagery. The instrument that does this can be mounted on either an aircraft or satellite. The word photograph is specifically used for images recorded onto photographic film by a camera lens system. This section deals primarily with air photographs – i.e. photographs taken looking vertically down from an aircraft – but most of the comments apply equally to the handling and use of hard copy satellite images. Details about how satellite images are acquired and presented, and how they can be used as a remote sensing geophysical tool (spectral geology), will be found in Chap. 8.

In air photography, a camera mounted in an aircraft takes a series of photographs as the plane flies in regular parallel passes over the terrain. Air photographs have the advantage of being relatively cheap to collect and, since they are taken at low altitude, can show great detail. Overlapping adjacent photographs along the flight path (Fig. 2.3) enables subsequent stereoscopic (3-dimensional) viewing (Fig. 2.5). Air photographs typically offer a resolution of ground features that range in size from a few centimetres upwards, depending on the height of the aircraft above the ground and the quality of the camera optics used. Film is an analog method of recording data that offers exceptionally high resolution that is ultimately limited only by the grain size of the chemical emulsion on the film. The resolution of the film used for air photographs is an order of magnitude greater that is currently achievable with electronic recording methods. Air photographs are typically collected for normal viewing at scales of from 1:500 to 1:100,000, but, unlike digital images, they can be enlarged many times without losing resolution.

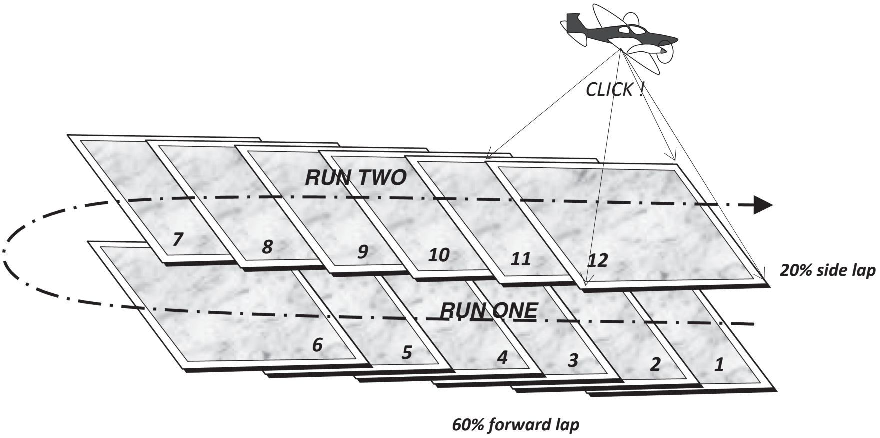

Fig. 2.3 Typical specification of an air photo survey designed to obtain full stereo coverage

2.2.2 Acquiring Air Photographs

Many governments (including all first world countries) have acquired air photo coverage of their territories and these can usually be purchased from the relevant government agency. Needless to say, the quality and coverage of this product varies enormously, but since it is a cheap resource, it is always worth checking to see what is available. In areas where there has been a high level of mineral exploration, surveys flown by previous explorers may also be available. If none of these avenues yields a useful product, it is possible to commission your own survey. This is comparable in cost to purchasing high resolution satellite imagery for the same area and gives the opportunity to specify a scale and coverage that will suit your project.

2.2.3 Geological Interpretation

Air photographs (along with other similar remote sensed products such as satellite and radar imagery) provide both a mapping base on which to record field observations and an integrated view of landscape on which map-scale patterns of lithology and structure can be directly observed or interpreted. Where available at a suitable scale and resolution, they are the pre-eminent medium upon which to construct a geological map.

For any geological mapping programme making use of remote sensed imagery, image interpretation represents the idea-generating, integrative, control and planning phases of that programme. The initial interpretation made from the images will provide:

- definition of areas of outcrop and areas of superficial cover;
- preliminary geological interpretation based on topographic features, drainage patterns, colours and textures of rocks, soils and vegetation, trend lines of linear features, etc.;
- geological hypotheses for field checking;
- selection of the best areas to test these hypotheses;
- familiarity with the topography and access routes to assist in logistic planning of the field programme – access roads and tracks, fording points for streams and gullies, potential helicopter landing sites, etc.

Air photo or satellite image interpretation needs to be carried out before, during and after the field phases of the mapping process. Obviously, detailed interpretation making use of stereo viewing can be most conveniently done at an office desk, but, as ideas change or evolve, interpretation of photo features will have to be attempted in the field as well. The ability to use a pocket stereoscope on the outcrop is an essential skill to acquire.

Since making and interpreting geological observations on the photo and outcrop are two aspects of the same process, they should ideally be carried out by the same person.[13] Whenever possible, the field geologist should do his own interpretation.

Geological interpretation of remote sensed imagery complements field mapping and should never be regarded as an adequate substitute for it.

Skills required for the geological interpretation of remote sensed imagery are very much the same as those needed for field mapping. However, some practical techniques need to be learned in order to turn air photo observations into usable geological maps. The next section describes some of these techniques.

2.2.4 Determining Scale

The scale of an air photograph is determined by the height above the ground of the airplane taking the photograph, divided by the focal length of the camera used (Fig. 2.4). Thus:

$$\text{Photo scale} = 1\text{:}\ \frac{\text{Airplane height above ground}}{\text{Focal length of camera}}$$

A scale is generally printed onto the edge of an air photograph but this is a nominal scale only and should always be checked for a number of scenes across the area of the air photo survey.

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[13] Highly skilled and experienced geologists are available who specialize in the field of air photo and satellite image interpretation. Their use is indicated for training purposes; where they have particular knowledge of the geology or landforms in the area to be mapped; or where there is little possibility of any substantial field access to the region.

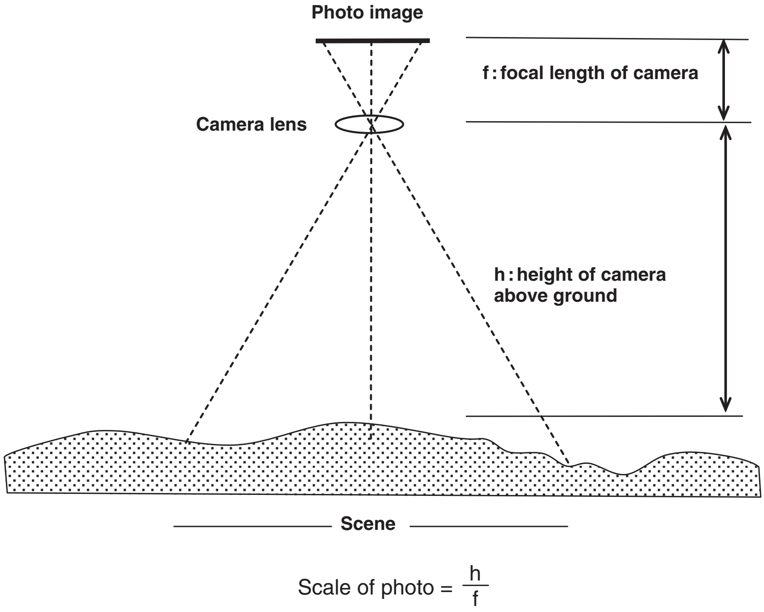

Fig. 2.4 How to calculate the scale of an air photograph

The airplane altimeter height (i.e. height above sea level) and camera focal length are also normally marked on to the edges of an air photograph and provide a means of calculating the exact scale, using the above formula, provided the average height of the ground above sea level is known for that scene. Cameras designed for photographic surveys have very long focal lengths to enable them to fly at greater heights for a given scale.

Even though the pilot of the plane tries to maintain a constant ground height whilst flying a photographic survey, this is not always possible. The scale can thus vary from image to image. The variation in scale from this cause is usually small, but is greatest for large-scale photographs and in areas of strong relief.

Another way of checking the scale is to measure the length of a known feature in the central portion of the photo (such as a section of road or stream) and compare it with the same section identified on a detailed topographic map of the same area. Make several such measurements along different bearings on each image and take the average to get the true scale for the scene.

In addition to these scale variations, the stated photo scale is correct only for the central area of the photograph and is progressively distorted towards its edges. Since the distortion increases exponentially outwards, the central 60% of the scene has only minimal distortion which can generally be ignored. The radial distortion also affects angular relationships. For this reason, if at all possible, interpretation should not be carried to the edges of a photograph. This is easy to do on the edges of photos along the flight line (the forward lap) where a 60% overlap is usually available with adjacent frames, but more difficult on the photo edges across the flight line (the side lap) where the overlap with adjacent runs is generally only 20%[14] or less.

Air photos usually have a north arrow plotted on their edge but this arrow cannot necessarily be taken as accurate – any yawing of the plane at the moment when the photo was taken can make this considerably in error. This problem will usually affect only a few photographs and can be picked up and corrected when adjacent photos are compared during the initial interpretation period. It is a good idea to compare each photo with a topographic base map and, where necessary, correct the north arrow marked on the photograph.

2.2.5 Stereoscopic Image Pairs

When images of a feature from two different angles are taken, there is a relative shift in the apparent position of the feature on the images. This effect is known as parallax. The two images form a left and right stereo pair and, taken together, contain three dimensional information about the feature. To recover this information, the images must be arranged for viewing so that the left eye sees the left image and the right eye sees the right image. The brain then combines the two views to create a three-dimensional impression of the feature, in exactly the same way as the eye-brain combination would have created three-dimensional information if they had directly viewing the feature in the real world.

Images are normally placed for viewing at a distance of around 200 mm from the eyes (H – height), and eyes are approximately 55–65 mm apart (B – base distance). On viewing stereoscopic image pairs, the ratio of height to base (H:D) is therefore around 3. If the same ratio is used during acquisition of the images there will be no scale distortion on viewing. For example, to take scale-correct stereoscopic photographs of an outcrop in the field, follow the procedure:

1. photograph the outcrop – this becomes the left image;
2. estimate the distance (H) to the outcrop (say, 12 m);
3. step a distance of H/3 (B) to the right (4 m in our example) and take a second photograph of the outcrop – this becomes the right image.

When subsequently mounted side by side on the page of a notebook or report, the two images, when viewed so that the left eye sees the left image and the right eye the right image; will give a distortion-free 3-dimentional view of the outcrop.

Figure 2.5 illustrates an air photo survey with a plane flying at 200 m taking photographs of the ground beneath it every 65 m. For this survey the ratio of H to B is 3

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[14] Photography for mountainous areas, where flying predetermined flight lines may be difficult, needs a wider side lap of 25% or more.

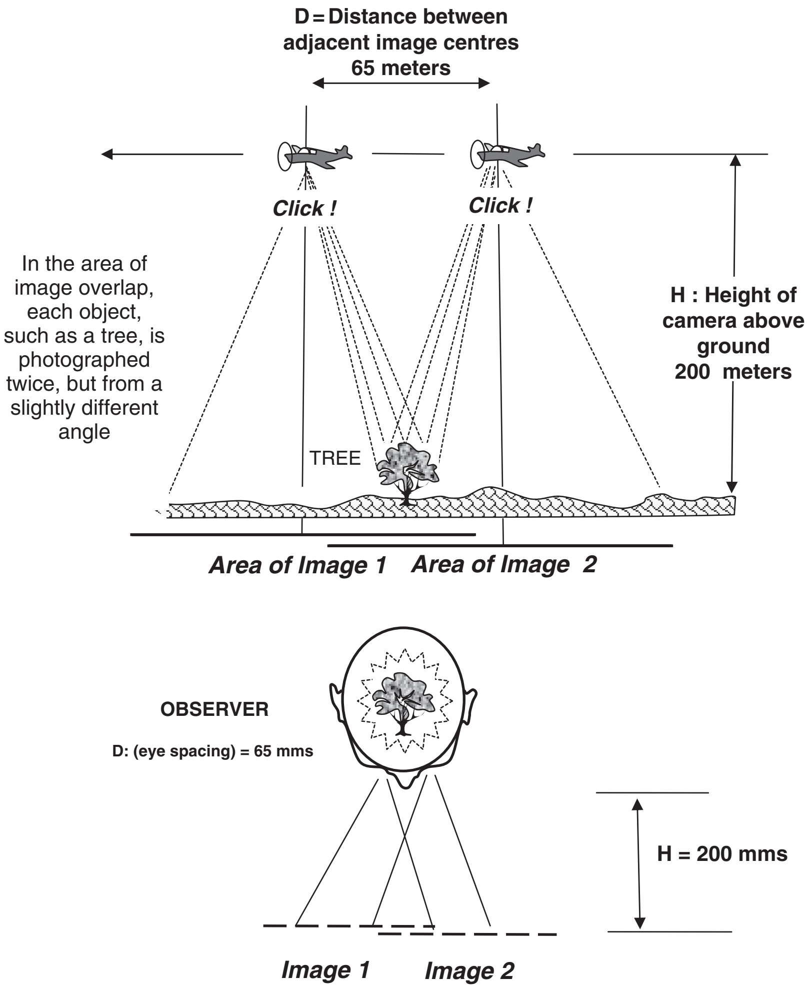

Fig. 2.5 How the perception of depth in a stereoscopic photo pair is determined. When viewing images, the ratio of the distance between the eyes (D) and the distance to the image (H) is approximately 3. If the images have been collected using the same ratio of D to H – as illustrated – there will be no vertical scale distortion on viewing. If the ratio of H/D is greater than 3 (which would occur if the photos were taken closer together or from a greater height above ground) viewing the stereo pair will exaggerate the apparent height of object

so there will be no vertical exaggeration when viewing adjacent images stereoscopically. However, with almost all air photo surveys, a height to base ratio of 3 would entail flying very low and require an unacceptably large number of photographs to cover any significant area. Because of this, most surveys are flown with an H:B ratio greater than 3, leading to an exaggeration of the vertical dimension on stereoscopic viewing – i.e. objects appear much steeper than they are in reality. Vertical exaggeration can be a useful feature in very flat terrain, as small height variations are emphasised, but in rugged terrain the effect can be rather startling, and needs to be allowed for. Dips of outcropping strata, for example, will appear much steeper than they really are.

With practise it is possible to view small stereo pairs and get the stereo effect without any optical aid. This can be a handy skill to acquire, but it will only ever work for small size images that can be placed close together. Optical instruments called stereoscopes make this process much easier and they are essential for viewing large format images. The smallest and cheapest stereoscopes are small folding models (Fig. 2.6) – these can be very useful for viewing air photographs in the field. However, pocket stereoscopes have generally poor optics and offer no, or very low, magnification. A further disadvantage is that with standard size air photographs it is necessary to bend back the edge of one print in order the view the entire overlap area of a photo pair.

To achieve the full benefit from stereoscopic viewing of air photographs or satellite images, a mirror stereoscope is necessary. Many different models of mirror stereoscope are commercially available, but it is important to remember that with these, as with all optical instruments, you get what you pay for. The best models come with binocular eyepieces and offer enlargements of the image up to 10× (Fig. 2.6). Large mirror stereoscopes will comfortably span a pair of air photographs, although the instrument has to be moved from side to side and back and forward to cover the full overlap area. If the stereoscope is mounted on a frame that permits unimpeded horizontal movement above the images the viewing process can be made considerably easier. Such mounting frames are essential for viewing very large format stereoscopic pairs such as satellite images. Commercial frames (often called mounting "tables") are available but these are expensive and sometimes make annotation of the images difficult. Figure 2.6 illustrates a cheap and easily made homemade stereoscope mounting frame which has proved very effective for geological interpretation[15] of air photographs and satellite images.

2.2.6 Image Handling Techniques

- Surface reflectance can be a problem on highly glazed prints. Such prints also tend to curl and dog-ear more easily than matt prints. For this reason most geologists prefer to order prints with a matt surface for fieldwork. However, high-gloss prints reflect more light and for that reason can be easier to read below a film overlay.

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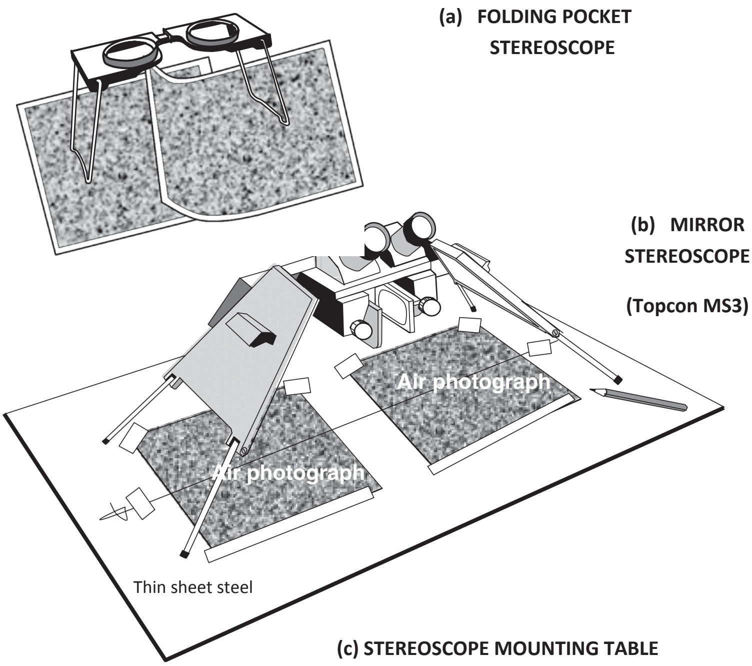
[15] The frame is made from wood and aluminium angle. It is articulated using standard wheeled drawer runners.



(c) STEREOSCOPE MOUNTING TABLE

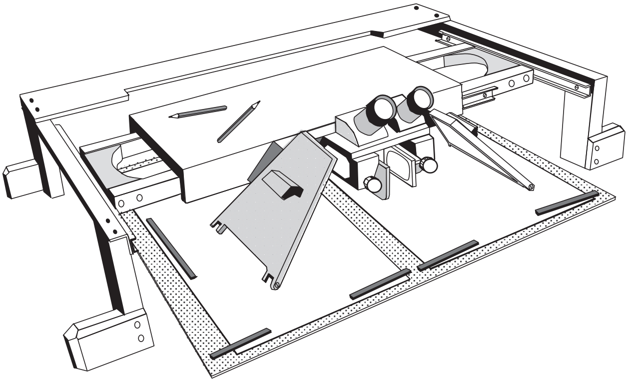


Fig. 2.6 Different types of stereoscope. With a small pocket stereoscope (**a**) the edge of one photograph needs to be bent back in order to view the whole overlap area of air photographs. A large mirror stereoscope (**b**) will span a pair of standard air photographs and can be easily slid around to view the whole image. A stretched thread is used as an aid in aligning photo centres with the optical axis of the scope. The steel sheet allows plastic strip magnets to be employed to hold photos flat and in place. For stereoscopic viewing of large prints such as satellite images, mounting the stereoscope in a frame (**c**) that allows it unimpeded movement above the images is essential. The mounting table illustrated was made by the author from aluminium angle and wood – it is articulated with wheeled drawer runners to allow smooth movement from side to side and back and forward. A fluorescent light attached to the underside of the stereoscope carriage illuminates the images

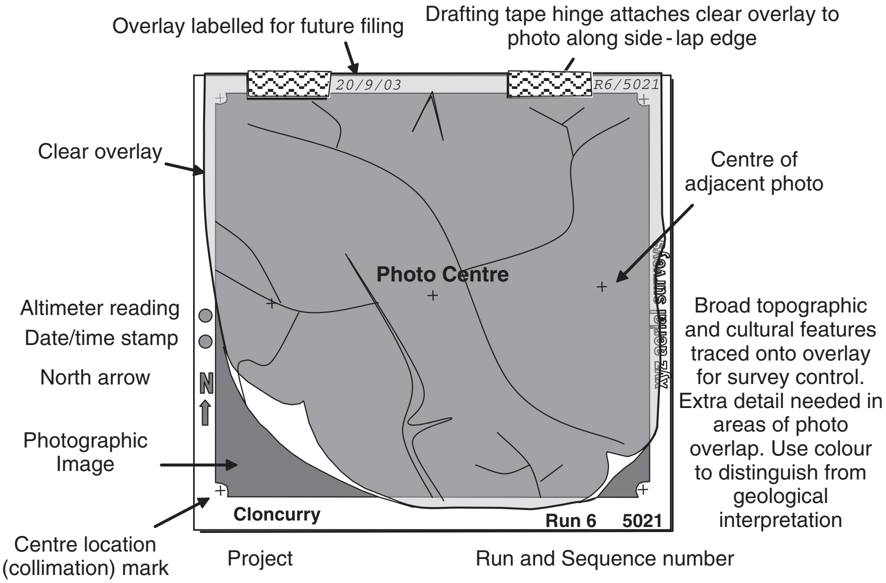


Fig. 2.7 An air photograph prepared as a base for geological mapping

- It is recommended that interpretations of the remote sensed imagery be marked on to a clear overlay.[16] The overlay should be attached to the top edge of the image (i.e. the upper or side lap edge of air photographs) so that it can be rolled back clear from the adjacent image and stereo viewer frame. Experience shows that drafting tape is best for attaching the overlay to the print as it will not split along the fold and can be easily removed (Fig. 2.7). When working with air photographs that have full stereo coverage (60% forward lap), it is only necessary to put overlays on every second photograph.
- With satellite stereo pairs, computer processing ensures that the right hand image is orthorectified and georeferenced (see Sects. 8.4 and 10.5 for definition of these terms) while the parallax displacements that contain information about the vertical relief of the scene are placed on the left hand image. When viewing these images, the clear overlay should be attached to the top edge of the RH image and all annotations and interpretations made on to this sheet. This means that interpreted geology will automatically be an ortho map.
- An alternative method used by some geologists is to mark observations directly onto the surface of the image using a pencil that does not damage the print and can be readily removed (e.g. a chinagraph or omnichrome pencil). However, putting

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[16] Overlays are available in pre-cut sheets of clear to part-translucent drafting film. Clear sheets do not obscure the photo below, but are difficult to write on without special writing materials. Matt surface films readily take pencil marks but may have to be flicked out of the way when detail of the photo has to be observed.

interpretation lines on a print surface obscures the original detail of the image on which these lines were based and makes it hard to see alternative interpretations. This can make it difficult to change early interpretations.

- The overlay should be labelled with the image identification number or the run number and photo sequence number (Fig. 2.7).
- With air photographs, the centre point (sometimes called the principal point) of the photo should be located. This point lies at the intersection of lines joining special location marks which are printed in the centre of each edge of the photo (these marks are called collimation marks and are sometimes in the corner of the photo).
- Locate (by inspection) on each air photo the centre points of the adjacent photos along the flight path. This can be done because of the 60% forward lap between photos. There will thus be three points located on each photo. Transfer these points to the overlay.
- In order to position adjacent photographs so that they are exactly aligned for stereo viewing the following procedure can now be used. Place adjacent photos side by side below the stereo-viewer so that the three centre points marked on to each photo lie as nearly as possible along a single straight line (a stretched thread can make this procedure easier , as shown on Fig. 2.6). The straight line should line up with the "E–W" optical axis of the stereoscope. Looking at the photographs through the viewer, move the photos together or apart along that line so as to bring them into stereoscopic alignment. Once this is achieved, the photographs are positioned so that most[17] of their area of overlap is correctly aligned for stereo viewing and it should need only minimal subsequent adjustment as the field of the viewer is moved across the images.
- When working in the field in areas with complex geology and mineralization, annotations marked on to an air photo overlay can become very crowded. Many geologists overcome this by using up to three overlays, mounted separately on three sides of the photo. One overlay can then be used for showing lithologies, one for structural observations and the third for mineralisation and alteration.
- Another way of organizing information on the photo overlay when working in the field is to mark a location by means of a small pin-hole pricked through the print (Fig. 2.8). Information about that location, such as sample number, notebook reference number, GPS way point number and so on, is then written on the back of the print.

2.2.7 Working with Enlarged Air Photographs

Air photographs can be enlarged many times[18] and still provide a useable base map for field work. The enlargement has to be made photographically from the original film negative and only the central 60% of each photo (where distortion is

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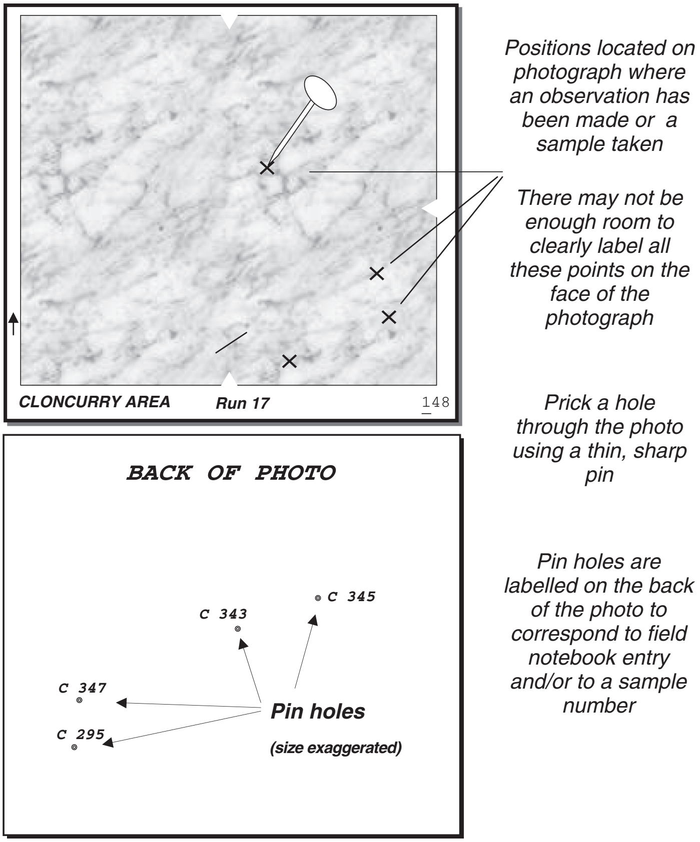
[17] It is generally impossible to exactly align all the overlap area of the photos due to edge distortions.

[18] Air photos enlarged up to 20 times have been successfully used as mapping bases.



Positions located on photograph where an observation has been made or a sample taken

There may not be enough room to clearly label all these points on the face of the photograph

Prick a hole through the photo using a thin, sharp pin

Pin holes are labelled on the back of the photo to correspond to field notebook entry and/or to a sample number

Fig. 2.8 Using a sharp pin to transfer location points from the face to the back of a photograph. Annotating points on the back of the photo leaves the face side clear for geological interpretation.

negligible) should be used. Enlarged photos cannot be easily viewed stereoscopically so a standard-scale stereo pair should be kept handy to aid in field positioning and interpretation.

The enlarged photo will usually be too big to be handled in the field and may have to be cut into smaller pieces. Such cut-down images have to be treated with great care because mapping needs to be carried right to their edges. This is because there is no overlap with adjacent images and no protective border around each cut-down photograph. The same problem arises when working in the field with large satellite images. To overcome this problem the following procedure is recommended (Fig. 2.9):

- Cut the images into as large portions as can be conveniently handled in the field. For most geologists this is probably about 60 × 40 cm.

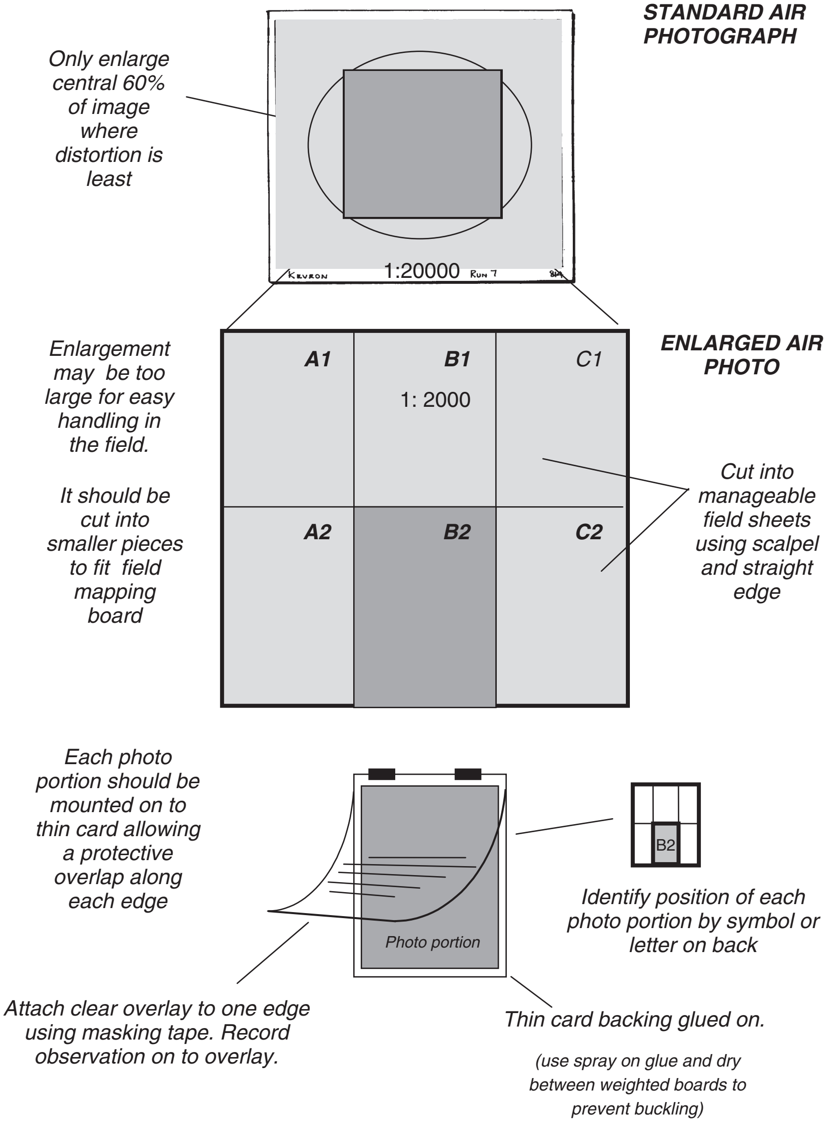


Fig. 2.9 Preparing an air photo enlargement for geological mapping

- Glue each photo portion to a backing of thin card using a spray adhesive. The backing should be slightly larger than the image to protect its edges from becoming dog-eared.
- Clearly label each photo portion on the back with a code so that adjacent photo portions can be quickly identified. A matrix system using letters for columns and numbers for rows works well. The back of each photo portion should also be

marked with the scale, north arrow, original run and print number and any other relevant details about the project.
- Attach drafting film overlays to the photos in the manner described for preparing standard size prints.
- Make a field mapping clip-board out of a piece of hardboard and several spring clips.
- The board should be a few millimetres wider all round than the photos. When not in use, a second board of the same size can be used as a protective cover for the prints.

2.2.8 Data Transfer to Base Map

With air photographs, because of the scale distortion, geological boundaries plotted on an overlay do not represent an accurate map projection. Although the errors on any one photograph are not be great, if interpretations from adjacent photos are combined to make a larger map, the resulting errors can be cumulative and eventually may cause a gross distortion of true geological relationships. Ideally, the interpretation of each photo can be transferred on to an orthophoto[19] by matching features. Orthophotos are, however, not always available and are expensive to produce. Geological interpretation can also be plotted on to a photo-mosaic, but such mosaics also contain localized scale distortions and discontinuities. The easiest way therefore is to transfer the interpreted data from each photo overlay on to a scale-correct map base.

The ideal topographic base map for plotting photo geology should have the following features:

- The same scale as the photographs (a print can be photo enlarged or reduced if necessary);
- Sufficient topographic/cultural features (rivers, tracks, fence lines, buildings, etc.) to enable the photos to be exactly located;
- No unnecessary detail which would tend to obscure the geological information to be plotted on it;
- Availability on transparent drafting film.

Maps with these features can often be bought directly from government mapping agencies and are known as a line base. In most developed countries topographic

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[19] An orthophoto is a distortion-free photographic image produced from standard air photos by computer scanning. Once in digital format the image is corrected for radial distortion and a Digital Elevation Model (DEM) is used to correct for altitude differences across the scene. The process is known as ortho rectification. An orthophoto map is an orthophoto to which metric grid coordinates and (sometimes) annotated line work identifying topographic/cultural features has been added – a process called georeferencing. For more on orthorectification and georeferencing see Chap. 10.

map data are also available in digital form. It is possible to buy these data on disc or on-line and to edit the base map required using a CAD (computer aided drafting software) system. A print-out of a line base can then be made at an appropriate scale on film or paper.

The procedures recommended for transferring geology from an air photo overlay to the line base are as follows:

- Check with the base map to see which features on the map can also be seen on the photograph. Ideal features are points such as fence corners, bends in roads, bends in rivers or river junctions, wind-pumps, buildings, etc. Trace the more important of these features on to the photo overlay. It is particularly important to pick up features near the edges of the photo where a match will need to be made with data on the adjacent photo; this is also the area where scale distortion is greatest. Fewer control points need to be identified in the photo centre. It is a good idea to use colour to distinguish this topographic/cultural detail on the overlay from lines and symbols showing the interpreted geology.
- Place the photo overlay below the base map and position its centre point by matching the selected features common to map and photograph. Mark the photo centre onto the base map. Maps showing plotted photo centres can often be bought from the same agency that sells the photographs, but such maps are designed as a guide for purchasing only and are not very accurate. Plot your own centres.
- Trace the geological interpretation on to the base map starting from the centre of the overlay. As the tracing moves out from the centre, move the overlay so as to maintain a match between overlay and line base, using the reference topographic features adjacent to the geology being traced.

There is an element of necessary fudging in this technique to achieve smooth geological boundaries. Special care has to be taken in the overlap areas between photographs. Limited scale and angular distortions will inevitably creep in, but if the above procedure is followed these errors will be small, localized, non cumulative and will not affect essential geological relationships.

2.3 Mapping with a Plane Table

This section describes how to make a geological map using a simple plane table. A plane table is a small horizontally-mounted mapping board used in the field so that the bearings to features of interest can be directly plotted onto a paper sheet pinned to the board.

Before the mapmaking process begins, the geologist must study the area and determine what features are to be recorded.

The plane table is a small board, generally about 50–60 cm square, mounted horizontally on a tripod and locked to face in any chosen direction. Plane tables

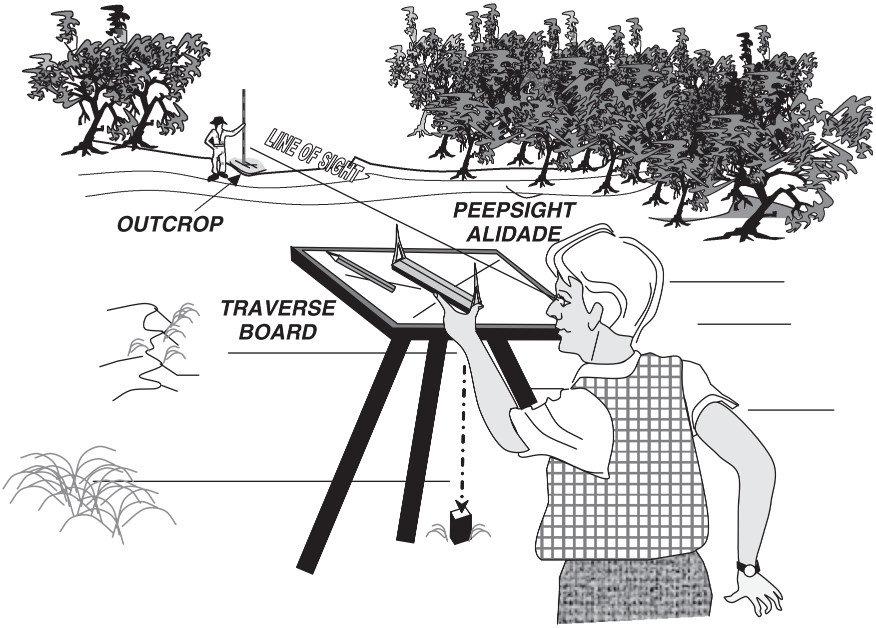

Fig. 2.10 Detailed geological outcrop mapping using a plane table. In this example, a simple home-made peep-sight alidade is being used

(sometimes called "traverse boards") are made especially for this job, but one can readily be made to fit on to the tripod support of a theodolite (Fig. 2.10*)*.

The essential beginning for any survey is establishing two points in the survey area at a known distance apart and within easy sighting distance of each other (say up to 200 m). These positions will be referred to as the first and second survey points; once established using a surveyor's tape or chain, they are marked on the ground with a peg or flagging tape, or both.

The plane table is mounted in a horizontal position directly above the first survey point and oriented with a compass so that one edge faces north. It is then locked in that position. A sheet of paper is fixed on to the table and a mark is made at some suitable place on the paper to indicate the position of the table. A sighting instrument called an alidade is then laid on the map with one edge on the marked set-up point. In the illustration of Fig. 2.10, a simple home-made alidade, called a peepsight alidade, is being used.

The alidade is rotated around the marked point so as to sight on to the second survey point. A pencil line is then drawn along the edge of the alidade, marking the bearing to the second point. Because the distance between the two points is known, the position of the second point can now be plotted on the map according to a suitable scale.

Now the lines marking the bearings to any other points of interest within the view of the observer can be marked on to the map in the same way, radiating out from the

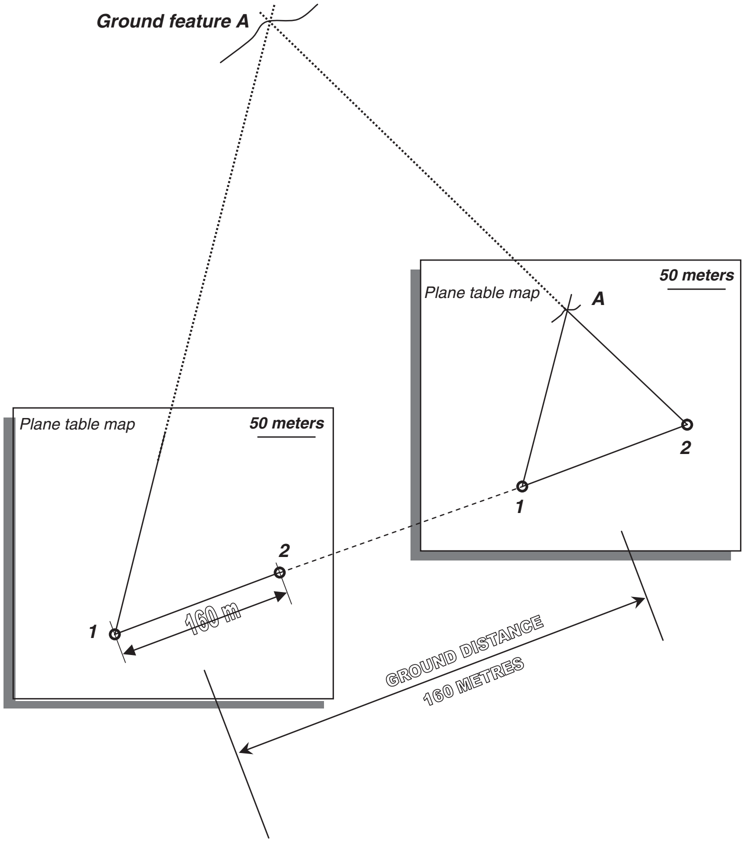

Fig. 2.11 Positioning a point by triangulation during plane table mapping. Points 1 and 2 are at a known distance apart – in this case 160 m. By positioning the plane table over each point in turn, and taking bearings on the feature A, its map position can be established

first set-up point (Fig. 2.11*)*. It is not necessary to measure any of these bearings with a compass. The features on which sightings are made can be geological, topographic or cultural features, or arbitrary survey points. The best technique is to sight on to a survey pole that is moved from point to point by an assistant on the instructions of the mapper – portable 2-way radios will help with this process. The assistant then identifies and labels each survey point (using a marker such as a peg or flagging tape). The identification of the bearing is also recorded on to the map.

When the bearings of as many features as required have been recorded in this way as a series of lines on the map, the plane table is then moved to a position above the second starting point. The table is then rotated around its vertical axis so that the line marking the bearing between the two starting points is back-sighted on start point one; the table is then locked in this position. Now a second set of bearing lines, radiating out from the second start position, are taken to all the features that were identified. Where the two bearing lines on any one feature cross, that point is exactly positioned on the map – this process is known as triangulation. Any difference in relative levels between the surveyed points does not affect the accuracy of the map projection. Once a network of survey points have been established in this way, the survey can be infinitely extended in any direction by selecting any two of these points as the base line for new triangulations.

Plotting geological observations on to the survey base depends on using the exactly positioned survey points for control. In most cases these points will have been chosen on geological features and will have been put in closely where the geology is complex. With a large network of suitably positioned survey points, it is a relatively easy task to sketch in geological boundaries between the known points. In a plane table survey, it is necessary to know in advance what geological features are to be recorded and to select the survey points accordingly. Another technique is for the geologist to walk the outcrop with survey marker in hand, calling out (or using a radio transceiver) to the assistant to take the appropriate bearings and record geological data that is dictated. The technique or mix of techniques that are chosen will depend on the geologist, the assistance available, and the nature of the surveying/geological problem.

In heavily vegetated or hilly country, survey points can only be established where sighting lines are possible. Detail between the networks of triangulated points will have to be subsequently mapped in by means of a tape and compass survey.

For prospect mapping, the simple set-up described above is probably all that the geologist will need, especially as more complex survey instruments may not be available. However, more sophisticated alidades can simplify the mapping process. By sighting through the ocular of a telescopic alidade, more accurate bearings over much greater distances can be made. If the assistant carries a graduated survey staff, the interval between two sighting hairs (called stadia hairs) superimposed on the telescopic image of the staff, provide a direct measure of the distance to the staff. The position of the point can then be directly plotted on the map without the need for triangulation. This surveying process is called tacheometry. The inclination of the telescope, recorded on a built-in scale, gives the vertical angle to the plotted point, and can be used to make a contour map of the area of the survey. Modern electronic distance-measuring survey instruments, employing reflected infra-red or laser beams, can also be used for plane table map-making.

2.4 Mapping on a Pegged Grid

2.4.1 Requirements of the Grid

A pegged grid consists of a regular array of pegs or stakes placed in the ground at accurately surveyed positions and used to provide quickly accessible survey control points to locate all subsequent exploration stages. The following points should be borne in mind:

- Ideally, for detailed geological mapping purposes, at least one grid peg should be visible from any point within the area to be mapped. Such grids may therefore need to be closer spaced than a grid designed solely for collection of geochemical or geophysical data. This aspect should be considered at the planning stage of the programme. In relatively open country, a grid spacing of 80 × 40 m is ideal.
- The orientation of grid lines should be at a high angle to the dominant strike of the rocks, to the extent that the strike is known.
- As a general rule, grids used for mineral exploration do not have to be established with extreme accuracy – placing pegs to within a meter or so of their correct position is acceptable. All types of data collected on the grid – geology, geochemistry, geophysics, drill hole data – will still correlate. If it ever becomes important, the position of any feature can be subsequently established to whatever level of accuracy is desired.
- To prevent small surveying errors from accumulating into very large errors, the grid should be established by first surveying a base line at right angles to the proposed grid lines. Points on the base line should be surveyed in as precisely as possible using a theodolite and chain. The theodolite is then used to accurately establish the right angle bearing of the first few pegs on each cross line of the grid.[20] From this point, the remainder of the grid pegs can be rapidly placed by using a tape for distance and simply back-sighting to maintain a straight pegged line. Where dense vegetation or rugged topography prevents back-sighting, short cross lines can be pegged using a compass and tape. For grid lines over about 1 km long, tape and compass surveying can cause unacceptable cumulative errors, and positioning with a theodolite is recommended.
- In hilly country, the establishment of an accurate grid requires the use of slope corrections. The slope angle between the two grid positions is measured with a clinometer. To obtain the slope distance which corresponds to a given horizontal grid distance, divide the required grid distance by the cosine of the slope angle. This calculation can easily be done with a pocket calculator but since the grid spacings are fixed, a sufficiently accurate slope distance for any given slope angle can quickly be read off from a table of pre-calculated values such as Table 2.2.
- If a detailed contour map is not otherwise available, the slope angle between pegs should be recorded and used to compile a contour map of the area. Contours are essential in hilly country to understand the outcrop patterns of rock units on the map, particularly in regions of shallow dipping beds.
- Grid peg spacing in distances that are multiples of 20 m should be considered, as this allows for more even subdivisions than the more traditional multiples of 50 m.

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[20] Establishing a cross line at right angles to a base line can also be done using an optical square – a hand-held sighting instrument which enables two pegs to be placed so as to form a right angle with the observer.

Table 2.2 Table for converting slope distance into horizontal distance

	Horizontal distance (m)									
Slope angles (degrees)	5	10	20	25	40	50	60	75	80	100
	Slope distance (m)									
5	5.0	10.0	20.1	25.1	40.2	50.2	60.2	75.3	80.3	100.4
10	5.1	10.1	20.3	25.4	40.6	50.8	60.9	76.1	81.2	101.5
15	5.2	10.3	20.7	25.9	41.4	51.8	62.1	77.6	82.8	103.5
20	5.4	10.6	21.3	26.6	42.5	53.2	63.8	79.8	85.1	106.4
25	5.5	11.0	22.1	27.6	44.1	55.2	66.2	82.8	88.3	110.4
30	5.8	11.5	23.1	28.9	46.2	57.7	69.3	86.6	92.4	115.4
35	6.1	12.2	24.4	30.5	48.8	61.0	73.3	91.6	97.7	122.1
40	6.5	13.0	26.1	32.6	52.2	65.3	78.3	97.9	104.4	130.5
45	7.1	14.1	28.3	35.4	56.6	70.7	84.9	106.1	113.1	141.4
50	7.8	15.5	31.1	38.9	62.2	77.8	93.3	116.6	124.4	155.5
55	8.7	17.4	34.8	43.5	69.7	87.1	104.5	130.7	139.4	174.2
60	10.0	20.0	40.0	50.0	80.0	100.0	120.0	150.0	160.0	200.0

- The origin of the grid should lie well beyond the area of interest so that all grid coordinates in the area are positive whole numbers. Conventionally, the origin is placed to the southwest of the area so that all coordinates can be expressed as distances north (northing) or east (easting) of the grid origin.
- If possible, choose the origin of the grid so that easting and northing coordinates through the prospects of principal interest have dissimilar numbers. This will help to reduce potential future errors.
- Where a grid oriented N–S and E–W is required, consider using national metric grid coordinates (i.e. UTM, see Sect. 10.5). The advantage of this is that published map-based data sets can be easily tied to the local grid observations. Using national metric coordinates requires that at least one point on the ground grid is accurately positioned by survey into the national grid. Only the last four digits of the regional grid need be shown on the grid pegs.
- Clearly and permanently label grid pegs as shown in Fig. 2.12. Wooden pegs are usually cheapest and are ultimately biodegradable. For a more permanent survey consider using galvanized steel markers (fence droppers make good survey pegs). Steel pegs are essential in areas where bush fires and/or termite activity is common and the grid is required to last for more than one season.

2.4.2 Making the Map

Mapping is carried out on to field sheets that are generally graph paper of A3 or A4 size. The thin, shiny-surface papers of most commercially available pads of graph paper make poor field mapping sheets. If possible, use a heavyweight,

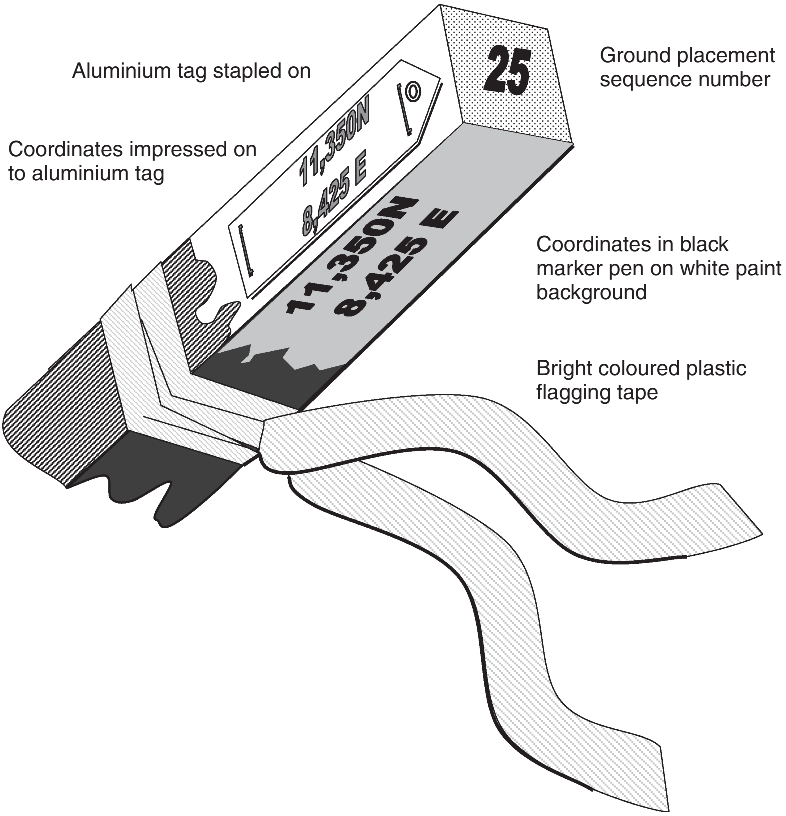

Fig. 2.12 Recommended labelling system for grid pegs. These are short wood or steel stakes hammered into the ground at regular surveyed intervals to provide ongoing survey control for all exploration stages from geological mapping to drilling

matt-surface paper with a 1 cm ruled grid (you may have to get these specially printed). Waterproof sheets of A4 graph paper are available if mapping has to be carried out in wet conditions.

The positions of the grid pegs are marked on to the map sheets according to the scale chosen before field work commences. Field map sheets are valuable documents and, along with any field notebooks, should be carefully labelled and filed at the end of the work. Usually the area to be mapped is larger than can be covered by one field sheet. In setting up the field sheets, allow for an overlap between adjacent sheets and clearly label each sheet so that adjacent sheets can be quickly located.

As a surveying aid, at an early stage in the mapping process, it is of great value to create an extra network of location lines on the map sheet by surveying on to the map any topographic or cultural features of the area such as ridge lines, streams, tracks, fence lines, etc. that may be present. In the example shown (Fig. 2.13), the survey control provided by a 100 × 50 m pegged grid was supplemented by first surveying the stream, track, fence line, costeans and drill holes on to the map

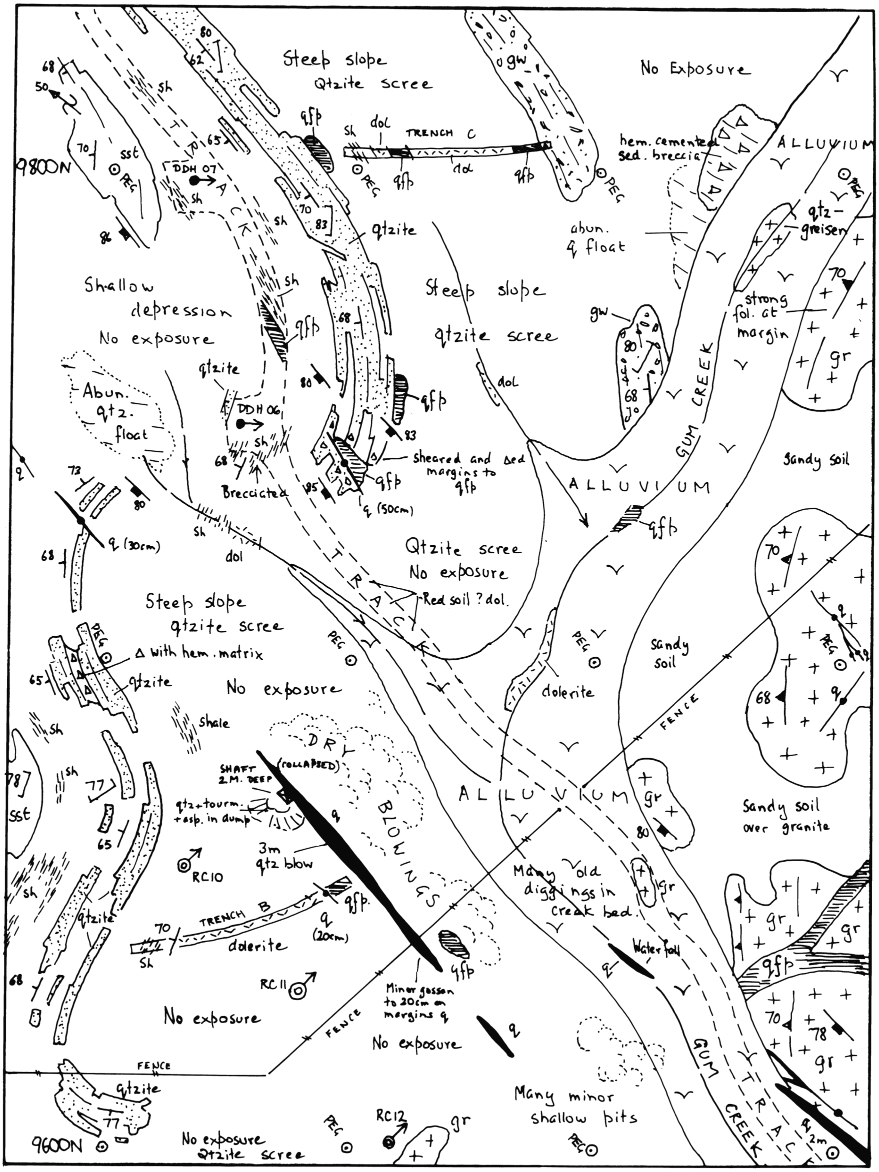

Fig. 2.13 An example of a 1:1,000 scale outcrop geological map of a mineral prospect in the Northern Territory of Australia. This is one of a number of adjacent field sheets. Mapping was controlled by a pegged grid on 100 × 50 m spacing

before the detail of the geology was recorded. As well as a survey control, in hilly country the position of ridge lines and drainages are necessary to complement the topographic contour information in order to understand the outcrop patterns of shallow-dipping beds.

As a general rule, the pegged grid should be regarded as a survey aid with no geological significance. Above all, the grid is not necessarily to be regarded as a predetermined set of traverse lines. In the field the geologist should follow her own ideas on the geology, and not the grid line.[21] If the chosen mapping strategy is to walk a traverse across strike then a traverse should be planned according to where the most productive outcrop is to be found, always bearing in mind that traverses do not have to be ruler-straight lines. For example, in many areas, often the only outcrop is to be found is in stream beds, and these must feature prominently in the mapping route chosen. The important thing to try to achieve is that the amount of attention which any outcrop receives is in proportion to its geological importance, not its closeness to a grid peg.

When it comes to positioning a feature on the map, a compass bearing can be taken from the feature to the nearest grid peg. Usually, the peg will be sufficiently close so that distance from peg to feature can be measured by pacing or even by estimate, although more accurate location of the feature can be achieved by triangulation between two or more grid pegs. To plot these measurements, a protractor and scale ruler are necessary and important field mapping tools. Every point or line placed on the map does not need to be accurately surveyed in. Once a network of key points or lines has been exactly positioned, the remainder of the geological boundaries are simply sketched in, so as to preserve the correct style and relationships seen in the outcrop. This is illustrated in Fig. 2.13. On this map, the outcrop boundaries are drawn so as to reflect the characteristic shapes of outcrop observed for the different rock types: note that the quartzite outcrop shapes are well-defined and rectilinear; the sandstone outcrop shape is massive and blocky; the shale has insignificant low outcrop in narrow strike runs whilst the granite presents ovoid and somewhat amoeboid outcrop shapes.[22]

Observations are plotted as they are made, in pencil, on to the field map sheets with the aim of creating a complete map in the field. Structural measurements are plotted with the appropriate map symbol (using a square protractor), thus continually building up the geological picture as work progresses. There is no need to record the measurements separately in a notebook, unless they are required for subsequent structural analysis. Since the principal function of geological maps is, by definition,[23] to show the distribution of strike, it is in most cases (for exception, see

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[21] In very dense scrub or forest, the cleared grid line often provides the only practicable traverse route. Even here, however, every effort should be made to pick up significant outcrops between the lines and to map cross-cutting access lines such as any tracks or creek sections.

[22] This used to be called map-makers' (or geologists') wobble and is one of the things that can distinguish a great geological map from a merely pedestrian one. This is not artistic licence: Chaos Theory describes what the geologist is doing. For each lithology, the map outline of the outcrops has a characteristic fractal dimension – a fraction somewhere between 1 and 2. The fractal number is lowest for a "smooth" outline such as the granite, and highest for a "rough" outline such as the quartzite.

[23] Strikes are the trace of planes on maps just as dips are their trace on sections.

below) much more useful to plot the strike and dip of measured planes on to the map than dip and dip direction.

As far as map-scale pattern and outcrop distribution is concerned, the strike is the most important measurement to make in terrain characterized by steep-dipping structures. The opposite is true where very shallow-dipping beds predominate: in such terrains, the strike can be quite variable and may have little significance, but dips tend to be more constant and have much greater control on outcrop patterns of rock units.

As the elements of the map are slowly assembled in this way, the map can be used to make predictions about the areas not yet mapped and so guide the next set of field observations, as described in Sect. 2.1.3.

2.5 Mapping with Tape and Compass

This technique is ideal for quickly making detailed geological maps of small areas of high interest. The logistics of the technique mean that it is particularly suited to making linear "strip" maps, such as maps of a stream section, ridge line, trench, road cutting or a line of old pits and diggings. It is also a useful technique for surveying in geological, topographic or cultural detail between the pegs of a widely spaced grid or the established traverse points of a triangulation survey. A surveyor's steel chain or tape measure is the most accurate distance measuring devices but they can only be easily used if an assistant is available. A Hip-Chain^{TM} is less accurate but is an acceptable alternative when time is short or there is no assistance available.

In the example shown (Fig. 2.14*)* a tape and compass survey has been used to map a short drainage that was identified as anomalous during a regional stream sediment survey. The map also provided an accurate base for plotting geological observations and recording the location of the sample points of detailed follow-up geochemical sampling.

The recommended procedure to make such maps is as follows:

- Start at one end of the area to be mapped. Knowing the approximate size and orientation of the area to be covered, select a suitable scale and label the field map sheet accordingly. Position the starting point of the traverse on the map.
- The assistant walks with one end of the tape to the first chosen survey point. The geologist takes a bearing on the assistant and, knowing the distance, plots the position of that point on to his or her field map sheet, using a protractor and scale ruler. Alternatively, the geologist takes a bearing on the first point and then walks to it, measuring the distance with the hip-chain. A good bearing compass such as Suunto^{TM} or prismatic should be used.
- If the ground is very steep, a correction for the vertical distance traversed will have to be made to the tape interval. Measure the slope angle with a clinometer and, knowing the ground distance between the points, correct the position of the survey point as marked on to the map (for how to do this, see Sect. 2.4.1,

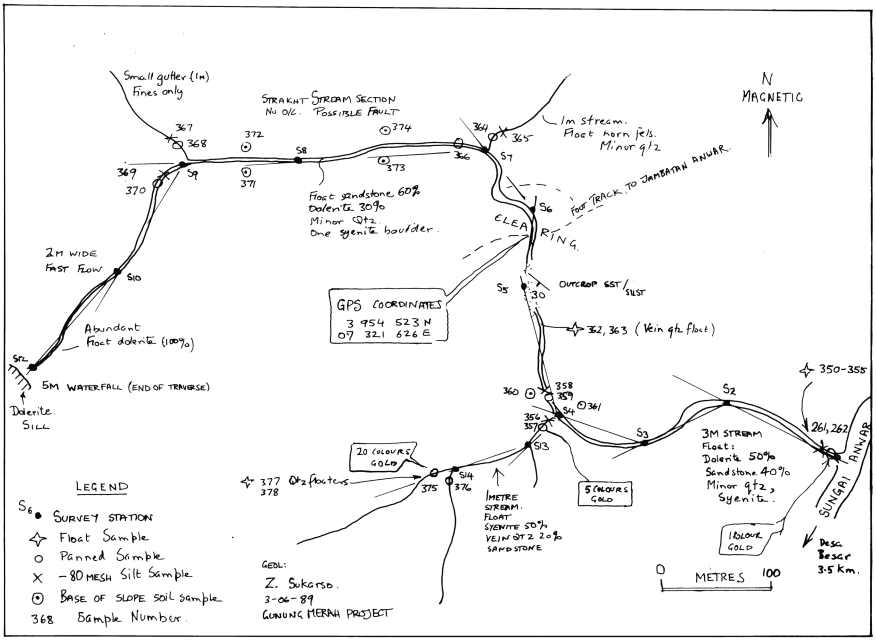

Fig. 2.14 An example of a tape and compass map prepared during first-pass exploration of a tropical rain forest covered area. The map was used as a base to record sample positions and geological observations along a small stream during the follow-up to an initial stream sediment gold anomaly in a panned heavy mineral concentrate taken from where the stream joins the main river

above). Leaving the tape stretched along the ground, walk to the first survey point, plotting geological observations along the traverse. Topographic details (such as bends in a river bed) can be sketched in between the known points.

- Observations of geological features a short distance away from the survey line can be recorded on the map by pacing or estimating distances, combined with a compass bearing. If necessary, very accurate positioning can be obtained by taking bearings from two known points of the traverse and triangulating, or by taking one bearing from a known point and taping the distance to the feature. It is not necessary to exactly survey in every feature that is to be recorded: once a few points are established, all other observations can usually be positioned by eye in relation to them with sufficient accuracy.
- Repeat the process to the next survey point and so on, to complete the traverse.
- Each surveyed point should be identified with a number on the map and marked on the ground with plastic flagging, a metal tag or a survey stake. These are exactly defined positions that can be used subsequently as a base for starting new survey/mapping traverses away from the original line of observations.
- Make geological or geophysical observations or collect geochemical samples as mapping proceeds, locating sample points directly on the map.

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