Compass Techniques

I. The Brunton Compass

A. Parts of the Brunton Pocket Transit

1. compass- measuring magnetic bearing
2. clinometer- measuring vertical inclination of planes
3. hand level- sights for line surveying

    a. mechanisms
        (1) clinometer level = use for taking vertical angles
        (2) bullseye level = use for taking compass readings
        (3) graduated circle
        (4) compass needle
        (5) sighting arm
        (6) sighting window
        (7) declination adjusting screw
        (8) lid with mirror
        (9) lift pin/needle brake

B. Making Compass Readings

1. Set magnetic declination
    a. use adjusting screw
    b. refer to topo map or mag. dec. charts

2. Compass bearings = line orientations in space relative to geographic directions (quadrant vs. azimuth methods)
    a. open lid with sighting arm extended
    b. center bull's eye bubble
    c. align compass along desired line
    d. read bearing indicated by white end of compass needle
    e. check bearing and record

        (1) warnings: watch for magnetized objects that could alter compass reading

            (a) Fe-rich rock bodies can only use sun compass

C. Using clinometer

1. align vertical edge of compass with angle of plane
2. adjust bubble level of clinometer
3. read angle from vernier scale on compass

D. Computing vertical elevation

1. measure eye height from ground surface (E.H.)
2. sight compass to top of object (e.g. top of a pole)
3. adjust vertical bubble level and read angle (theta)
4. measure horizontal distance from compass point to object (H.D.)
5. solve: total vertical height of pole = (H.D.)(tan(theta)) + E.H.

E. Measuring horizontal distances
   1. measuring wheel
   2. tape measure
   3. pace estimation

F. Using Hand Level to Measure Elevation Differences

   1. set compass clinometer to 0
   2. open compass with sight and lid mirror toward eye
   3. measure eye height (E.H.)
   4. sight up slope, keep track of no. of moves and no. of E.H.

G. Measuring Strike and Dip

   1. Definitions

      a. Strike = line connecting points of equal elevation on planar surface (e.g. rock bed)
         (1) line bearing as azimuth or quadrant
      b. Dip = vertical angle of inclined surface, measured down from horizontal, perpendicular to strike
         (1) vertical angle + direction of dip

      c. Orientation of Lines in Space

         (1) Trend: compass bearing of line in space
         (2) Plunge: vertical angle from horizontal, and direction of angle in space

   2. Methods of Measure
      a. sighting
      b. direct measure

H. Compass Bearings

1. Bearing- the direction from one point to another, usually expressed in degrees east or west of true north (quadrant method) or in degrees from 0-360 (azimuth bearing) where north is 0^o or 360^o, east is 90^o, south is 180^o, and west is 270^o.

2. Measuring Bearings- To determine the bearing/direction from one point to another do the following:

a. Draw a line from the first point to the second point

b. using a protractor, center the origin of the protractor on the first point, align the bottom edge with the bottom edge of the map, and the 90 degree tic parallel with true north at the top of the map.

c. Read the angle between north at the 90 degree mark of the protractor, and the line between the two points in question.

1. give answer in either the quadrant or azimuth notation.

ence grid from which to pace out locality positions (Fig. 1–3). Other suitable landmarks for locality descriptions are sharply defined hilltops, stream intersections, road or railroad crossings, solid buildings, and similarly permanent features. Where localities are so far from these features that a compass bearing and paced distance cannot be used to describe them in the field notes, they may be located by taking bearings on several prominent points (Section 4–2).

Locality descriptions should begin with the name of the quadrangle or some large and well-established geographic feature, proceed to smaller and more local features, and, finally, describe the immediate landmarks and appearance of the outcrop itself. The field notes shown in Fig. 1–2 include an example of a locality description (note 6).

References Cited

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2

Using the Compass, Clinometer, and Hand Level

2–1. The Brunton Compass

A compass, clinometer, and hand level can be used to make a great variety of surveys and to measure the attitudes of various geologic structures. These three basic instruments are combined in the Brunton Pocket Transit, which is commonly called the Brunton compass. This compass is held by hand for most routine procedures, as those described in this chapter; however, it can be mounted on a tripod for more precise measurements, or can be used with a special ruler on a plane table (Section 6–2). Although the detailed instructions given in this chapter pertain especially to the Brunton compass, the same general procedures can be adapted readily to other kinds of compasses, clinometers, and hand levels.

The various parts of the Brunton compass are shown in Fig. 2–1. The compass is made of brass and aluminum—materials that will not affect the magnetized compass needle. When the compass is open, the compass needle rests on the pivot needle. The compass needle can be braked to a stop by pushing the lift pin, which is located near the rim of the box. When the compass box is closed, the lift pin protects the pivot needle from wear by lifting up the compass needle.

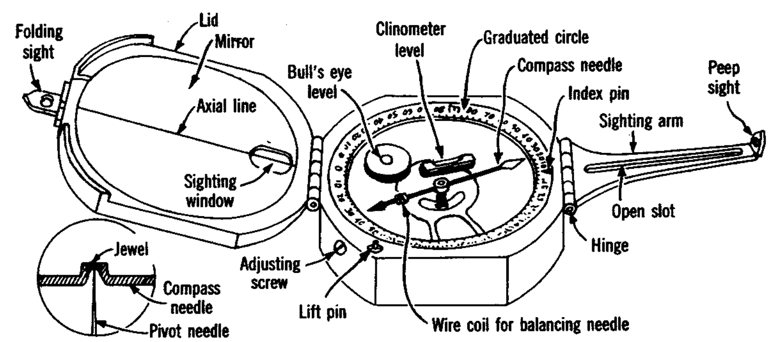


Fig. 2–1. The Brunton compass. Insert at lower left shows enlarged section through needle bearing.

The round bull's eye bubble is used to level the compass when a bearing is read, and the tube bubble is used to take readings with the clinometer. The clinometer is moved by a small lever on the underside of the compass box (not shown in the figure).

A compass should be checked to ascertain that: (1) both levels have bubbles, (2) the hinges are tight enough so that the lid, sighting arm, and peep sights do not fold down under their own weight, and (3) the point of the sighting arm meets the black axial line of the mirror when the mirror and sighting arm are turned together until they touch. Other adjustments that may be required are described in Section 2–10.

2–2. Setting the Magnetic Declination

The graduated circle of the compass can be rotated by turning the adjusting screw on the side of the case. The 0 point of the graduated circle is brought to the point of the index pin to measure bearings from magnetic north. To measure bearings from true north (the usual case), the graduated circle must be rotated to correct for the local magnetic declination. The local declination and its change per year are given in the margin of quadrangle maps; however, the correction for annual change will be only approximate if the map is more than about 20 years old. The declination can also be determined from an isogonic chart (Appendix 6). Finally, the declination at any given point can be determined by setting the compass on a firm, level surface and sighting on Polaris, the North Star. This reading should be corrected approximately for elongation (Section 7–9).

Because the east and west sides of the compass circle are reversed, it may be momentarily confusing as to which way to turn the circle. Each setting should be reasoned out and checked. A declination of 20° east, for example, means that magnetic north is 20° east of true north, and therefore the circle is turned so that the index points to *20* on the *E* side of 0. To check this, the compass is held level and oriented so that the white end of the needle comes to rest at 0. The entire compass is then rotated 20° in the direction known (geographically) to be east of north. If the needle then points in the direction of the sighting arm, which is magnetic north, the declination has been set correctly.

2–3. Taking Bearings with the Compass

A *bearing* is the compass direction from one point to another. A bearing always has a unidirectional sense; for example, if the bearing

from *A* to *B* is *N* 30 *W*, the bearing from *B* to *A* can only be *S* 30 *E*. Using the Brunton compass, the correct bearing sense is from the compass to the point sighted when the sighting arm is aimed at the point. The white end of the needle gives the bearing directly because the *E* and *W* markings are transposed. To read accurate bearings, three things must be done simultaneously: (1) the compass must be leveled, (2) the point sighted must be centered exactly in the sights, and (3) the needle must be brought nearly to rest. When the point sighted is visible from the level of the waist or chest, the following procedure should be used.

1. Open the lid about 135°; turn the sighting arm out and turn up its hinged point (Fig. 2–2*A*).
2. Standing with the feet somewhat apart, hold the compass at waist height with the box cupped in the left hand.
3. Center the bull's eye bubble, and, keeping it approximately centered, adjust the mirror with the right hand until the point sighted and the end of the sighting arm appear in it.
4. Holding the compass exactly level, rotate the whole compass (on an imaginary vertical axis) until the mirror images of the point sighted and the tip of the sighting arm are superimposed on the black axial line of the mirror.
5. Read the bearing indicated by the white end of the needle, which should be nearly at rest.
6. After reading the bearing, check to make sure the line of sight is correct and the compass is level.
7. Record or plot the bearing at once.

When the point sighted is visible only at eye level or by a steep downhill sight, the following instructions apply.

1. Fold out the sighting arm as above, but open the lid only about 45° (Fig. 2–2*B*).

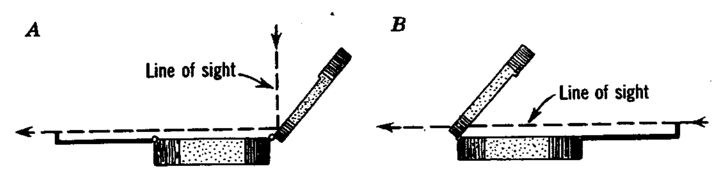


Fig. 2–2. Compass set for taking a bearing at waist height (*A*) and at height of eye (*B*).

2. Hold the compass in the left hand at eye level, with the sighting arm pointing toward, and about 1 ft from, the right eye.
3. Level the compass approximately by observing the mirror image of the bull's eye bubble, and, holding the compass approximately level, rotate it until the point sighted appears in the small sighting window of the lid.
4. Holding the compass exactly level, rotate it until the point sighted and the point of the sighting arm coincide with the axial line of the window.
5. Read the bearing in the mirror, double checking for alignment and level.
6. Transpose the direction of the bearing before recording or plotting it (the compass was pointed in reverse of its bearing direction).

With practice, bearings can be read to the nearest ½° provided the needle is steady. When holding the compass at waist level, the largest errors result from sighting the wrong point in the mirror. In the second method, a good deal of patience is required to level and read the compass from a mirror image. In either method, the compass must be leveled accurately to give good results on inclined sights. If the swing of the compass needle cannot be damped by the lift pin, the bearing must be read as the center of several degrees of swing. Unless much patience is used, these readings are likely to have errors of 1 or 2°.

2–4. Magnetic Deflections of Compass Bearings

The compass will give incorrect bearings if there is any local deflection of the earth's magnetic field. Objects containing iron, such as knives, hammers, and belt buckles, should be kept at a safe distance while a reading is made. This distance can be determined by placing the compass on a level surface and bringing the object toward it until the needle is deflected. A strong pocket magnet must never be carried near a compass. Steel fences, railroad rails, and steel pipelines should be avoided if possible.

Rocks and soils rich in iron, especially those containing the mineral magnetite, can cause deflections that are difficult to detect. Bodies of basalt, gabbro, skarn, and ultrabasic rocks are particularly likely to affect compass readings. Relatively strong effects can be tested by bringing large pieces of rock close to the compass. If the magnetic mass is small compared to the distance between two stations, foresights and backsights between the stations will give inconsistent re-

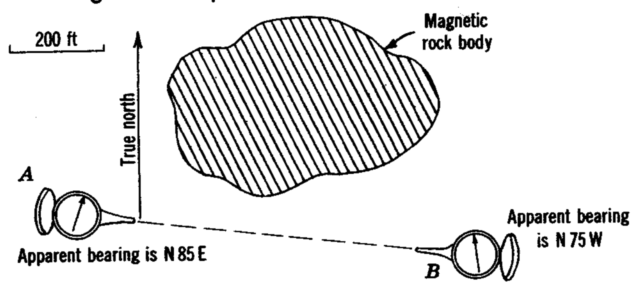


Fig. 2–3. Deflection of compass needles at two ends of a line that passes near a small magnetic rock body.

sults (Fig. 2–3). Where larger masses are involved, the deflection can be measured by pinpointing two stations on an accurate map, measuring the bearing between them with a protractor, and comparing this bearing with a compass bearing taken between the same stations in the field. This measurement will correct the declination for that part of the area. The same result may be achieved by taking readings on Polaris at a number of points within the area to be mapped. If the magnetic disturbances are moderate and vary systematically over a given area, a local isogonic map can be constructed from which corrections of compass readings may be made. If magnetic deflections are large and distributed irregularly, mapping must generally be done with other instruments, as the peep-sight alidade (Section 6–2) or the *sun compass*, a nonmagnetic instrument operated on the basis of the time of day and the direction of the sun's rays. It is also possible to make a compass traverse in such a way that the deflections are accounted for (Section 3–5).

2–5. Measuring Vertical Angles with the Clinometer

Vertical angles can be read to the nearest quarter of a degree with the clinometer of the Brunton compass. Instructions for this procedure are:

1. Open the lid about 45° and fold out the sighting arm, with its point turned up at right angles.
2. Hold the compass in a vertical plane, with the sighting arm pointing toward the right eye (Fig. 2–4). The compass must be about 1 ft from the eye so that the point sighted and the axial line in the sighting window can be focused clearly.

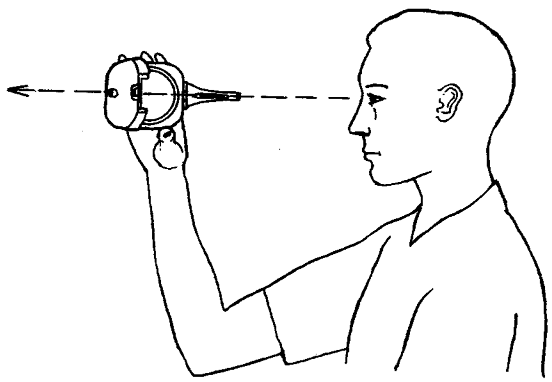


Fig. 2-4. Using the Brunton compass as a clinometer.

3. Look through the window of the lid and find the point to be sighted, then tilt the compass until the point of the sighting arm, the axial line of the window, and the point sighted coincide.

4. Move the clinometer by the lever on the back of the compass box until the tube bubble is centered, as observed in the mirror.

5. Check to make sure the sights are still aligned, then bring the compass down and read and record the angle.

Computing difference in elevation. The approximate difference in elevation between the point occupied and the point sighted can be computed in the field if the slope distance is paced and if a small table

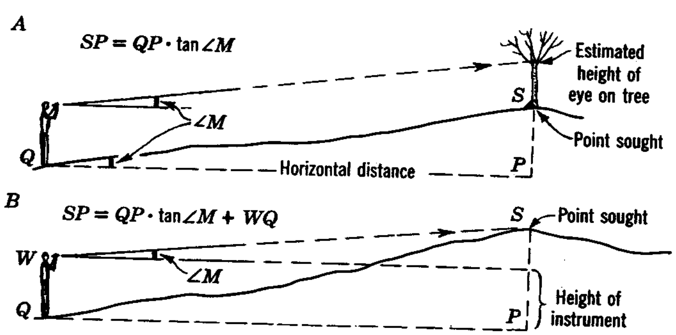


Fig. 2-5. Finding difference in elevation (*SP*) from a vertical angle (*M*) and horizontal distance (*QP*). (*A*) Relation used when sighting on a point at height of eye. (*B*) Relation used when sighting uphill to point itself.

of sines of angles is available (difference in elevation = slope distance × sine of vertical angle). The difference in elevation can also be determined if the horizontal distance between the points can be scaled from a map or aerial photograph, the difference in elevation then being computed from a table of tangents. The height of the instrument above the point occupied is taken into account either by (1) sighting to a point that is at an equal distance above the ground (Fig. 2-5*A*) or (2) sighting directly to the point on the ground and correcting the difference in elevation by adding the height of the instrument for uphill sights and subtracting it for downhill sights (Fig. 2-5*B*).

2-6. Using the Brunton Compass as a Hand Level

The Brunton compass is converted to a hand level by setting the clinometer exactly at 0, opening the lid 45°, and extending the sighting arm with the sighting point turned up. The compass is held in the same way as when measuring vertical angles. It is tilted slowly until the mirror image of the tube bubble is centered. Any point lined up with the tip of the sighting arm and the axial line of the sighting window is now at the same elevation as the eye of the observer. By carefully rotating the entire instrument with a horizontal motion, a series of points that are at the same elevation can be noted.

Difference in elevation by leveling. The difference in elevation between two points can be measured by using the Brunton compass as a hand level. The measurement is started by standing at the lower of the two points and finding a point on the ground that is level with the eye and on a course that can be walked between the

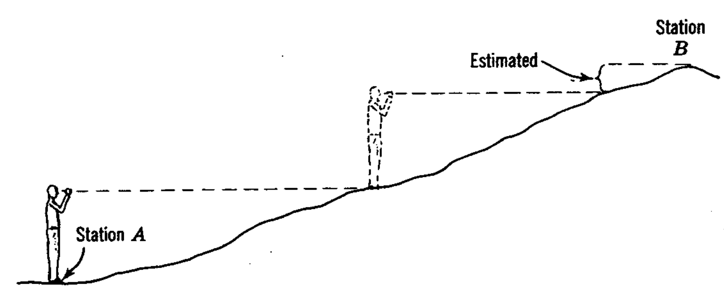


Fig. 2-6. Measuring the difference in elevation between two stations by using a hand level and counting eye-level increments.

two end points. As the first level sight is made, an object such as a stick, leaf, or stone is marked mentally and kept in sight while walking to it. Standing on this marker, another point at eye level is chosen farther uphill, and the procedure is repeated until the end point is reached (Fig. 2–6). The number of moves is tallied and multiplied by the height of the surveyor's eye, with the last fractional reading estimated to the nearest even foot or half a foot. If the country is reasonably open, the traverse can be made both quickly and accurately. The serious error of miscounting the tally can be prevented by keeping a pencil tally on the cover of the compass or by using a tally counter.

2–7. Measuring Strike and Dip

The strike and dip of planar geologic structures, such as bedding, faults, joints, and foliations, can be determined by several methods with the Brunton compass. Strike is generally defined as the line of intersection between a horizontal plane and the planar surface being measured. It is found by measuring the compass direction of a horizontal line on the surface. Dip is the slope of the surface at right angles to this line. The best method for measuring a given strike and dip depends on the nature of the outcrop and the degree of accuracy desired. The amount of the dip, too, may affect the choice because steeply dipping planar structures can be measured far more accurately and easily than gently dipping ones. Special methods are needed to measure dips of less than 5° accurately.

In the section on taking bearings (Section 2–3), it was noted that a bearing has a unidirectional sense and that the white end of the compass needle must be read in all cases. Traversing and locating points by intersection require this strict usage. In the case of a strike line, however, there is no reason for such a distinction. It is recommended that for measuring strike only the *north half* of the compass be used, regardless of which end of the needle points there. Strikes would thereby be read as northeast or northwest, never southeast or southwest. This helps eliminate the occasional serious error of transposing a strike to the opposite quadrant when reading, plotting, or recording it. These errors can occur easily where two men are working together and calling out structural data from one to the other.

The instructions that follow refer to the strike and dip of a bed or beds, but the same methods can be used for measuring other planar structures.

1. Most accurate method for one outcrop. This method requires an outcrop that shows at least one bedding surface in three dimensions. If the bedding surface is smooth and planar, no more than a square foot or so of surface need be apparent, but if it is irregular, several square feet must be visible. Where road cuts or stream banks truncate beds smoothly, a hammer can be used to expose and to clean off a bedding surface. The measurement is made by stepping back 10 ft or so from the outcrop to a point from which the bedding surface can be seen clearly. The observer then moves slowly to the right or left until he is in that one position where the bedding surface just disappears and the bedding appears as a straight line (Fig. 2–7). In this position, his eye is in the plane that includes the bedding surface. Using the Brunton compass as a hand level, the point on the edge of the bedding surface that is level with the eye is found. This horizontal line of sight is the strike of the bed, and its bearing is determined and plotted.

To measure the dip, the observer opens the lid and sighting arm of the compass and holds it in the line of sight used to measure the strike. The compass is then tilted until the upper edge of the box and lid appear to lie along the bedding plane (Fig. 2–7*B*). The clinometer lever is rotated until the tube bubble is centered, and the dip is then read and recorded to the nearest degree. The intersection of the strike line and the dip line on the map is customarily taken to be the point at which the reading was made.

If the bedding line contains no distinctive feature that marks the point on a level with the observer's eye, it is necessary to mark the point with a pebble, stick, or some other object; otherwise, the reading will be approximate only.

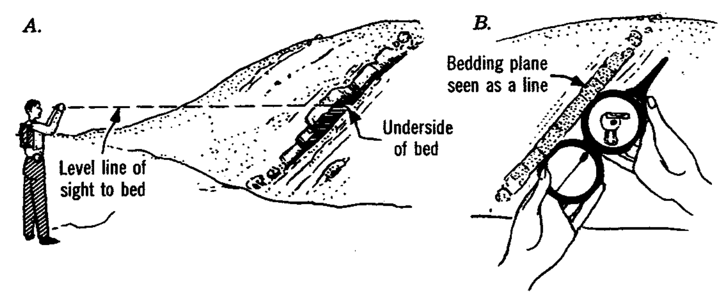


Fig. 2–7. Measuring strike and dip. (*A*) Sighting a level line in the plane of a bedding surface. (*B*) Measuring the dip of a bedding surface.

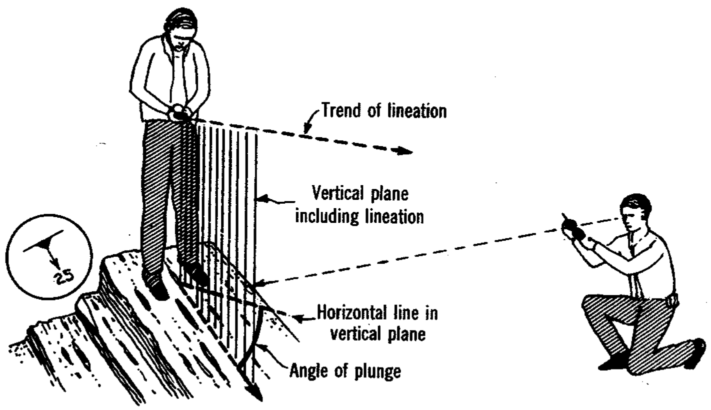


Fig. 2–10. Measuring the trend of linear structures (upright figure) and the amount of their plunge (kneeling figure). The map symbol (insert) shows how the lineation arrow can be combined with the strike and dip symbol of the foliation surfaces.

is parallel to the trend of the feature, the bearing at the white end of the needle is read. The trend is then plotted on the map as a line originating at the point occupied by the observer.

To measure the plunge of the feature, the observer moves so that he is looking at right angles to its trend (Fig. 2–10, right). The reading is taken on the trace of the linear feature seen from this position, exactly as in taking the dip of the trace of a bed. An arrow point is then drawn on the map at the downward plunging end of the trend line, and the amount of plunge is lettered at the end of this arrow. For horizontal linear features, an arrow point is drawn at both ends of the line.

2–10. Care and Adjustment of the Brunton Compass

The compass should never be carried open in the hand while walking over rough or rocky ground. If an extra mirror and glass cover are included in the field gear, these can be replaced in the field, but if the hinges are bent or the level vials broken, the instrument must be sent to the manufacturer for repair.

If the compass is used in the rain, or if it is accidentally dropped in water, it should be opened and dried because the needle will not function properly when its bearing is wet. The glass cover can be

removed by forcing the point of a knife blade under the spring washer that holds it in place. This should be done at a point opposite the dove-tail join of the washer, using care not to crack the glass cover along its edge. With the washer off, the glass cover can be lifted from the box, and the needle taken off its bearing. The cone-shaped pit of the jewel bearing should be cleaned and dried with a sharpened toothpick and a bit of soft cloth or soft paper. The needle lift is then removed and the inside of the compass dried and cleaned. Care should be taken not to push so hard against the clinometer level vial that it turns on its axis. After the needle-lift arm, needle, and glass cover are reassembled, the spring washer should be placed on the glass cover by joining its dove-tailed ends first, placing them firmly against the compass box and then forcing the rest of the washer down by moving the fingers in both directions away from the dove-tail join. If this cannot be done with the fingers, two small pieces of wood can be used.

The mirror can be removed by tapping in the small retaining pin and removing a spring washer like that on the box. The new mirror must be inserted so that its black sighting line is at right angles to the hinge axis of the lid. This can be done approximately by rotating the mirror until the sighting line bisects the sighting window in the lid. The setting should then be checked by closing the lid against the upturned point of the sighting arm and determining if the point of the arm meets the sighting line of the mirror.

Before a new or a borrowed compass is used in the field, it should be checked to make certain the clinometer level is correctly set. To do this, the clinometer is set at 0, and the compass is placed on a smooth board that has been leveled exactly with an alidade or a good carpenter's level (a bull's eye level is not sufficiently accurate for this). If the tube bubble does not come to center, the compass is opened as described above and the clinometer level vial moved appropriately. Ordinarily this can be done without loosening the clinometer set screw. The new setting is checked by placing the compass on the board again, and the procedure repeated until the bubble is centered exactly.

In starting work in a new field area, one may find that the dip of the earth's magnetic field is so great as to cause the compass needle to rub against the glass lid when the compass is held level. To correct this, the glass cover is removed and the copper wire coil on the needle moved one way or the other until the needle lies level.

3

The Compass Traverse

3–1. General Scheme of a Geologic Traverse

In a *traverse* a series of points are surveyed by measuring the direction and distance from one point to a second, and from the second to a third, and so on to the last point. The directional course of this series of measurements is generally irregular; if it is eventually brought around to the starting point, the traverse is said to be *closed.* Each of the points of the traverse is called a *station,* while the measured distance between two stations may be called a *leg* of the traverse. The traverse is used as a skeletal map on which geologic data are plotted along or near the traverse legs. These data may be compiled with those from other traverses to make a complete geologic map. They may also be used to construct a vertical cross section and columnar section showing the rock units and structures traversed. The traverse is commonly used to measure thicknesses of rock units, to compile detailed descriptions of sedimentary or volcanic sequences, and to study deformation in complexly faulted or folded rocks. If a topographic map of suitable scale and accuracy is available, it should be used as a base on which to plot the traverse. Published topographic maps, however, have scales of 1:24,000 to 1:62,500, and many geologic studies require scales larger than 1:6,000 (1 in. = 500 ft). Most detailed studies therefore require constructing a map from the traverse data.

The scale of the traverse is chosen so that the smallest units that must be shown to scale can be plotted easily. If the purpose of the traverse requires, for example, that beds 10 ft thick must be shown to scale, the best scale for the work is 1 in. = 100 ft. In general, anything that cannot be plotted as a feature $\frac{1}{10}$ in. wide cannot be mapped easily to scale, although features that plot $\frac{1}{20}$ in. wide can be shown accurately if great care is used.

The method by which the traverse should be surveyed is determined by the accuracy required and the time and equipment available. For many projects, a compass is adequate for determining the bearings of the legs, and the legs can be measured with a tape or by pacing. An advantage of pacing is that it can be done by one man; its accuracy

over reasonably even ground is adequate for most projects whose working scale is 1 in. = 100 ft or more. For more exacting and detailed traverses, a tape should be used to measure distances. The alidade and plane table are commonly used where magnetic variations are large, where terrain is rough, or where distances of several miles must be traversed accurately (Section 8–12). Traverses requiring still greater precision may be made with a transit and steel tape (Section 7–13).

3–2. Determining Pace

In geologic field studies, distances are commonly measured by pacing. It should be possible to pace over smooth terrain with errors of only a foot or two in each 100 ft. The pace should be calibrated and tested for slopes and rough ground as well as for smooth terrain. This can be done by walking a taped course of 200 ft or more and dividing the distance by the number of paces. One or two other courses should then be paced to test the calibrations. To keep the mental tally of paces at a reasonable rate, a pace is generally counted at every fall of the right foot. The calibrated courses should be walked in the same manner as that used normally in the field; a pace should never be forced to an even 5 or 6 ft.

Smooth slopes of low or moderate declivity may be measured by taking normal steps and then correcting the slope distance trigonometrically (map distance = slope distance × cosine of the vertical angle of slope). Slopes that are too steep to walk with normal strides can be paced by establishing one's pace for measured uphill and downhill courses. Pacing over rocky, brushy, or irregular ground requires patience and practice. It can often be done by correcting the count to normal as pacing proceeds. Right-angle offsets can be made around obstacles in some places; in other places, the number of normal paces through an obstacle can be estimated by spotting the places where steps would fall if the obstacle were not there.

The greatest source of error in pacing is miscounting, especially dropping 10 or 100 paces in a long measurement. For this reason traverse legs should be paced in both directions. For much pace and compass work it is desirable to use a *tally counter,* a small odometer-like counter operated by a lever. A *pedometer,* which tallies automatically each time it is jolted by a footfall, is useful for open ground but does not permit corrections for offsets and broken paces.

3–3. Selecting a Course and Planning a Traverse

As in all geologic projects, reconnaissance and comparison of the possible courses for a survey save time in the long run. Where possible, the traverse course should cross the strike of beds or other structures at about 90°. The course must have adequate rock exposures and be accessible enough to permit an efficient survey. These requirements are met ideally by roads that give a series of cuts across the strike of the rocks. Railroads have the drawback of affecting bearings taken with a compass. Many stream courses cross the strike directly and have abundant rock exposures, but pacing along streams may be difficult. Open ridges and beaches commonly afford excellent traverse courses.

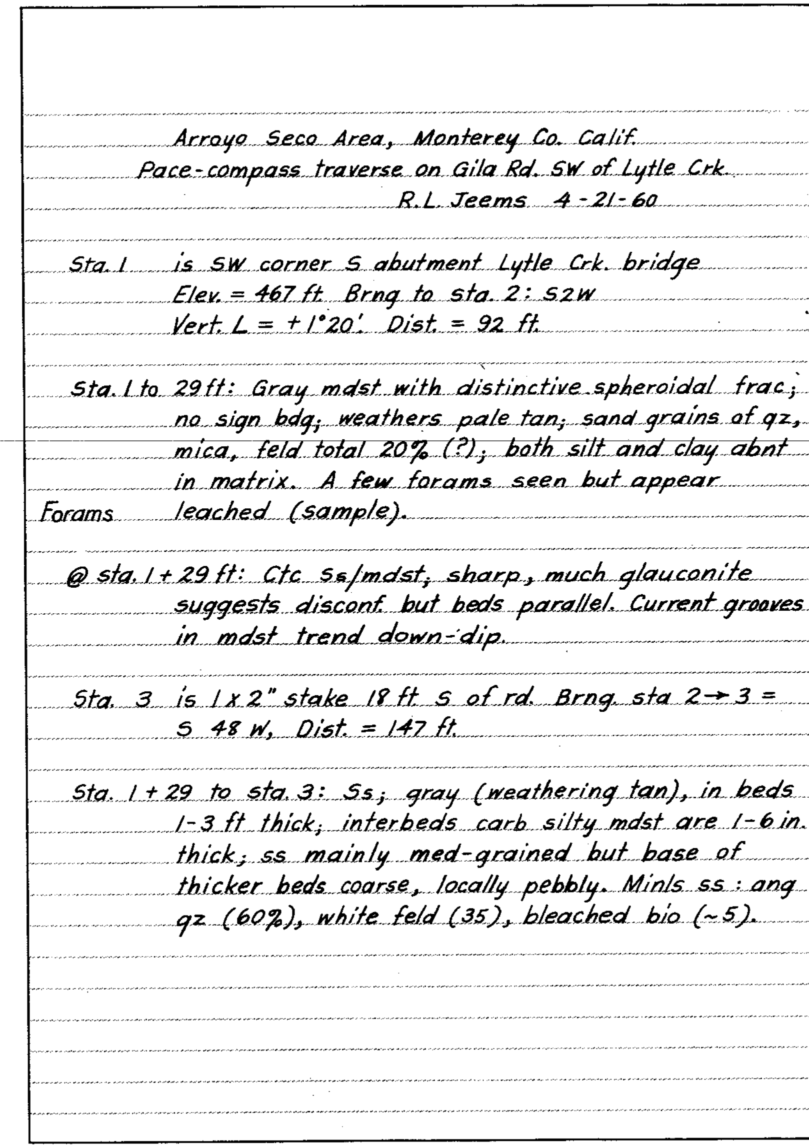
In addition to locating the traverse, the reconnaissance should provide answers to the following questions:

1. Is the sequence of rocks monotonously the same, or can the rocks be grouped into two or more units, each characterized by a certain lithology?
2. What scale must be used to show the thinnest rock units that seem significant to the study?
3. If the data from the study will be presented in a geologic cross section or columnar section, how will the sizes of the illustrations limit the data collected and the working scale of the traverse?

Generally, more data must be collected than will be used in the final illustrations, but information must not become so detailed that the principal objectives of a survey are obscured. Field notes will be difficult to use, for example, if they present voluminous, random descriptions of every bed observed.

3–4. First Steps in a Compass Traverse

The procedures of a typical compass traverse include: (1) surveying the stations and legs of the traverse, (2) measuring a profile along the traverse course, (3) plotting the stations and geological features on a field sheet, and (4) describing the geologic features in field notes. The equipment, most of which is described in Section 1–3, should include a geologist's hammer, Brunton compass, clip board or notebook, pocket knife, medium-hard pencil with clip and eraser for plotting, ballpoint pen or medium pencil for taking notes, hand lens, knapsack, specimen bags, protractor, and 6-inch scale. The scale



Arroyo Seco Area, Monterey Co. Calif.
Pace-compass traverse on Gila Rd. SW of Lytle Crk.
R.L. Jeems 4-21-60

Sta. 1 is SW corner S abutment Lytle Crk. bridge
Elev. = 467 ft Brng to sta. 2: S2W
Vert. L = +1°20'. Dist. = 92 ft.

Sta. 1 to 29 ft: Gray mdst with distinctive spheroidal frac; no sign bdg; weathers pale tan; sand grains of qz, mica, feld total 20% (?); both silt and clay abnt in matrix. A few forams seen but appear
Forams leached (sample).

@ sta. 1 + 29 ft: Ctc Ss/mdst; sharp, much glauconite suggests disconf. but beds parallel. Current grooves in mdst trend down-dip.

Sta. 3 is 1 x 2" stake 18 ft S of rd. Brng. sta 2→3 = S 48 W, Dist. = 147 ft.

Sta. 1 + 29 to sta. 3: Ss; gray (weathering tan), in beds 1-3 ft thick; interbeds carb silty mdst are 1-6 in. thick; ss mainly med-grained but base of thicker beds coarse, locally pebbly. Minls ss: ang qz (60%), white feld (35), bleached bio (~5).

Fig. 3–1. First note page for geologic compass traverse.

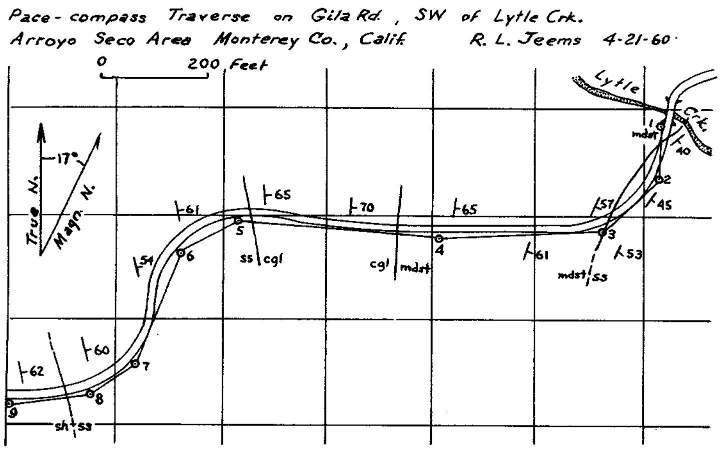


Fig. 3–2. Skeletal map of the traverse, plotted as it is surveyed.

should be divided in tenths of an inch or in other divisions that allow direct conversion to the scale of the field plot. Several sheets of cross-ruled paper are needed for the field plot.

The traverse should be begun and/or ended at permanent markers that can be found readily by other persons. Bench marks, triangulation stations, highway or railroad turning point markers, culvert posts, solid fences, or property corners are all suitable. If these are lacking, solid 2 × 2 in. stakes can be used. In any case, these points must be described in the notes.

The traverse is begun by standing at one of the end points and sighting along the general line of the traverse to the farthest point visible along a course that can be paced. The distance to this tentative station is paced, and if the point proves to be a good choice, it is marked with a stake or other device, and a bearing is read back to the starting point. If possible, the distance should then be checked by pacing back to the starting point. The bearing to the station is then taken, and if it agrees within a degree (preferably, a half a degree) with that of the backsight, the field map is started by plotting this first leg. The bearing and distance are entered in the notes, as shown in Fig. 3–1.

If the field plot of the traverse is made on cross-ruled paper, the ruled lines can be used as a north-south and east-west grid for plotting bearings. The sheet should be given a title, as that shown in Fig. 3–2.

Before the first leg is plotted on it, the general layout of the traverse must be planned so the plot will not go off the sheet on the second or third leg.

Generally, the scale of this map need be only half as large as that of the final illustration. Its purpose is to develop a continuous picture of both the geographic features and the geologic structures as they are traversed. This permits checking the continuity of faults and contacts that cross the traverse course more than once. Bearings and structural attitudes that have been misread or transposed can be detected by orienting the map in the field and comparing the plotted symbols with the outcrops.

3–5. Traversing by Turning Angles

If magnetic disturbances are appreciable (Section 2–4), traverses should be surveyed by turning angles between adjacent legs. Before starting the traverse, it is necessary to determine the bearing of a line that can be sighted from the first traverse station. This can generally be done by: (1) pinpointing the first traverse station on a map, (2) drawing a line on the map from this point to any other point that can be seen from the first traverse station, and (3) measuring the bearing of this line with a protractor. If no usable point can be seen, or if there is no base map, the bearing of the initial leg can be determined by taking a sight on Polaris (Section 2–2); otherwise the compass bearing of the first leg must be assumed to be correct.

The traverse may then proceed as follows:

1. Read and record the compass bearing to the point used to establish a bearing from the first station, as line 1-*M* in Fig. 3–3.
2. Read and record the compass bearing to the first forward station of the traverse, as line 1-2 in the figure.
3. Determine the angle between these lines ($\angle a$) from the bearings. Compare the computation with the field map to make certain the correct quadrants have been used.
4. Plot the first traverse leg by using this angle.

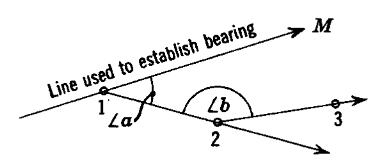


Fig. 3–3. Surveying a traverse course by turning angles.

5. Read and record the bearing from Station 2 to Station 1.
6. Read the bearing to Station 3, and compute the angle ($\angle b$) *from the bearings read at Station 2.*
7. Plot the leg 2-3 on the basis of this angle, and continue in a similar way through the other stations.

Although this method will correct for magnetic deflections at each traverse station, local variations between the stations will not be corrected. Structure symbols plotted at or near stations will therefore be correct, but others may be incorrect.

3–6. Plotting Geologic Features on the Traverse

The following geologic structures should be plotted on the field map: (1) contacts between rock units, (2) strike and dip of bedding and other planar structures required for a given project, (3) faults, with dip arrow and, if possible, note of upthrown and downthrown sides, (4) axial trace of folds, with trend and plunge of axis, (5) other linear structures required for a given project, and (6) names or brief notes labeling the more important rocks and features. The plotting should be done with a sharp medium-hard pencil and in the following way: (1) the distance from the nearest station is scaled off along the traverse leg; (2) offset, if any, is plotted to give the location of the structure; (3) the strike or trend of the structure is drawn with a protractor; (4) a dip line or arrowhead is added and the amount of dip or plunge lettered in; (5) *the traverse plot is oriented relative to the terrain, and the attitude shown by the symbol is compared with the outcrop;* (6) if there is doubt about its accuracy, the structure is remeasured. No amount of intuitive thinking in the office can improve on symbols plotted in this way.

Notes should include descriptions of lithology and all small-scale structures that may be helpful in interpreting the history of the rocks. Some notes will be detailed descriptions of specific localities; others will be overall descriptions of rock units. Unit descriptions should include the lithologic characters that make the unit distinctive, the nature of the contacts, and the range of lithologic variations within the unit (Section 1–5). If a detailed cross section is to be prepared from the traverse, drawings of entire road cuts or other outcrops may be helpful.

The notes should be recorded in the order in which features are encountered on the traverse. The stations are generally given consecutive numbers while the notes between them may be listed conveniently by the number of feet from the last station. If parts of the traverse are revisited and supplementary notes are taken, these numbers offer a simple means of fitting new data into place.

3–7. Vertical Profile of the Traverse

The vertical profile of the traverse must be surveyed in order to measure rock units accurately and to project geologic features to a vertical cross section. If the traverse course runs irregularly up and down, the profile should be surveyed as the traverse proceeds. This can be done by measuring vertical angles between stations and to points where the grade of the profile breaks, and computing differences in elevation (Section 2–5). It can also be done by using the Brunton compass as a hand level and finding differences in elevation directly (Section 2–6). If the traverse course is on an evenly sloping road, stream, or ridge, the profile need not be measured at every station; instead, an overall survey of the gradient can be made after the traverse is completed.

Structures must be plotted on the map at the point where they intersect the profile of the traverse or where they intersect an arbitrary datum surface above the profile. Along most road cuts it is convenient to plot structures at waist height (3½ ft) above the road. Structures that cannot be projected reliably to this level must be surveyed individually, and their vertical distances above the datum must be recorded. Figure 3–4 illustrates why this must be done.

The line of section of a geologic cross section will almost always be offset somewhat from the traverse course. The profile of the traverse will therefore not give the true ground profile for the section.

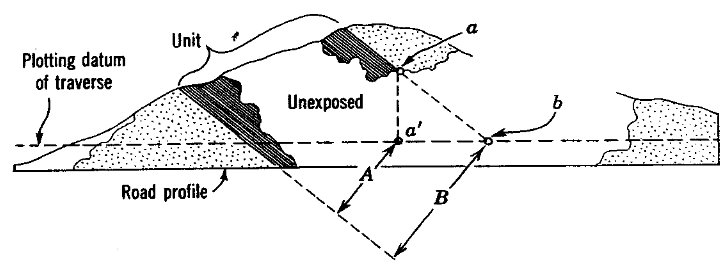


Fig. 3–4. Large road cut, exposing a contact at *a*. This contact must either be plotted at *b*, or the elevation at *a* must be recorded. If it were plotted at *a′*, the thickness of the unit would be measured by *A* instead of *B*.

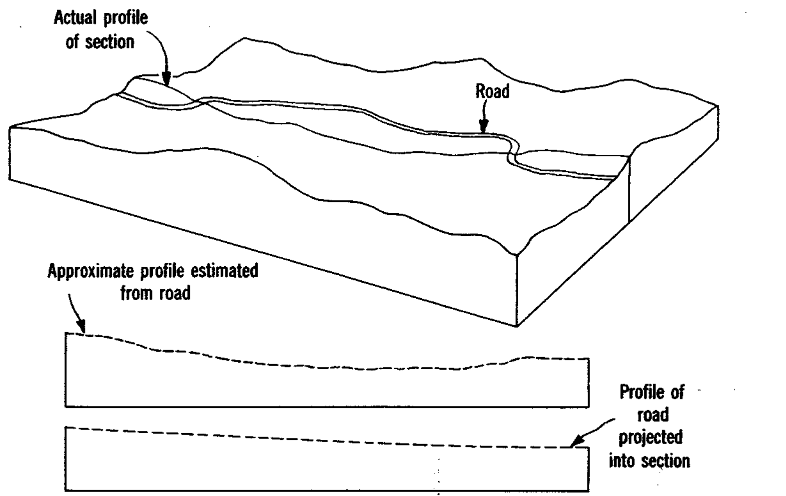


Fig. 3–5. Three possible profiles for a cross section. The traverse course is along the road.

As shown in Fig. 3–5, this problem may be met in three ways. First, the actual ground profile may be surveyed along the line of the cross section. This requires that the section line be chosen first, as described in Section 3–8. The survey of this profile may take considerable time and effort if the terrain is irregular or covered by trees and brush. The second possibility is to estimate an approximate profile along the line of section by reading vertical angles from the traverse course and sketching the terrain between. If this is done, the profile on the final illustration must be dashed and labeled as approximate. The third possibility is to ignore the profile along the line of section and to use the profile of the traverse on the final illustration, dashing it and labeling it suitably.

3–8. Making Illustrations from the Traverse Data

Data from a detailed traverse are generally compiled into a map, a vertical cross section, and a columnar section. These figures may become the only permanent record of the traverse. They are generally drawn in ink on a transparent sheet from which prints can be made. The materials required are a drawing board, T-square, 10-inch or 12-inch triangle, medium-hard pencil, eraser, ruling pen, a piece of tracing linen or heavy drawing paper of appropriate size, crow-quill

pen and holder, black waterproof ink, 12-inch scale, and an accurate protractor with a base of 6 or more inches. Additional items that may be useful are a contour pen, a drop-circle compass, lettering guides, and a pen cleaner.

The traverse should be plotted accurately in pencil before any ink is used. This reduces ink erasures and provides a means of arranging the figures in a single illustration. The instructions that follow suggest consecutive steps for this procedure.

1. Using the exact bearings and distances recorded in the traverse notes, plot the traverse course accurately in pencil at the same scale that will be used for the inked illustration.
2. Add all geologic and geographic features, making strike lines about ⅜ in. long; lettering of numbers need be legible only.
3. Draw the line of the cross section, choosing it so that it will pass as close as possible to the outcrops covered by the traverse and at the same time cross the strike of the rocks as nearly to 90° as possible.
4. Project contacts, faults, and strike lines to the line of the cross section. This must be done by special methods if the rocks are folded. In Fig. 3–6*A*, for example, the units are pinched in an unnatural way if the contacts are projected straight to the line of section. The area is on the limb of a plunging fold, and the contacts should curve into the line of section as shown in *B*. To make these projections accurately, it is necessary to know the general shape or kind of fold involved and to use methods suitable for projecting folded beds from scattered structure symbols. These methods have been described by Badgley (1959, especially Chapter 3) and in part by Busk (1957); they are also presented briefly in most textbooks on structural geology.
5. Draw a tentative base line for the vertical cross section; this line should have exactly the same length as the section line of the traverse map and *be exactly parallel to it.* The cross section on the final plate should be oriented so that its right-hand end is either its more easterly end or is oriented due north.

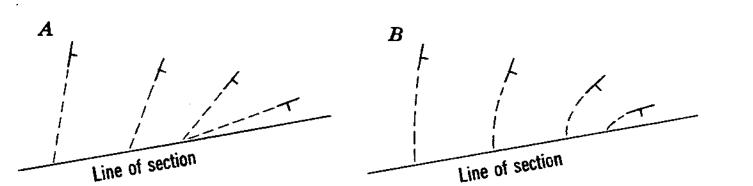


Fig. 3–6. Projecting folded beds into the line of section.

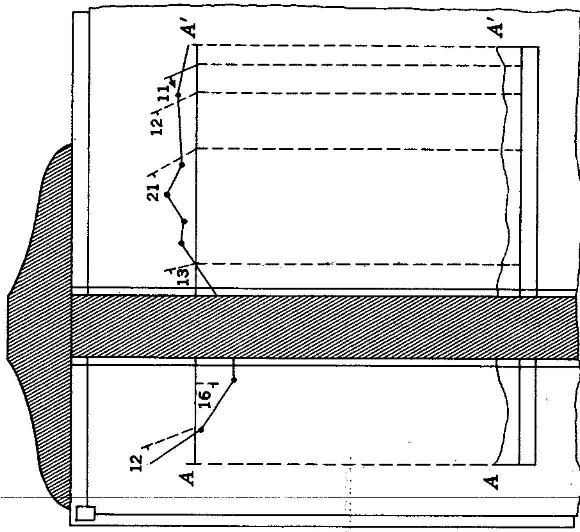


Fig. 3–7. Using a T-square to project features from the line of section *AA′* to the cross section.

6. About ¾ in. above the base line of the section, plot a profile line that represents the datum at which all or most of the structure readings were taken in the field.

7. Tape the sheet to a drawing board so that the section line is parallel to an edge of the board. Using a T-square on this edge, project all structures from the section line of the traverse to the profile of the cross section or to whatever elevation was used for each structure reading (Fig. 3–7).

8. Draw bedding lines where structure readings have been projected to the profile, making each about ¼ in. long. Where the line of section crosses the strike obliquely, the bedding shown on the cross section must dip less steeply than the dip measured in the field. This dip, called the *apparent dip,* can be determined from the true dip by using the diagram of Appendix 9.

9. Complete structures under the profile line, projecting them down to whatever depth the geologic data will permit. In many cases this will require shifting the base of the section that was drawn provisionally in step 5. Folded beds must be constructed accurately, as noted in step 4. Examine the structures mapped on either side of the line

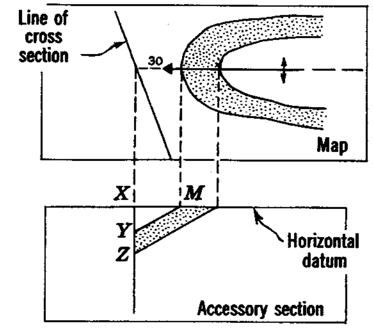


Fig. 3–8. Constructing an accessory vertical section to determine where a folded unit will plunge into a cross section. Projection lines are dashed. The distances *XY* and *XZ* are transferred to the main cross section. These distances can also be found by trigonometric calculations; for example, $XY = XM \cdot \tan 30°$.

of section to determine if some may cut the section below the ground profile. Folded units, for example, may plunge into the section, and faults that strike parallel to the section may dip into it below the surface (Fig. 3–8). An example of a cross section is shown in Fig. 11–5.

10. Determine the true thicknesses of the rock units. They may be scaled from the cross section if the section cuts the strike of the units at about 90°. If this is not the case, calculate the thicknesses trigonometrically, as described in Section 12–8.

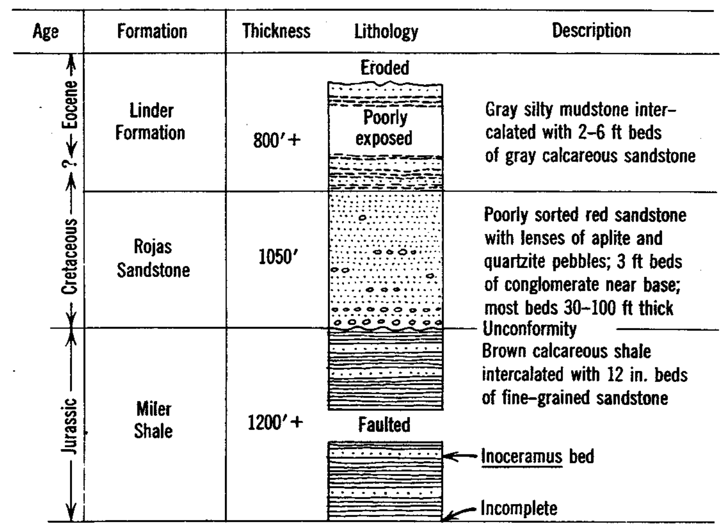


Fig. 3–9. Columnar section, showing a sequence that has been divided into three rock units.

11. Using a pencil and a separate piece of cross-section paper, build up a columnar section of the rocks traversed, starting with the youngest at the top. This may be done at a larger scale than the other figures. Signify breaks in the sequence caused by unconformities, faults, or lack of exposures (Fig. 3–9).

12. Prepare very brief but informative lithologic descriptions for each unit. Letter them in pencil beside the trial column in order to space them correctly.

13. Draw in the lithology of each unit on the column by making a diagrammatic but accurate record of the kinds, proportions, and positions of the rocks. The symbols of Appendix 5 can be used for most units. Check the symbols against the lithologic descriptions.

14. If the map and the sections are to be drawn in one illustration, arrange the separate penciled sheets so that the bases of the cross section and columnar section are parallel. Space the separate drawings so that they are legible but take up as little space as possible. Trace them on a single transparent sheet, or transfer them to a sheet of opaque paper. Add a title that gives a geographic name to the project, the geologist's name, and the date of the survey. Add a bar scale and a north arrow (showing the magnetic declination).

References Cited

Badgley, P. C., 1959, *Structural methods for the exploration geologist:* New York, Harper and Brothers, 280 pp.

Busk, H. G., 1957, *Earth flexures, their geometry and their representation and analysis in geological section, with special references to the problems of oil finding:* New York, William Trussel, 106 pp. (an unabridged republication of the 1929 edition).

4 Plotting Geologic Features on a Base Map

4–1. Selecting and Preparing a Base Map

Maps used for plotting geologic features and note numbers in the field are called *base maps*. *Planimetric* base maps show drainage, culture (man-made features), and perhaps scattered elevations; *topographic* base maps show contours as well. Accurate topographic maps are ideal base maps, for cross sections can be made from them in any direction, and their contours provide several means of plotting outcrops accurately.

To be useful, a given map must have a suitable scale, must have been made recently enough to show existing culture and drainage, and must have contours that delineate the topography accurately. The 7½-minute (1:24,000) topographic maps of the U.S. Geological Survey are excellent base maps. Their scale is such that features 200 ft wide (0.1 in. on the map) can be plotted easily, and features 100 ft wide can be shown to scale if drawn with care (an average pencil line covers 5 to 10 ft of a feature at this scale). Because most of these maps have been made from aerial photographs, however, trails, minor roads, and buildings that lie under trees may be shown inaccurately.

Many quadrangle maps with a scale of 1:62,500 are useful base maps, but some older maps having this scale may be generalized or obsolete. Small features must be plotted carefully on them because features 500 ft across on the ground are only 0.1 in. wide on the map. Moreover, it make take considerable time in the field to locate individual points on these maps, for many topographic and man-made features are not shown on them. It is often preferable to map on aerial photographs with a larger scale and then transfer the geologic features to a topographic map (Section 5–11).

It may be desirable to have a base map enlarged two or three times to give more space for plotting symbols and note numbers. Enlarging does not increase the accuracy of the base map, but it may improve the geological mapping because of the greater ease of plotting. Enlargements must be made so as not to distort the scale of the map and must be printed on paper that will take ink and pencil marks. Ordinary photostat prints are not suitable for most mapping.