Stratigraphic Sections

11-1. Preliminary Steps

Stratigraphic sequences are measured and described in many kinds of projects and are generally presented as columnar sections or detailed descriptive logs. These surveys have three basic purposes: (1) to obtain accurate thicknesses of mapped units; (2) to record full sequential descriptions of the rocks within the units; and (3) to obtain exact stratigraphic positions of fossils and rock samples.

Well-exposed sections are often surveyed during a mapping project in order to recognize stratigraphic position in places where the same rocks are poorly exposed or broken by faults. Stratigraphic measurements may also have specific purposes, such as determining areal variations in thickness or lithology; connecting surface mapping with subsurface logs of wells; and describing type sections of new formations (Section 5-3). In addition to their use in sedimentary sequences, stratigraphic sections may be compiled for volcanic sequences, for metamorphic rocks, and for stratified plutons. Additional suggestions for specific projects as well as for methods of measurement have been given by Kottlowski (1965).

Accurate stratigraphic measurements and descriptions require much time and effort and thus warrant thorough preparation. The preliminary steps that follow are suggested for field projects consisting chiefly of stratigraphic measurements. In cases where extensive geologic mapping precedes measurements, most of the steps will already have been taken.

1. Researching rock units will firm up the purpose of the project and indicate features that should be examined during the field work. Geologic mapping is reviewed in order to compile areal variations in thickness and broad structural relations, such as unconformities, gradations to other units, and positions of dated samples in nearby areas. The units are discussed with geologists who have studied them elsewhere.

2. Selecting locations. Ideally, each section should: (a) be well exposed; (b) be measurable within an area of small size (to be as nearly as possible a true stratigraphic column); and (c) be undisturbed by faulting or other deformation that cannot be resolved. These requirements are assessed mainly during field reconnaissance, but study of aerial photographs, geologic maps, topographic maps, and soil maps will help to narrow the selection. Road and railroad cuts, aqueducts, and stream courses often provide the most continuous exposures but may intersect bedding at such low angles as to extend the study too far laterally. If dips are at low angles, steep valley walls scored by ephemeral streams may be ideal sites.

3. Reconnaissance is the most important step in planning (Section 1-4). Landowners or local residents may be questioned regarding access and permission and can often supply valuable information on locations of outcrops or on records from local wells and inaccessible mine workings. The best locations are examined and, if outcrops are scattered, possible courses for measurement are walked out to see if a complete section can be pieced together (Section 11-2). Landslides, faults, and folds that affect the sections are studied to determine if they can be resolved. Closely spaced exposures of the sequence are compared to test its lateral uniformity. Samples are collected to determine if materials are fresh enough for micropaleontologic or petrologic studies (Sections 3-7 and 3-8). The openness of the terrain is noted in cases where telescopic surveying instruments will be used.

4. Precision of stratigraphic measurements arises from two different aspects of a study. The first is the mechanical precision of the surveying methods that will be used (Sections 11-4 to 11-8). The second is how finely the rocks should be subdivided, measured, and described (Section 11-2). The time and funds available affect both aspects of precision. The scale of stratigraphic columns that will be prepared may also affect them (Section 11-9).

5. Preparations for the field. Besides accumulating equipment and supplies ordinarily used in field work (Section 2-1), stratigraphic measurements may require surveying equipment (Section 11-4 to 11-8), special equipment for sampling (mattock, shovel, sledge, rock drill, or crowbar), and equipment for scraping or washing rock faces. Field sheets or notebooks may be set up in advance to help systematize rock descriptions.

11-2. Subdividing and Describing a Section

The description of the section is generally undertaken in this order: (1) location and study of contacts between formations or members; (2) subdivision of these formal units into the informal units that will be described; (3) trial measurements and descriptions of several of these units; (4) systematic measurements and descriptions of the entire section; and (5) reexamination of parts of the section, as necessary.

Formations or members in the section provide a means of correlation with the same units elsewhere. Their contacts should be located exactly at the line of section and should be studied for at least several hundred meters on either side of the section. The contacts are based on prior mapping in the area or on published descriptions (Section 5-3). Any contact that cannot be located firmly is described as being within a certain measured interval.

The subdivisions used in the measurement are physically distinct groupings of rocks that will be of value in unifying parts of the description, in
preparing a columnar section, and in interpreting the section. Other geologists may use these units to locate specific parts of the sequence in the field. Ideal stratigraphic units are based on lithologic characteristics that have genetic meaning, and the more practical are also based on obvious surficial characters, such as degree of exposure, steepness of slope, thicknesses of beds, kinds of vegetative cover, and color of rock and soil. Thickness is not an important criterion provided the unit is physically distinct. A thin tuff bed in a sedimentary sequence, for example, would be a valuable unit. Disconformities should be used as contacts between units even if they seem minor.

A trial description and measurement of part of the section serve to calibrate procedures to the time available and the purpose of the project. These genetic meaning, and the more practical are also based on obvious surficial characteristics, such as degree of exposure, steepness of slope, thicknesses of beds, kinds of vegetative cover, and color of rock and soil. Thickness is not an important criterion provided the unit is physically distinct. A thin tuff bed in a sedimentary sequence, for example, would be a valuable unit. Disconformities should be used as contacts between units even if they seem minor.

Systematic measurement and description of the full section is best made by advancing up-section, in order to see the sequence in depositional order. This approach is especially important for sections with occasional scour or omission surfaces, or for sequences composed of depositional cycles or rhythms. Outcrops are generally easiest to find and examine when walking upslope, especially if the survey is somewhat pressed for time. In any case, all aspects of approach, study, and precision should be kept as consistent as possible during the survey.

Restudying or recollecting parts of the section may prove necessary if important features or relations are recognized after the measurement is well underway. The section may also have to be restudied after thin sections, fossil identifications, or analytical data have been examined. Recopying parts of the section should be no problem if a number of stations are marked permanently, or if the units are lithologically distinctive and they were described carefully and fully in the first place.

**Descriptions** are accumulated per measured unit as the survey proceeds. They should be as complete as time permits, but they are usually recorded in telegraphic style and with use of abbreviations. They are generally started with the name of the rock or rocks that make up the measured unit, followed by data in a systematic order suitable to the project and to the specific rocks being described. The order in Fig. 11-1 is appropriate for general study of a sedimentary sequence, and the characteristics listed in Section 3-3 and those described in Chapters 9, 10, 13, 14, and 15 give additional categories of data. Consistency of order is important because of the need to compare units later and to synthesize overall formation descriptions. It may be worthwhile to make up and duplicate check sheets if a large number of units must be measured in a short time or if data will be digitized (Fig. 11-2).

If a columnar section will be prepared from the data, a graphic log depicting shapes and relative thicknesses of beds and their primary structures is highly desirable (Fig. 11-3). Drawing the log forces one to look systematically at important features and to generalize them consistently. The log also affords a detailed basis for drawing the final columnar section.

Sample sites are recorded in the notes by specific measure and are plotted to scale on the graphic log. Sites of samples that will be analyzed or used biostratigraphically should be marked clearly on the outcrop or photographed with a hammer or other scale at the sample point.

**11-3. Covered, Deformed, or Laterally Variable Strata**

Offsets are commonly needed to piece together separated exposures of a stratigraphic sequence (Fig. 11-4). Ideally, an offset is made by walking along a specific bed or bedding surface that connects the stratigraphically upper part of one exposure to the lower part of a nearby exposure. In cases where the offset must be made across a covered area, a specific bed or a

Fig. 11-1. Field notes from a detailed description of a measured formation.
Section Wore/en Fm. along Rte. 33 in Ringwood Canyon  Unit 7
Measured thickness 28 m  Attitude NISW 65 W
Measured by M. Lawry  Date 2 Apr 84  Comments V. well exposed. Better fossil collections can be made.
Rock or sediment name: Sandstone, subquartzose, feldspathic
Color moist: v. pale brn 10YR 7/3  Dry: 10YR 8/3
Bedding: distinct  vague
Thick: 5 m 1 m 1 cm 1 mm
laminations:
Fossils: (G)  (F)  (x)  (s)  (o)  (s)  (a)  (f)  (w)
Primary structures: Planar x-bedding local large burrows  abundant -- unit 60-75% bioturbated.
Grain sizes range: 5/12 128 32 8 2 .5 .1 .03 .008
median: 256 64 16 4 1 mm .25 .06 .015 .004
Degree of sorting: very well well moderate poor very poor
Grain shapes: very angular angular subangular subrounded rounded
Packing: loose moderate tight pressed
Fabric: Fossils and sparse (3%) mica are locally planar (where not bioturbated)
Weathering degree much none
depth 100 m 10 m 1 m
Composition: quartz 24%  
Lithic clasts: granite 3%  
chert 3%  
aplite 3%  
slate 1%  
argillite 1%  
hornfels 1%  
s dol schist 1%  
ss 1%  
basalt 1%  
rhyolite 1%
Cement: cal dol 1%  
qz 1%  
opal clay 1%  
Fe-oxide 25%  
gyp tar 1%  
anhyd 1%  
zolite 1%
Fig. 11-2. Check sheet for describing measured stratigraphic units, with slant-lettering, brackets, arrows, and underlines showing data recorded for a specific case.

unique set of beds can sometimes be recognized in both exposures. Lacking these direct means of correlation, the offset must be made by walking along a visually projected line of bedding, as by the method described in Section 5.2 under "Using strike and dip to locate contacts."

Cover. Despite careful selection, a section line may cross intervals that are unexposed and cannot be resolved by lateral offsets. If an interval is hidden only by soil, its lithology may be approximated from soil texture, from fragments brought up by burrowing animals, by augering through the upper part of the soil, or by digging shallow pits. Intervals covered by

Fig. 11-3. Part of a graphic log and accompanying unit descriptions, constructed from the base of the formation upward. The fossil symbols are explained in Appendix 9, the rock symbols in Appendix 8, and the color notation in Appendix 6.

Fig. 11-4. Offsets (heavy dashed lines) between measured courses (heavy solid lines) in gullies and along a craggy outcrop.
surfacial deposits may have to be recorded as unknown parts of the section; however, some can be resolved by unusually long offsets or by study of the same general part of the sequence in neighboring areas.

The approximate thickness of strata in covered intervals must be determined in order to obtain the thickness of the unit overall. Covered intervals are measured by using strikes and dips like those stratigraphically above and below the covered interval and measuring as if the interval were exposed.

**Faults** typically are not exposed and therefore constitute a major problem in measuring stratigraphic sections. The suggestions in Section 5-4 may help in recognizing unexposed faults. In particular, any linear strip of unexposed ground should be checked by tracing specific beds or other structures (dikes, veins, etc.) up to the strip and seeing if they project across it to the other side.

The section being measured is generally the best means of correlating stratigraphic units from one side of a fault to another. Where faults and units have been mapped, the relations described in Section 12-5 may help in correlating fragments of a faulted section and thus in determining the stratigraphic interval that is missing or duplicated along a specific fault.

**Landslides** can generally be recognized by their morphology, by variability of bedding attitudes in the slide mass, or by backward tilt of beds (Section 10-7). In measuring sequences of poorly exposed rocks or surficial deposits, large exposures are often formed at the main scarps of slides or in the gullies that tend to form along the lateral shear surfaces (Figs. 10-9 and 10-10).

**Folding** commonly changes thicknesses of folded units, most typically by thinning strata in the limbs of folds and seemingly thickening them in the hinge areas (Fig. 12-12). These effects are absent only in parallel (concentric) folds, which are probably far less common than generally supposed. The effects may be tested by measuring specific rock units on limbs and in the hinge area. If that is not possible, the shapes of outcrop-size folds may suggest the sort of changes likely in large folds. The only firm resolution, however, requires mapping folds and constructing a cross section at right angles to hinge lines, a so-called profile view or right section of the fold (Fig. 12-10).

To use this view in determining the approximate original thickness of a unit, it is first necessary to determine the mechanism of apparent thinning and thickening, which may have been (1) compactional closing of pore space during folding, or (2) plastic deformation of the solid grains in the rock. If the deformation was only compactional, the approximate original thickness is most nearly represented by the thickness at the hinge. If the solid grains of the rock were deformed plastically, the approximate original thickness can be determined as shown in Fig. 11-5. The result is generally a minimum thickness, because rocks are typically also condensed by compaction.

Compaction is indicated by low porosity in rocks normally with high porosity, as mudstone, and by undeformed grains and weak grain fabrics, if any, in limestone and sandstone. Plastic deformation is indicated by cleavage oblique to bedding in the hinge areas of folds, and by strong fabrics and deformed grains in limestone and sandstone. If the deformed grains are also elongated parallel to the hinge line, the amount of extension in that direction must be determined in order to further correct the thickness of the deformed rock unit. Sections 12-1, 12-2, and 12-4 include suggestions for recognizing compactive deformation and for measuring grain fabrics and rock strains due to plastic deformation.

Small folds in an otherwise unfolded sequence may or may not cause problems in stratigraphic measurements. Single beds containing soft-sediment folds (Section 9-3) are measured according to their present thickness. A group of beds affected by soft-sediment folding may be part of a major slump and should, if possible, be traced laterally to determine the original thickness of that interval. Finally, small overturned folds associated with shear zones along specific stratigraphic intervals may indicate detachment faulting (Section 12-5). These intervals may have to be mapped over a large area to determine if part of the section is missing.

**Lateral variations** in original thickness or lithology are not a problem if a section is measured on a fairly straight course at right angles to bedding and the results are intended to show thicknesses along that line. If the purpose of a section is to illustrate average or typical thickness and lithology over some larger area, additional sections should be measured and averaged to form the section. If exposures are abundant, lateral variations can be walked out and a typical section selected directly.

### 11-4. Measurement with the Jacob Staff

In this method, strata are measured in true thickness as the section is traversed and described. The method requires only one person and is especially suited to areas of at least moderate exposure where outcrops are fairly closely spaced near the section course. It may be the only usable method in
rough or brushy country where long taped measurements and long sights are difficult or impossible.

A Jacob staff is a board or pole graduated in suitable units (as decimeters and centimeters) and somewhat longer than the eye height of the person using it. A staff can be made from a piece of planed lumber measuring approximately \(2.5 \times 5 \times 200\) cm (1 X 2 X 75 in.) and of light but strong wood, as Douglas fir. The graduations are ruled across the broader face and must be exactly perpendicular to the staff's length. A Brunton or Silva compass, used as a clinometer, is held firmly against this face parallel to the graduations (Fig. 11-6A). Suppliers (see Section 2-1) generally stock a telescoping Jacob staff and attachments for mounting a Brunton compass to it.

In principle, a measurement is made by aligning the staff at right angles to bedding and sighting down-dip to the point subtended by the measure (Fig. 11-6B). The distance from the base of the staff to the sighting axis of the clinometer is thus equal to the thickness of strata from the base of the staff to the point sighted. The complete procedure is as follows:

1. Measure the strike and dip of bedding at the place of the measurement; record the attitude and set the clinometer at the angle of dip.

2. Open the compass lid \(60^\circ\) and hold the compass firmly against the staff as shown in Fig. 11-6A, with its base parallel to the graduations on the staff and at a comfortable eye-height. Record this height and, if convenient, use it for all other full measures.

3. Place the staff at the base of the unit to be measured and tilt it down-dip (exactly perpendicular to strike) until the clinometer bubble is centered.

4. Study the point sighted on the ground to determine if the staff can be placed on it; if so, note the point carefully by eye and advance the staff to it.

5. If the point sighted cannot be used, move the base of the staff along the same bedding surface until a suitable point can be sighted.

6. Before taking the next measure, tally the first.

7. Proceed similarly to the top of the unit, and for the last fractional measure hold the compass at whatever height is appropriate to sight the top, and record that partial measure.

The thickness of the unit is equal to the tallied number of measures multiplied by the staff-height used, plus the final partial measure.

Because the method requires sighting with a small instrument, it may be tempting to save time by aligning the staff by estimation. Moderate errors in alignment, however, can cause large errors in measurements (Fig. 11-7). In addition, when sighting up or down a slope, one tends to tilt the staff so that it is perpendicular to the ground surface. Errors thus tend to be systematic and to accumulate through a series of measures. When the staff is correctly oriented with the clinometer, the error should be no more than a few centimeters per measure and will tend to be compensated in successive measures. Other methods should nonetheless be considered when both the slope and dip are at low angles.

Sighting with a staff as just described becomes increasingly awkward as...
dips become steeper. Lines of sight typically become shorter, however, and thus accuracy is maintained (Fig. 11-8A). For dips greater than 70°, the operator can kneel and look along strike, viewing the clinometer face-on and making the projection to the ground by estimation (Fig. 11-8B). Beds meeting the surface of the ground at 90° can be scaled by direct measurement (Fig. 11-8C), and the staff can be reversed to measure steeply dipping beds where the average slope is steep to very steep (Fig. 11-8D) or beds are overturned (Fig. 11-8E).

Steep walls of valleys eroded across strike often have the best exposures, and they must be measured by views parallel to strike. In such cases, the clinometer is set to the dip as usual but the lid of the compass is opened so as to make an angle of 90° with the compass face (Fig. 11-9A). The observer holds the compass against the staff and stands facing the compass and outcrop, looking exactly along strike (Fig. 11-9B). The outcrop is sighted along the upper edge of the lid, and the staff is held so that the side facing the observer is vertical. An exact vertical orientation can be obtained by holding a small carpenter’s level against the staff.

An efficient procedure is to measure a full unit (or some 10 measures or so if the unit is thick) and then return to the base of this measured interval to start describing the rocks bed by bed or measure by measure. The top of the unit should first be marked so that it can be found again easily. Beds and intervals thicker than a staff-measure are measured in the same way as the section is measured. Thinner ones generally can be measured directly with the staff or with a roll-up tape. When the description of the unit or other measured interval is completed, the thicknesses are summed and compared with the overall measurement.

Fig. 11-9. Sighting along strike with a Jacob staff. A. Holding the Brunton compass against the staff and sighting along edge of lid. B. Position for taking a measure.

Fig. 11-10. Successive positions of an observer and formula for measuring strata with a Brunton compass, by sighting perpendicular to strike (A), and parallel to strike (B). AB is the eye height of the geologist, and AC the thickness measured.

11-5. Measurement using Eye Height and a Brunton Compass

The Brunton compass can be used to measure sections rapidly when no other equipment is available. It is not suitable for measuring the details of a variable section, however, because it cannot be used for partial measures. Horizontal strata are measured by setting the clinometer at 0° and taking eye-height measures as in leveling (Section 2-7). For inclined strata, the clinometer is set at the local angle of dip and the compass is used to sight down dip much like it is with a Jacob staff (Fig. 11-10A). The number of measures through a unit or exposed interval is tallied and multiplied by the trigonometric relation shown in the figure. Strata that can be observed most easily when looking along strike are measured by setting the clinometer at 0° and sighting eye-height measures that are then converted to thickness trigonometrically (Fig. 11-10B). The point sighted is projected by eye down the trace of bedding to a convenient place to stand for the next measure.

Precision depends on knowing one’s eye height in the footwear being used, standing straight at the exact spot sighted, measuring the strike and dip frequently, and sighting exactly along lines of dip or strike.

Tanner (1953) noted the ease and adaptability of the Brunton method and added a version for places where the measurement must be made oblique to the dip, such as where a stream bed or roadcut provides the only exposure.

Fig. 11-11. Stratigraphic measurement along a linear exposure (RT) that is oblique to strike and thus shows apparent dip of beds. RTV is the direction angle used in Appendix 13.
The clinometer is set to the apparent dip in the exposure and sights are made parallel to the exposure (line $RT$ in Fig. 11-11). The number of measurements along the exposure is the same as it would be by using the true dip and sighting down dip (as along the line $RV$). The thickness is thus equal to the number of eye-height measures times eye height, multiplied by the cosine of the true dip (Fig. 11-10A).

If true dip cannot be measured, it can be determined from the apparent dip by measuring the angle $RTV$ and using Appendix 13.

If the line $RT$ is inclined more than $10^\circ$, a correction must be made for the fact that the angle $RTV$ is not a horizontal angle. Angle $RTV$ is reduced by $1^\circ$ if $RT$ is inclined at $15^\circ$, by $2^\circ$ if it is inclined at $20^\circ$, and by $3^\circ$ if it is at $30^\circ$.

The method also requires that the direction of the line $RT$ be measured with extra care (to the nearest degree) in cases where this line is within $15^\circ$ of the line of strike.

11-6. Tape-Compass-Clinometer Method

A stratigraphic unit can be measured indirectly by taping its intercept on a topographic slope (the distances $AB$ in Fig. 11-12), measuring the dip of bedding and the inclination of the slope (angles $x$ and $y$ in Fig. 11-12), and calculating the thickness by the appropriate formula. This method is more precise than the Jacob staff method in cases where the ground surface crosses bedding at angles less than $20^\circ$ (Fig. 11-7). It is ideally suited for comparatively smooth slopes where outcrops lie along more or less straight courses for distances of 20 m or more. These courses need not be parallel, and offsets can be made as described in Section 11-3 or by a short compass and-tape traverse (Section 5-1).

The calculation of thickness is simple in cases where the taped line is perpendicular to the strike of the beds (Fig. 11-12). Where the taped line is oblique to the strike, which is typical if the line is to follow the best array of exposures, the thickness is found by a formula derived by Palmer (1916) (Fig. 11-13). This calculation may be made fairly quickly with a pocket calculator or by using a nomograph (Palmer, 1916; Mertie, 1922).

If the difference between the angle of slope and the dip is less than $10^\circ$, and especially where the slope and dip are in the same direction, precision can become a problem because sines of angles around $10^\circ$ change nearly 1 part in 10 for every degree. The following precautions are therefore important:

1. Check the accuracy of the clinometer before the survey (Section 2-4).
2. Use two persons for the survey if possible.
3. Be certain that the angle of slope is measured on a line exactly parallel to the tape. Thus: (a) in taping, hold the tape the same distance above the ground at both ends, and (b) in measuring the vertical angle, stand exactly at one point and sight to a point eye height above the ground at the far end of the taped line.
4. Measure strike and dip by sighting rather than by contact methods (Section 3-5).

A measure is made as follows:

1. Starting at the stratigraphic base of the section, hold (or secure) the 0

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Fig. 11-12. Formulas used for determining thickness where the slope measurement $(AB)$ is at right angles to strike: (1) slope and dip are opposed and slope angle plus dip angle is less than $90^\circ$; (2) slope and dip are opposed and slope angle plus dip angle is greater than $90^\circ$; (3) slope and dip are in the same direction and dip angle is greater than slope angle; and (4) slope and dip are in the same direction and dip angle is less than slope angle.

Fig. 11-13. Where the taped line $(s)$ is oblique to the strike (angle $a$), the true dip (angle $d$) and vertical angle of the taped course (angle $b$) can be used to find the stratigraphic thickness by the formula: $\text{thickness} = s \sin a \sin d \cos b + \cos d \sin b$ for cases where dip and slope of the taped course are opposed. Where they are in the same direction, the $+$ sign is changed to a $-$ sign.
end of the tape at the base of the section and carry the reel to the first full length or the first break in slope. Pull the tape taut and mark the measure with a chaining pin, nail, or stake.

2. Record the distance, then measure the bearing of the taped line and the local strike and dip as exactly as possible, and record them.

3. Measure and record the slope angle as described in step 3 above.

4. Describe the sequence in stratigraphic order, positioning each lithic contact by projecting it (parallel to bedding) to the tape, which is held taut and on the same slope as that just measured (Fig. 11-14).

5. Measure strike and dip at several places along the line and determine an average as necessary. If the attitude changes abruptly, measure the distance to that point and treat the parts of the line separately.

6. Calculate the overall thickness by the appropriate formula (Figs. 11-12 and 11-13); then calculate the thicknesses of the units included, if any, and check their total thickness against the overall thickness. Or, if more convenient, calculate the thicknesses later and return as necessary to correct errors of measurement.

7. Advance the tape so that the 0 end is at the first point marked by the nail or stake, offset if necessary (Section 11-3), and continue by the steps just described.

11-7. Transit Method

The transit is ideally suited for measuring stratigraphic sections in areas of low relief where beds dip at angles less than 15°, and it should be considered for any section that must be measured with unusual precision. Advantages over the alidade and plane table are: (1) a transit can be set up more solidly and more quickly; (2) it can be used to measure vertical angles more quickly and more precisely; (3) it permits measurement of a greater range of vertical angles; (4) it can be used to sight down slopes too steep to be visible from a plane table; (5) it can be operated at stations where there is not enough footroom to work around a plane table; and (6) the mountaineering transit and most modern "micro" models are less cumbersome to carry. Descriptions of transits and instructions for checking, adjusting, and operating them are included in texts on surveying and, for recent models, are supplied with the instruments.

The transit method used most commonly is almost like the tape-compass-clinometer method (Section 11-6) except that vertical angles and angles between the line of strike and the taped course are measured with the transit. As with the ordinary clinometer, the transit must be aligned parallel to the tautly stretched tape, and this can be done by holding a Jacob staff (or any graduated rod) at one end of the line and sighting a point equal to the height of the transit axis above the station mark on the ground.

The stations where the transit is set up are generally marked permanently with a firmly set stake and a small nail. The strata in between may be measured and described as in Section 11-6, or by using a Jacob staff in cases where angles of dip and slope permit adequate precision. The staked stations are a basis for collecting samples or additional data at a later time. In some cases it may be most efficient for two or three persons to survey the line with a transit and tape, and then for one person to measure and describe the section on the basis of the staked stations.

11-8. Plane Table Methods

These methods are ideal where dips and slopes are too gentle for accurate measurements with either the Jacob staff or tape and clinometer and where outcrops are so scattered that a transit and tape survey is impractical. The alidade and plane table may also be needed where no suitable geologic map is available and the sequence is complicated by faults or folds. In such cases, a strip or skeletal map must be constructed along the section course, and the plane table and alidade permit doing this as the measurement proceeds.

An important initial consideration is the scale required to measure the section to some limiting degree of precision. If the section must be measured to the nearest meter or so, and plotting precision is approximately 0.2 mm on the plane table sheet, the map scale would have to be greater than 1:5000 and preferably 1:2500 or more. At a scale of 1:2500, a standard plane table sheet is just large enough to map a strip 1.5 km long.

The length of the strip to be mapped and the map scale also affect the selection of the kind of survey that will give adequate precision. An uncontrolled stadia traverse should be precise enough to map a strip less than 0.5 km long at scales of 1:2500 or more, providing stadia distances are kept under 100 m and checked by a backsight when the plane table is advanced from one station to the next (Section 8-7, last subsection). Stadia measurements may also be used to map outcrops off the section line, as needed to fill in the stratigraphic section or to determine positions of faults and geometry of folds. Detailed measurement and description of the section itself, however, are better made with a Jacob staff or tape, because otherwise one.
person will be standing at the plane table for long periods between stadia sightings. The stadia points would thus provide a geologic framework for the more detailed measurements.

If the section strip is between 0.5 and 1.5 km long, a traverse can still be adequately precise for scales of 1:2500 or larger, but the main traverse legs should be taped rather than measured by stadia. Strata exposed along the taped traverse legs can be measured directly by the tape, as in the transit method described above. Strata exposed on either side of the traverse line may be mapped by stadia.

Section strips longer than 1.5 km, and thus extending beyond one plane table sheet if mapped at scales of 1:2500 or larger, should probably be controlled by setting up and intersecting a chain of triangulation stations (Section 8-7). This control is especially advisable where structural relations must be mapped in order to measure the section or where there is no large-scale topographic map by which to check the overall dimensions of the plane table map. Mapping between the control stations is done by stadia (Section 8-9) and the details of the stratigraphic section can be accumulated by any of the direct methods described in this chapter.

In areas of gently dipping strata, errors in vertical position introduce almost equal errors in stratigraphic thickness. Vertical distances must thus be measured as precisely as possible, as by using the stepping method rather than measuring vertical angles (Section 8-5). An advantage of the plane table is that the three-point method can be used easily to determine accurate strikes and dips (Section 3-5).

11-9. Presenting Stratigraphic Sections

Graphic columnar sections are the traditional means of presenting measured sequences (Fig 11-15). Brief descriptions of the units may be lettered by an explanation consisting of a small box for each lithologic symbol and for the other symbols alongside the column. No explanation is included in Fig. 11-15, but symbol boxes of lithologic patterns are shown in Appendix 8 and other symbols in Appendix 9. The following elements of a stratigraphic column are essential and are keyed to Fig. 11-15 by numbers: (1) title, indicating topic, general location, and whether the section is single (measured in one coherent course), composite (pieced from two or more section segments), averaged, or generalized; (2) name(s) of geologist(s) and date of the survey; (3) method of measurement; (4) graphic scale; (5) map or description of locality; (6) major chronostratigraphic units, if known; (7) lesser chronostratigraphic units, if known; (8) names and boundaries of rock units (Section 5-3); (9) graphic column composed of standard lithologic patterns; (10) unconformities; (11) faults, with thickness of tectonic gaps, if known;

<table>
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<tr>
<th>Layer</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Tuff, vitric, dacitic, partially welded for 35 m above base</td>
</tr>
<tr>
<td>2.</td>
<td>Conglomerate, red, alluvial, with bed of rhyolite vitric tuff (R-18, 3.9 m.y., K-Ar)</td>
</tr>
<tr>
<td>3.</td>
<td>Shale, greenish gray, locally laminated siltstone and claystone but mainly bioturbated; 2-7 m beds of micrite interbedded rhythmically</td>
</tr>
<tr>
<td>4.</td>
<td>Sandstone, pale gray, quartzose, in .3-2 m beds, with large dolomitic concretions</td>
</tr>
<tr>
<td>5.</td>
<td>Limestone, dolomitic in upper part; pale brown micrite, locally with bioclasts and oolites but chiefly crystalized; beds of oolitic grainstone in upper part</td>
</tr>
</tbody>
</table>

Fig. 11-15. Columnar section with title and accessory data. Numbered items are identified in the text.
(12) covered intervals, as measured; (13) positions of key beds; and (14) positions of important samples, with number and perhaps data.

Other kinds of information that may be included are: (15) designations of formal or informal measured units; (16) an irregular edge indicating relative resistance of the rocks; (17) summary descriptions of formations or other units (especially desirable if the section will not be accompanied by an explanatory text); (18) thicknesses of units; (19) intervals of deformed rocks; and (20) symbols or numbers indicating kinds of fossils, primary structures, porosities, cements, shows of petroleum, and so on. Some of the latter features may be added directly to the lithologic column, as at (21).

Columns are constructed from the stratigraphic base upward and should be plotted first in pencil in order to insure spaces for gaps at faults and unconformities. Sections that are thicker than the height of the plate can be broken into two or more segments, with the stratigraphic base at the lower left and the top at the upper right. Bedding and unit boundaries are drawn horizontal except in detailed sections or generalized sections of distinctly nontabular deposits, as some gravels and volcanic units (Fig. 11-15, and see Mullineaux, 1970, p. 37).

Uses of columnar sections in reports are described in Sections 16-2 and 16-3.

**Stratigraphic logs** are used to describe sections in the text of reports. Although telegraphic in style, they may describe each measured unit as fully as warranted, and thus present sections in greater detail than all but the most detailed columnar sections. They are not usually published unless they are the type section of a formation or member; however, they may be the main vehicle in an unpublished report.

Logs are arranged so that the youngest rocks appear first in the text. The smallest measured units are numbered to make the sequence clear. Order of presenting data should be kept as consistent as possible, as in the fragment that follows:

*Smith formation*

3. Shale, black, soft, locally leaf-bearing ................. 5 m
2. Sandstone, dark gray, moderately resistant, carbonaceous, feldspathic, in beds 0.5-2 m thick, the thinner with carbonaceous 1-cm laminae; thick beds heavily burrowed ......................... 23 m
1. Conglomerate, light gray, highly resistant, of rounded chert pebbles, fine sand matrix, imbricated ...... 2 m

Total Smith Formation ......................... 232 m

Base of formation is an unconformity on well-exposed Byron Shale.

An additional description at the base of the log is generally used to locate the base of the section exactly, and a description at the base or the top of the log gives methods of measurement, date, and personnel. Descriptions inserted at all major offsets give their locations and the bedding attitudes at the top of one exposure and the base of the other. The purpose of these descriptions is to guide other geologists to the base of the section and completely through it. Examples are given by Love (1973).

**References Cited**


