DAVID BLOOM

PROCEDURES IN FIELD GEOLOGY

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CONTENTS

THE BRUNTON COMPASS

This compass (Fig. 1), which was first patended in 1984 ... Brunton, is "standard equipment" for the American geologist. ... multi-purpose instrument, serving a variety of functions.

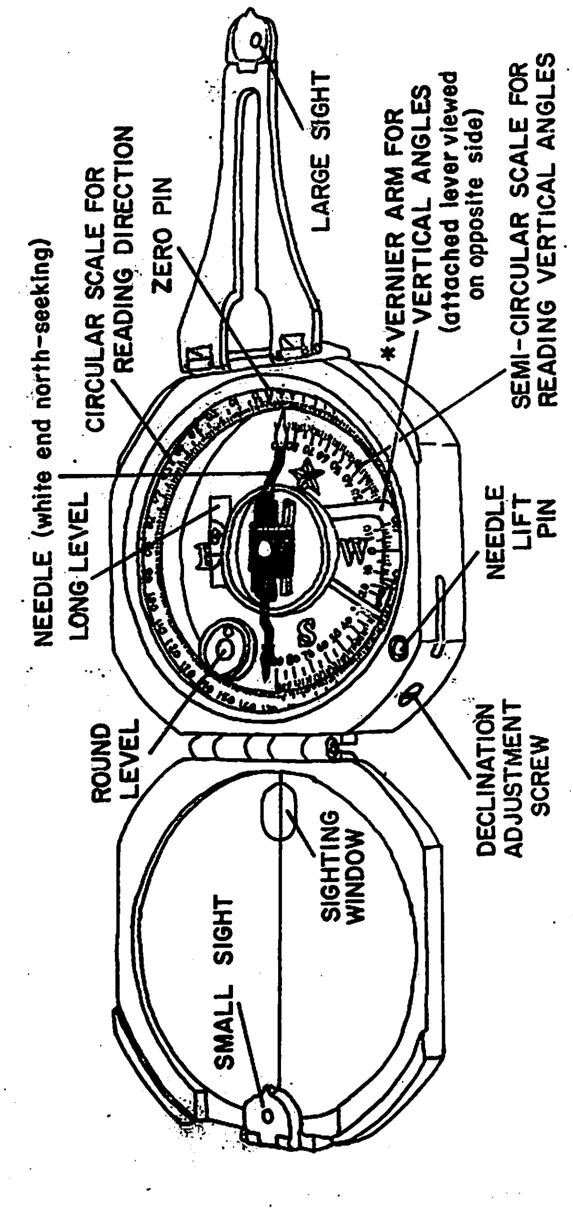


Fig. I.– The Brunton compass

"Quarter-circle" scale (hidden in this perspective) is to provide engineers with % grade (hor./vert.).

* Scale on vernier arm provides for reading fractions of 1° when mounted on a tripod.

1. Magnetic compass - The common procedure for measuring the direction to an observed object is:

(a) Hold the compass in both hands, so that your forearms steady the instrument against your waist (Fig. 2). The compass body should be horizontal, the lid angled back toward your body, and the large sight upright. Position the lid so that the observed object can be viewed, with the mirror, along the axis of the large sight (either through its slot or across its tip). While holding the compass in this positon, bring the round level to center.

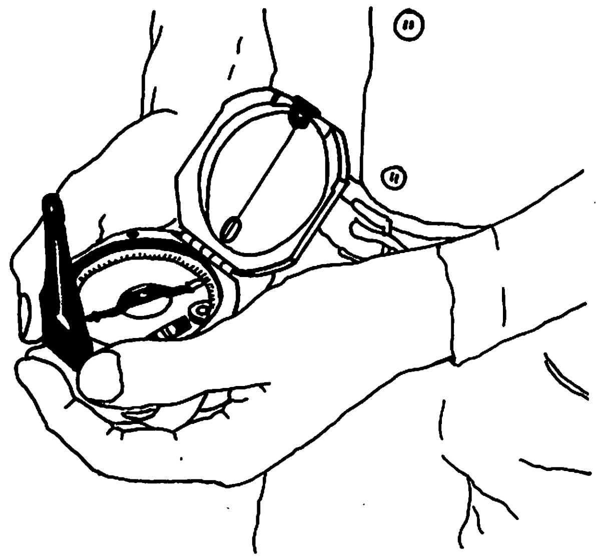


Fig. 2.- Holding the Brunton compass in the common manner for measuring direction.

(b) With the round level centered, check the object's reflection, and, if need be, rotate your entire body to bring into alignment (a) your eye, (b) the center line of the mirror, (c) the axis of the large sight, and (d) the observed object. It is permissible to move your head in order to achieve this alignment, but be careful not to tilt the round level.

(c) Read the bearing, or azimuth, which is indicated by the white (north-seeking) end of the arrow. This value can be read directly from the graduated circle because of the way in which it is graduated and labeled.

There are two types of labeling format:

Quadrant ("bearing type") - Older and more traditional, this type of circle is graduated in four quadrants of 0°-90° each. North is indicated by 0° near the large sight, and south is indicated by 0° near the lid hinge. East is indicated with an E, and west is indicated with a W. It might first appear that E and W are reversed, but this is to enable you to read the bearing directly while holding the Brunton in the usual position (Fig. 2).

The four quadrants (each 0°-90°) are conventionally designated by the couplets NE, NW, SE, and SW. To express a particular bearing, simply insert the number (of degrees) indicated by the white (north-seeking) end of the arrow between the elements of that couplet which designates the quadrant in which that number occurs. (Sample expression: N 60° E.)

Azimuth ("aximuth type") - Increasingly common are Bruntons with circles graduated from 0°-360°. On the earth's surface (and on maps), azimuth is conventionally measured in a clockwise direction, so that north is 0° (= 360°), east is 90°, south is 180°, and west is 270°. The azimuth face of a Brunton is also graduated from north but in a counter-clockwise direction. This enables you to read the azimuth directly, as indicated by the white (north-seeking) end of the needle, while holding the Brunton in the usual position (Fig. 2). This type of Brunton is growing in its popularity because errors are less easily made, and the simple numerical designation of azimuth lends itself more readily to computer processing.

This common orientation of the Brunton (Fig. 2) is satisfactory for measuring the direction of an object whose "altitude" (borrowing from astronomy) is up to several tens of degrees above the observer. However, in a case where the object is more than 10°-15° below the observer, the object's reflection cannot be viewed while holding the Brunton as in Figure 2. In this latter case, an alternative positioning of the Brunton must be employed (Fig. 3). Though accurate in this position, the compass is more difficult to read for one, possibly two reasons: you will find that your eye is not directly above the compass face (Fig. 3), so you must read the face with oblique vision, which especially obscures that part of the graduated circle nearest you. Also, depending on the position of the needle, the large sight might hide the needle's tip from view, necessitating pulling the large sight back toward you to a point where the needle tip is no longer hidden; this can result in slight mis-alignment of the compass before the reading is finally taken. Important: when the Brunton is held in this position (Fig. 3), it is essential to read the bearing (or azimuth) indicated by the black (south-seeking) tip of the needle.

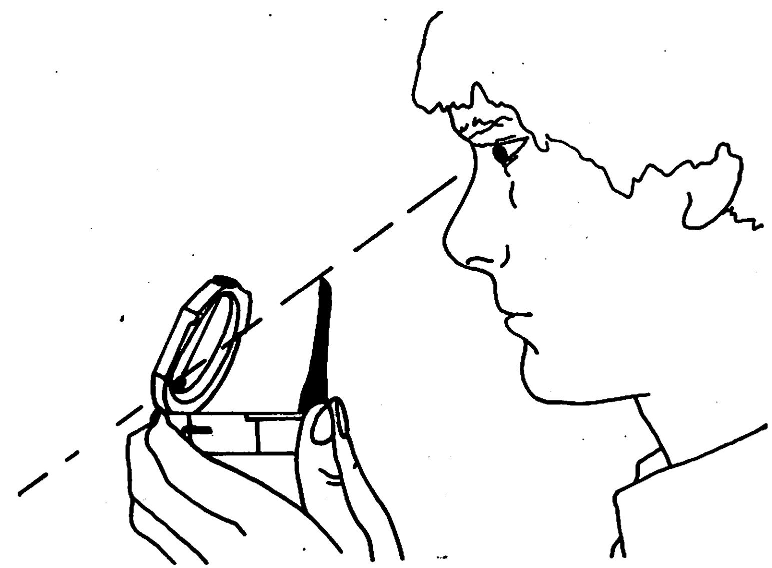


Fig. 3.- Holding the Brunton compass in a manner for measuring direction to an object that is more than 10°-15° below the observer.

Before continuing with our discussion of the uses to which a Brunton can be put, adjustment of the compass to provide for magnetic declination should be explained.

Magnetic declination - Although magnetic north is close to earth's north rotational pole, which defines grid north (= so-called true north), the two are sufficiently far apart that only along the agonic line (Fig. 4) does the compass direction of magnetic north coincide with that of grid north. West of this line, magnetic north is east of grid north; east of this line, magnetic north is west of grid north. Some maps, for example U.S. Geological Survey topographic quadrangle maps, indicate the direction and amount of magnetic declination for the particular vicinity covered by the map. Magnetic declination should be taken into account or else errors in orienteering can result.

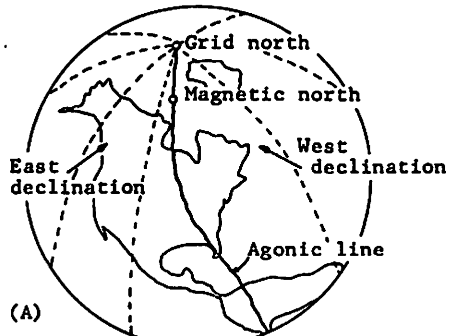
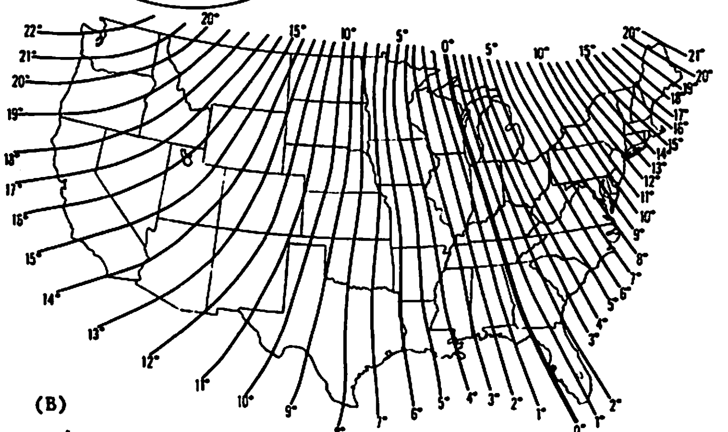


Fig. 4.- Magnetic declination maps.(A): western hemisphere portrayal. Notice: compass arrows point to magnetic pole, rather than along lines of longitude. (B): Lines of equal magnetic declination in 1975.



Specifically, for every one degree of declination you ignore, you will be off 92 feet lateral (perpendicular) to your intended direction after one mile of travel. For example, heading northward in western Wyoming (magnetic declination: 16°) you would be 1,500 feet to the east of your intended destination after only one mile of travel! The Brunton is designed so that you can adjust it to take into account magnetic declination and thereby maintain map accuracy. There is a declination adjustment screw on this side of the Brunton (Fig. 1) with which you can turn the graduated circle relative to the compass case (i.e., relative to the fixed "zero pin" of Figure 1). The question arises: in case of east declination, should the circle be turned clockwise or counter-clockwise? An easy way to solve this puzzle follows (example: magnetic declination = 16°E):

(1) Position the Brunton against your waist as in Figure 2.
(2) Turn your body so that the white (north-seeking) end of the needle points to the zero pin.
(3) You know from the given magnetic declination that the compass is now pointing toward azimuth 16° (or..."quadrant" N. 16° E.).
(4) So...without changing the orientation of the compass, adjust the declination screw until it "reads" an azimuth of 16° (i.e., 16° is at the zero pin).

Now, isn't that easier than memorizing "clockwise if east, counter-clockwise if west"?

PACE-AND-BRUNTON MAPPING

An individual's pace can be determined by pacing a measured distance (ex., 100 ft.). Pace is conventionally considered to be two steps, so in counting, only every right (or left) step is counted.

A pace-and-Brunton map is simply a plot of the positions of selected points on the ground, either natural or man-made, which is constructed from bearings and paced-distances among those points (Fig.5).

Example:

LEG	AZIMUTH	DISTANCE
A-B	61°	145'
B-C	94°	95'
C-D	160°	80'
D-E	139°	50'
E-F	262°	245'
F-A	337°	90'

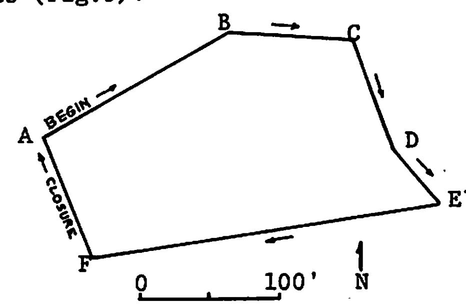


Fig. 5. - Plot of pace-and-Brunton data.

CORRECTING ERROR IN PACE-AND-BRUNTON CLOSURE

A traverse constructed by pace-and-Brunton, or even tape-and-Brunton, will invariably result in some amount of error of closure (Fig.6a). An approximate correction method follows:

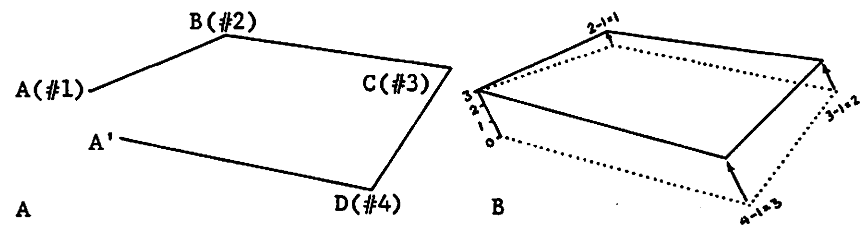


Fig. 6. - Solution of error of closure resulting from a pace-and-Brunton traverse.

(a) Divide the distance between A' and A into n equal segments, where n = number of intended stations (ignore A') less one. In this case n = 3 (Fig.6b).

(b) Move every station, except the first (A), in a direction parallel to A'→A. The amount that each station should be moved is equal to the length of one segment of A'- A multiplied by the number of that station less one.

(c) Connect all adjusted stations, including D - A.

INTERSECTION METHOD OF TRIANGULATION

This method plots the position of an <u>unoccupied point</u> by triangulation.

Simply take the bearing of the point to be plotted from two different established stations. Rays are projected from these two stations, with their proper orientations, and their intersection marks the location of the unoccupied point (Fig. 7). For maximum accuracy the angle formed by the two rays should fall between 60° and 90°.

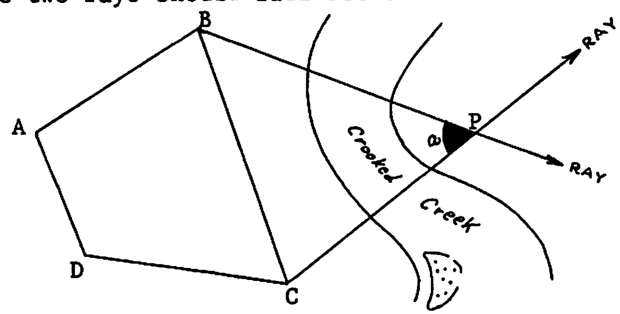


Fig. 7. - Solving for the location of unoccupied point P by intersection of two rays projected from established points B and C. Angle α should be between 60° and 90°.

RESECTION METHOD OF TRIANGULATION

This method plots the position of an <u>occupied point</u> by triangulating on two established points.

Simply take the bearings of two established points and project rays from those points toward you, that is...in directions 180° from the bearings you have read (or simply read the black south-seeking end of the needle and plot those bearings directly from the two points. The point of intersection marks your location. Once again, 60° - 90° angle!

When working with a map, you can sometimes plot your location with a single ray (Fig.8).

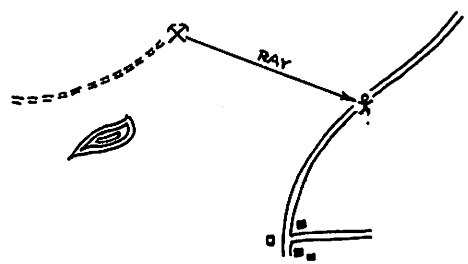


Fig. 8. - Example of situation permiting your plotting your location with a single ray when you are positioned along a linear feature (a road, fence, stream, etc.) that is shown on your map. Here the person is taking the bearing of another feature shown on the map, a quarry.

USING THE BRUNTON AS A PROTRACTOR

If you lack a protractor for plotting a ray on a map (as in Figure 8), you can field orient your map and then use the Brunton as a protractor:

(a) Place the map on the ground, place the edge of the Brunton along a N-S section line, and rotate the map to bring the Brunton's needle to zero index. The map is now field oriented.

(b) With the map in this position, place the edge of the Brunton at the sighted object, and rotate the Brunton about that object to a position where the Brunton's needle indicates the same bearing that you measured as the direction to the object.

(c) Project a ray from the object on the map, along the straight edge of the Brunton, to intersect the linear feature along which you are located. The point of intersection marks your position on the map.

2. To measure vertical angles - The long level of the Brunton, and its companion semi-circular scale (Fig. 1), provide for measuring vertical angles. The correct position for the Brunton when measuring vertical angles is with the case vertical (rather than horizontal), with the long level above the needle pivot (i.e., the case is in the right hand), and the opened lid is in the left (Fig.8A). Reason: the long level is slightly curved, especially in older models, so that the bubble is more easily centered when the long level is properly oriented. Procedure:

(a) Bend peep-sight tip of large sight so that you can sight either through the peep-sight or along its point, through the sighting window of the mirror to observed object.

(b) Swing lid into position that allows viewing the reflection of the compass face.

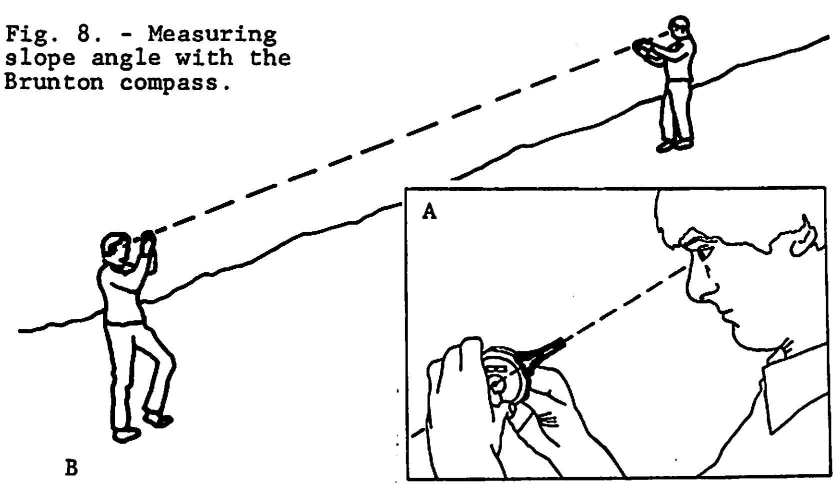
(c) Rotate long level, with lever on base of compass, to level position.

(d) Re-check position of sighted object; adjust long level if necessary. Repeat as necessary.

(e) Remove fingers from long-level lever, look directly at face of compass, and read angle to nearest degree.

When working with a partner (Fig. 8B), both parties should shout their individual reading and, when differing, average the two.

Fig. 8. - Measuring slope angle with the Brunton compass.

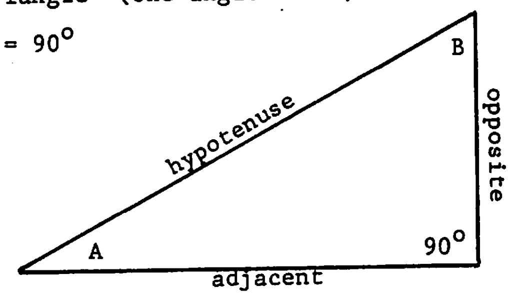


TRIGONOMETRY REVISITED (for reference)

A "right triangle" (one angle = 90^o)

So...A + B = 90^o

Fig. 9



	Reciprocals
sine A = opposite/hypotenuse	cosecant
cosine A = adjacent/hypotenuse	secant
tangent A = opposite/adjacent	cotangent

And....

$(\sin A)^2 + (\cos A)^2 = 1$ $\sin A/\cos A = \tan A$

TO SOLVE FOR MAP (HORIZONTAL) DISTANCE REPRESENTED BY SLOPE

(After determining slope angle as in Figure 8.)

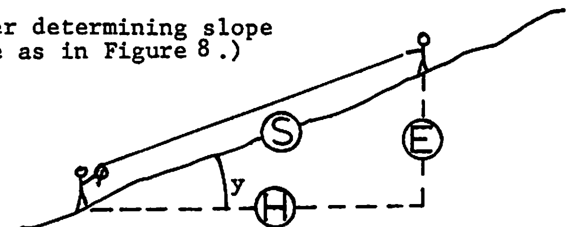


Fig. 10

a. Tape or pace to determine slope distance (S)
b. H = S cos y

TO SOLVE FOR DIFFERENCE IN ELEVATION

a. E = S sin y

To solve for difference in elevation by counting eye-height intervals, using Brunton as hand-level: (Example: to determine difference in elevation between points A and B):

Set long level at zero index and hold as if measuring vertical (slope) angle (Fig. 8). Or, for convenience, a simple tube-like instrument, called a "hand level", can be used.

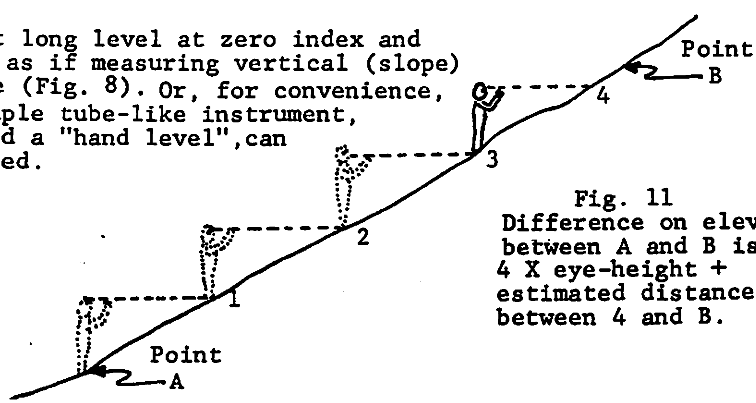


Fig. 11
Difference on eleva- between A and B is 4 X eye-height + estimated distance between 4 and B.

3. Measuring strike and dip - Definitions:

DIP: has (a) magnitude and (b) direction. The magnitude is the angle of inclination; that is, the angle between the inclined layer (or fault) and a horizontal surface. (b) the direction of dip is the map direction in which the layer (or fault) is inclined downward.

STRIKE: Any dipping (inclined) layer (or fault) intersects a hypothetical horizontal surface. The map direction of their line of intersection is called strike. Strike has traditionally been expressed in terms of the acute angle between the line of intersection and north, for example...N. 30^o E. (not S. 30^o W or E. 60^o N.).

Inasmuch as the direction of dip is necessarily perpendicular to strike, once the strike is stated, only the quadrant of dip direction need be given. Example: strike N. 45^o W; dip NE at (magnitude) 30^o.

A growing practice is to express strike as a simple azimuth value. Inasmuch as a line (the strike line) has two directions, a choice must be made (ex., 10^o or 190^o?). By convention, an American geologist records the azimuth along which he/she looks, when positioned so that the dip direction is to his/her right (the so-called "right-hand rule"). Further simplification is provided by the fact that, when using this method, only the magnitude of dip need be recorded. (The direction of dip is indicated by the recorded strike.)

Fig. 12. - Contact method of measuring strike with a Brunton compass. Map board provides a flat extension of the planar feature being measured.

(a) Contact method of measuring strike and dip of inclined beds.--Few beds are sufficiently smooth for contact strike and dip measurements. However, irregularities in the exposed bedding surface can be "ironed out" by placing a notebook or (better) a map board on the surface (Fig.12). The Brunton is "squared off" in its design, so that when the bottom edge of the case is held on an inclined surface, and, at the same time, the round bubble is centered, the axis of the Brunton is parallel to strike. So...read the azimuth (or quadrant direction if so designed) directly. Choose the appropriate one of the two possible strike directions (as per the American convention), and record. Contact dip can be achieved (Fig.13) by positioning the Brunton's case in a vertical position against the inclined surface and swinging it to the position of maximum possible vertical angle indicated by the long bubble (Figs. 1,). The orientation of maximum vertical angle will necessarily be "true dip", in a direction perpendicular to strike.

A

B

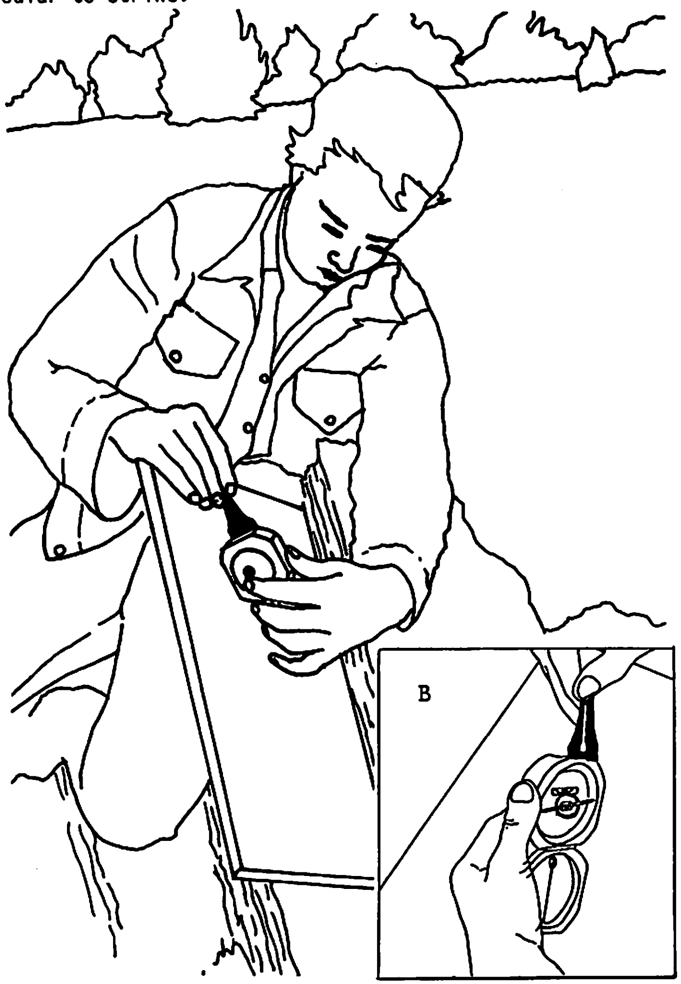


Fig. 13. - Contact method of measuring dip with a Brunton compass. Map board provides a flat extension of the planar feature being measured.

(b) Using two outcrops to measure strike and dip of inclined beds (most accurate method).--

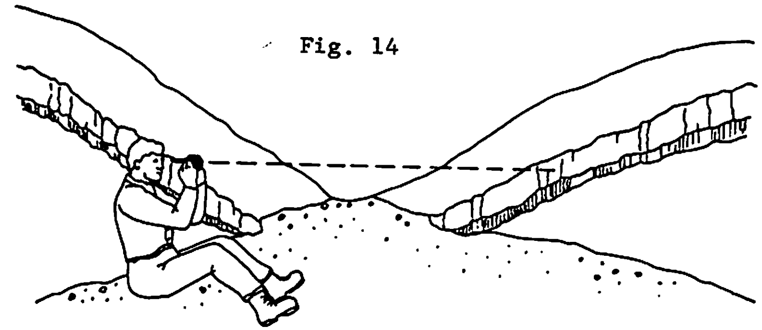
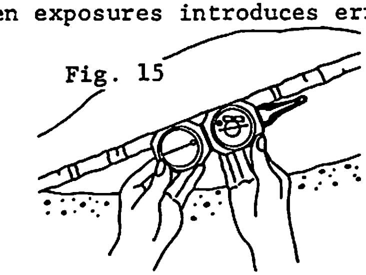


Fig. 14

With your head at some particular stratigraphic datum, and with the compass long level set at zero index, sight to the same stratigraphic datum across the valley along a line that is horizontal (i.e., level the bubble in the long level). The map direction of this horizontal line is strike. Caution: a fault between exposures introduces error!

Now hold your Brunton at arm's length and bring its edge into alignment with the stratigraphic datum. While holding it in this orientation, adjust the long level to its level position (i.e., center the bubble). Read the dip.

Fig. 15



Note: This technique can be used with a single outcrop if there is enough of the bedding surface exposed to allow you to look along that surface. That is...if you can position yourself so that your line of sight is both (a) within the plane of the bed and (b) horizontal, then your line of sight is strike. Dip can be measured as above.

TRICKS OF THE TRADE

The contact method of measuring strike shown in Figure 12 will not work in cases where the dip is very low because the raised ring that protects the long level lever obstructs the procedure. In such cases, measuring strike is still possible: Set the long level at zero index and place the base of the Brunton flat on the inclined surface to be measured. Now, rotate the Brunton as needed to bring the bubble of the long level to center. Can you see that the axis of the Brunton is now parallel to strike?

When working in metamorphic terrain, one commonly has occasion to measure the trend and plunge of linear features. Definitions:

Trend - the map direction (i.e., bearing or azimuth) in which a linear feature points downward.

Plunge - the vertical angle between an inclined linear feature and a horizontal plane.

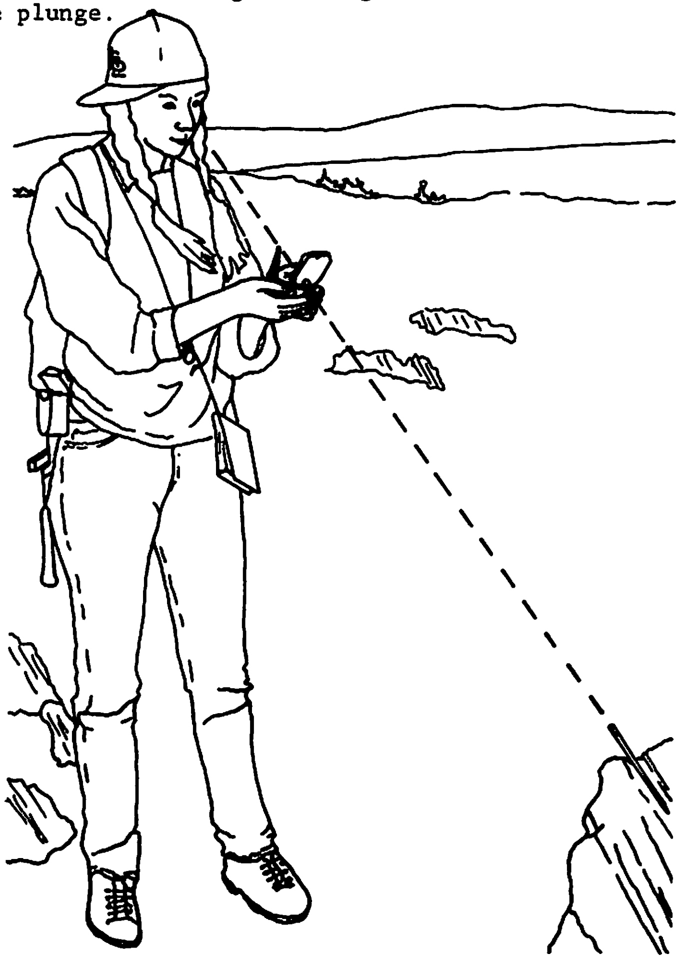
It is commonly difficult to apply contact methods to measuring the orientation of linear features. Where this is the case, reasonably accurate measurements can be obtained as follows (Fig.16).

(a) A pencil can be used to good advantage to accentuate subtle lineations and to maintain a reference line while undertaking a reading. (A bit of tape can anchor the pencil if needed.) Be sure that the pencil is oriented so that it is, in fact, an extension of the lineation to be measured.

(b) To measure the trend of the pencil, hold the Brunton as in Figure 3, and move to a position so that you can look directly down the shaft of the pencil. Read the azimuth as instructed on page 3. Stay put!

(c) To measure the plunge of the pencil, hold the Brunton as if measuring a slope angle (Fig.8), sight down the pencil's shaft, and bring the long level to horizontal. Read the plunge.

Fig. 16



SPECIAL CASES (CONTINUED)

In some metamorphic terrains, quartz veins will occur at the surface as mere rubble. There will be no hint of a tabular shape, so a sense of dip direction will be lacking. Strike will be impossible to measure as well because the earth's surface intersected by the quartz vein is not likely to be horizontal. So...only the trace of the vein can be measured. Even so, this can, in some cases, be useful information,so such traces are commonly recorded.

Sighting on a field partner is usually easier than sighting along rubbly quartz veins, so a practical method is illustrated in Figure 17. Furthermore, two readings are better than one, so...as was suggested in averaging yours and you partner's reading of slope angles (page 7), average your two readings here, if they differ.

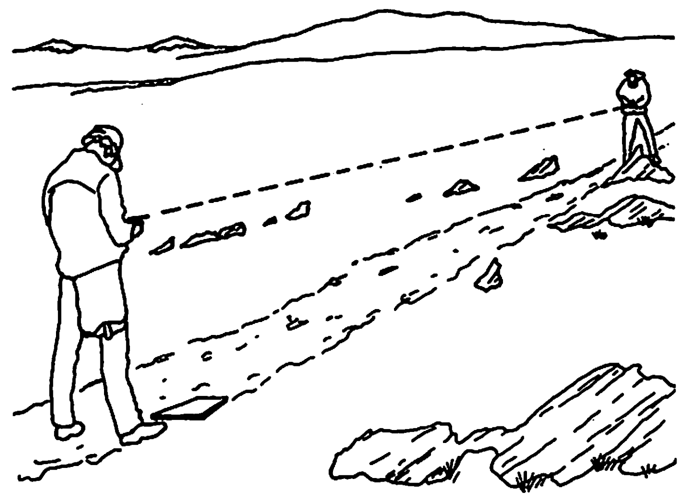
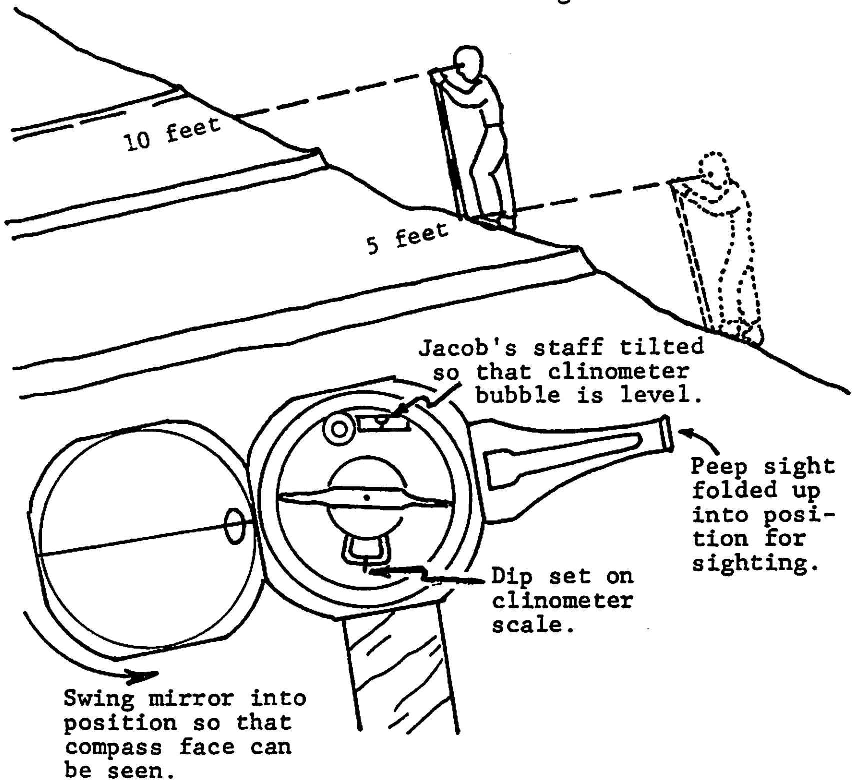


Fig. 17. - Taking bearing of the trace of a poorly exposed quartz vein (marked by a "path" of quartz rubble).

MEASURING INCLINED STRATIGRAPHIC SECTIONS WITH BRUNTON AND JACOB'S STAFF:

Fig. 18



1. Each new position traverses a stratigraphic interval equal to the length of the Jacob's staff.
2. The direction of the traverse must be in the direction of dip.
3. Lateral "off-setting" can freely be done in order to gain a topographic position that is more favorable for continuing, and for crossing faults. Simply follow a stratigraphic datum to wherever, and procede at the same footage as before.
4. Always measure in Jacob's staff increments. Interpolate into the section any stratigraphic horizons whose positions must be recorded.

SOLVING FOR STRATIGRAPHIC THICKNESS (T) FROM SLOPE DISTANCE (S) DETERMINED BY TAPING OR PACING:

1. Where slope and dip are in opposite directions:

Case A: Slope angle (y) plus dip angle (x) < 90.

$T = S \sin(x+y)$

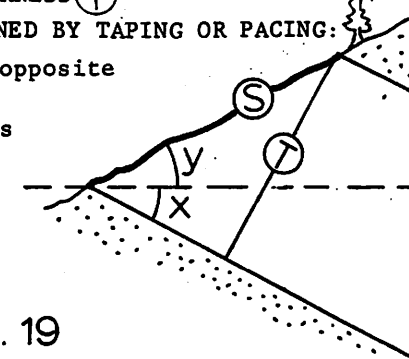


Fig. 19

Case B: Slope angle (y) plus dip angle (x) > 90.

$T = S \cos(x+y-90)$

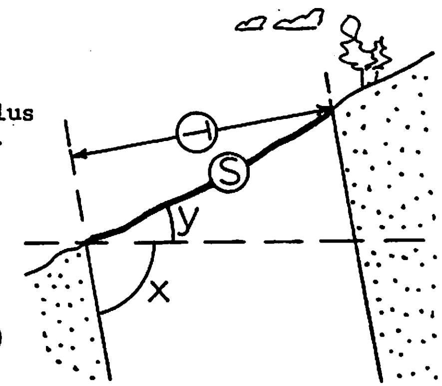


Fig. 20

2. Where slope and dip are in the same direction:

Case A: Slope angle (y) < dip angle (x)

$T = S \sin(x-y)$

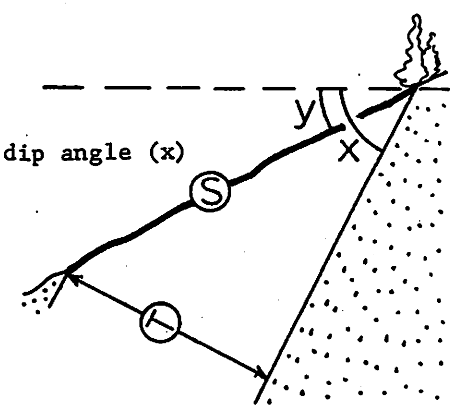


Fig. 21

Case B: Slope angle (y) > dip angle (x)

$T = S \sin(y-x)$

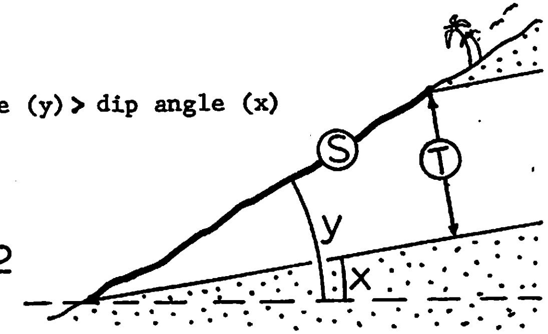


Fig. 22

THE SILVA COMPASS

A growing number of geologists prefer the Silva compass for certain field procedures. There are several models of Silva advertized in various wilderness supply catalogs. The model that is best suited to geological field work is one of the Ranger group, specifically model 15 TDCL. Ranger varieties are superior to other Silvas in that they allow for adjustment for magnetic declination. The 15 TDCL is the

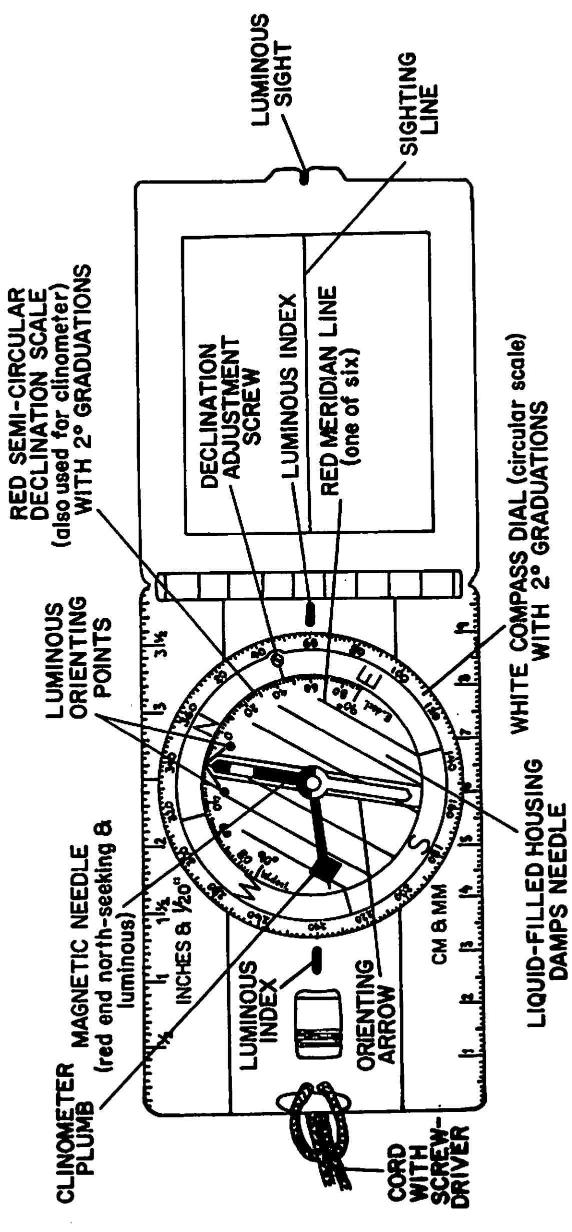


Fig. 23.- SILVA RANGER MODEL 15 TDCL (graduated 0°-360° with clinometer)

most versatile of the Rangers in that it has a clinometer, and it is graduated 0° - 360°, rather than in quadrants.

The Silva is not designed for sighting vertical angles, so it cannot be used to measure slope angles (like the use of the Brunton in Figure 8), nor can it be used with a Jacob's staff (Fig. 18). The Silva clinometer does allow for measuting dip and strike, but, inasmuch as the Silva lacks a round level, measuring strike is not as accurate as with a Brunton. Moreover, because the Silva is smaller than the Brunton, the angular scales are graduated in two-degree increments, rather than in one-degree increments like the Brunton, and this limits the accuracy of the Silva further.

The foregoing limitations notwithstanding, when it comes to plotting field measurements onto a map, the Silva is superior because it has a broad flat base, which is graduated both in centimeters/millimeters and in inches for convenient scaling, and it has a compass capsule that rotates independently of the base.

1. Setting magnetic declination on the Silva - East and west declinations are indicated on the red declination semi-circular scale of the Silva. Using the screw-driver provided at the end of the security cord, turn the declination adjustment screw to bring the black outline of the orienting arrow to the desired degrees of declination (toward the E. decl. or toward the W. decl.).

2. Measuring field direction with the Silva - This can be done either approximately (Fig. 24A) or with added precision (Fig. 24B).

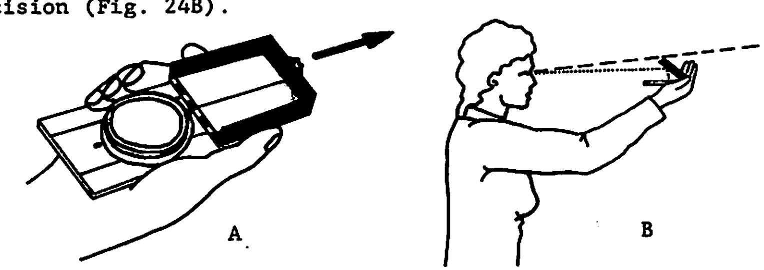


Fig. 24. - Holding the Silva compass to measure direction in the approximate (A) and more precise (B) modes. The Brunton is represented by manufacturers as adaptable to a mode similar to that of B above (the "prismatic compass" mode), but its scale is extremely difficult to read in this position.

A. In the "approximate mode", hold the Silva at waist level and simply point it in the direction of the object sighted (Fig. 24A). While in this position, turn the compass capsule so as to align the black-outlined orienting arrow beneath the magnetic needle. Do this so that the pointed head of the orienting arrow coincides with the red (north-seeking) end of the magnetic needle. Finally, read the azimuth indicated by the luminous index near the hinge.

B. When greater precision in measuring direction is needed, hold the Silva as shown in Figure 24B, and employ the sights provided: while viewing the object over the luminous sight at the end of the mirrowed lid, turn the compass so as to align the sighting line of the mirror with the reflection of either luminous index painted on the compass base. Continue with the procedure described in A above.

3. Measuring contact strike and dip with the Silva - Hold the Silva level against an inclined plane (as with the Brunton in Figure 12), and then continue with the procedure described in section 2A on page 17. The direction that you measure is strike. Whether you record this direction, or 180° from it, is dictated by the "right-hand rule" explained on page 9.

In order to measure dip with a Silva, you must first turn the compass capsule so as to bring the magnetic declination scale into proper orientation (Fig. 25).

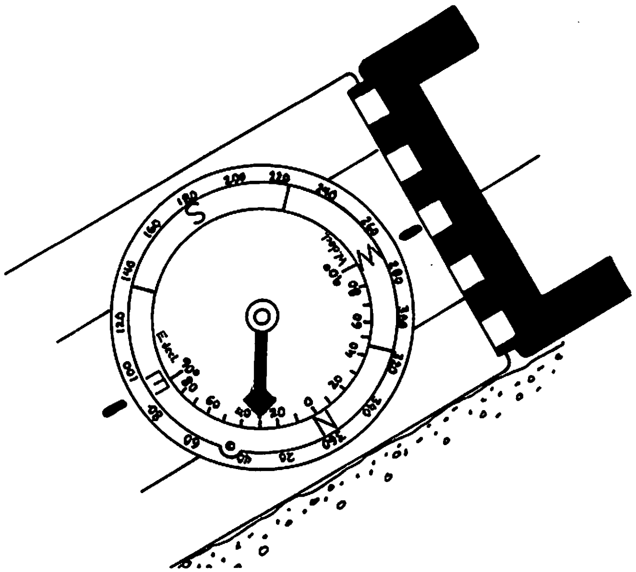


Fig. 25. - Schematic of Silva with semi-circular magnetic declination scale adjusted to allow for measurement of dip of inclined surface. This example shows a dip of 30°.

Orientation can be achieved by bringing either E (90°) or W (270°) to either luminous index painted on the base. Inasmuch as the declination scale is fixed to the azimuth scale of the compass capsule, the 90° positions on the declination scale will also be at the luminous indicies. Now hold the Silva against the inclined surface (as with the Brunton in Figure 13). The vertical angle (dip) will be indicated by the red clinometer plumb arrow against the magnetic declination scale. (If the semi-circular scale is upside-down, owing to the particular orientation of the Silva, simply turn the compass capsule through 180° to bring it into the "readable" position. As with the Brunton, experiment with the Silva in this mode until you are satisfied that you have detected the maximum possible vertical angle (i.e., true dip).

4. Plotting directions onto a map - Once that a direction has been measured with a Silva (ex., determination of strike on page 18), that direction can conveniently be plotted on a map: With the compass capsule still set for the particular measured direction (strike, trend, trace, etc.), place the Silva on the map so that (a) one of the graduated margins of the compass base is at the location where the direction is to be plotted, and (b) the red meridian lines within the compass capsule are parallel to N-S section lines on the map (Fig. 26).

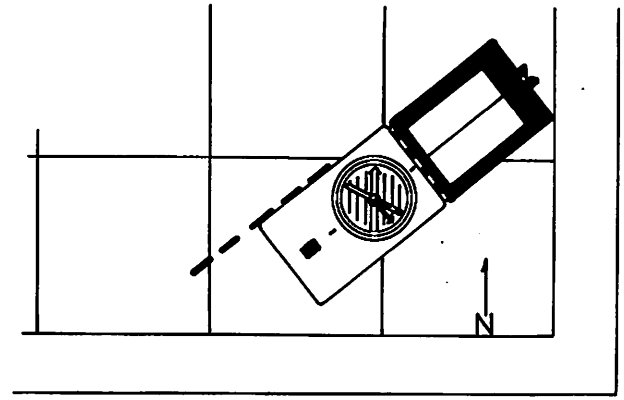


Fig. 26. - Silva positioned on a map for plotting a direction indicated by the bold dashed line. Notice that the meridian lines within the compass capsule (six in number) are parallel to N-S section lines.

In this orientation, a line representing the direction to be plotted can be drawn along a graduated margin. The graduations along the margins (centimeters/millimeters and inches) can be used to good advantage when plotting a directional leg of a paced or taped traverse. Notice that once a direction has been measured, its plotting does not depend on the position of the magnetic needle, so the map need not be oriented in the field.

As can be seen from the foregoing, the Silva serves as a much more convenient protractor than does the Brunton. Recall from pages 6 and 7 that for the Brunton to be used as a plotting protractor, the map must be properly oriented. Not so for the Silva.

5. Using the Silva to measure rake (or pitch) - The fact that that the Silva's compass capsule can be rotated independently of its base provides an easy technique for measuring the rake of a lineation.

Definition - Rake (or pitch) is the angle that a lineation on an inclined plane makes with a horizontal line (=strike) in that plane (Fig. 27).

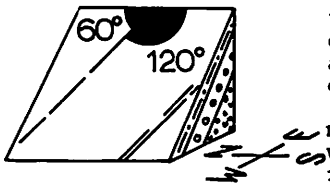


Fig. 27. - Rake of a lineation. Two conventions: Rake is expressed as an acute angle, along with the quadrant bearing of its trend (60° NW in example), or rake is expressed as an angle measured clockwise from strike, with strike of the "right-hand rule" of page 9 (120° in example).

The rake of a lineation is commonly measured in cases where the lineation occurs on a dipping bedding plane, the strike and dip of which are known. The intent is to later rotate the dipping plane, with the aid of a stereonet, in order to resolve the orientation of the lineation before structural deformation.

Procedure:

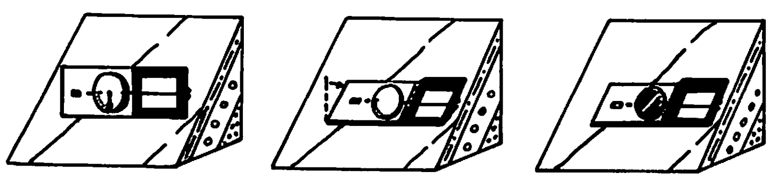
(a) Set the semi-circular magnetic declination scale at index for measuring a vertical angle (as described on page 18), and place the Silva on edge on the dipping surface at or near a lineation.

(b) With the Silva on edge, as in (a), rotate it about the axis of the vertical clinometer plumb arrow to a position where the plumb arrow indicates zero on the declination scale. The Silva's edge now marks the strike of the dipping surface on which it is resting (Fig. 28A).

(c) Now, using the edge in contact with the dipping surface as a hinge-line, flatten the Silva's base against the surface and hold firmly in place (Fig. 28B).

(d) Rotate the compass capsule so as to bring the meridian lines into parallel alignment with the lineation(s) (Fig. 28C).

(e) Rake is indicated (on the circular azimuth scale) by one of the two luminous indices painted on the compass base. Which of the two indices should be used will depend on the particular convention in practice (Fig.27).

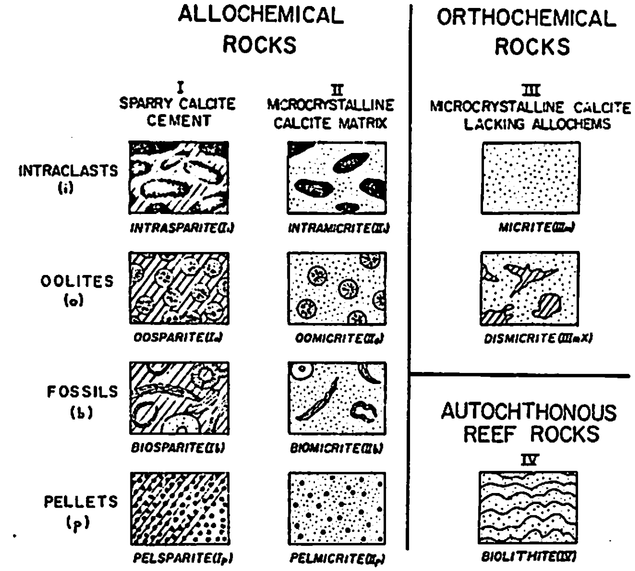


A B C

Fig. 28. - Measuring the rake of a lineation on a dipping bedding surface with a Silva compass.

Fig. 29

R.L. Folk (AAPG Memoir 1) Spectral Subdivision of Limestones



1. Allochems - intraclasts, oolites (or ooids), fossils, and pellets.

2. Intraclasts - unconsolidated fragments of seafloor, therefore usually mud-textured; recognized (vs. hard-rock pebbles) by (a) neighboring hard grains inpinging on their margins, (b) hard grains within the clast protruding from clast margin, (c) contiguous clasts with squashed mutual contact, and (d) usually of a single lithology (oligomictic, rather than polymictic like terrigenous pebbles).

3. In sparry rocks grains (allochems) are in contact with one another, although in two-dimension they appear to be "floating". In the micrite group, grains do "float".

4. Some authors separate pellets from intraclasts on the basis of size. Origin is a better basis: pellets - fecal in origin; intraclasts - "rip-clasts".

5. The few micrites that do occur are most commonly dismicrites, micrites with spar-filled primary voids produced by (a)burrowing, (b)disiccation, (c)slumping, (d)gas escape, etc. A variety of dismicrite crowded with desiccation and gas-escape features is called "birdseye" limestone and is a reliable indicator of a peritidal setting.

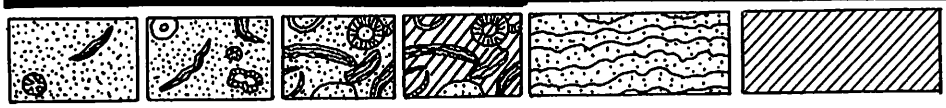
6. Reef rock, other than a chunk of algal stromatolite, is difficult to impossible to identify in hand-specimen.

7. Problem: this classification ignores calcisiltites. Reason: at the time, Folk believed micrite to be genetically separate from allochems; i.e., that micrite is an inorganic precipitate ("snow"), with a distinct super-fine grain size. It is now realized that lime mud (micrite) grades into the allochem grain sizes, so that there is a transitional textural class, which is doubtless finely comminuted skeletal debris. (Biotrashite?) Micrites, in the strict 4 micron-size class, are extremely rare. Most workers simply increase the upper size limit of micrite defined by Folk.

R.J. Dunham (AAPG Memoir 1) Classification of Carbonate Rocks According to Depositional Texture

DEPOSITIONAL TEXTURE RECOGNIZABLE					DEPOSITIONAL TEXTURE NOT RECOGNIZABLE
Original Components Not Bound Together During Deposition				Original components were bound together during deposition... as shown by intergrown skeletal matter, lamination contrary to gravity, or sediment-floored cavities that are roofed over by organic or questionably organic matter and are too large to be interstices.	Crystalline Carbonate
Contains mud (particles of clay and fine silt size)			Lacks mud and is grain-supported		(Subdivide according to classifications designed to bear on physical texture or diagenesis.)
Mud-supported		Grain-supported			
Less than 10 percent grains	More than 10 percent grains				
Mudstone	Wackestone	Packstone	Grainstone	Boundstone	

Fig. 30



Sketches (by T.F.) facilitate correlating Dunham's classification with that of Folk. That part of the table outlined (by T.F.) with the bold-lined box represents the essence of Dunham's scheme.

1. Dunham emphasized the importance of distinguishing between wackestone and packstone because...should the grains undergo a stage of dissolution during diageneses, with the mud matrix unaffected, there would develop porosity and permeability in packstones, whereas there would develop only porosity in wackestones.

2. The problem in distinguishing between wackestones and packstones arises from the fact that all grains appear to be "floating" when viewed in two-dimension. Uniform spacing of grains (in 2-D) suggests packstone.

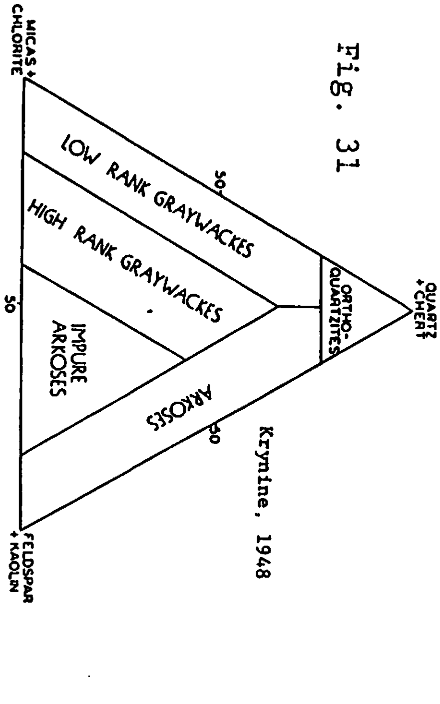
3. The question of wackestone vs. packstone is a bit over emphasized, because packstones are understandably rare. (How do grains and mud accumulate together so that the grains are self-supported, yet the intergranular spaces are thoroughly occuluded with mud? The few packstones that do occur might have been produced by compaction of wackestones...the mud fraction having been compressed, bringing grains into contact.

4. Dunham's "crystalline carbonate" includes both (1) dolostone and (2) limestone, usually lime mudstone, that has recrystallized to a senseless "sea" of sparry calcite. This equals Folk's "microspar".

CLASSIFICATION OF SANDSTONES

(Needed: one petrographic microscope.)

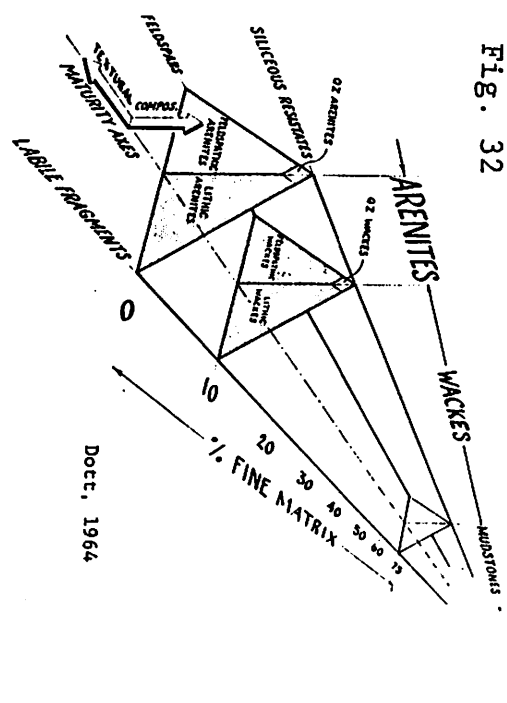
Fig. 31



Krynine, 1948

Mineral composition of the detrital fraction of the major petrographic series of sedimentary rocks. Note that the micas and chlorite may occur as rock fragments, as large, loose, individual flakes, or as a micaceous clayey paste.

Fig. 32

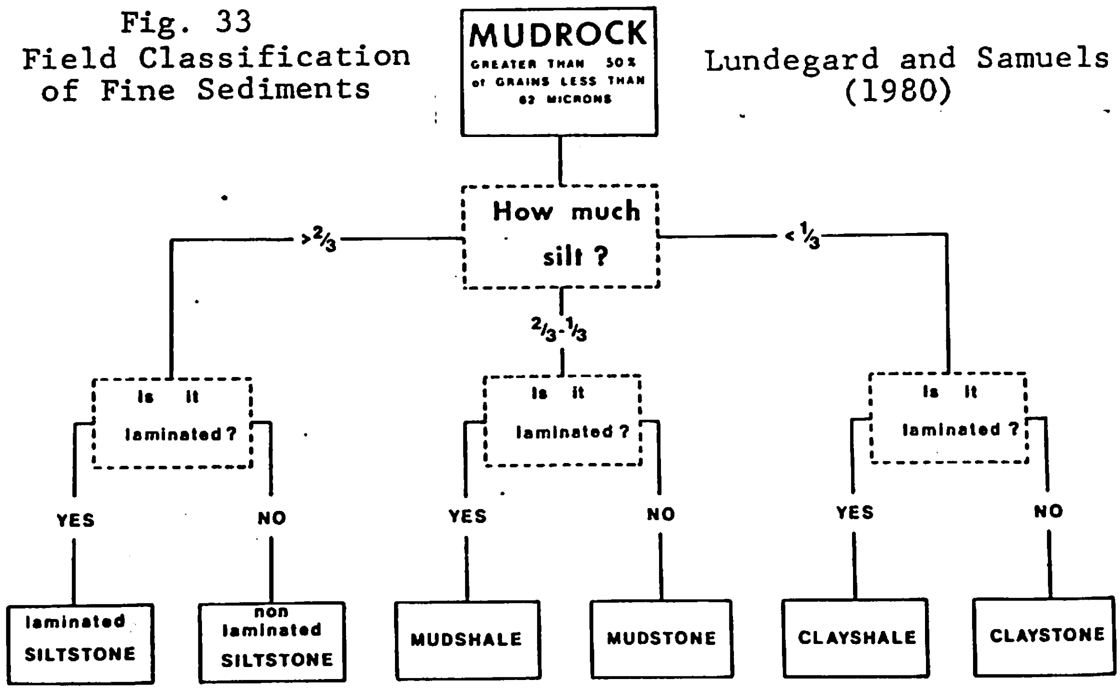


Dott, 1964

Modified portrayal of Gilbert's classification of silicate sandstones incorporating Folk's dual maturity concepts.

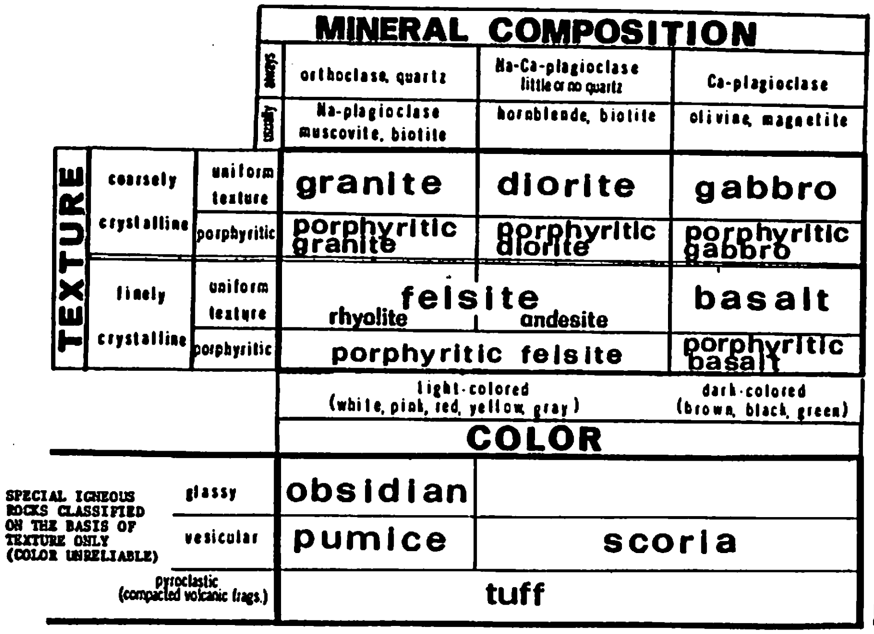
Fig. 33
Field Classification
of Fine Sediments

Lundegard and Samuels
(1980)



24

Fig. 34. IGNEOUS ROCK CLASSIFICATION CHART



25

Sedimentary Rocks -

Principle rock name, compositional adjectives - color, grain size(s), degree of induration; minor constituents; fossils. Bedding (thickness, notable features).

Igneous Rocks -

Principle rock name, compositional adjectives - color, crystal size(s); minor constituents. Notable fabric features. Field occurrence. Nature of contacts.

Metamorphic Rocks -

Principle rock name, color. Assessory minerals and their textures. Details of any foliations and lineations. Field occurrence. Nature of contacts.

Geomorphic Profile of Sedimentary Rocks -

In some cases it is more communicative to include a geomorphic profile when illustrating a sedimentary stratigraphic section. The closer that the scale of the field sketch is to that of the final drafted illustration, the easier the transcribing.

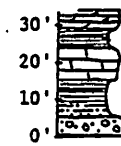
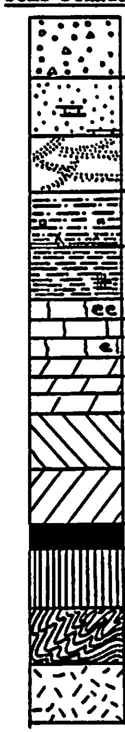


Fig. 35

Some Standard Symbols for Representing Rock Types -



Conglomerate (cherty)

Coarse-grained sandstone (Calcareous)

Cross-bedded sandstone

Siltstone (pyritic and bentonitic)

Shale (carbonaceous)

Limestone (fossiliferous)

Dolomite

Anhydrite

Gypsum

Coal

Salt

Metamorphic Rocks

Igneous Rocks

X Bentonite
Concretion or nodule
Δ Chert
Glauconite
+ Feldspar
v Mica
□ Pyrite
ee Megafossils
Microfossils
Carbonaceous matter

Fig. 36

Fig. 37.- Global latitude and longitude scheme. Scale of angular values graduated from 0° prime meridian.

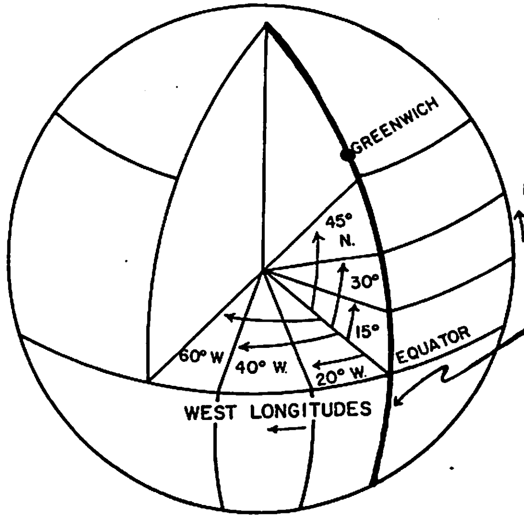
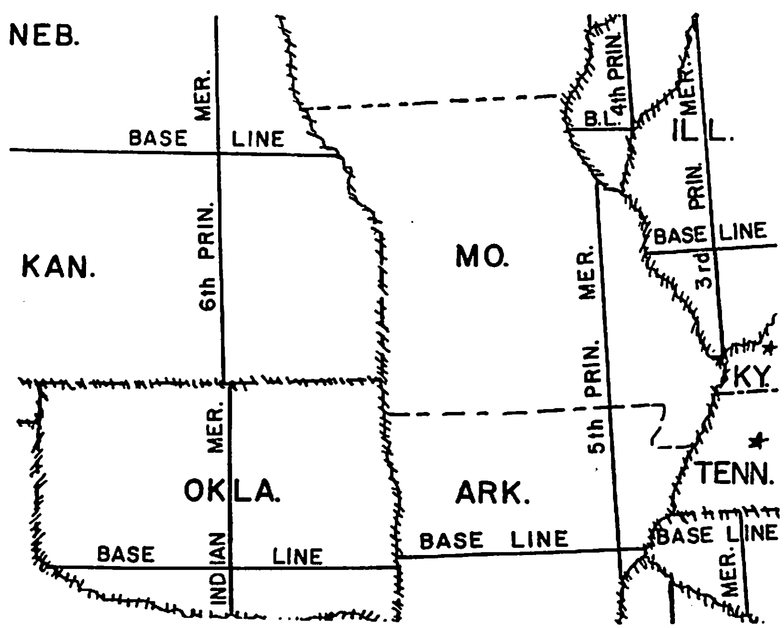
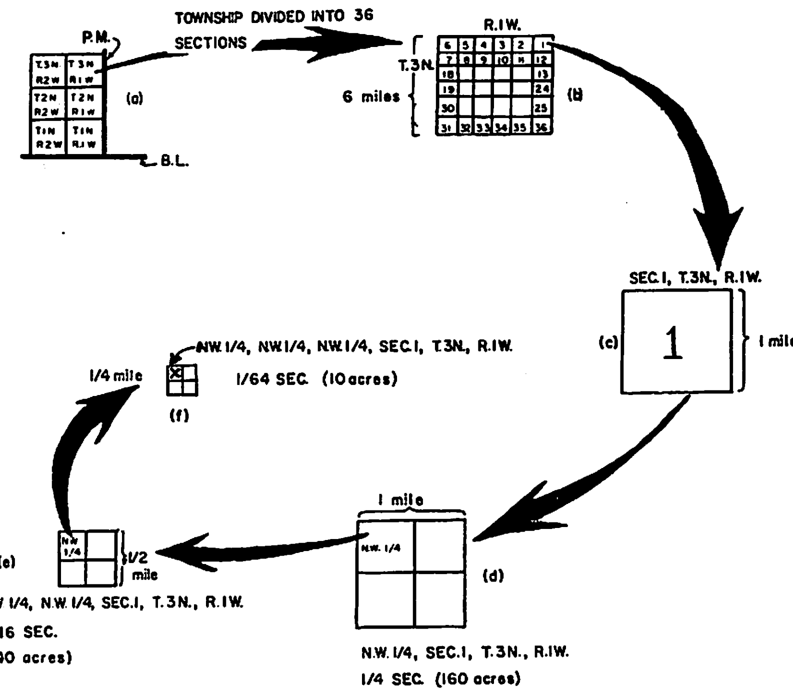


Fig. 38. - Example of way in which meridians are arranged, from which township and range lines are distributed.





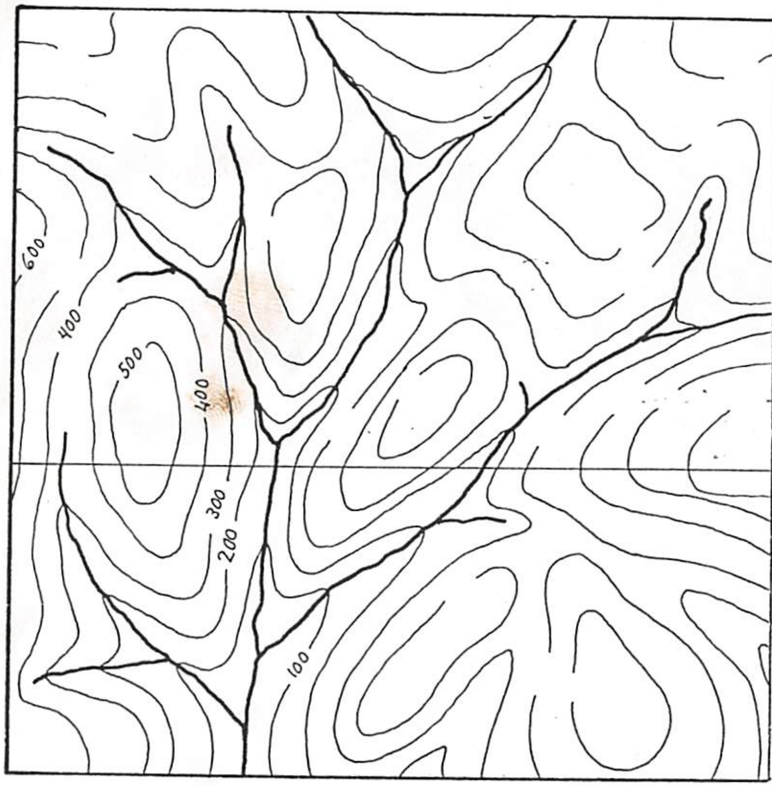
SYMBOLS EXPLAINED

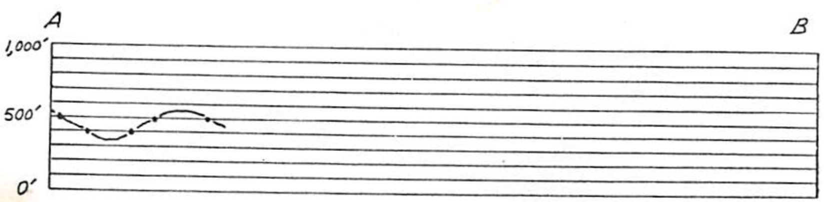
P.M. - principal meridian
B.L. - base line
R. - range
T. - township

Fig. 39. - System of subdivision of townships into sections and subdivisions of sections.

Fig. 40

CONSTRUCTION OF A TOPOGRAPHIC PROFILE



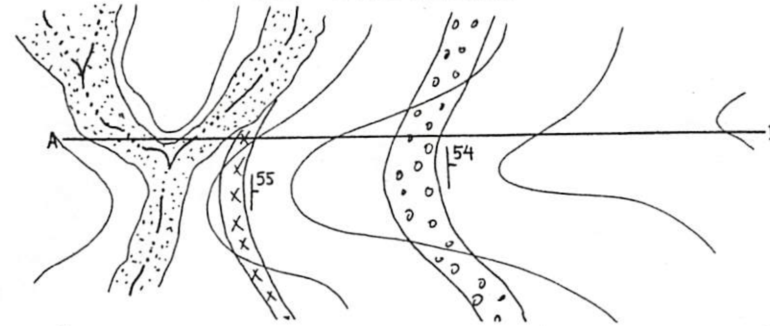


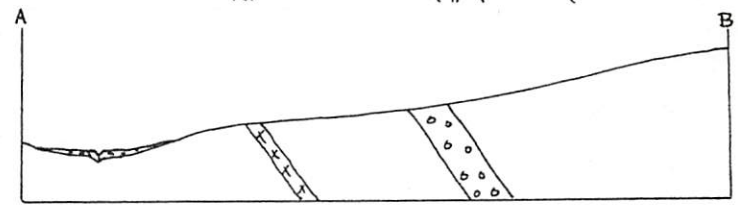
The vertical scale can be equal to that of the horizontal, or, for reasons of relief, it can be exaggerated.

With the aid of graph paper, or with carefully ruled paper like that above, simply project the profile traverse onto the ruled paper....contour value for elevation value.

Fig. 41

GEOLOGIC CROSS-SECTION





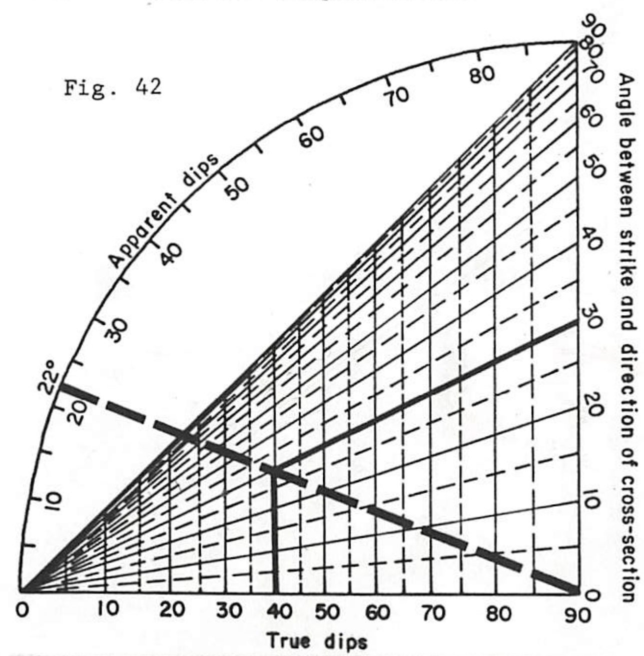
If the topographic profile is correctly constructed, and if strike and dip have been correctly measured, then the thickness of a stratigraphic unit portrayed in cross-section will be accurate....provided that the direction of the cross-section is perpendicular to strike.

In cases where the line of cross-section is <u>not</u> perpendicular to strike, the dip portrayed will be less than the true dip (i.e., it will be an apparent dip).

The apparent dip value to be plotted for any particular true dip, for any degree of divergence from strike can be easily computed from the diagram below.

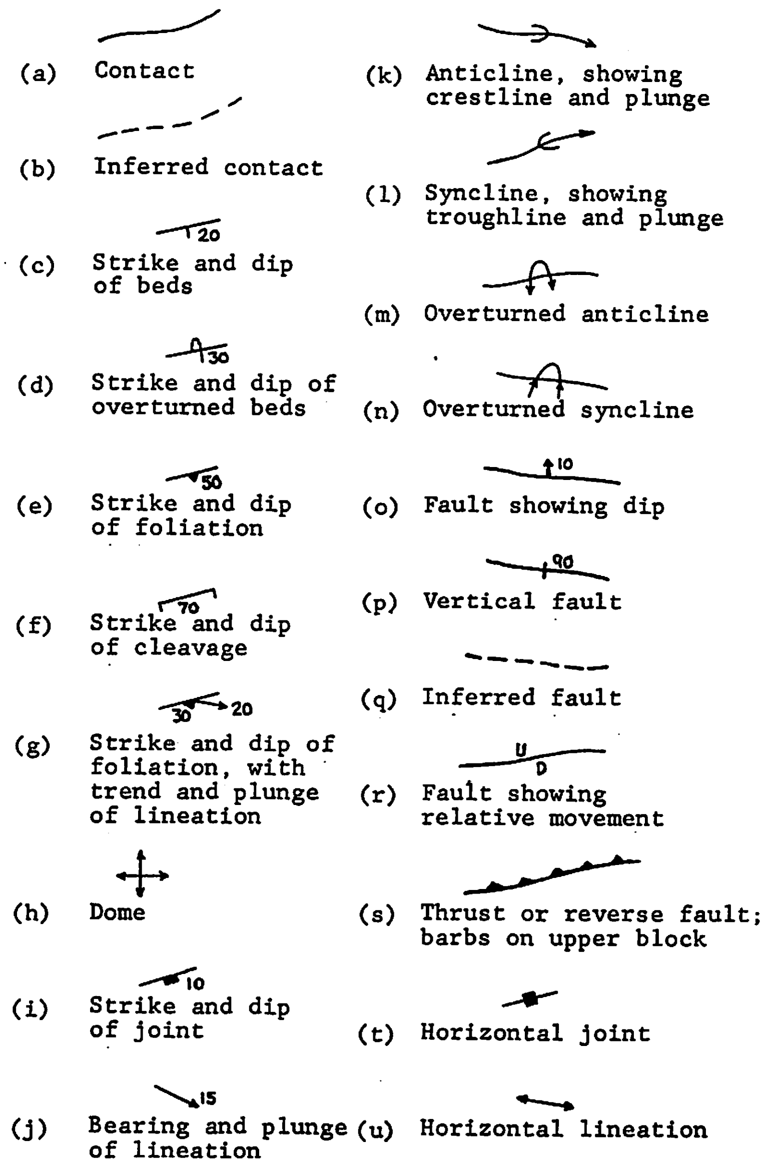
$$\text{cot apparent dip} = \frac{\text{cot true dip}}{\text{sin divergence from strike}}$$

Fig. 42



Modified from W.S. Tangier Smith, 1925

Fig. 43
GEOLOGIC MAP SYMBOLS



NORTHWESTERN WYOMING

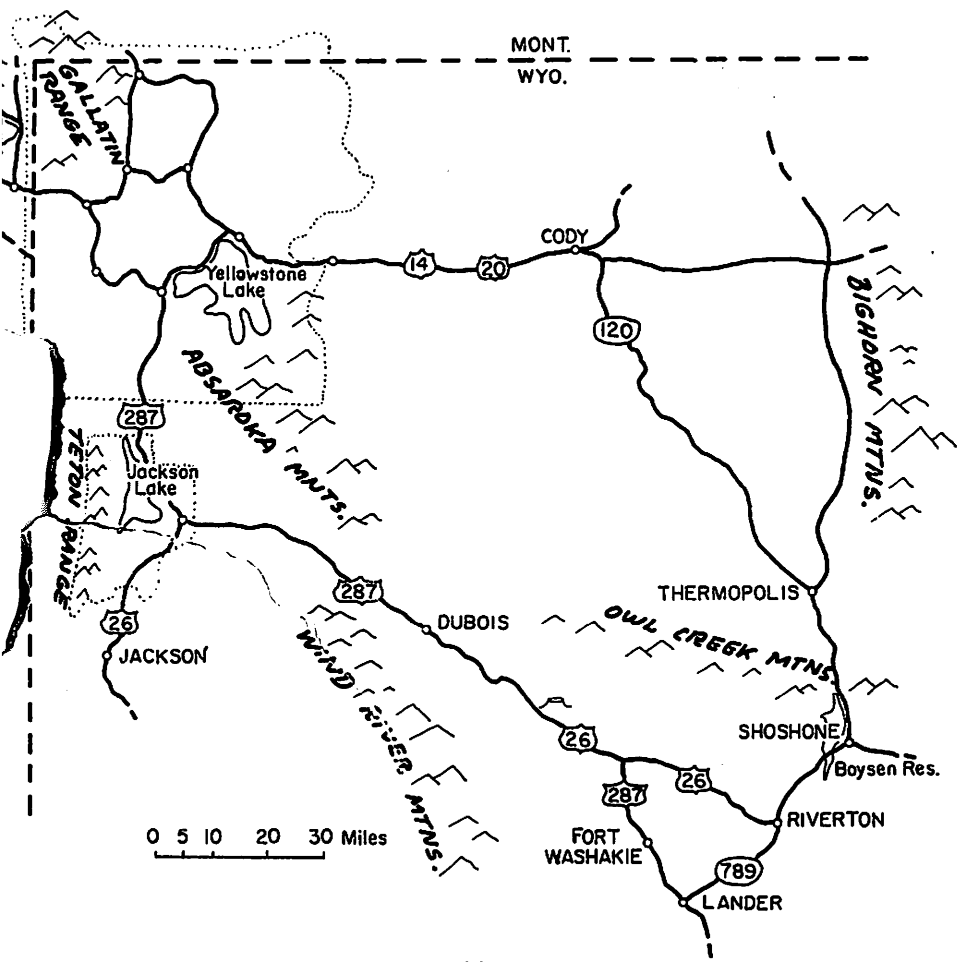


Fig. 44

Bus Leaves Camp at 7:30 a.m.
Duty Roster (for field-kitchen duties) will be posted on bus.

DO'S AND DON'TS (mostly don'ts)

1. Travel "light", but include:

Sleeping bag (optional pad)	You will need your notebook and pencil(s), but you will not need:
Coat, hat, gloves	
Rain gear	
Toilet articles	mapboard
$ for breakfasts & lunches	Brunton
Insect repellent	hammer
Hand lens	acid bottle
Flashlight	Silva
Full canteen	Jacob staff, etc.

2. On this trip we will be making numerous stops at places of geological or logistical (food, gas, etc.) importance. There is a lot to see, and it is important that we not waste time. Therefore, at each stop you will be told when the bus will leave. Synchronize your watches with those of the leaders, and return to the bus promptly. STRAGGLERS MAY BE LEFT BEHIND.

3. The thermal areas we will visit in Yellowstone are potentially dangerous, with their boiling water and unstable ground. STAY ON DESIGNATED BOARDWALKS AND TRAILS.

4. Don't break rocks within the Park or in any other way alter its appearance. Violators will be prosecuted!

5. Don't (repeat...don't) approach the bears. There have been several tragedies in our national parks. Don't encourage another.

6. Don't have (bear) food in or around ... quarters; All food will be locked in a vehicle a...

7. Don't wander off alone in the wi...

ROAD ...
LANDER TO GRAND TET...
(condensed and modified from...

0.0 LANDER, Leave town he...

15.0 FT. WASHAKIE

17.0 WIND RIVER FM. (F... S.W. corner of ... rison, Phospho...

24.6 IGNEOUS DIKE... cutting Wi...

28.1 QUATERNAR... east. ... stones...

30.7 JUNC...

32.9 RO...

39.9 CROWHEART BUTTE (east). In March, 1866 the Shoshone and Bannock fought the Crow over hunting rights in the Wind River Basin. Named because the victorious Washakie, Chief of the Shoshone, displayed a Crow's heart on his lance at war dance after the battle. The landscape consists of Wind River Fm. (Eocene-tuffaceous claystone and sandstone).

58.5 For the next 5 miles we will be passing through east-dipping exposures of the Mesozoic section that you recently studied at Derby Dome.

65.7 NEARLY VERTICAL SUNDANCE (west) in fault contact with Gypsum Spring and Nugget.

70.0 EXTENSIVE STRIKE SECTION of varigated Wind River Fm. (east).

75.2 DUBOIS. Supply center for near-by dude ranches. Gas stop.

84.8 ABSAROKA MTNS (northeast). Stratified volcaniclastics, andesites and tuffs of the Wiggins Formation (Oligocene).

106.8 TOGWOTEE PASS on the Continental Divide; elev. 9658 ft. (Tog-wo-tee was famous Indian guide). Shoshone Forest to the south, Teton Forest to the north. Wiggins Fm. in cliff to the south.

108.6 GREENISH TUFFS of Tepee Trail Fm. (Eocene) in roadcut.

108.9 1000-foot stretch of roadcut through EOCENE (?) BASALTIC AGGLOMERATE.

116.5 KNOB-AND-KETTLE TOPOGRAPHY, sublty developed to the south, formed during Pleistocene Bull Lake glacial stage.

121.3 PICTURE TURN-OUT. Majestic Teton Mtns. to the west.

123.7 ROADCUT FAILURE IN PLASTIC BEDS of Harebell Fm. (U. Cretaceous). Repeated problems here because roadcut disrupted older stabilized landslide.

129.3 MT. LEIDY (south); Pinyon Congl. (Paleocene) discordant on Cretaceous.

134.0 MORAN JCT. Turn south on #26, #89 for a 13.1 mile side trip.

136.3 BACON RIDGE SANDSTONE (CRETACEOUS) on ridge to the east; 900-1250 feet thick.

136.7 SIGNAL MTN. (west) capped by glacial deposits. Good view of overall glacial topography from the top of Signal Mtn.

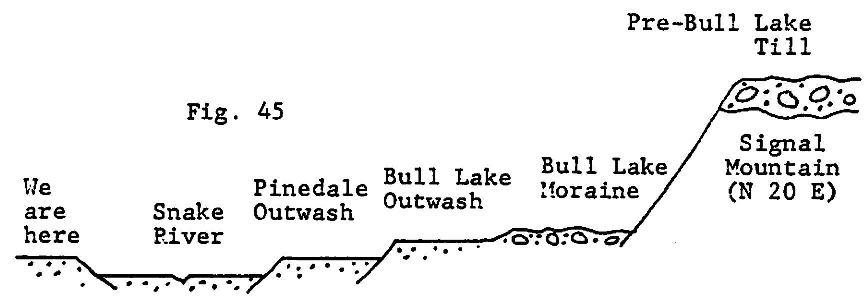
140.3 TRIANGLE X RANCH (east). "Spencer's Mountain" was filmed here.

143.8 SNAKE RIVER OVERLOOK. Three glacial stages have been recognized in Jackson Hole:

(youngest) PINEDALE (9,000 years ago)
BULL LAKE (35,000-000years ago)
(oldest) PRE-BULL LAKE (200,000 years ago)

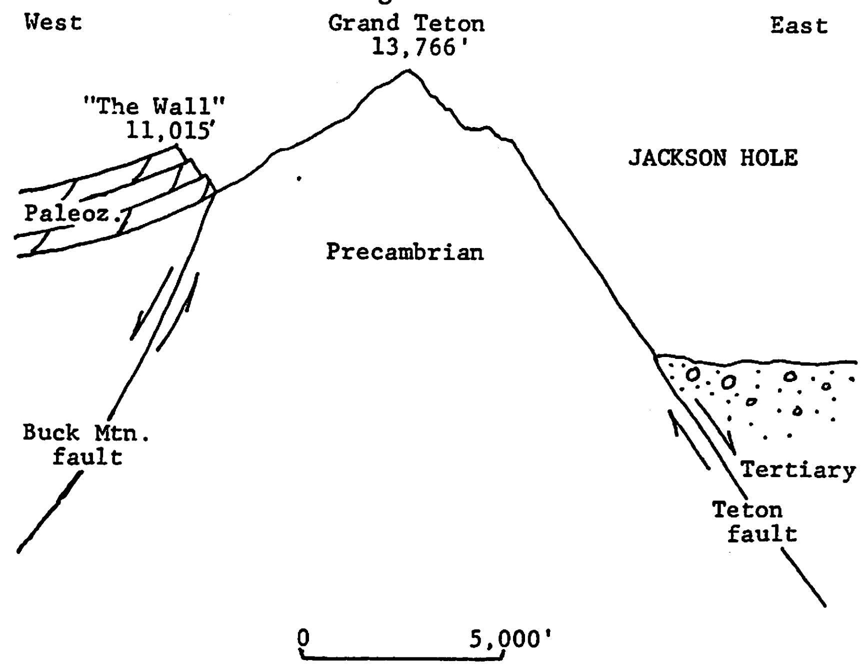
Most of the glacial ice entered Jackson Hole from the north, with some contributions from glaciers located in the Tetons and Wind River Mountains. Records of three stages can be seen at this stop.

Fig. 45



147.1 TETON POINT TURN-OUT. Plaque describes geology of mountains. Laramide deformation during the latest Cretaceous produced a northwest trending arch that was broken first in the Eocene (Buck Mountain Fault) and later during the Pliocene (Teton Fault) by block faulting that uplifted the Tetons 9,000-14,000 feet and tilted them to the west.

Fig. 46



ON MOUNTAIN S. 35° E. IS SCAR OF 1925 GROS VENTRE LANDSLIDE

The slide impounded water (Slide Lake) that destroyed natural dam two years later, killing 6 people in the Town of Kelly.

(Turn Around and return to Moran Jct.)

160.2 MORAN JCT. Turn left on US 287 and US 89 for Yellowstone Park.

163.9 SIGNAL MTN. to the south. Welded tuffs, resembling lava flows, capped by glacial deposits of Pre-Bull Lake Stage.

164.3 "CONFUSION CORNER" (turn right on U.S. 287 and for Yellowstone Park).

165.0 ROADCUT IN WHITE PUMICITE, TUFF AND SHALE OF MID-PLIOCENE TEEWINOT FM. dipping 25° westward, Jackson Lake Lodge in part rests on this, and therefore required considerable steel pilings.

165.5 JACKSON LAKE LODGE (1955 cost; 6,000,000 of John D. Jr.'s dollars).

166.9 THE ROUNDED HILL TO THE NORTH IS PILGRIM PEAK. It is capped by 1000 feet of Rhyolite, Pumicite, and Welded Tuff of the Teewinot Fm. (Pliocene).

170.1 COLTER BAY. Named for John Colter, famous explorer and fur trapper known for his nude flight from his Indian captors.

173.3 TO THE EAST, VALLEY SCOURED BY LARGE ICE SHEET that moved southward from the Yellowstone Park area during Pre-Bull Lake Glacial Stage (one of several similar southward-tending glaciated valleys in area).

173.9 ROADCUTS in glacio-fluvial deposits.

176.2 JACKSON LAKE, the largest of several glacial lakes formed by a combination of:

a) deep glacial scouring by south flowing glaciers.
b) westward tilting of the floor of Jackson Hole.
c) damming by glacial moraines

181.5 We are entering the southern end of the Yellowstone volcanic field. For the next 4-5 miles, the red-brown cliffs to the west and east are composed of rhyolite and welded tuff of probable Pliocene age.

188.0 SOUTH ENTRANCE to Yellowstone Park.

GEOLOGY OF GRAND TETON NATIONAL PARK
(Taken from Love, J.D. and John C. Reed, Jr., 1971, Creation the Teton Landscape, 120 p.)

"Les Trois Tetons" (the three breasts) mark the skyline of Americas most spectacular mountain range...spectacular because (1) it is relatively young, and (2) it has been largely shaped by glacial erosion. The highest peak, Grand Teton, is at an elevation of 13,766 feet above sea level.

The Teton Mtns. mark the eastern-most example of basin-and-range structure. They are fault-block mountains. The high central peaks tower some 7,000 feet above Jackson Hole Valley, a vast block of Cenozoic and older rock that is some 30,000 feet lower than correlative rocks in the Teton range. Geologists believe that this 25,000-30,000 feet of displacement along the Teton fault has occurred within the past 9 million years. From this, the rate of movement along the fault has been on the order of 1 foot in 300-400 years, perhaps locally as much as 1 foot in 100 years. Occasional earthquakes in the area, along with fresh fault scarps, signal continued movement along this fault.

Why did the Tetons rise? Geologists have wondered if there was a simple redistribution of material deep within the earth, from the Jackson Hole area to the Teton Mtns area, thus explaining both Jackson Hole subsidence and Teton elevation. Problem: the "volume" of subsidence is far greater than the "volume" of elevation. North and east of Teton Park are the vast lava plataus of Yellowstone Park and the strinkingly layered volcanic rocks of the Absaroka Range. Could these volcanics explain the excessive subsidence of Jackson Hole? (After all, all three are Tertiary features.) Problem: The estimated 10,000 cubic miles of these tertiary volcanic rocks exceed, by many times, the "volume" of Jackson Hole subsidence. So....where did the rest of the volcanic material come from? Answer: From Teton Basin and the Snake River drainage west of Teton Mtns. Still....why the uplift of the Teton Range????

Jackson Lake is impounded by terminal moraine on the north. The moraine dam is a part of a complex of Pinedale glacial deposits, collectively called the Burned Ridge moraine. "Knob and Kettle" topography characterizes this moraine in places. A lower, sagebrush flatland marks the Pinedale outwash plain. (The outwash doesn't hold water as well as does the moraine so....no trees.) Terminal moraines were also developed at the toes of glaciers emerging from the steep canyons that mark the east front of the Tetons. The terminal moraine produced by Jenny Lake Glacier neatly contains modern-day Jenny Lake, the "Little Switzerland" area. Pinedale glaciers occupied much of Jackson Hole as recently as 9,000 years B.P., at a time when Indians were already living in the area. Bits of information, both from North America and Europe, indicate that there was a period called the "climatic optimum" about 6,000 years B.P. when the climate was warmer and drier than at present. No doubt the Pinedale glaciers were even more restricted than than now.

YELLOWSTONE PARK

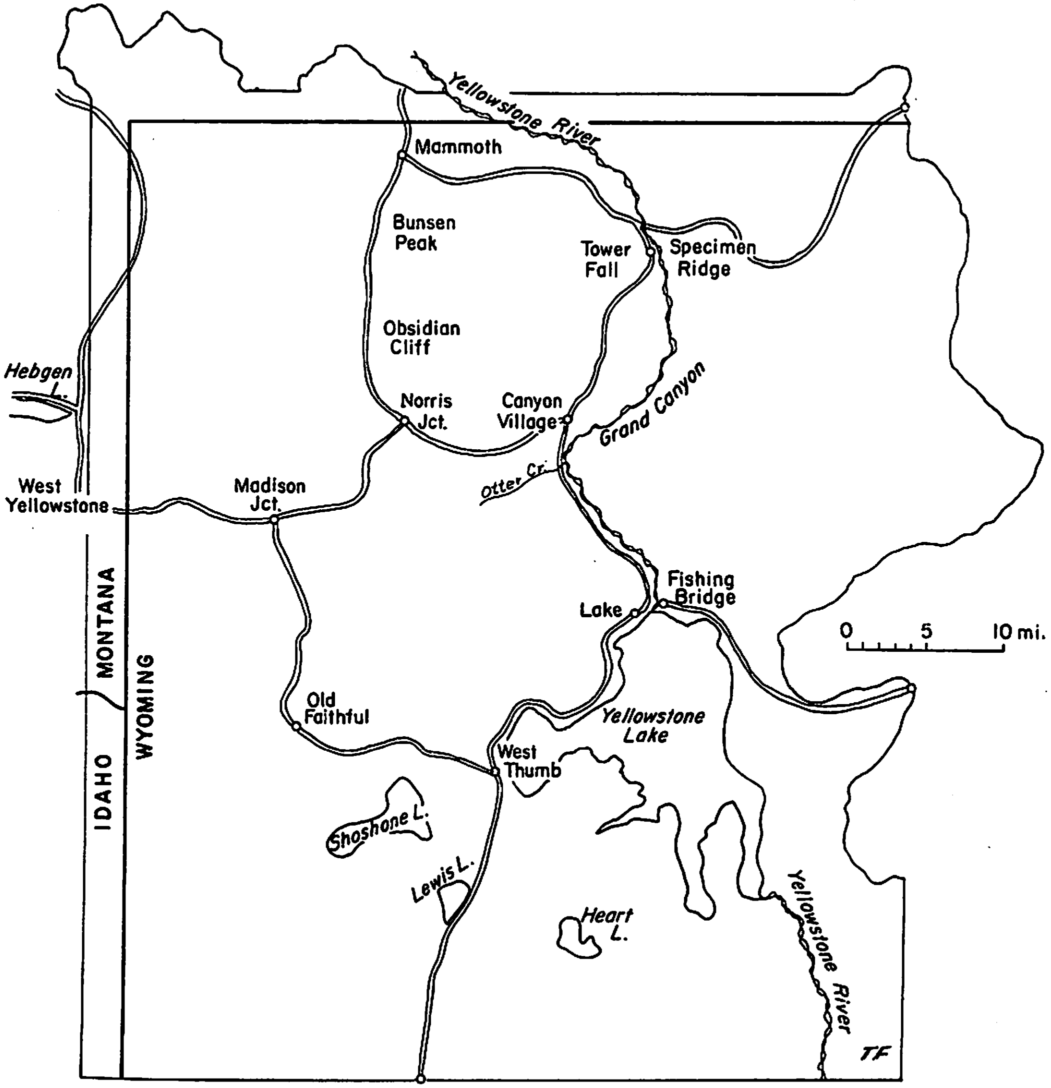


Fig. 47

GEOLOGY OF YELLOWSTONE NATIONAL PARK
(Taken from Keefer, William R., 1976, The Geologic Story of Yellowstone National Park: U.S. Geological Survey Bull, 1347, 92 p.)

Yellowstone holds special significance because it was our first national park...established under the presidency of U.S. Grant in 1872. Descriptions of the area date back to Joseph Meek (1829), F.V. Hayden (1871), and even earlier tall tales by the legendary Jim Bridger. Accompanying Hayden in 1871 were a photographer, William Jackson, and an artist, Thomas Moran. Their names live on in the form of a spectacular lake and a majestic peak.

Above all, Yellowstone is famous for its thermal setting. The normal geothermal gradient of earth's approximately 1°F per 100 feet, is greatly exceeded in the Yellowstone area. A research well, drilled to a depth of 1,088 feet, encountered a bottom-hole temperature of 465°F. So...the geothermal gradient is 40 times that of ordinary thermal gradient areas. Locally in Yellowstone, this is even greater.

How a geyser works: At sea level, water at the bottom of a 100-feet deep well would have to be heated to 288°F to boil, (rather than the 212°F required at earth's surface). At Yellowstone elevations, water boils at about 199°F, so the temperature required for boiling at a depth of 100 feet would be less than the 288°, but not much less. Eventually the temperature required for boiling at the bottom of a geyser "plumbing system" is achieved, and the water swells with steam, forcing part of the water up and out of the geyser's mouth. As this water spills out, the confining pressure is thereby reduced, and...pop! Superheated water is expelled as explosive steam!

Volcanic activity in the park, with which the thermal activity is related, dates back to early Eocene time, some 50 million years B.P. The result: the vast pile of volcanic rocks that comprise the Absaroka and Washburn Ranges and part of the Gallatin Range. These rocks are dominantly andesitic, but basalts occur locally. A noteworthy occurrence of these Eocene extrusives buried some 27 successive forests, one on top of the other, at "Specimen Ridge." A curious thing about these fossil forests is that they include sycamore, walnut, magnolia, chesnut, oak, redwood, maple, and dogwood--tropical to sub-tropical varieties! Intrusive igneous rocks associated with this activity are especially common along the Gallatin Range skyline. An example, Bunsen Peak (2-3 miles south of Mammoth) is either a volcanic neck or a stock.

Little is known of the geologic events in Yellowstone during the Oligocene and Miocene. There is no rock record of these two epochs (except for volcanic conglomerates of the Oligocene Wiggins Formation to the east). Many features of the present Yellowstone landscape reflect structural adjustments during the Pliocene, some 10 million years ago. At that time the entire area was uplifted several thousand feet above its present level, which accounts for the high average elevation of Yellowstone today. It was this activity that accounted for the elevation of the Teton Range to the south.

Near the beginning of the Quaternary Period (2-3 million years B.P.) an enormous amount of magma had accummulated beneath Yellowstone. Eventual eruption, which was much more explosive than that of the Eocene Absarokas, created two noteable calderas. The earlier caldera (2,000,000 years B.P.) has been largely obliterated by subsequent geologic processes. The outline of the later caldera (600,000 years B.P.), which is more obvious, marks an explosive event that, by comparison, makes that of Krakatoa (1883) "small potatoes". The Yellowstone Tuff resulted from this 600,000-year old event. The basin occupied by Yellowstone Lake is in part the result of caldera collapse, but much of the original depression has been filled with subsequent lava flows that comprise the Plateau Rhylolite and later basaltic flows. The most recent volcanic rocks of the park are 60,000-75,000 years old. A noteable occurrence of the Plateau Rhyolite is at Obsidian Cliff, where a 200-foot escarpment of obsidian glares down from Jim Bridger's "Mountain of Glass."

Yellowstone Park was glaciated at least three times during the Quaternary:

Pinedale: 25,000-8,500 years B.P.
Bull Lake: 125,000-45,000 years B.P.
pre-Bull Lake: 300,000-200,000 years B.P.

The oldest, the pre-Bull Lake, resulted in moraines sandwiched among lava flows of the Plateau Rhyolite. As expected, the youngest glacial stage, the Pinedale, is the most easily discernable. It is believed that during Pinedale time ice accumulated to a thickness of 3,000 ft., centering over the present site of Yellowstone Lake. Some 90 percent of Yellowstone was ice-covered, with only the highest ranges emergent. Ice thickness notwithstanding, ice did not flow down the Grand Canyon of the Yellowstone, hence its V-shape. The Pinedale ice largely melted away by about 12,000 years ago. Even the valley glaciers had disappeared by about 8,500 years ago. Then, following the "climatic optimum" of about 6,000 years ago, scattered icefields developed and persist until now, but there are no glaciers within the park at present.

THE STEREOGRAPHIC NET

The aim of the stereographic method is to represent three-dimensional orientations of planes and linears in two-dimension (i.e., on a sheet of paper), and to illustrate relationships among such features. This is done by placing the plane, or linear, centrally within a sphere so that it passes through the sphere's center, for example the inclined plane in Figure 1. In contrast to mineralogists, who use the upper hemisphere of such a sphere for projection purposes, the structural geologist uses the lower hemisphere. For example, let's represent the inclined plane of Figure 1, which is striking due N and dipping 50 W. Inasmuch as the plane passes through the center of the sphere, its intersection with the sphere forms a "great circle". That part of the great circle in the lower hemisphere (that part intersected by the shaded half of the inclined plane) is projected to the "equatorial plane" (marked with N-S and E-W axes) by constructing lines between the great circle and a zenithal point (north pole of the sphere) as in Figure 2. This projection is shown in two-dimension as the "cyclogram" of Figure 3. (If points of intersection between the inclined plane and the lower hemisphere were projected exactly vertically to the equatorial plane, rather than to the zenith, there would be awkward crowding of low-dipping planes that would plot at the periphery of the equatorial plane.)

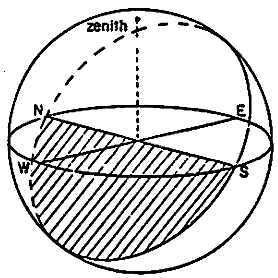


Fig. 1

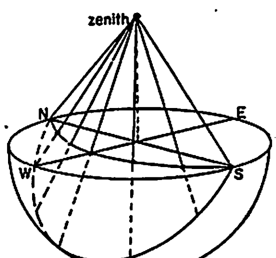


Fig. 2

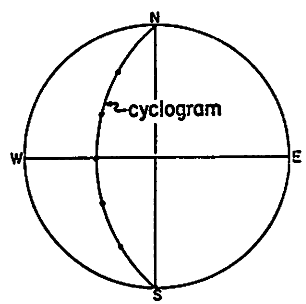


Fig. 3

A stereographic net is constructed by projecting a family of great circles analogous to the meridians or lines of longitude shown in Figure 4. In addition, "small circles", analogous to parallels or lines of latitude shown in Figure 4 are also projected to the equatorial plane. The great circles and small circles of Figure 4 are graduated in increments of 30 degrees. Their projection to the equatorial plane is shown in two-dimension in Figure 5. A complete stereographic net, graduated in increments of 10 degrees, is shown in Figure 6.

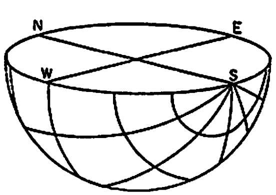


Fig. 4

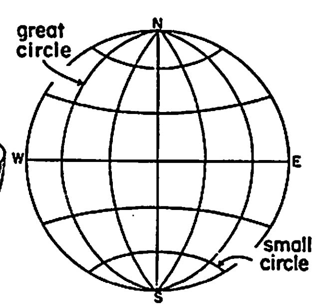


Fig. 5

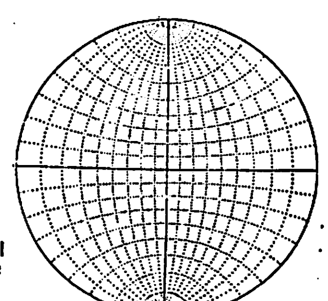


Fig. 6

USING THE STEREOGRAPHIC NET FOR REPRESENTING ORIENTATION OF

1. Planar features
   - A. Primary - bedding and cross-bedding.
   - B. Secondary - axial planes of folds, faults, foliation (slaty cleavage, shistosity, and gneissic banding).
2. Linear features.
   - A. Primary - sole marks.
   - B. Secondary - lineations, fold axes.

The stereo net is prepared for use by pushing a thumbtack from the bottom through its center. (The head of the tack can be taped to the bottom of the net.) A transparent overlay is forced on to the tack so that it can be rotated over the net. The overlay is marked N,S,E, & W at points coincident with those of the net. The overlay is said to now be in its coincident position.

TO REPRESENT AN INCLINED (DIPPING) PLANE:

Example: a plane striking N 30 E and dipping 50 NW.

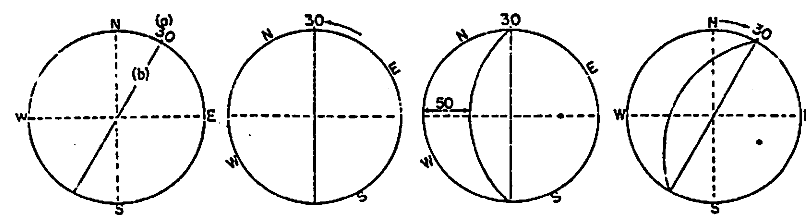
Note: on diagrams, such as those below, the dashed N-S and E-W axes represent the fixed orientation of the underlying stereo net; the N,S,E and W labels are on the overlay and indicate the degree to which it is rotated.

A. (With overlay in its coincident position) Using the small circles, (a) count off 30 degrees from north to east along the perimeter of the net. Mark this position, and (b) extend a line from it, through the net's center, to the opposite side of the perimeter. This line, with the overlay in coincident position, represents the strike of the plane.

B. Rotate the overlay counter-clockwise so as to bring the strike line into coincidence with the net's N-S axis.

C. Inasmuch as the plane dips NW, using the longitudinal circles, (a) count off 50 degrees from west to east along the W-E axis. (b) Trace the longitudinal circle that occurs at this 50-degree point onto the overlay, making a cyclogram.

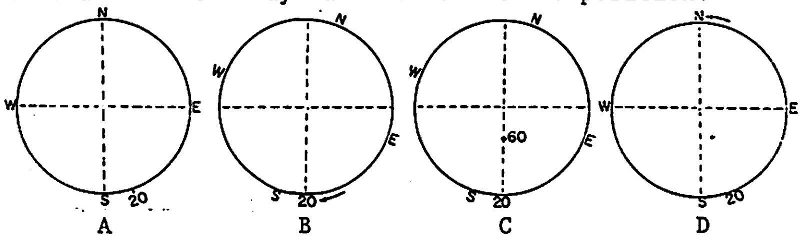
D. Rotate the overlay clockwise back to its coincident position. The cyclogram representing the inclined plane is now in its appropriate position.



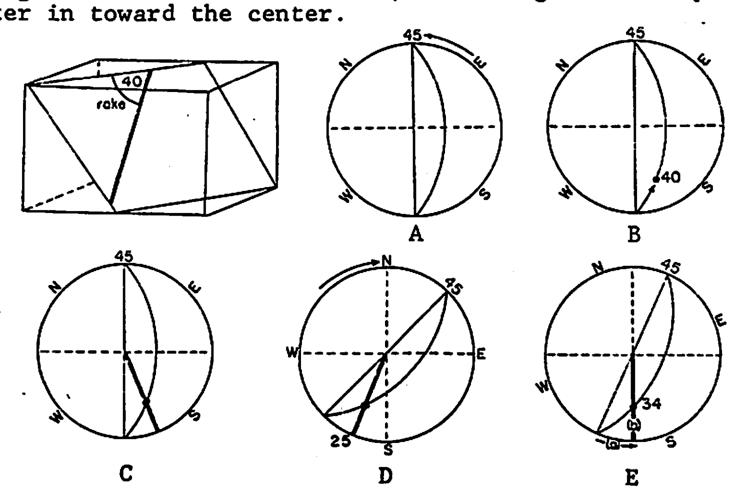
A B C D

The orientation of an inclined plane can also be represented by the plane's "pole point". A pole point is plotted on the equatorial plane by projecting a single point on the lower hemisphere to the zenithal point. This single point is where the lower hemisphere is struck by a line that is perpendicular to the inclined plane and which descends from the center of the net. In order to plot the pole point of the inclined plane illustrated above, repeat the first two steps (A & B), but then, instead of counting in 50 degrees along the W-E axis from the western perimeter of the net (step C), count off 50 degrees from west to east along the W-E axis but begin at the center of the net. On rotating the overlay back to its coincidence position, the pole point will be in its appropriate position. The pole point for this inclined plane (with strike N 30 E and dip 50 NW) is shown both in diagram C and in diagram D above.

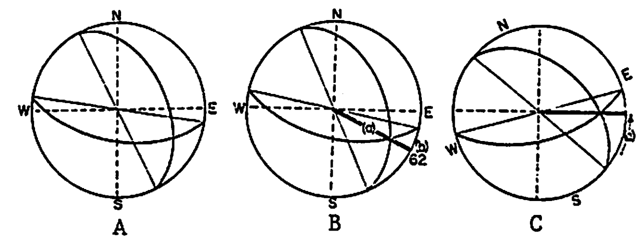
TO REPRESENT AN INCLINED (PLUNGING) LINE
Example: a line with a bearing of S 20 E and plunge of 60.
A. (With overlay in its coincident position) Using the small circles, count off 20 degrees from south to east along the perimeter of the net. Mark this position.
B. Rotate the mark to the nearest axis, in this case clockwise to the net's S pole.
C. Count off 60 degrees from the net's S pole up the N-S axis and mark this point.
D. Rotate the overlay back to coincident position.



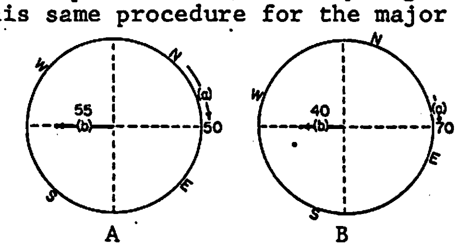
TO REPRESENT THE RAKE (PITCH)OF A LINE (LINEAR) THAT OCCURS ON AN INCLINED PLANE:
Example: a plane striking N 45 E and dipping 60 SE, on which there occurs a line with a rake of 40 degrees in a general SW direction. (The cyclogram for the inclined plane has already been constructed.)
A. Rotate overlay to bring strike of cyclogram coincident with N-S axis.
B. From the south pole of the stereo net, count off 40 degrees (the rake) along the cyclogram great circle, using small-circle graduations to measure the 40 degrees.
C. Extend a line from the center of the stereo net, through the 40-degree point, to the perimeter of the stereo net.
D. Rotate overlay so as to restore coincidence between the overlay and the stereo net. The exact bearing of the line con be read at the point where the constructed line intersects the net's perimeter, using small-circle increments to measure. (Bearing: S 25 W)
E. If (a) constructed line is rotated to a principle diameter of the stereo net (either the N-S or E-W axis),(b) plunge of the line can be read, measuring from the perimeter in toward the center.



TO REPRESENT A LINE FORMED BY THE INTERSECTION OF TWO PLANES:
Example: Two cyclograms representing the opposing limbs of a fold have been plotted (A below). Problem: solve for the bearing and plunge of their hinge line.
B. (a) Draw a line from the center of the stereo net, through the point where the two cyclograms intersect, to the perimeter. (b) Read the bearing of the hinge line directly from the perimeter, using small-circle increments. (Bearing: S 62 E)
C. (a) Rotate the line representing the hinge line to the nearest principal diameter (the E-W axis) and (b) read the plunge of the line from the perimeter in toward the center using, as usual, great-circle increments for measuring.



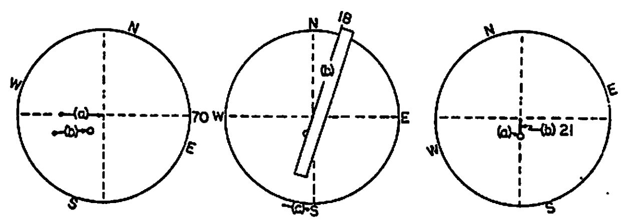
TO SOLVE FOR ORIGINAL ORIENTATION OF STRUCTURALLY ORIENTED CROSS-BEDS
This procedure involves the plotting of both the orientation of the major stratification and that of the cross-bed set on a single overlay. Then, the major stratification is rotated, about a horizontal axis, to a horizontal position. The cross-bed set is rotated by a proportionate amount, about a horizontal axis, producing its original ("pre-structure") orientation.
This procedure can be laboriously accomplished by plotting and rotating cyclograms, but a much quicker method involves the plotting of pole points. Recall that a pole point is a projection of a line that is perpendicular to an inclined plane. This provides an added convenience, because there is a growing trend toward describing an inclined plane in terms of (a)azimuth of dip and (b)magnitude of dip. This is because azimuth of dip can be directly and easily entered into a computer program, whereas strike (in terms of either azimuth of quadrant) has to be further reduced for processing.
Example: major stratification has a dip azimuth of 70 and magnitude of 40; a cross-bed set has a dip azimuth of 50 and magnitude of 55. Problem: solve for original ("pre-structure") azimuth and magnitude of cross-bed dip.
A. Plot the pole point for the cross-beds by (a) rotating the azimuth value (50) to the nearest principal diameter (E-W axis) and (b) measuring, from the center outward (away from the azimuth point of 50) the dip magnitude (55).
B. Repeat this same procedure for the major stratification.



C. Inasmuch as the major stratification dips with a magnitude of 40, it must be rotated, about a horizontal axis by that amount, so (a) migrate its pole point back to the center. With the overlay in this same position, (b) rotate the pole point of the cross-beds by the same amount (40) along a small circle.

D. In order to read the azimuth of dip of the inclined plane represented by this pole point (the original azimuth of the dip of the cross-bed), (a) rotate the overlay to its coincident position and extend a straight-edge from the pole point, through the net's center (b) to the perimeter beyond, where the original azimuth of dip can be read (18°)

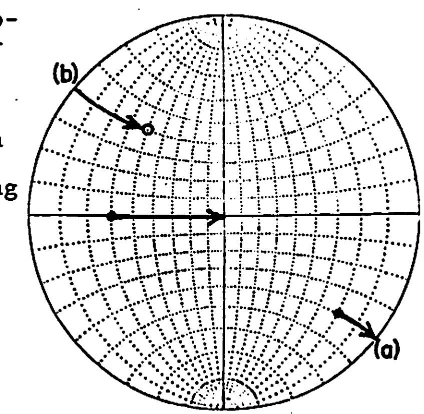
E. To read the original dip magnitude of the cross-beds, (a) rotate the corrected pole point to the nearest principal diameter (N-S axis) and (b) measure from the center outward, using small-circle increments. Dip magnitude: 21.



C D E

This same procedure can of course be used for determining the earlier structural orientation of strata that are discordantly overlain by inclined strata.

In special cases, the rotation of the major stratification, about a horizontal axis, causes the cross-bed pole point to migrate off of the overlay (see illustration at the right). Where this happens (a), continue rotating that pole point in the same direction and along the same small-circle value but at a place 180 degrees along the perimeter of the stereo net (b).



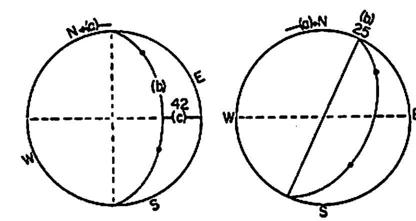
TO DETERMINE STRIKE AND DIP WITH TWO APPARENT DIPS

Inasmuch as a line of apparent dip lies within the dipping plane, two such lines can define the orientation of that plane.

First, plot a point representing the bearing and plunge of a line of apparent dip on the overlay (as already explained on page). For example, a line of apparent dip plunging N 50 E at 20. Next, plot a second line of apparent dip plunging S 30 E at 35.

A. Rotate the points through (a) to a position where they both fall on the same great circle. Trace that great circle (b) onto the overlay. Read the true dip (c) from the E perimeter in toward the cyclogram: 42°.

B. Return the overlay to its coincident position, and (b) read the true strike (N 25 E). The direction of the true dip can now, by inspection, be seen to be SE.



A B

GEOLOGIC ROAD TRAVERSE
(by pace-and-Brunton)

The length of each leg is limited by the curvature of the road. A sample format follows, from which the map below has been plotted. The length of pace for this geologist has been measured at 6 feet. The method of recording dip and strike is according to the "right-hand rule" explained on page 9.

Location of traverse:__________________________Date:________

LEG	AZIMUTH	#PACES	ITEM	DESCRIPTION
A-B	290	0	A	Beginning pt.; congl.
		100	Strat. contact	Congl. underlain by shale; strike 70, dip 30.
		166	B	-----------
B-C	12	175	Strat. contact	Shale underlain by sandst.; strike 70, dip 33.
		250	Strat. contact	Sandst. overlain by shale; strike 250, dip 45.
		255	C	-----------
C-D	40	300	Strat. contact	Shale overlain by congl.; strike 250, dip 43.
		350	D	-----------

(Nctice that paces are converted to feet on the map below.)