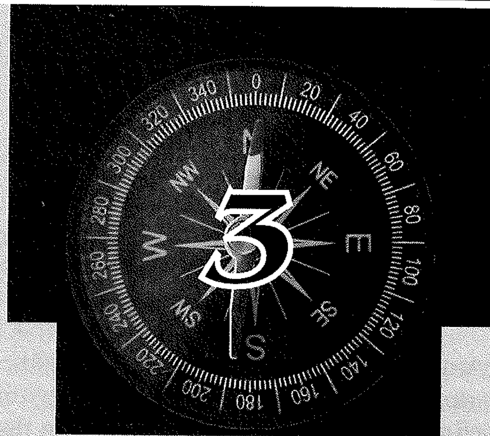
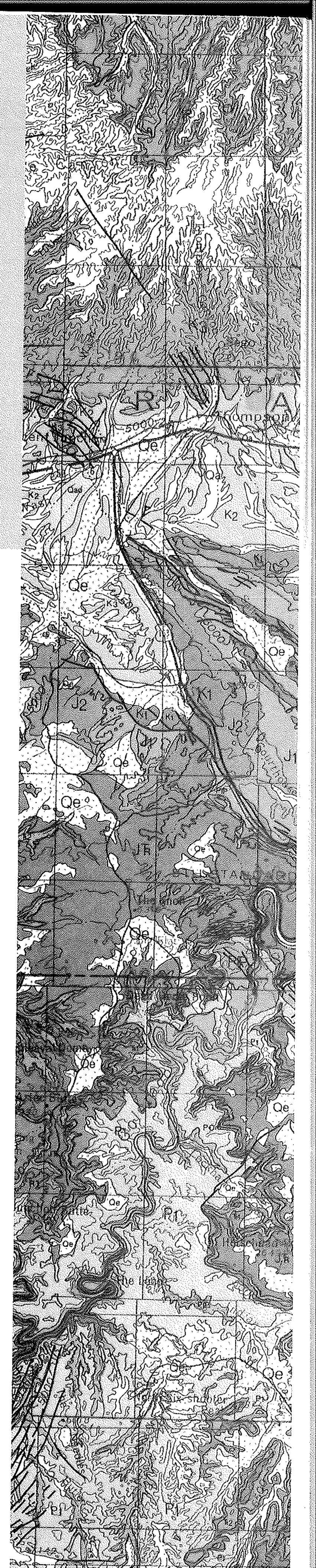


Preparation of Geologic Maps



Preparing a geologic map provides an excellent opportunity to combine skills in map reading, rock identification, measurement of structural features, and drafting. Before the map is complete, you will also use your abilities to visualize the three-dimensional shape of the rock units and how they relate to the form of the land. Because geologists prepare maps on the basis of a limited number of observations, the final product is an interpretation of what they can see and how those observations can be projected across covered areas. Finally, the map is a guide to what can be inferred about the subsurface and about the geological evolution of the area. This chapter outlines procedures and methods you may follow in carrying out a mapping project. A basic review of rock identification follows in Chapter 4.

Preliminary Preparations

Define the Map Area

Before starting a mapping project, establish the boundaries of the area to be included on the map and draw these boundaries on a base map. It is always advisable to investigate immediately surrounding areas, and it is often helpful to map beyond the borders of the map area. You may find outcrops that will help you define the location of contacts, or you may discover faults or folds that may extend into your map area.

Collect and Review Existing Information

Locate as much information about the geology of the area you are mapping as possible. Look for earlier maps and descriptions of the rock bodies that are likely to crop out in your map area. This type of information may be obtained by talking with geologists who are familiar with the area, or by making a search of bibliographies of the geology of the region. The American Geosciences Institute offers the GeoRef Database (http://www.americangeosciences.org/georef/georef-information-services), a comprehensive, worldwide database of the geosciences. The Association of American State Geologists (http://www.stategeologists.org) has links to state geological surveys, and for federal documents and maps, see the USGS website (http://www.usgs.gov/products). The Expanded Academic ASAP and FirstSearch databases contain excellent coverage of articles in periodicals and news sources. Even if more detailed maps are not available, you should be able to find state geological maps that will provide general information about the structure and stratigraphic units that occur within the area you plan to map. If you are unable to locate information about the age and lithology of the rock units in the area, you will need to define these using the guidelines provided later in this chapter and in Chapter 4.

If you are undertaking a mapping exercise as part of a field course, you will either be given detailed descriptions of the rock units that occur within your map area, or you will be asked to define and describe the map units within the area.

Select a Base Map

Most geological maps of large areas are drawn on topographic map bases. Many geologists use both aerial photographs and topographic maps as base maps for location of places where data are being collected, even though the final map is prepared on a topographic map base. Because photographs record many features (e.g., trees, fences) that do not appear on topographic maps, it is frequently easier to determine your location in the field on an aerial photograph than it is on a topographic base. If photographs are used to record field observations, it is useful to use a pin to mark locations on the photograph. Then the location number or notes may be written on the back of the photograph and will not obscure the photographic image. When topographic maps are not available, aerial photographs are commonly used as a base. Orthophotographs have been corrected for distortion and make excellent base maps or maps on which to record data when contours are less important than recognition of landmarks on the ground surface.

The purpose for which the geologic map is being prepared influences the selection of a base. If the area being mapped is small and great detail is needed on the geology, a topographic map base may have to be prepared especially for the project. This is commonly the case where geologic maps are being prepared of mines or sites for building and dam foundations. Topographic maps may be prepared using surveying instruments, such as alidades, levels, or transits. The techniques used are described in most surveying texts.

In the United States, most geological maps prepared by government surveys are prepared on topographic maps at scales of 1:24,000, 1:50,000, 1:62,500, 1:100,000, or 1:250,000.

Making a Reconnaissance Survey of the Area

A quick reconnaissance survey can save you considerable time in mapping. By making a quick tour of the area, you will have a good idea of where the best rock exposures are located, how to access various parts of the area, and where houses and property boundaries are located. You should make brief notes on a copy of your base map to indicate major changes in rock types and obvious structural features such as folds.

Obtain Permission to Enter Private Property

Be sure to introduce yourself to property owners in the area where you plan to map. Explain what you are doing and when you expect to be on their property. While many people are indifferent to trespassers, some consider trespassing a serious violation and may even have trespassers arrested. It is generally a good idea to secure permissions from as many of the property owners as possible before starting to map. Otherwise, you should be cautious about crossing poorly marked property boundaries.

Collecting and Recording Observations

Decide Where to Collect Data

Deciding where to collect data will depend on how extensive the exposures of rock are in your area, access to those exposures, and the amount of time you have to complete the mapping. As a general principle, you cannot have too much data. But you may not have enough time to occupy every rock exposure in the area, and the lithology and structure of rocks may not change much from one outcrop to another. In such places, a few widely spaced observations may be sufficient. The scale of your map will determine how closely spaced data points can be placed on the map without having information overlap. **Your primary objectives are to identify and locate contacts between the rock units.**

Making Traverses

Geologists generally use two techniques in deciding where to collect data. One technique involves collecting data encountered along selected traverses. The other technique involves finding and then tracing a contact across country wherever it goes. Generally geologists start mapping by making traverses. Initial traverses may be made along roads, along streams, or along ridges. It may be possible to complete the final map by correlating data from these traverses and scattered outcrops rather than by walking out each contact. However, if the structure of the area is complex, it may be necessary to trace out some contacts, but this can be a slow process. Generally, the final map is an interpretation of observations, some of which are located on contacts, but most of which are not.

You are likely to find outcrops in the following locations:

1. **Along roads**. Select a starting point for the traverse that is easily located on your base. Knowing the scale of your base, you can locate points where observations are to be made by measuring with a tape, with a counting wheel, or by pacing. (You should determine your stride and pace before you start mapping.)
2. **Along streams**. Pay careful attention to bends in the stream, places where tributaries shown on the base map enter the stream, rapids, sudden changes in gradient, or other natural features that appear on the base map (aerial photographs will be most useful where you are mapping away from cultural features). If you are uncertain about your location, check the bearing of straight sections of the stream and compare your reading with your base.
3. **Along ridges**. Features that can be used for location on ridges may be scarce, but ridges afford good viewpoints from which distance features can be seen. Locate yourself by taking bearings on features you can identify on your base. Use the surveying method known as resection (see p. 33) to locate yourself.
4. **On slopes**. Be especially careful about location of points when you are traversing up or down a mountain slope. It is easy to overestimate the elevation you have gained in climbing upslope. Use an altimeter as a way of checking your location on a slope. But remember that altimeters are sensitive to atmospheric pressure changes, so they may not be reliable if the weather is changing rapidly. As a precaution, set your altimeter at a place to which you will return when your traverse is completed. If the altimeter does not give the same reading at this place at the end of the traverse, a change in atmospheric pressure has taken place. You will also know if the pressure increased or decreased. It may be even more helpful to check the altimeter whenever you are at a known elevation. Reset the altimeter where elevation is known and make corrections for elevations if changes have occurred since it was last reset.

Make corrections for altimeter readings as follows: (a) Set altimeter and record time while you are located at a point of known elevation (e.g., a bench mark or BM). (b) Read altimeter and record time at each observation point. (c) Record the amount by which the altimeter is off when elevation is again known, and record time. (d) Assume that the error has accumulated at a uniform rate. (e) Plot change in elevation against time. (f) Correct elevations at observation points using the correction indicated on the plot for the time at which the observations were made.

Tracing Contacts

Following the contact between rock units, or zigzagging across a contact, is the best possible way of determining the trace of a contact. Unfortunately, this method is also time consuming, and in many areas outcrops are so scattered that it is not a practical way of mapping. In some areas, contacts may be clearly identifiable on aerial photographs or other types of images. In such areas, the position of the contact should be verified in the field and transferred from the photographic image to the base.

Record Observations

Record your observations in a field notebook. Notebooks containing water-resistant paper are available through many outlets. These are obviously valuable if you are working in an area where rain is likely. Be sure to use a pencil or waterproof ink.

The base map you are using in the field should be protected from damage by rain or other hazards. It is convenient to mount the map (in sections if it is large) on hardboard, Plexiglas, or some other firm backing. Aluminum cases are available commercially. If the map is small or can be cut into small sections, it may be more convenient to mount these small pieces in your notebook.

Key the notes you take to a point on the base map. Place a point (it is often useful to place a small circle around the point) on the base, and record the key number beside it. Be certain that the number you select has not been previously used. To avoid this problem, it is advisable to number all observations within a single map area consecutively. Do not start a new set of numbers for each day, week, or month. To do so is likely to lead to chaos in the end!

Keeping a Field Notebook

In your notebook, record the key number, the date, and describe the location of the point as precisely as possible. In making geological observations, assume that you will never return to that location. Record all of the information you may later need. That will include a complete description of the rock types present, the strike and dip of bedding, and other structural features (e.g., cleavage) that are present. If you know the name of the rock unit present at this location, record that. If you are uncertain about the identification, be sure to record that. Be sure to note any evidence indicating whether the strata are right side up or upside down.

Determine Your Location

It is essential that you know where you are located when you make and record field observations. Incorrectly located data will almost certainly complicate your interpretation and may cause you to misplace contacts, or even infer faults or folds, that are not present in the area.

The degree of precision needed for a map project will determine which methods are suitable for locating data points. The degree of precision needed depends on the purpose for which the map is being prepared and the scale of the map. For example, a geologic map of a quarry or a building site covering a few thousand meters will likely require a much higher precision than a map covering hundreds or thousands of kilometers of countryside. High-precision maps generally require the use of plane table and alidade, or other surveying techniques that are beyond the scope of this book.

Using Features on Base Maps or Aerial Photographs

This is the simplest method of locating points where you plan to collect data. In using this method, be careful to determine the year in which the base map or photograph was made. Cultural features may change dramatically over short periods of time as people build new houses, driveways, or fence lines, and as highway departments change the positions of roads and bridges. Even natural features may change as forest lands are cut and stream channels modified by engineering works. If you are using aerial photographs, be sure to note the time of year when the photograph was made.

Measuring Distances

Unless you are at a point of intersection of two features (e.g., roads or streams), you will need to determine how far you are from a feature you have positively identified on your map. You can obtain a rough estimate of that distance by pacing. To do this you must first know the length of your stride or pace. Using a tape measure, lay out a line of known length (30 meters or more). Walking with a comfortable stride, count the number of strides you take to cover that distance, and then calculate your average stride length. A pace is two stride lengths. For long distances you may wish to use a pedometer—an instrument that counts the number of paces. For a more accurate measurement of ground distance, use a tape or a distance measuring wheel. For even higher accuracy, use an optical or laser rangefinder. A laser rangefinder may be accurate to within 1 meter at a distance of several hundred meters. Note that the distances measured with optical or laser rangefinders are horizontal distances. Distances determined by pacing or placing a tape along the ground are ground distances—not map distances.

Pace-and-Compass Surveying

When the area to be mapped is so small that topographic maps or aerial photographs are not suitable for use as base maps, a new base map must be prepared. When the level of precision required is not great, you can prepare a map by using the pace-and-compass method. Geologists commonly use a Brunton compass to determine the bearing of lines, and they pace (or measure with a tape) distances between points on the survey. You can get a good impression of the accuracy of a pace-and-compass survey by surveying a closed loop. After the survey is made, points are plotted on a base map. If the measurements are accurate the last point will coincide with the initial point.

Exercise 3-1 A Pace-and-Compass Survey

Start by determining your pace along the edge of a football field. Once you are satisfied you know your pace, make the following survey.

1. Map the corners of the football field.
2. Locate additional points close to the field.
3. Draw a map of the field and show any additional points you located. Use a piece of graph paper using a scale of 0.5 inch = 100 feet. Orient the map relative to north, and draw a "declination" diagram and scale. Express the scale as a fraction.

Location by Resection

A method known as resection may also be used to determine the location of points that are not readily accessible or where distances cannot be accurately measured by use of pacing or taping (e.g., where the point to be located is not on level ground). If you are located at a point from which two or more known points (points that you can recognize on your base map) are visible, you can locate yourself. To locate yourself, take a bearing on the two known points. Then draw a line on your base map using the reverse bearings. (If the bearing from your location to a known point is N30E, the reverse bearing from that point to you is S30W.) You are located at the point where the two reverse bearings intersect.

Caution: A small error in measuring the bearings to these two points can result in a large error in your location. The accuracy of resection increases as the angle between the two lines used to make the determination increases.

Determining Location with GPS

Global Positioning System (GPS) is a worldwide surveying and navigation system. It uses signals sent from an array of 24 orbiting satellites to GPS receivers that can compute the geographic position, velocity of movement, and time at the receiver. It is necessary for the receiver to obtain signals from at least four of these satellites in order to calculate the three-dimensional position of the receiver. A position can be expressed in terms of latitude and longitude or UTM coordinates (see p. 16) and elevation; it can also be converted from one to the other. If good signals can be received, most commercial grade, handheld receivers have a horizontal accuracy of about 3 meters using the wide area augmentation system (WAAS) (Figure 3-1). When strong signals are not obtained a horizontal accuracy of 10 meters is more likely. The accuracy of elevation determination is not as good. Units capable of implementing differential corrections and include higher quality antennas have an accuracy of less than 1 meter for location determinations. Even more precise data may be obtained by survey grade equipment. This equipment is expensive and requires a license from the Federal Communications Commission to operate.

Many commercial receivers come programmed with a set of topographic maps—additional maps can be purchased and downloaded. The map appears in the window of the receiver and locations can be marked and saved on the map. Depending on the manufacturer, locations are referred to as either waypoints or landmarks. Most GPS instruments allow you to define each waypoint with a name and symbol, and can keep track of hundreds of locations. For use in geologic mapping, once the geographic coordinates of a waypoint have been determined, the position of the waypoint can be transferred to a topographic map. The person doing the mapping can locate outcrops or trace contacts by occupying and marking their position on the map. The mapper must record information about the outcrop (strike, dip, lithology, and other relevant information) in a field notebook in the same way used with other mapping techniques.

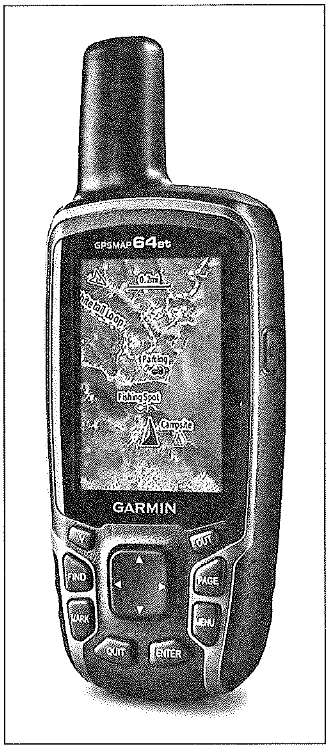


Figure 3-1 This Garmin GPS model is capable of showing the location of positions on the ground (called waypoints) superimposed on topographic maps of the area. (Courtesy of Garmin.)

Route navigation, in which the position of a series of locations are recorded, is commonly used by people using GPS for mapping or hiking. The GPS receiver records direction and distances between waypoints along the route. If positions are close together, or if the unit is left on while moving along a route, you can set the receiver to automatically drop trackpoints on the map spaced according to time or distance.

Precautions When Using a GPS Receiver

Before using a GPS receiver it must be initialized for the area in which it is being used. Instructions about initialization will be found in the owner's manual. Since many of these units are constructed in other parts of the world, a new receiver must be initialized for its new location. It is also important to initialize a receiver that has not been used for several months.

In order to get clear signals from satellites, the receiver should be located where there is a clear view of the sky. Signals from the satellites may be blocked by trees, buildings, or slopes. The accuracy of the receiver may be checked by taking it to a place where the geographic coordinates and elevation are known. Bench marks or triangulation stations are best, but other features shown on topographic maps (such as buildings) provide some measure of precision.

It is a good idea to turn the receiver off when moving from one location to another, both to save battery life and to avoid confusing the adjustment of the receiver to the signal due to unintentional shifts in position, such as moving the receiver by swinging it as you walk.

Use of Drones in Mapping

Drones equipped with remote cameras are being used for geologic mapping in some areas. The great advantage of the drone is its ability to obtain views from positions that may be difficult or even impossible for individuals to reach, such as cliffs or views over water-covered areas. Aside from their cost, limits on the altitude at which drones may be allowed to fly restrict their use for routine regional mapping.

Geographic Information System (GIS)

GIS is a computer-based technology that emerged in the 1980s as a way of integrating a great variety of types of data on a geographic base. Many of the systems are designed to study earth-based geographic relationships determined by geologic information, but GIS is also applied in many other fields such as engineering, transportation, business, insurance, and even telecommunications. Our concern is with systems designed to store, integrate, analyze, and present geographical data. Its earth-based uses range from compiling geologic maps to assess the quality of groundwater or the risk of groundwater contamination; predict earthquakes, volcanic eruptions, and landslide hazards; characterize energy and mineral resources; determine the location of waste repositories; and evaluate all types of land-use planning and management.

One of the earliest uses of GIS took place in the early 1960s as part of the Canadian Land Inventory, a study that made a determination of the capability of rural Canadian land. Still in use today, this study involves the mapping of soils, agriculture, wildlife, waterfowl, forestry, and land use on topographic maps at a scale of 1:250,000. We can think of each of these elements in the study as a digitized layer on a map in which the base layer is a digitized topographic map. These layers can be superimposed and analyzed to reveal such things as the relationship between soil type and forests or agricultural production. Much the same thing is done when using GIS to produce geologic maps.

In the GIS production of geological maps a digitized topographic map is the base layer. Data about the geology is collected in the field by a geologist, who records the position of the observations and information such as rock type, strike and dip, name of the formation, etc. These observations may be made manually or with GPS instruments that record the waypoints as geographic coordinates (latitude and longitude) and with an identification that can tie the location to the geological observations made at that point. This field data is then entered into a GIS software program, where information is then digitized and superimposed on the base. A number of these programs are commercially available, such as Maptitude Mapping and Global Mapper. The geologist must then determine and digitize the location of contacts between rock units, faults, the edges of intrusions, etc. and any other data (well locations, foliation measurements, joints, cleavage, etc.) that has been collected. At this time the map is often turned over to a cartographer who finishes the map.

One of the great advantages of having a digitized geological map is that if the map needs to be revised as a result of new observations or information, such as the discovery of surficial geology in an area where only bedrock geology was mapped, the new information can be incorporated without having to redo the entire map.

Describing the Outcrop

When you leave an outcrop, your field notebook and base map should contain a precise location of the outcrop, a description of the type of rock or rocks present at that location, and information about the structure of those rocks (see Chapter 4). Description of the rock structure should always include the strike and dip of sedimentary layers, the orientation of the axis and axial plane of folds (see Chapter 10), and any evidence you see of faulting (see Chapter 11). Your final geologic map will show the contacts between igneous, metamorphic, and sedimentary rocks. Each of these types of rock may be further subdivided into what geologists call map units or rock units.

Stratigraphic Units Used on Geologic Maps of Bedrock

Sedimentary rocks compose the bedrock over nearly three-quarters of the land surface of the Earth. Most of these were deposited as sediment on the sea floor. In general, marine sediments form through the settling of matter through water to the sea floor, where a layer is built up. If the material being supplied or the physical, chemical, or biological factors influencing the environment change, the nature of the layers being formed also changes. Similar processes operate in lakes and other freshwater bodies. These processes of sedimentation bring into existence a feature known as stratification, a structure produced by deposition of sediments in beds, layers, laminae, lenses, wedges, and other essentially tabular units. The sediments may be fragmental or crystalline; formed from the settling of solid, insoluble debris; or the product of chemical precipitation. They may be composed of organic remains, or may be the result of some combination of these processes. Stratification results from variations in color, texture (size, shape, and fabric), density, composition, or fossil content from one layer to the next. If the layered rock can be recognized in the field and mapped as units on the basis of objective criteria, it may be used to define a **rock unit** (Figure 3-2).

Recognition of rock units is so important that geologists use a standard of nomenclature to describe them. Here are the various types of rock units:

- Groups
  - Formations
    - Members
      - Lenses—lentils—tongues—beds

The basic unit, the **formation**, is a lithologically distinctive product of essentially continuous sedimentation selected from a local succession of strata as a convenient unit for purposes of mapping, description, and reference. In general, one or two constituents, such as massive layers of sandstone or thick units of alternating shale and sandstone, dominate the composition of a formation. Formations usually have two names; the first is the name of the locality where the unit was first described or the name of a place where it is exceptionally well exposed, called the type section. The second name, when it is used, gives the rock type, if the formation is composed mainly of a single rock type (e.g., Martinsburg Shale, Tuscarora Sandstone, or Antietam Quartzite). If the lithology is not so distinctive that a single rock type name can be used, the geographic name is followed by the word *formation.*

Groups

If a number of formations in a sequence have similar lithology or were formed in a closely related environment, geologists may refer to the sequence as a group (i.e.,

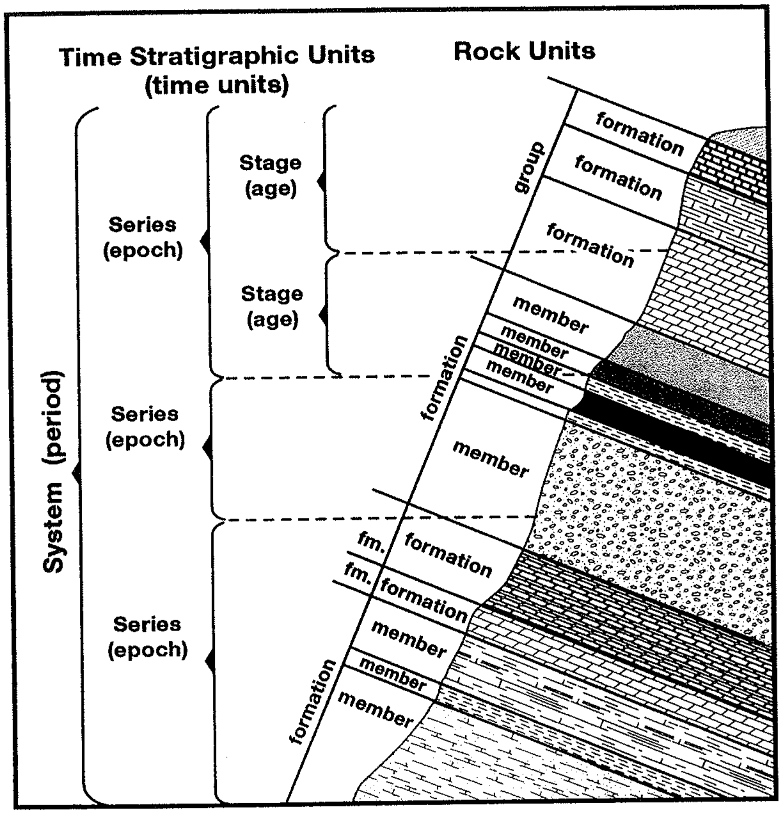


Figure 3-2 In defining rock units for purposes of mapping and study of stratigraphy, geologists subdivided stratigraphic sections into formations, members of formations, and groups of formations. Not all formations are subdivided into members; nor are all formations parts of groups. Geologic time is subdivided into eras, periods, epochs, and ages, and the rocks formed during each of these time subdivisions are called systems, series, and stages. The rocks formed during time subdivisions are time stratigraphic units.

Clinton Group, Medina Group, Chilhowee Group). In some instances, unconformities separate a group from over- and underlying formations.

Members, Beds, Lenses

In stratigraphic studies and where mapping is done in detail, it may be desirable to subdivide formations. These subdivisions are called members if they extend over a large area; they are called lentils or lenses if they are only locally distributed; and they are called tongues or wedges if they wedge out in one direction between sediments of different lithology. The terms *beds* and *laminae* are also used for these smallest subdivisions.

Although all geologic maps illustrate the geographic distribution of natural sediment and rock materials at or near the ground surface, most maps show formations. More detailed maps may show members, beds, or lenses. The type of subdivisions used depends on the stratigraphy of the area, as well as on the scale and the intended use of the map.

Making Measurements with Compasses

Geologists use compasses to measure the orientation of lines and planes. The orientation of a line is determined by measuring its bearing and plunge. The **bearing** or **azimuth of a line** is the compass direction of that line (Chapter 2). The **plunge of a line** (Figure 3-3) is the angle of inclination of the line measured in a vertical plane containing that line. The orientation of planes is described in terms of their strike and dip (Figure 3-4a). The **strike of a plane** is the compass direction (bearing) of a horizontal line on the plane. The **dip of a plane** is the angle of inclination of the plane, measured in a plane that is perpendicular to the strike. The direction of dip must always be indicated. *Note:* Planes that strike northeast may dip either southeast or northwest, so the direction must be indicated (Figure 3-4b). Similarly, planes that strike northwest may dip either northeast or southwest.

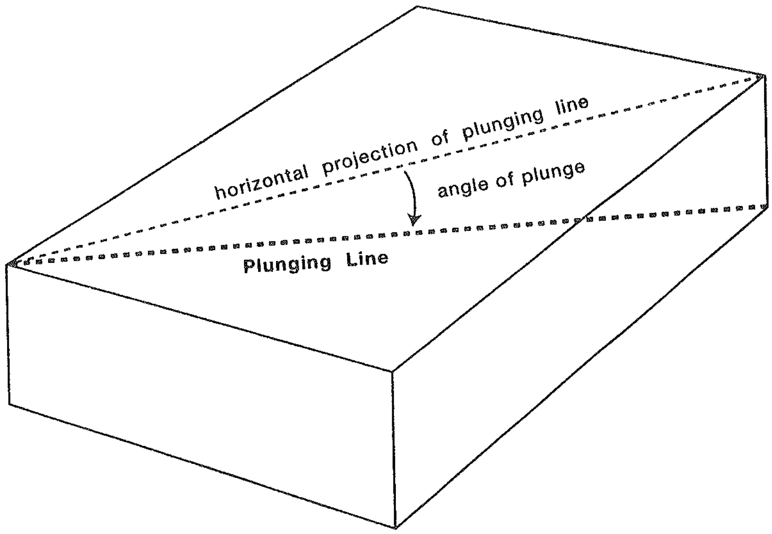


Figure 3-3 Define a horizontal line by measuring its bearing (see Chapter 2). Define an inclined line by measuring the bearing of its horizontal projection and its plunge, the angle of inclination of the line measured in a vertical plane.

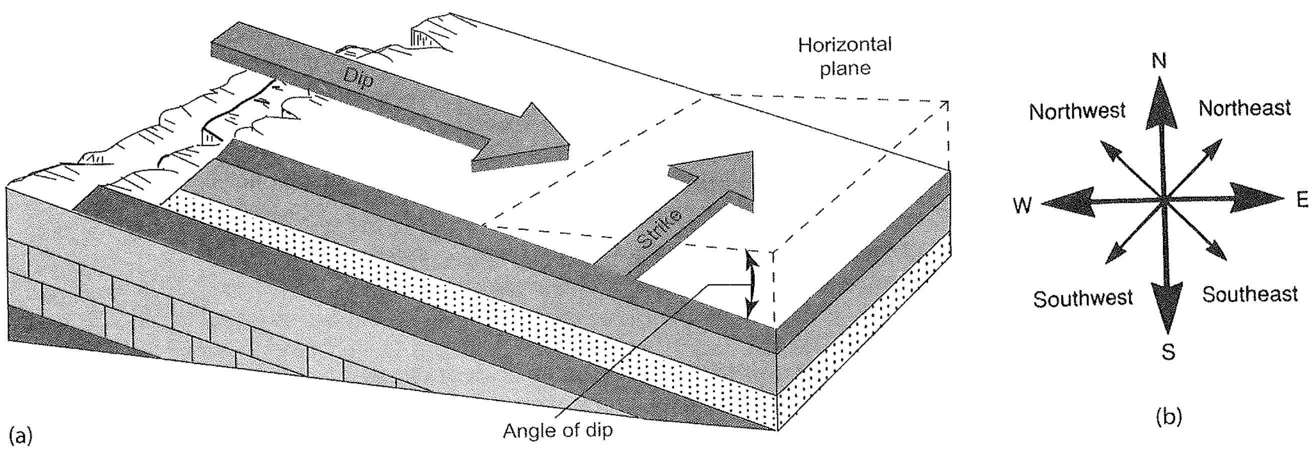
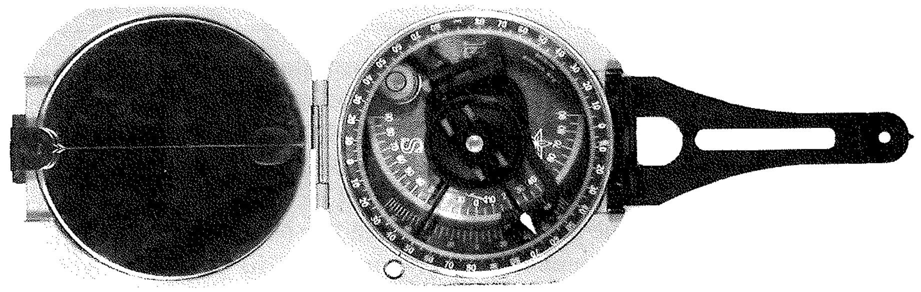


Figure 3-4 (a) The strike and dip of a bed are indicated on this block diagram. The direction of dip is at right angles to the strike direction. (b) Sketch showing the quadrants of the compass. This can be used to help visualize the possible directions of dip if the strike is known.

Several different types of compasses are available, but two types of compasses, the Brunton and Silva (Figures 3-5 and 3-6), are most widely used by geologists. Both of these are designed to make measurement of compass direction and inclinations simple, but they are slightly different from most other compasses in that they contain level bubbles, a mechanism for measuring angles in a vertical plane, and in that east and west are reversed. Because the orientation of lines and planes is generally plotted on base maps relative to true north, it is desirable to measure true bearing. Both of the compasses allow you to do this.

Declination is the angle between magnetic and true north. Declination varies by more than 20 degrees in the United States. Consequently, all measurements shown on geologic maps are shown relative to true north rather than magnetic north. The needle in a compass is aligned relative to magnetic north; therefore, you must either take magnetic readings and convert them to true readings before plotting them, or you must have a compass that can be adjusted to permit readings relative to true north. It is possible to make this type of setting on both Brunton and Silva compasses. Setting declination should be among the first steps you take before starting fieldwork in an area. Check and, if necessary, reset the declination on the compass. Small screws are used to make these adjustments.



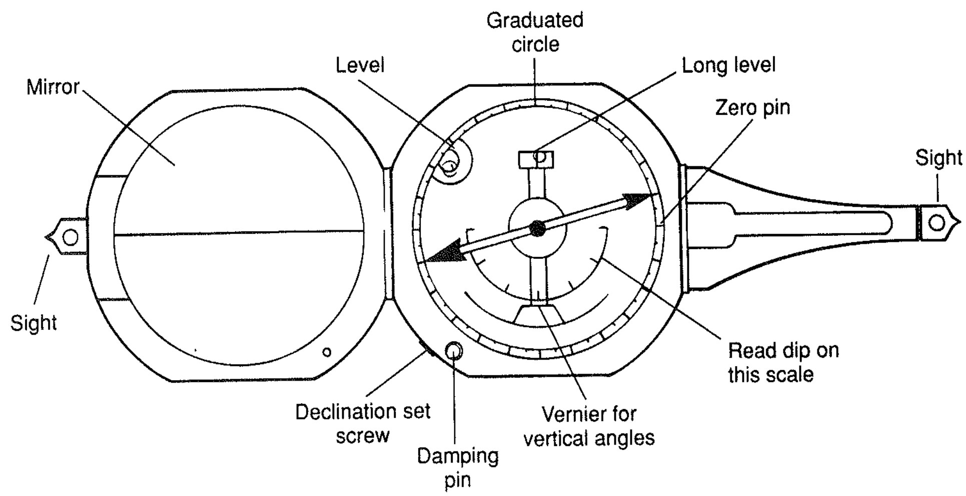
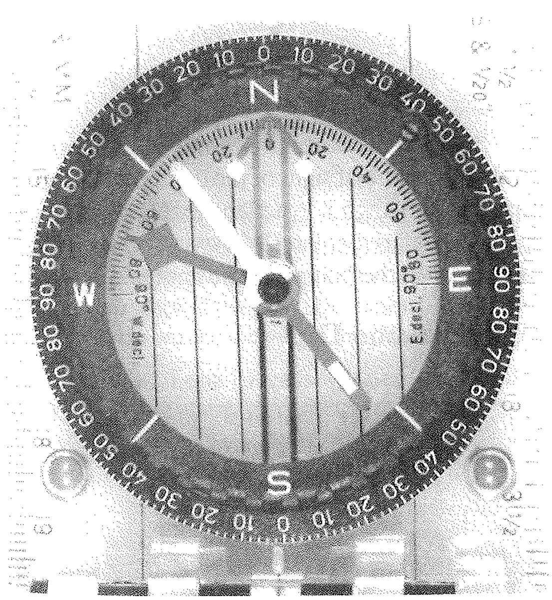


Figure 3-5 Photograph and sketch showing the principal parts of a Brunton compass.



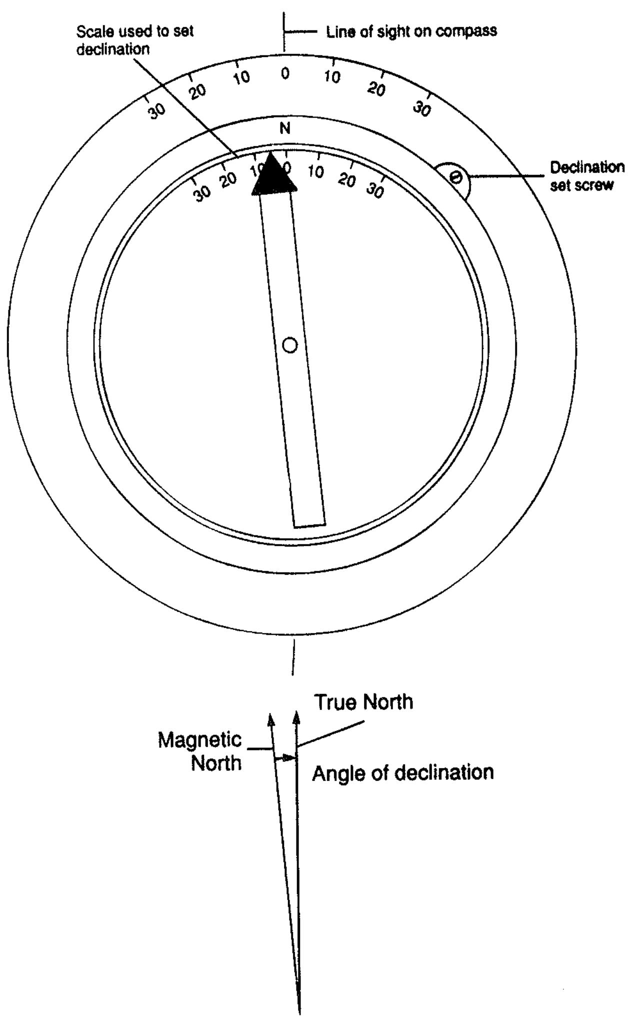


Figure 3-6 Photograph and sketch showing the principal parts of a Silva compass. Adjusting the set screw sets declination. The set screw is turned until the line of sight of the compass points toward true north when the north end of the magnetic needle points to zero.

To set the declination on a compass, find out the declination in an area by obtaining a topographic map of the area. Declination is shown along the bottom margin. To set declination correctly, (a) set the declination to zero, (b) take a bearing on a point, (c) correct the magnetic bearing reading by adding or subtracting the declination from it (in this way, you will know the true bearing), and (d) set the declination on the compass so that bearing to the same point gives a true reading (see Figure 3.6).

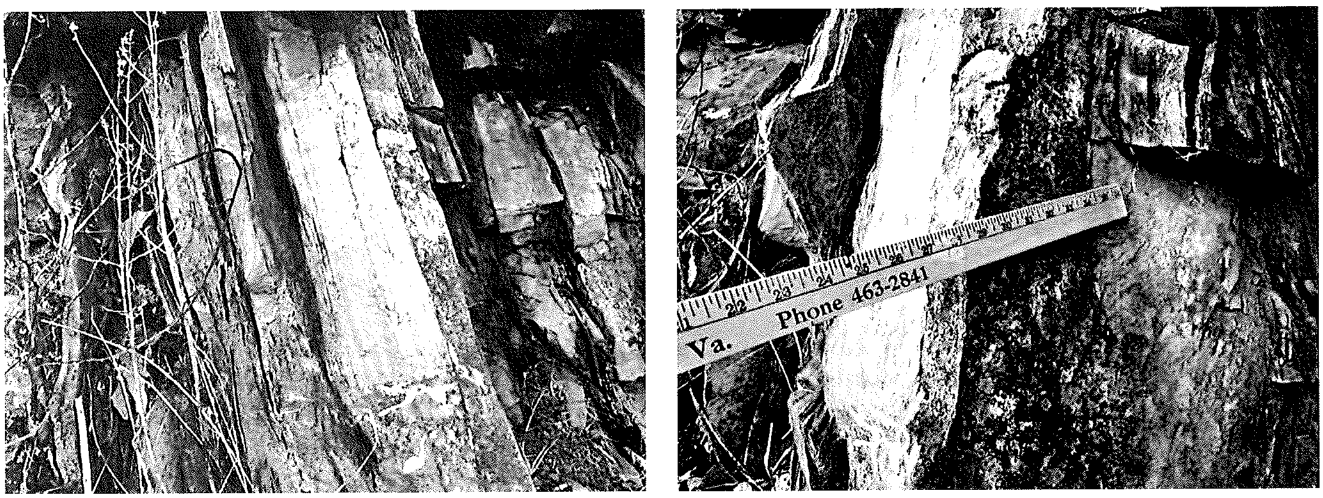
Pointers on Making Measurements

1. The edge of the compass box is parallel to the line of sight of the compass. Therefore, the bearing of the compass edge is the same as the bearing of the line of sight. In taking a bearing from one point to another, you should use the sights on the compass. On a Brunton, turn the top of the compass up to about a 45-degree angle and line up the sight on one end of the compass with the center line of the mirror.
2. To read strike with the Brunton compass, place the edge of the compass on the plane and level the compass, using the circular level inside the compass box to ensure that you are reading a horizontal line. Or, stand back away from the outcrop, level the compass, and sight along exposed planes. Because bedding planes are often irregular, you may obtain more reliable results from the second method.
3. To read dips with the Brunton compass, turn the compass on its side; note the arcuate scale in the bottom of the compass box, to which a level bubble is attached, and the lever on the back of the compass that moves the part of this scale to which the level is attached. Place the compass on the plane you are measuring, being careful to orient it perpendicular to the strike. Be sure the scale used to measure dip is located in the bottom half of the compass. Then rotate the scale until the small leveling device is level, and read the dip on the fixed scale.
4. To read strike with the Silva compass, place the compass on the plane as nearly horizontal as possible (or align the line of sight with the trend of a horizontal line on the plane). Next, rotate the outer circle until the arrow in the bottom of the box is aligned with the compass needle. Then read the bearing of the line from the circular scale around the edge of the compass.
5. To read dips with the Silva compass, first turn the outer circle until the E–W markings on the outer circle are aligned along the line of sight of the compass. Place the compass on the plane you are measuring and align it in a plane that is perpendicular to the plane you are measuring. The small red pointer will swing into a vertical position. Read the dip on the arcuate scale in the bottom of the compass box.

Common Problems in Measuring Strike and Dip

1. **Identifying bedding**. Bedding planes are usually easy to see in sedimentary rock sequences in which layers have different colors or are of greatly different composition. However, difficulties may arise when the changes in composition are slight; when units are thick, making massive beds hard to see; or when bedding may be confused with rock cleavage or even fractures. Remember that strata are distinguished from one another by changes in color, texture, or composition. These changes may be quite subtle. Keep looking until you feel confident of what you are measuring. Faulty readings will make interpretation of the data confusing or will lead to errors in interpretation. It is better to have no reading than to have one that is incorrect!
2. **Finding a horizontal line on the bedding plane**. The Brunton compass contains a level bubble in a circular well. When this bubble indicates that the compass box is level, the edges of the compass are horizontal lines. Place one of the side edges on the plane you are measuring, and you should have no problem. If you experience difficulties, try placing a pencil on the plane in a horizontal line, or get a small carpenter's level and use it to find a horizontal line on the plane.

3. **Indicating the correct dip direction**. Remember that the plane cannot dip in the same direction that the plane strikes. If, in recording your data, you see this error, look again to determine the direction of dip. It may help to stand away from the outcrop and look in the direction of the strike. If the plane dips to your right while you face northeast, the plane must dip southeast; if you are facing northwest and the plane dips to your right, it must dip northeast.
4. **Sighting along strike**. When you are standing in line with the strike of a bed and looking in the direction of strike, you will be unable to see the top or bottom surface of that bed (Figure 3-7). If you are off to the side of the strike direction, you will be able to see portions of the top or bottom of the bed. Move until you are in the line of strike. Then measure the direction from your position to a point on the bed at about the same elevation as the compass. Where erosion-resistant layers cross a stream, riffles may be created, as seen in Figure 3-8. If the riffles lie in a straight line across the stream, they are an excellent indicator of the strike of the layers.



(a) (b)

Figure 3-7 (a) You can not see the surface of the layers in this photograph; so you must be looking in the direction of their strike. A horizontal line oriented directly toward the contact between two of these layers indicates their strike. This method is often used to measure the strike of the layers. (b) This view of a limestone bed was taken at an oblique angle to the strike of the bed. The ruler held against the surface of the layer is horizontal, indicating the strike of the bed. If you look at an outcrop like this and can see the surface of the bed, you are not looking in the direction of the strike.

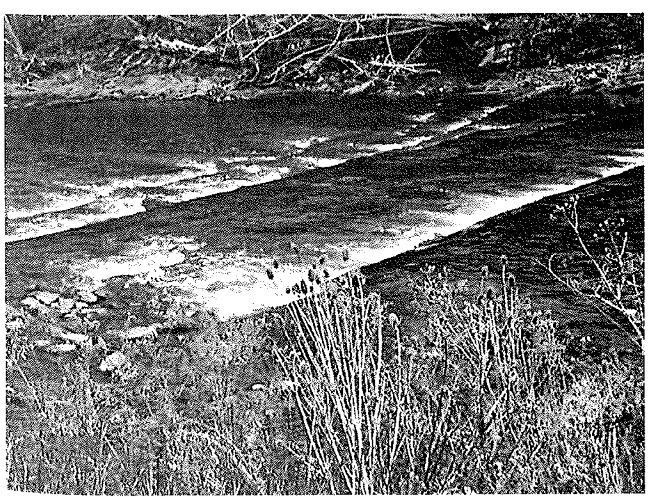


Figure 3-8 Because the water surface is nearly horizontal, the riffles in this stream indicate the strike of the layers in the underlying bedrock.

Compiling Field Observations on the Base Map

Field data initially recorded as key points on field maps should be transferred to base maps that are the same scale and type as the final product. A good technique involves covering a copy of the final base map with a sheet of mylar or other suitable transparent plastic material on which data can be recorded (Figure 3-9a). Mylar is durable, and it is easy to erase. Professional geologists commonly obtain mylar copies of the topographic base maps. Mylar is a stable base and will not change dimensions as paper does when humidity and temperature fluctuate. Use a hard, sharp pencil (or India ink) to record data on the compilation sheets. Special pencils designed for use on Mylar are available.

Each point where data have been collected in the field should be identified on the base map. Many geologists prefer to use two overlay sheets on the base. One overlay (Figure 3-9b) contains points that identify observations; the second (Figure 3-9c on p. 44) shows the type of data collected at each point. Generally, a strike and dip symbol is placed at the observation point, and a symbol for the rock unit is placed beside it. If you are uncertain about the identification of the unit, place a question mark by the data point.

Interpreting the Data

If you compile the data you collect each day, a pattern related to the structure of the rock units in the area and the way they are expressed in the topography should begin to emerge. Later chapters of this book describe the patterns associated with beds that are homoclinal (those with a uniform dip), folded, or faulted, as well as those that contain unconformities or are intruded by large bodies of igneous rocks. You will learn to recognize map patterns that are indicative of these conditions.

In general, look for the following features, which will help you diagnose the regional structure from your compiled map data:

1. Gradual changes in strike or dip of beds suggests warping or the presence of folds.
2. An abrupt change in rock units along a strike suggests the presence of a fault or unconformity.
3. Indications that beds are upside down suggests faults or strong folding.
4. In a normal stratigraphic section, younger beds lie above older beds. Any reversal of order suggests folding or faulting.
5. If rock units are missing in what appears otherwise to be a normal section, you have likely crossed a fault or unconformity.
6. If rock units are duplicated without changes in dip, you have probably crossed a reverse or thrust fault.
7. Most faults are not well exposed. Usually, faults are recognized by abnormal stratigraphic relations, such as duplication or omission of a section.

Maps that depict both bedrock and surficial materials are much easier to interpret if the surficial materials are removed from the map and considered separately. This "stripping" of the surficial materials may be done mentally, but it is helpful to place an overlay on the map and trace the contacts of bedrock units, faults, etc. In making this tracing, the contacts between beds and faults are projected under the surficial materials. In areas of relatively simple bedrock structure, projecting contacts is easily done, but where the geologic structure is complex or the surficial materials are extensive, considerable uncertainty may exist.

Unconformities are erosion surfaces that have been buried by younger sedimentary deposits. If the rock beneath an unconformity is igneous or metamorphic, the

(a)

(b)

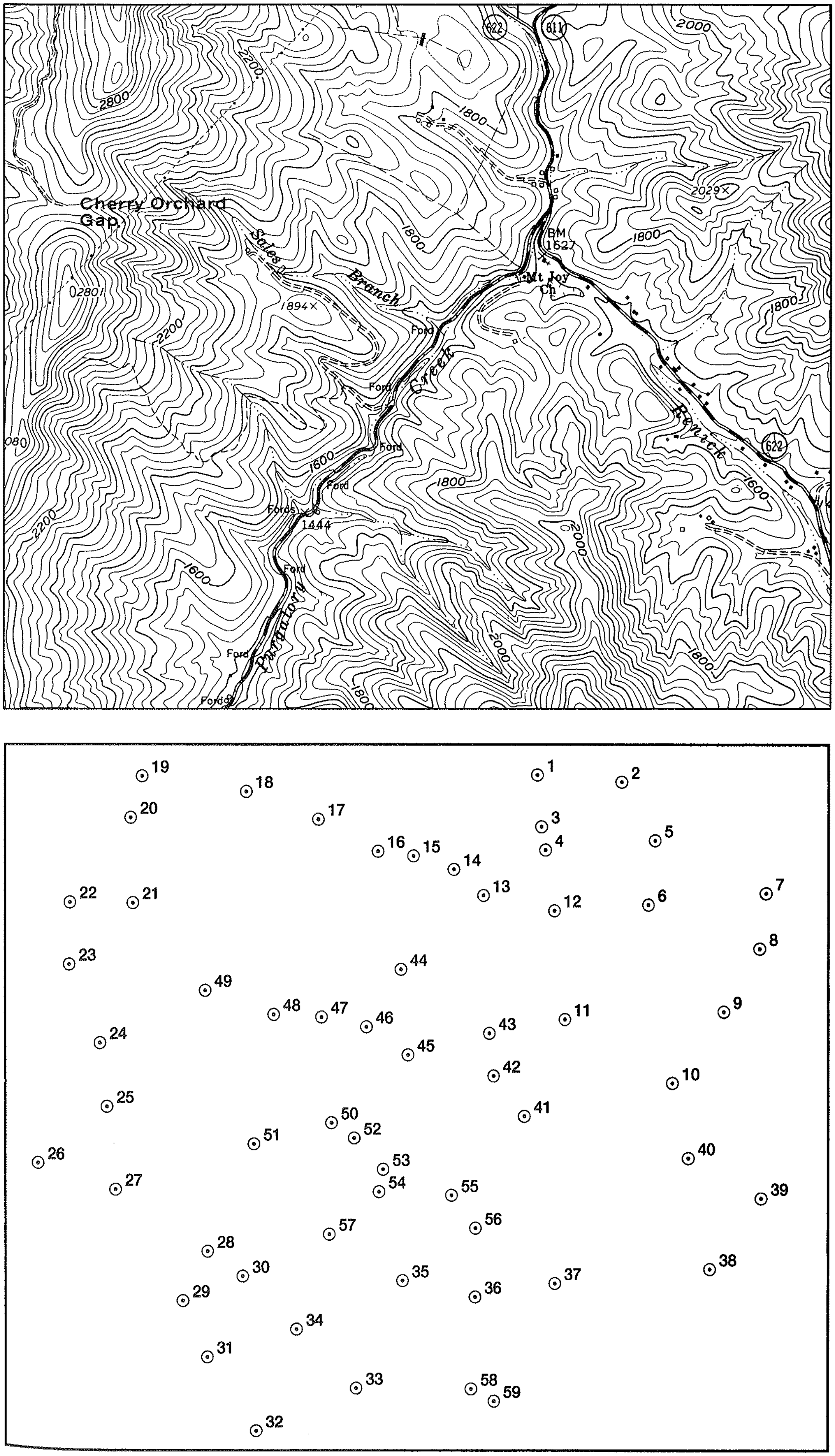
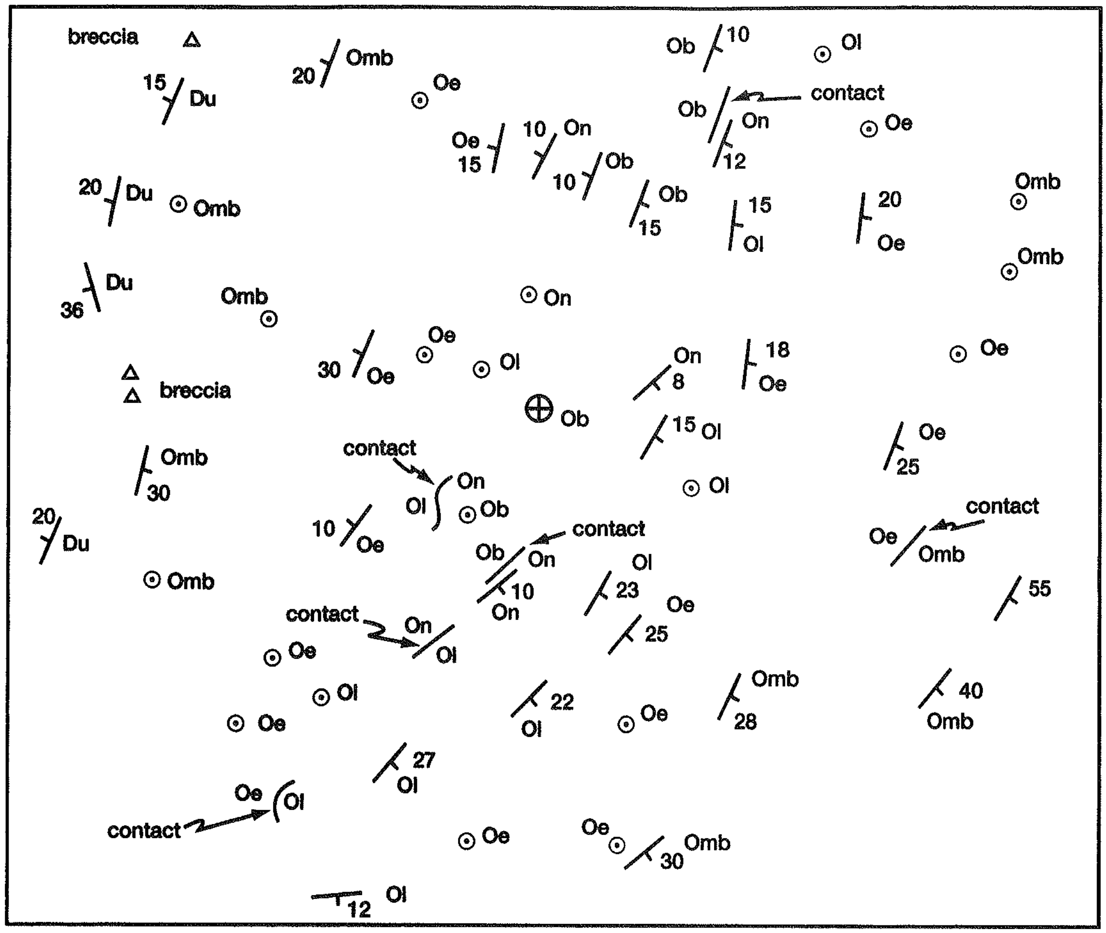


Figure 3-9 Steps in the preparation of a geologic map. (a) A topographic map is generally used as a base. (b) Localities at which data are collected are marked on an overlay. *(continued)*

(c)



(d)

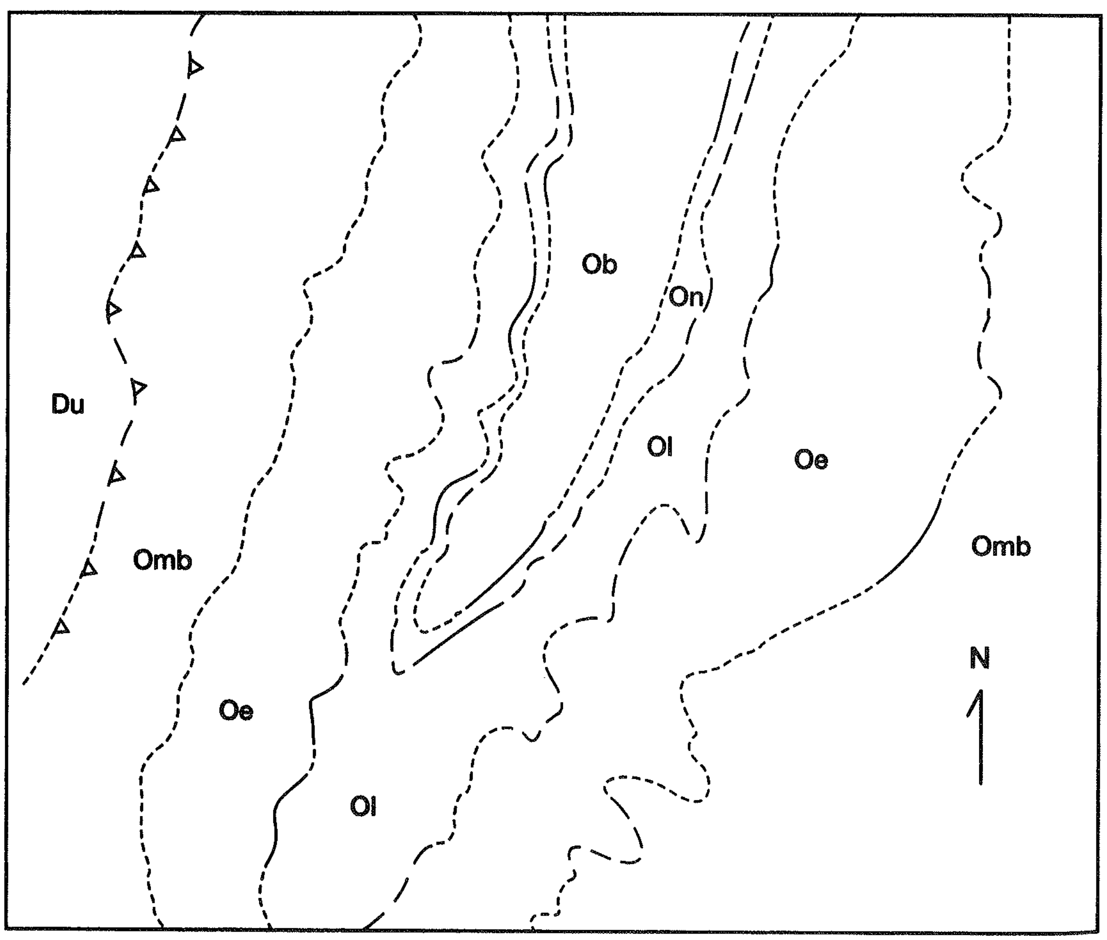


Figure 3-9
(c) For each of these localities, the type of rock, strike and dip data, and other information is recorded in the field notebook. Data from the field notebook are plotted on another overlay for each locality. In some places, strike and dip information is available.
(d) Contacts based on the data shown in (c) are sketched. The final map should show representative strike and dip data as well as contacts, a north arrow, and a scale.

erosion surface is referred to as a nonconformity. If the rocks beneath the erosion surface were folded, tilted, or faulted before the erosion surface formed and an angular discordance is present between the rocks below and above the erosion surface, the unconformity is called an angular unconformity. If part of the section is missing as a result of nondeposition or erosion in an otherwise normal stratigraphic section, the name disconformity is applied to the erosion surface.

Field Checking Your Interpretation

Once you begin to formulate ideas about the type of structural configuration you think is present in your map area, try to think of ways you can test those ideas. Generally, the tests consist of predicting what you will find in a particular place and then field checking to see if observations confirm your hypothesis. Often field checking will refine your interpretation even if it is generally correct. If your hypothesis is wrong, you must then begin to formulate a new hypothesis about the structure. Experienced mappers continually formulate and test ideas as the mapping proceeds.

Preparing the Final Map

Computer graphics programs such as Canvas or Adobe Illustrator are being used to prepare geologic maps. These programs are capable of showing line work, lettering, symbols, and patterns. The Federal Geographic Data Committee offers their guidelines in *FGDC Digital Cartographic Standard for Geologic Map Symbolization* (FGDC-STD-013-2006). By scanning topographic maps, the geologic information can be superimposed on a topographic map base, and the final map can be printed in color. Digital maps have the advantage of being easily revised.

The following checklist gives some general guidelines for preparing your final map (see Figure 3-9d for a completed map). Your instructor may suggest which variations from these guidelines are suitable for your map. Check your final map to see that it conforms to these points:

1. The final map should consist of a base map (generally a topographic map) with an overlay showing the geology.
2. All of your line work should be done with permanent ink, or, if permitted, a hard pencil.
3. Use a tracing guide, dry transfer, or printout from a computer or other mechanical printing device for lettering.
4. The trace of contacts between rock units and faults must show on the map. Generally, some of these will be dotted, some dashed, and some solid (see the FGDC standards). These lines should be drafted with a sharp, hard pencil or drawn in ink.
5. All map symbols, including lines used for contacts that appear on the map, should be defined in the explanation.

Final Map Checklist

1. **Title**: Generally, the title should include a geographic name for the area.
2. **Scale**: The map scale should be shown as a fraction (e.g., 1:62,500) and a bar scale. The bar scale should be calibrated in metric units as well as English units.
3. **North arrows**: Arrows showing both magnetic and true north should be on the map. Indicate the declination beneath the north arrows.
4. **Stratigraphic column**: Arrange this column with the youngest rock unit at the top and the oldest rock unit at the bottom. The column should consist of

small boxes containing the symbol used on the map to identify the rock unit, and if the map is colored or if patterns are used, they should also appear in the box. Write the name of the rock unit next to the box.

5. **Author's name**.
6. **Strike and dip symbols**: These symbols indicate the orientation of rock units. Symbols should not be placed so close together that they overlap one another.
7. **Traces of the axes of folds**: These traces should show symbols to indicate the fold type.
8. **Traces of faults**: Fault traces should be shown with symbols to indicate the type of fault.
9. **Symbols used to identify formations**: The symbols should appear within each outcrop belt. It should be possible for someone who is unfamiliar with the map to determine the identification of the rocks found in every part of the map.
10. **Colors**: If colors are used on your map, they should be applied lightly. Use the side of a hard colored pencil. Be careful not to create streaks of color. Ideally, the color should be uniform. This may be obtained by rubbing the map with a soft piece of paper to help spread the color.
11. **Patterns**: If patterns are used on your map, select ones that will not make the map hard to read. The Federal Geographic Data Committee and the US Geological Society have implemented standards for geologic map symbols and patterns. For example, dots are used to represent sand and sandstones; dashes are used to represent shale; a brick pattern is used to indicate limestone; and small *v*s or *x*s are used to indicate igneous rocks. These patterns are available for download and can be used in illustration software (https://pubs.usgs.gov/tm/2006/11A02/).
12. **Cross sections**: Geologic maps are generally accompanied by geologic cross sections drawn along lines that cross the structure more or less at right angles to the trend of the structural features.

Your map should be legible, unambiguous, and complete, so someone who is unfamiliar with the area could use it.