CHAPTER 1: GEOLOGIC MAPS

This book is largely centered on explaining some introductory geology that can help the reader understand the geologic maps of the Middlesex Fells and gain a better understanding of the Fells' geologic makeup and history. As a starting point, this section of the book introduces you to geologic maps, the information they portray, and how they are made.

(Note: Terms in red and italics appear as entries in the companion glossary.)

1.1 AN INTRODUCTION TO GEOLOGIC MAPS

1.1.1 What is a geologic map?

Any map, or two-dimensional depiction of a surface, that displays any aspect of the geology of an area is a *geologic map*. Since the beginning of geologic map making over two hundred years ago (for example, see Winchester, 2005), geologic maps have become increasingly more complex. Many geologic maps attempt to not only show the geology exposed at the land surface but may also include subsurface views using various types of geologic data and *cross sections* (side views of vertical subsurface slices).

To give the map reader an indication of where features on the map are located in the real world, geologic maps display the geology overlain on a representation of the land surface that is known as a *base map*. Base maps may show streams, roads, and other cultural features, and may also include elevation contour lines that show land surface topography. Base maps all have the goal of getting you oriented and situated on the map. It is all about location! Topographic maps (Fig. 1.1) are commonly used by the U.S. Geological Survey (U.S.G.S., 2021), which is the government agency that makes and publishes geologic maps in the U.S. and performs geologic investigations for the federal government. Many state geological surveys also produce geologic maps. With the advent of computers, base maps are now sometimes aerial photography, like what is displayed on Google Earth, satellite images, computer generated shaded relief maps derived from *digital elevation models* (DEMs) portraying the shape of the land surface, or *LiDAR (Light Detection and Ranging)* imagery that depicts the land surface shape with reflected laser light. The maps can sometimes be viewed with the geology draped over a three-dimensional land surface that may be rotated on a computer screen – somewhat like the terrane in a video game. Soon, three-dimensional mapping that includes the subsurface may become a standard display of geology, possibly taking advantage of computer projections and holograms. The Massachusetts State Geological Survey is at the forefront of 3-D mapping that relies on drill hole data from water wells and test borings (Massachusetts Geological Survey, 2021). The Massachusetts Geological Survey web site provides general information on the geology of Massachusetts as well as resources on the geology of the Boston area. It also shows what geologic projects are currently underway in Massachusetts, many of which are related to water resources.

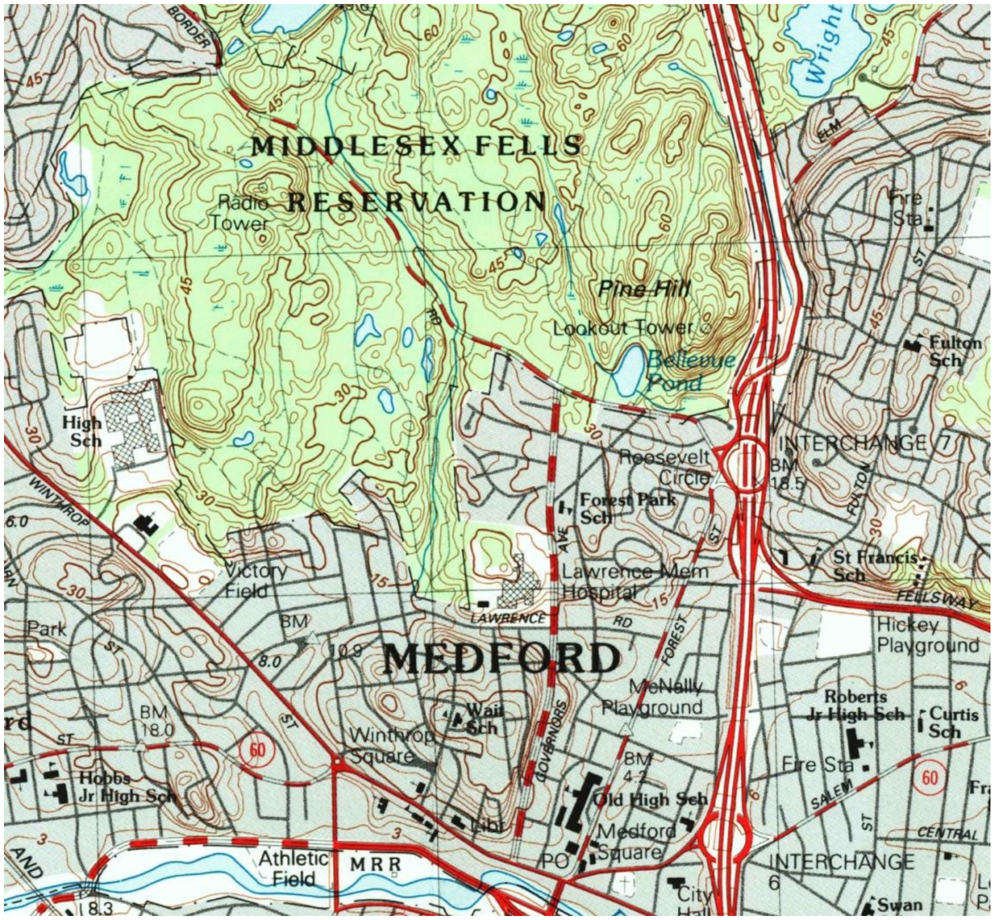

__Figure 1.1__ – Part of a typical USGS topographic map (center of Medford and southern Fells in the Boston North, Massachusetts Quadrangle) that shows streams and ponds, wetlands, roads and other cultural features, and contour lines of elevation in meters above sea level (brown). Green areas are woodlands, while gray areas are densely covered with buildings. Faint gray lines that define squares are square kilometers in the Universal Trans Mercator (UTM) grid system. The map is oriented on the page so that North is up. Maps like this are used as base maps for plotting geology and are available from the USGS (2021) online.

There are two fundamental types of geologic maps. A map can show different rock units making up the *bedrock* that underlies the land surface. This is a *bedrock geologic map,* and it is the map type that most people associate with a geologic map. Bedrock geologic maps classify the land surface by underlying rock type or rock formations and their ages along with associated data points (Fig. 1.2). These maps sometimes show areas where loose land surface deposits or *surficial deposits* conceal the underlying bedrock, but the map usually makes no attempt to classify surficial deposits in a manner that would let you understand their age or origin.

A geologic map can also classify the different geologic materials found at the land surface with associated data, focusing on surficial deposits and where bedrock is exposed but not classified. This is a *surficial geologic map* (Fig. 1.3). Surficial deposits are generally formed relatively recently in geologic history, and in New England are frequently the result of deposition by modern or recent streams, mass movement (e.g., gravitational movement of material down a slope such as during landslides), coastal and marine processes (e.g., beaches and marshes), and glaciation. Surficial geologic maps usually make no attempt to classify different bedrock types or units. Instead, they only show where the bedrock surface is exposed at the land surface.

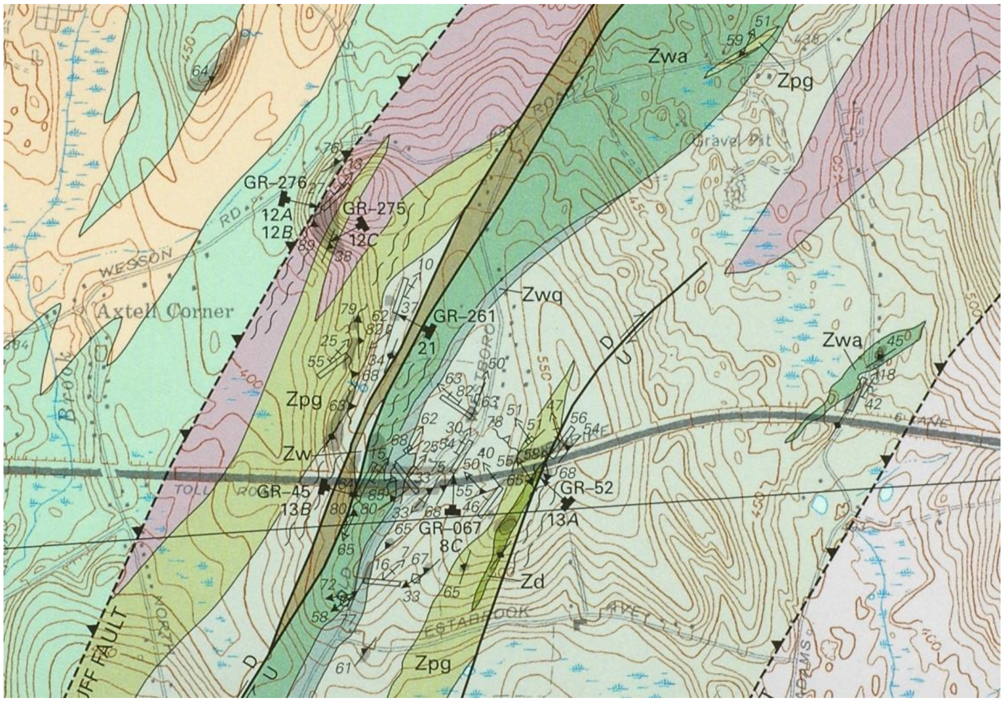

Figure 1.2 *– A typical bedrock geologic map in an area of eastern Massachusetts along the Mass Pike (gray line across image). The base map is a USGS topographic map of the Grafton, Massachusetts Quadrangle. This map shows different bedrock units separated by thin contact lines. Along with the bedrock units, which are late Proterozoic in age (Z units), there are symbols showing orientation data and heavy black lines that are faults. Surficial deposits are not shown on this map. USGS map of the Grafton Quadrangle by Walsh and others (2011).*

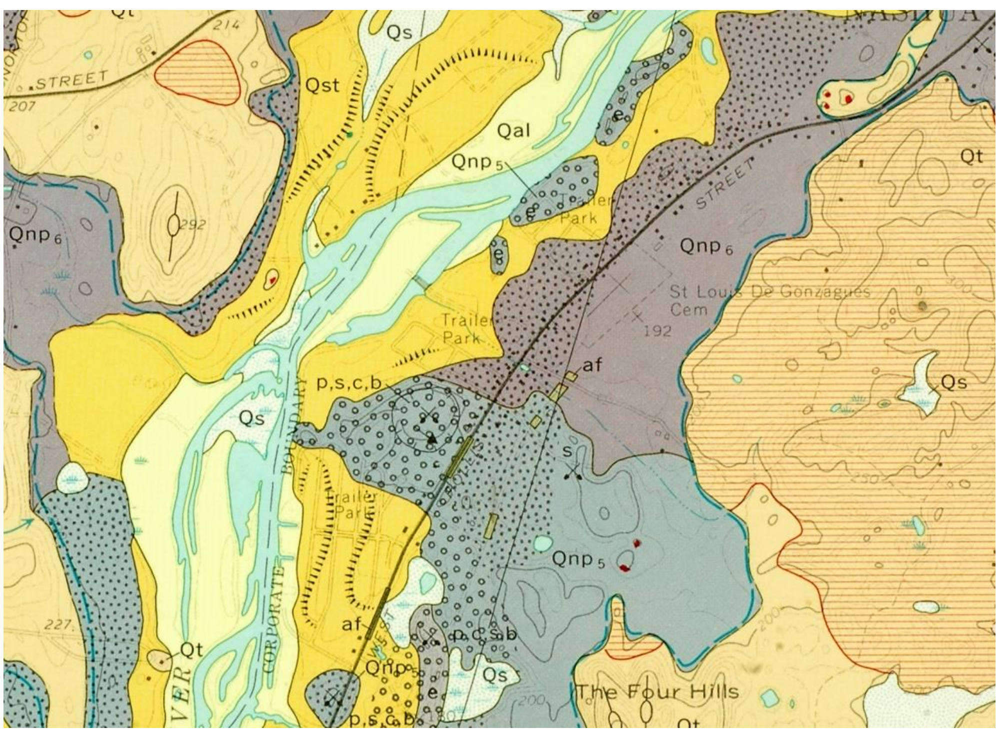

Figure 1.3 *– Part of a typical surficial geologic map in eastern Massachusetts. This map shows the character of surficial geologic units such as glacial (Qnp, Qt), stream (Qal, Qst), and swamp (Qs) deposits and data associated with them. It also shows where bedrock is exposed or has a shallow surficial deposit cover (red lined pattern and isolated red spots). The "Q" on the labels for surficial units indicates that they are from the Quaternary Period (last 2.5 million years). Patterns (dots and circles) indicate the grain size of glacial sand and gravel deposits. The dashed blue line delineates the shoreline of a glacial lake. USGS surficial geologic map of the Pepperell, Massachusetts Quadrangle by Koteff and Volckmann (1973).*

Bedrock and surficial geologic maps serve different functions and therefore show geologic data in different ways. If you were looking for oil or ore deposits, you would refer to a bedrock geologic map that shows the rock formations and bedrock structures that may help to locate petroleum reservoirs or ore deposits. If you were trying to define the limits of a flood plain you would use a surficial geologic map that shows modern stream deposits vs. ancient stream deposits that are higher than modern flooding levels. A construction engineer or a hydrologist interested in water resources, might use both to determine the thicknesses and types of surficial deposits and the type of underlying bedrock. The structure and drainage characteristics of the underlying geology are important for understanding the characteristics of geologic materials when designing a foundation, managing water resources, or remediating pollution.

1.1.2 How is Geology Displayed on Geologic Maps?

Geologic maps in the United States usually use a standard format and symbology that was developed by the U.S. Geological Survey beginning in the late 1800's. Where individual rock units occur on the map, they are each given a unique color or pattern and a unique alphanumeric symbol, which makes them easier to distinguish on the map (see Figs. 1.2 and 1.3). The symbol starts with a capital letter that is an abbreviation of the geologic time period in which the unit was formed, if it is known, followed by lower case letters that give an abbreviation of the name of the rock formation or surficial geologic unit. Lines that form boundaries between different units are called *contact lines* or *contacts*. There are also symbols on the map to indicate other forms of data, including lines, such as where faults intersect the land surface, and points, where data measurements are taken from a single site. Many of these symbols are used to display directional or orientation data that give us a better sense of the three-dimensional characteristics of the geologic units; for example, how layers are tilted or what direction glaciers were moving. When I was a student, everyone referred to guides that gave standard ways in which maps and reports were presented (Compton, 1985 or U.S.G.S, 2014). Every geologic map comes with an explanation that defines the units and symbols used on the map. This information gives some key insights into how the map was constructed. Not all geologists use symbols exactly the same way. These differences may be subtle, and each map may have unique conventions, which makes the explanation a critical part of understanding any map. (For more on the classification and naming of geologic units see Chapter 2.)

1.1.3 Why make a geologic map of the Middlesex Fells?

Because it's challenging and fun! While taking hikes in the Fells I became curious about its geology and the rock formations of the Boston area. I enjoy the challenges of geologic field work and unraveling a puzzle. Unraveling the geologic history of the Fells forced me to have some understanding of Boston area geology. While this is true, I also have plenty of other hobbies to keep me busy, and there are other reasons for making the map. At the level of detail that the maps show, I am hopefully improving our understanding of the geologic history of the Boston area and eastern New England. The Fells has excellent rock exposures that are not covered by glacial sediment, and this represents a rare opportunity in an urban area. It is the low hanging fruit! Amazingly, no geologist had mapped the complete area in the detail that is possible. This is surprising given the number of universities in the Boston area that have geology departments with very competent faculty who are interested in the geologic history of New England.

I think there are two reasons for the lack of detailed mapping in the Fells. First, the rocks in the Fells are sometimes frustratingly difficult to interpret in the field. Most people who have worked in the Fells have focused only on rocks in their specialty. Much of this work is published in New England Intercollegiate Geological Conference field trip guidebooks (NEIGC, 2021) and there had not been efforts to produce a detailed, comprehensive map since the 1970's. Second, understanding the geology of the Fells would be greatly assisted by an understanding of the rocks in surrounding areas. Unfortunately, many of the rocks in the Boston metropolitan area adjacent to the Fells are either covered by glacial deposits or concealed by the urban sprawl. The most detailed geologic map to date of the Middlesex Fells was produced by Clifford Kaye (1980) of the U.S. Geological Survey, but this was still a preliminary map. In fact, comparing this map with rocks in the field is what made me realize that there was a need for more accurate and more detailed geologic mapping of the Fells. Modern computer technology made this all possible.

Mapping in the Fells has evolved into an educational project. I have learned a lot, and it also gives me a chance to help people learn some science about the natural world. There is a lot that can be learned in the Fells with a few simple field observations and measurements, more than most people realize. It is my hope that there are children out there who will have their curiosity piqued by learning some geology, and thus some science. The geologic map also has practical applications. Geologic maps and their categorization of rock formations and surficial deposits are useful for planning of construction projects and resource management. It can help our understanding of groundwater flow and the character of water resources, and it provides information regarding natural hazards. I realize that the policies created when the Middlesex Fells Reservation was established allow only rare development within the Fells. However, surrounding areas of development have the same rock units, but the rock units are not as well exposed. I think it is better to have a more thorough understanding of the characteristics of the rocks based on a place like the Fells where they are well exposed. Development in adjacent area can then proceed in a more informed manner.

1.2 MAKING A GEOLOGIC MAP

1.2.1 Recording Map Data

As you might imagine, making a geologic map is a matter of recording what is exposed at the land surface. This can be done in the field, where a geologist will visit the field area and systematically survey what is exposed. This might also be accomplished by looking at aerial photographs, satellite images, and radar or laser imagery. This can work to a large degree if vegetation does not conceal your view of the land surface and the geology and rock types are not too complex to be mapped in this way. This can work well in mountainous or arid areas where the bedrock is well exposed (Fig. 1.4). For example, making a geologic map in the western United States can sometimes be accomplished using aerial photographs, even Google Earth, in combination with some short visits to the field area. However, producing a geologic map of the Fells, both because of its complexity and tree cover, requires good old-fashioned on-the-ground field work. This can be time-consuming depending on the terrain that is covered, the complexity of the geology, and the detail you are trying to portray. In this type of mapping, geologists rely on exposures of the bedrock surface or surficial deposits, which are called *outcrops*. The more outcrops, the merrier, because it improves your understanding of the geology and the accuracy of your map. Outcrops allow you to verify what is on the ground ('ground truth'). Not having many outcrops forces you to interpret large gaps between outcrops, which can lead to situations where the accuracy of the map can easily be challenged later when new exposures become available, or someone develops a better idea about how to interpret the gaps.

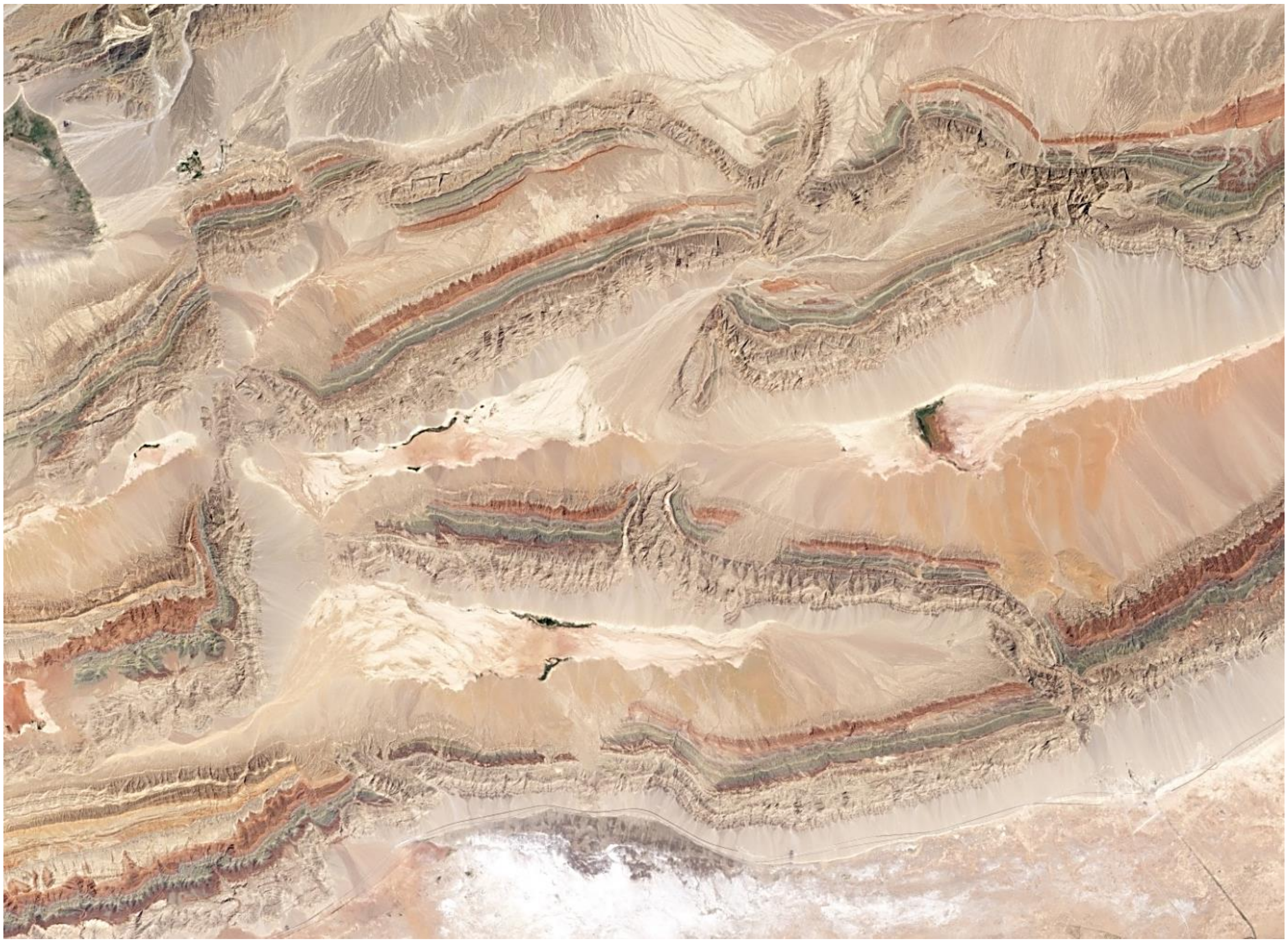

Figure 1.4 *– Part of a NASA satellite image of an area in northwestern China. The rock formations in this area are not concealed by vegetation, surficial deposits or soils, and it is possible from the very colorful exposures of these rocks to make a nearly complete geologic map from the image. You can see distinct colors of different rock formations (red and gray units) and there are also faults that interrupt the patterns made by the rock formations. Even in this case, one would have to know something about the rock formations from a ground study, or samples, to determine their age and true rock types. The more you want to know, the more likely it is that you will have to visit the area and collect samples. We call this the "ground truth". NASA Earth Observatory images by Robert Simmon and Jessie Allen using Landsat data from the USGS Earth Explorer.*

Integral to field mapping is having a way of locating yourself on a base map, either a map that you follow in the field and plot geologic data on as you go, or the collection of positions of geologic features through surveying or the recording of *GPS (Global Positioning System)* coordinates. GPS technology has revolutionized field work to the point where many geologists no longer know how to use surveying instruments such as plane tables and alidades. GPS technology has made detailed mapping in the Fells possible. Mapping is sometimes now done on a rugged laptop with GPS capability. Most geologists learn field mapping as a part of their education by taking field mapping courses taught in the summer called "field camp". These courses are specifically designed to teach field mapping techniques, like those discussed below, and to give students the experience of making a geologic map. The one sure way of learning how to read and appreciate information on geologic maps, is to make one.

Figure 1.5 *– Basic field equipment for geologic mapping: A) GPS device, B) Brunton Compass and case, C) location map for daily mapping agenda, D) map with transparent Mylar sheet glued to it for plotting geologic data locations, E) small chisel, F) permanent marker, G) acid bottle, H) tape measure with metric units, I) rock hammer (small sledgehammer in this case), J) field book and mechanical pencil, and K) hand lens or jeweler's loupe. Not shown are a camera and clipboard.*

1.2.2 Field Mapping Tools

The key tools for field mapping are a base map, field book, clipboard, *GPS device*, camera, compass with a dip meter or *inclinometer*, rock hammer, hand lens, and acid bottle (Fig. 1.5). The *field book* is used to record all the information observed in the field and acts as a field diary. Some geologists now use a computer laptop or tablet in the field, but it must be reliable and rugged enough to survive adverse weather conditions or being dropped. The *compass* is used to record directions in the field and the orientation of geologic features. As we will see later, the flat surface of a clipboard makes a handy writing surface but also makes compass measurements easier and more precise. The *rock hammer* is used to collect samples but is also used to better expose rock surfaces that may be covered with dirt and lichens that conceal the details of the rock. The *hand lens* is for observing small features in rocks that are difficult to see in detail with the naked eye, such as individual mineral grains. A hand lens is the same as a jeweler's loupe. A plastic dropper bottle of dilute hydrochloric acid (HCl) is sometimes carried in the field to test whether rocks are composed of calcium carbonate (calcite and limestone), which fizz when exposed to the acid. Geologists making surficial geologic maps may carry a small shovel instead of a rock hammer. A fully equipped field geologist will have to carry a lot of gear in addition to the rock samples that are collected.

1.2.3 Types of Data: Sites (Points) and Lines

Information collected to make a geologic map is usually in two forms, either *site data (points)* or lines. The most important lines on the map are the boundaries between units, called *contacts*, and faults. Site data is collected with a site name or number, precise GPS location, an assortment of measurements of geologic features, and possibly the collection of samples and camera images. This information is all entered in the *field book*. Samples provide material for detailed laboratory investigations. *Contacts* between different units and faults are the fundamental boundaries plotted on geologic maps. There is no simpler way of doing this than walking along them and recording their location as you go. However, following a contact or fault can take you through some rough terrain with poison ivy, briars, or wetlands, all with the hope that the contact will not be too badly concealed by vegetation and surficial deposits.

1.2.4 Measuring Orientation Data – Using a Compass

A key element of any geologic map is to show how things are oriented. This gives an indication of how features project into the subsurface and how different features may be geometrically related to each other. All oriented geologic features fall into one of two categories: lines or planes. Measurement of the orientations of these features is possible using a special compass that not only measures directions relative to *geographic or true north* (direction to north pole or Earth's rotational axis) but also has an *inclinometer* that can measure how many degrees something is tilted away from horizontal.

There are several types of compasses that can be used for making orientation measurements in the field but the most common of these compasses used by professional geologists in the U.S. is a *Brunton Compass* (Fig. 1.6). The large black pointer on the compass points in the direction recorded by the compass needle. Compass directions must be recorded when the bubble in the round (bullseye) level is centered so that the compass is horizontal, and the compass needle can freely spin. Like other compasses the needle aligns itself with the direction of Earth's magnetic field or the *geomagnetic field* at that location. The compass needle is rarely aligned with *Geographic North* because the north pole of the geomagnetic field does not coincide exactly with Geographic North and the geomagnetic field has an irregular shape. The angular difference at any place between *geomagnetic north* and Geographic North is known as the *geomagnetic declination*. The dip of the geomagnetic field away from horizontal at any given place is the *inclination*. Currently, in the Fells (southwest Spot Pond: latitude 42°27'N, longitude 71°06'W) compass needles point with a declination of 14.3°W and the field has an inclination of 66.8° (NOAA, 2021). The white (pointer) end of the compass needle (Fig. 1.6) points to a scale on the rim of the compass that is adjusted to read a direction relative to Geographic North. This adjustment must be tuned to a specific field area's declination.

The *inclinometer* in the compass also has a level (Fig. 1.7). This level is a small tube mounted on one end of an arm that can be rotated around the center of the compass. The end of the arm

Figure 1.6 *– A Brunton Compass which measures compass directions and has an inclinometer for measuring dip angles. The light green circle with a bullseye (yellow arrow) is a spirit level used to horizontally level the compass when measuring directions. The black foldout lever on the right side is the pointer. The scale on the rim of the compass housing is offset by about 14˚ from the pointer on the compass, i.e., “0” is not aligned with the pointer (red arrow). The scale is turned with a set screw and adjusted for the magnetic declination of the field area. In this case, it is adjusted for a magnetic declination in the Fells of 14.3˚W in 2021. Inside the lid of the compass is a mirror with a view hole (left side) that can be used for sighting on objects.*

Figure 1.7 *– (left) Close up view of Brunton Compass showing inclinometer arm (yellow arrow). Note that the scale on the arm has a center mark (“0” at tip of yellow arrow) that is lined up with 8˚ on the scale above it indicating the angle (dip) that would be measured when a side of the compass rests on a plane or line dipping at 8˚. (right) Back view of Brunton Compass showing lever that is rotated so the inclinometer arm can be leveled (red arrow on front) while one side of the compass housing is resting on a dipping plane.*

opposite the level has a scale with a “0” line at its center halfway between two 60s. The “0” mark is used to record degrees on a scale on the compass housing directly inside the arm. When the level is adjusted the scale records degrees away from horizontal (or *dip*) of the side of the compass housing when it rests on s dipping surface.

The Brunton Compass can be used to measure the orientation of linear geologic features, or *lineations*. (Fig. 1.8). Linear features include things such as mineral grains that have been stretched

Figure 1.8 *– Geologic features that are linear or lineations. Included are: (A) stretched or linear mineral grains (parallel to arrow), dark streaks are stretched quartz grains, in rock from the Adirondack Mountains of New York, (B) stretch marks on faults called slickensides (red) in Fells, and (C) glacial striations and grooves in Brighton, Massachusetts (pen is parallel to inferred ice flow direction) which is toward top of image.*

or aligned as rocks are deformed, and glacial scratches and grooves. A lineation's dip below horizontal in degrees is its *plunge* and the compass direction in which a lineation dips downward is the *azimuth* or *plunge direction*. The azimuth is easily recorded by aligning the pointer of the compass with the plunge direction of the feature being measured. The plunge angle is recorded by resting the side of the Brunton on the lineation and reading the plunge angle on the inclinometer. Some lineations do not have an azimuth because the line only gives us the trend. For example, the direction toward either end of a glacial scratch or groove is the *trend* of a line, while the azimuth or the direction of ice flow is the direction toward only one end of the line and must be interpreted.

The Brunton Compass is also used to measure the orientation of a variety of planar features, including the orientation of layers or beds, planes produced by rock deformation such as a metamorphic foliation (more on this later), flat fractures, and fault planes (Fig. 1.9). Planar features are recorded with two measurements, a *strike* and *dip* (Fig. 1.10). Because rock surfaces are seldom perfectly smooth, a clip board is often placed on the planar surface to provide a smooth surface for compass measurements. The *strike* is the direction or trend of a line defined by the intersection of the plane of interest and a theoretical horizontal surface, or you can say it is the unique direction of a horizontal line on a dipping plane. Strike may be recorded as either of the opposing directions of the strike line, but it has become customary in North America to record strike as a northerly direction. Another way of recording strike, and one that has become more widely used with computerization of data, is using what is called the *right-hand rule* (Fig. 1.10). If you place your right hand (palm down)

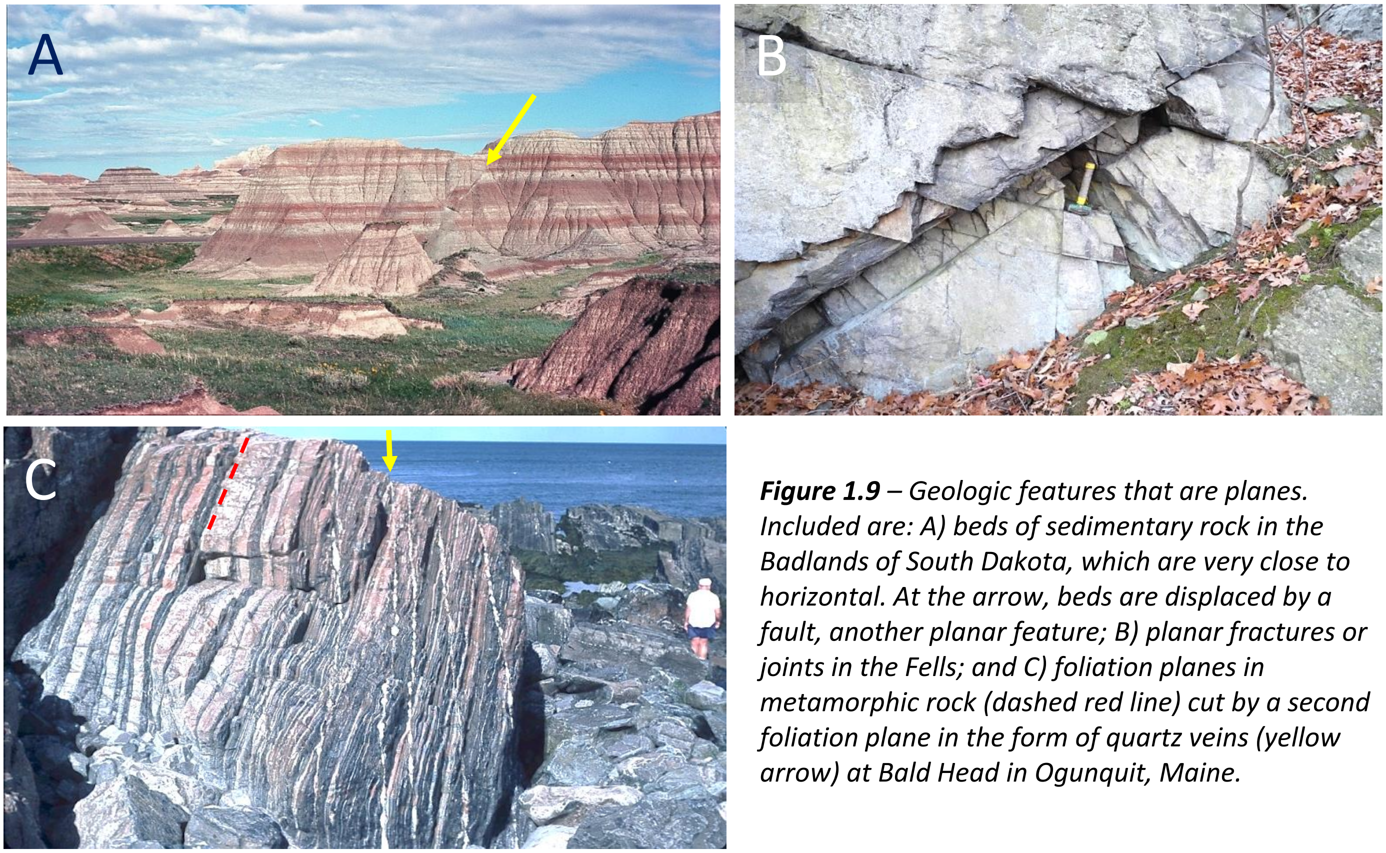

Figure 1.9 *– Geologic features that are planes. Included are: A) beds of sedimentary rock in the Badlands of South Dakota, which are very close to horizontal. At the arrow, beds are displaced by a fault, another planar feature; B) planar fractures or joints in the Fells; and C) foliation planes in metamorphic rock (dashed red line) cut by a second foliation plane in the form of quartz veins (yellow arrow) at Bald Head in Ogunquit, Maine.*

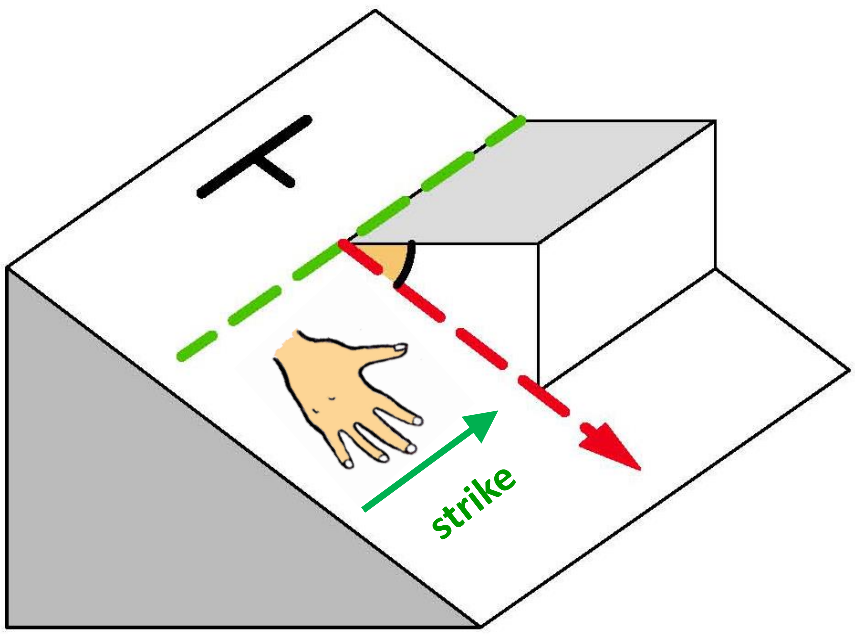

Figure 1.10 *– Strike and dip of a plane. Strike (green) is the direction of a horizontal line on a dipping plane, or a line defined by the intersection of a horizontal surface and the dipping plane. It is also a line perpendicular to the dip direction (red). Dip is the angle (tan color) at which the plane dips most steeply away from horizontal. Also shown is how to interpret the strike of a plane using the right-hand rule (green arrow). Using the right-hand rule, the strike direction is the direction of the thumb on your right hand when your hand is placed palm down on the plane with your fingers pointing down the dip. According to the right-hand rule the strike direction is always counterclockwise by 90° from the dip direction. The black symbol shown at the top of the dipping plane is the symbol used on geologic maps to indicate the strike and dip of a bedding plane in sedimentary layers.*

on the plane with your fingers pointing down the plane, your thumb will point in the direction in which strike should be recorded. In other words, strike is always to the left or counterclockwise by 90° from the dip direction. *Strike* is recorded by resting the bottom edge of the side of the compass housing on the plane and leveling the bullseye level in the compass while the pointer is pointing in the strike direction (Fig. 1.11). This can be aided by first placing a clipboard on the plane so it can be used as a flat surface to rest the compass. *Dip* is the angle a surface makes with horizontal as it dips downward. The dip is recorded by placing the side of the compass on the plane in the dip direction (perpendicular to strike) and reading the dip using the inclinometer. (Fig. 1.12) The direction of the dip should also be recorded as being in either the NE, SE, SW, or NW quadrant. If you are using the right-hand rule this will be 90° away from the strike in a clockwise direction.

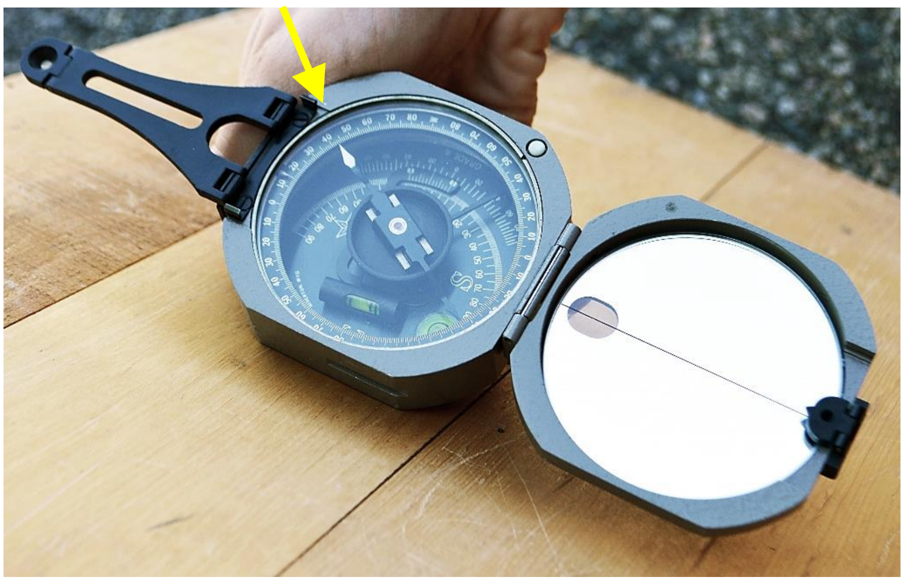

Figure 1.11 *– To record the strike of a dipping plane the lower edge of the side of a Brunton Compass is held against the plane (here a tilted wooden box) while the pointer on the compass is pointing in the direction of strike according to the right-hand rule. The view here is looking down on the compass in the downslope direction. When the bullseye level is centered, i.e., the compass is horizontal, the direction of the white end of the compass arrow is recorded. One should be careful in doing this if the rocks you are measuring are magnetic because they can deflect the compass reading. The compass in this image is reading N42°W (arrow).*

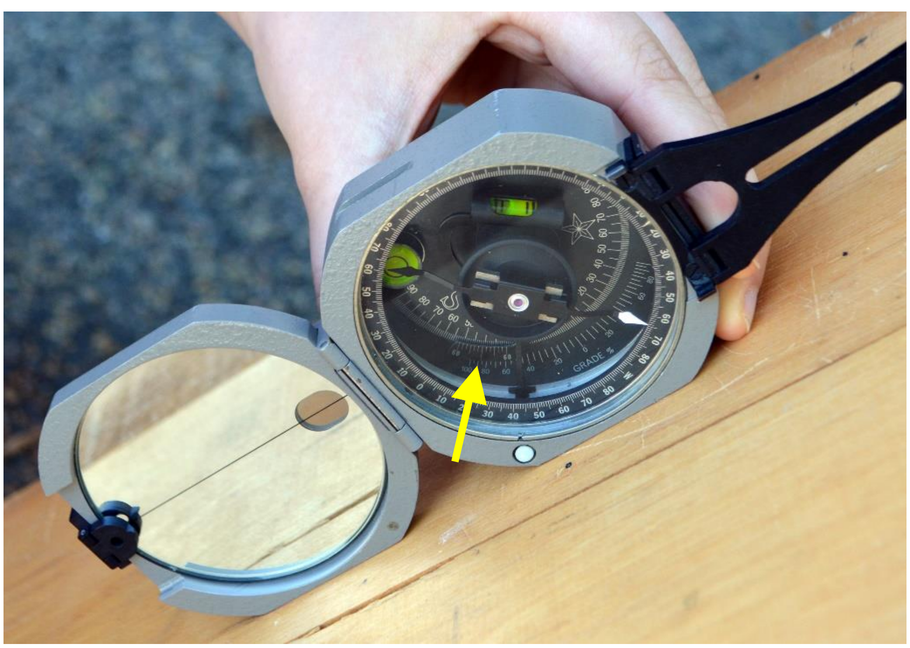

Figure 1.12 *– To record the dip of a plane with a Brunton Compass the side of the compass is held against the plane along the trend of the dip, i.e., perpendicular to strike. The inclinometer lever on the back of the compass (Fig. 1.7) is turned until the level on the arm is centered. The scale inside the arm reads the dip in degrees. Here the dip is 41° (arrow). The quadrant of the dip direction should also be recorded as either NE, SE, SW, or NW. The quadrant will be 90° clockwise from the strike direction using the right-hand rule.*

It is important to realize that some lineations occur on a plane where they do not plunge in the direction of the dip of the plane. (Fig. 1.13) In this case, one must view the direction of the lineation's dip from directly above. It will have a direction somewhere between the strike line and dip direction of the plane, and the plunge angle will be less than that of the dip of the plane; i.e., not the direction of maximum dip on the plane. Recording the azimuth (downward direction of plunge) and plunge of the lineation is still done as described above.

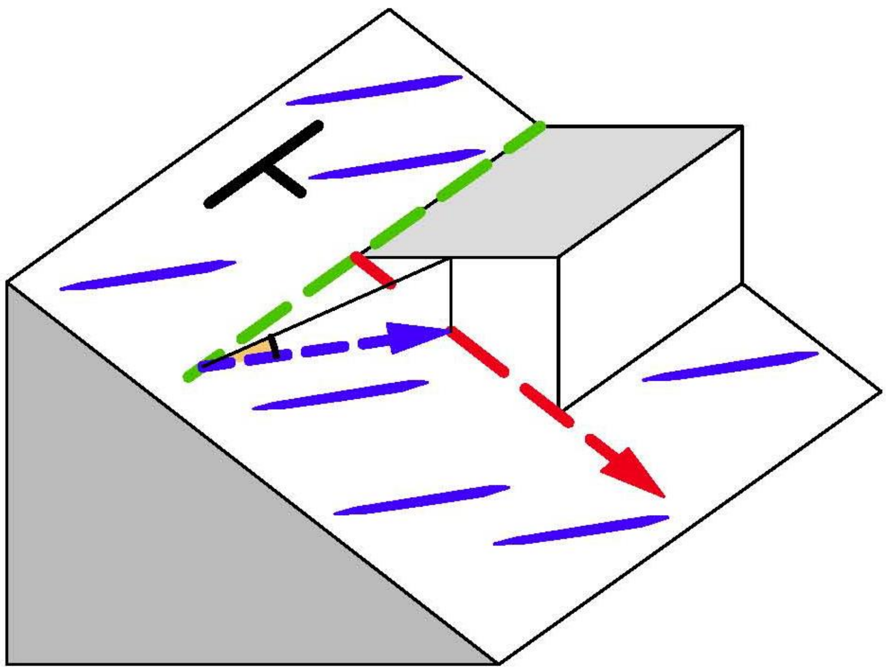

Figure 1.13 *– Lineations (elongate blue pods) that occur on a plane. The azimuth is the direction of plunge of the lineation on the plain when viewed from above (blue arrow) . The plunge (tan) is the angle between the lineation and horizontal.*

1.2.5 What about accuracy?

A key to good geologic mapping is being able to fill in as many holes as possible with outcrop data when plotting geologic units. After every day in the field, a geologist will compile the information collected that day on a clean base map or enter it into a computer mapping system, usually a *geographic information system (GIS)*, that not only allows you to make a map of the geology but also records data associated with objects (points, lines, and polygons or areas) on the map in the form of a table or spreadsheet (attribute table). It will become readily apparent when compiling field data where the field area needs more work. Compilation also prevents the loss of information that is recorded in the field. This is important because field copies of the base map get increasingly "dog-eared" and soiled. Mapping on humid summer days can be a dirty affair, and you can only imagine what happens when it starts to rain!

Geologists are always hoping for the ideal situation, which is to be able to walk out a visible contact between rock formations to show it accurately on the map. But what happens if this is not possible, as is often the case? This is where interpretation comes into play to fill in the holes between areas with outcrops. If outcrops are spaced far apart, it increases uncertainty, and at some point, it may be impossible to predict what is beneath the land surface. Some geologic maps will even display the actual outcrop areas on the map to give the reader a sense of the accuracy of the map. If you are lucky, drill holes or test borings in the area for construction projects or water wells may have logs that record sediment and rock types at depth. They can supplement your field observations and give the depth and subsurface trends of geologic units. When surficial deposits conceal the bedrock, this may be shown on the map, and isolated outcrops will be separate islands of rock exposure within areas covered by surficial deposits. While making a map of the Fells it has been possible to fill in most holes. As compared to most areas in the northeastern U.S., where a cover of glacial and stream deposits can represent a challenge to “ground truthing”, the Fells has abundant outcrops and excellent, nearly-continuous bedrock exposure.

In some areas, bedrock units break apart, leaving angular blocks of rubble that geologists refer to as *float*. Glacial transport of this material in the direction of past glacial movement (always to the SSE in the Fells) will redistribute this material, but this distribution pattern can still be used to locate contacts. As an example, in the Fells we never find boulders of a certain granite north of its northern contact with other rock types since the glaciers were moving southward. In the field, the contact of the granite is at least as far north as where these boulders occur, i.e., which is south of the contact.

It was not possible in the Fells to completely trace some igneous rock bodies known as dikes (discussed later) because they are often narrow in width and covered by thin surficial deposits. Areas where these units occur may be small and therefore more easily hidden. The resulting map only shows these bodies where they are exposed and traceable, and question marks identify where a dike could not be traced further because of a lack of outcrops. When in doubt, over interpretation is never a good idea and will only create doubts later about the accuracy of the map when more data become available.

1.2.6 Other Words of Advice (Oh Jeepers!)

Geologic mapping can be fun, but there are also some precautions that must be followed to remain safe. Above all, before going onto private property you need to get permission. It is rare that someone will deny you access. If anything, they will appreciate the fact that you asked in advance, and you will likely find people to be curious. When you go to remote areas, you should also have a way of communicating with the outside world, in case you get injured or lost. It can happen! Nowadays, a cell phone usually works.

You should be aware of some of the natural hazards of field work in the Northeast. Although the days of rattlesnakes are essentially gone in most places, it is still possible to encounter some living things that can be harmful or at least annoying. In the Fells and eastern Massachusetts, number one on the list are Deer Ticks (*Ixodes scapularis*). In the last 30 years Deer Tick populations have soared and, in most areas, at least 25% of the ticks carry Lyme Disease. Don’t take this disease lightly! It can be very debilitating. Ticks now also carry a few other diseases as well. It is why, in addition to better visibility with leaves being off the trees, I prefer doing field work in the late fall and winter before snow covers the ground. There are now sprays and treatments of Permethrin that you can use on field cloths to help keep ticks at bay. Manufacturers claim that Permethrin not only repels ticks but will also kill them. (I wouldn’t go that far yet!) If you are bitten by a tick, you should immediately see a doctor for treatment. Save the tick so a doctor can identify the type of tick that has bitten you.

At present, mosquitoes are more of an annoyance than a health threat as compared to ticks, but they do carry diseases that weren’t in eastern Massachusetts 20 years ago. During wet periods mosquitoes can be intense. Yellowjackets and hornets are also common in woodland areas, especially late in the summer to early fall. You usually disturb their nest, nothing more than a small hole in the ground, before you see them. This has happened to me three times with multiple stings each time. It will happen very quickly before you have a chance to defend yourself. Yellowjacket and hornet stings will be uncomfortable, but unless you have an allergic reaction, they are not generally harmful. However, if you are allergic this is nothing to take lightly, and you should get medical attention immediately. A yellow jacket sting turns into an itch for a few days, which is doubly annoying.

The final enemy is poison ivy. It is all over the place and to make a good geologic map in the field there is no way to avoid it. You can get it in the summer, when the leaves are out, or the winter from brown stems. Poison ivy resin on field boots can also last for months. I always take a shower immediately after returning from the field, not only to get rid of poison ivy, but also to thoroughly check for ticks. All these potential hazards exist in the Fells, so it is wise to stay on the trails. You need permission from the DCR to go off the official maintained trails regardless.

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