U.S. DEPARTMENT OF THE INTERIOR

U.S. GEOLOGICAL SURVEY

Teacher's Guide and Geologic Field Trip Guide, Little Spokane River-Dartford Area, Spokane County, Washington

Prepared for Midway Elementary School
Mead School District, Spokane, Washington

by

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Open-File Report 94-636

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1994

INTRODUCTION

This guide was prepared as an aid to teachers in fourth grade science classes, with an emphasis on geology. Its aim is to help children and teachers become aware of some of the geologic processes that they can observe occurring (albeit in some cases pretty slowly!) around them. Geology is a fascinating science, and the basic observations needed to start to understand the story that is told by the rocks around us are not difficult to make. In addition, hopefully through some of the examples and the field trip, some understanding will be gained that landscapes have not always looked the way they do today, nor will they remain static in the future. If children come away from the field trip not knowing a single rock name, but being able to make observations that help them to understand what is happening in the world around them, then this effort is a success.

The guide is divided into sections, the first being a brief overview of some of the basic rudiments of geology with suggestions for classroom activities, and the second being the field trip guide itself. The classroom activities are based on my experiences with elementary school children. The discussions of rocks, minerals, and processes are by no means complete, even at a fourth grade level. There also are many other topics which could be covered which can be studied in the Dartford area of Spokane County that simply would not fit into a guide of this scope. There are many excellent geology and science texts available to help students learn more about the details of nomenclature, if that is deemed necessary.

The field trip guide is specific to the Little Spokane River area, but the same sorts of observations of process, time, the relationships between different geologic units, and landscape evolution can be made in almost any area. The classroom activities and field trip guide sections can be used independently of the other. The classroom activities and discussion take about an hour and a half a day for four days, followed by a two and a half hour field trip.

First day
what is a geologist?
minerals and crystallization
Second day
Rocks- igneous, metamorphic, sedimentary
Geologic time and the rock cycle
Third day
Processes- erosion, sedimentation
faulting, folding, earthquakes, and plate tectonics
Fourth day
maps and map reading
Geologic history of the Dartford area
Fifth day -Field Trip

WHAT IS A GEOLOGIST?

A geologist is a person who studies the earth to find out how the earth works. Anybody can be a geologist— all it takes is opening your eyes and looking carefully at the world around you. If you look at our earth and try to figure out how and why a river or mountain is where it is, what kind of rocks are common in your neighborhood and why they are where they are, or wonder about earthquakes, volcanoes, rivers, or just about any other feature on or in the earth, you are a geologist. Boys and girls, men and women, all can be geologists.

Geologists are the people who find new mineral deposits. When you look around your classroom or your home, just about everything that you see that isn't made of wood or wood products, or that comes from plant fibers or animals, had its ultimate source in the ground. The material for everything made of metal is mined— iron, aluminum, tin, copper, lead, gold, and all the other metals. Glass comes from sand, bricks come from clay, wire comes from copper, desks come from iron, sheet rock comes from gypsum, concrete comes from limestone and gravel, even plastics and gasoline come from oil. All the materials to make these items we use every day come from the ground and have to be located by someone— and those people are called geologists.

Geologists also study earthquakes, which are the shock waves moving through the earth when two rock masses move against one another. Some places have more earthquakes than others, and geologists are the people who try to find out why. Someday we may know enough to be able to tell people when an earthquake will happen, but we don't yet know enough about what the earth does before an earthquake.

Geologists also study volcanoes, where hot molten rock comes out on the surface of the earth as magma or lava. Geologists want to know why and how the melting and transport of magma happens. Why do some volcanoes explode when they erupt, like Mt. St. Helens, and why are some, like in Hawaii, quiet enough that people can stand nearby and watch them erupt?

Geologists also study the rocks that form when glaciers, rivers, lakes, wind, and oceans move bits of older rocks around and drop the pieces as new deposits, or sediments. If the deposits of mud, sand, or gravel are given enough time without being disturbed and are cemented together somehow, they will turn into new rocks called sedimentary rocks.

Geologists also study metamorphic rocks, which are rocks that have been changed from what they started out like, because of being buried under other rocks and being heated and squeezed, but without being melted.

There are many kinds of geologists who study problems of immediate importance in our daily lives. Engineering geologists study how strong the earth is and how well it will support buildings, bridges, or roads. Petroleum geologists help find new oil deposits that form the raw material for gasoline to run our vehicles and to form the raw materials for plastics. Paleontologists study fossils to help us understand what the earth was like in the past and how life has changed over time.

MINERALS AND ROCKS

In order to understand the earth, we first need to understand a little about the building blocks out of which it is made. Everyone knows something about rocks, we see them every day: dig them up when we plant a tree, stub our toes on them when we aren't looking where we are going. But each rock has a story to tell us about how and where it formed, and if we learn to look at rocks carefully, we can start to understand them for the information they have to tell.

MINERALS

Minerals are what rocks are made from. A mineral is a solid with a definite chemical composition and an ordered atomic arrangement or structure. There are thousands of kinds of minerals, each with a unique chemical composition and structure. Not all minerals can form in all environments: each forms under certain conditions of temperature, pressure, and what atoms are available to go into the mineral. So the presence or absence of a mineral can tell us a lot about how the rock it is in formed. Minerals combine in different ways and in different amounts to form rocks.

In common usage, a crystal is simply a very well formed mineral, one that grew without interference so that it could grow in its preferred shape, or habit. For example, quartz, a very common mineral, forms beautiful clear six-sided prisms with pyramid-shaped ends when it grows in its preferred shape. Other minerals have different preferred shapes, and these shapes are defined by the way the atoms that the crystal grows from are arranged. You can think of a crystal as being built up of very tiny building blocks, which may or may not be cubes, stacked up in a repeating pattern to make the larger crystal (see figure 1). To understand the shapes of the building blocks and the way they prefer to stack up for any given mineral, we need to know a lot about chemistry and physics, two other sciences. The shapes, or habit, that minerals grow in are one way we can identify different minerals.

Minerals have distinct colors as well as preferred shapes, and the colors help us tell them apart. Quartz is a very simple chemical compound, consisting of one silicon atom and two oxygen atoms, arranged in a framework. When quartz is pure, it is as clear as water. But if a very small amount of other atoms are introduced, the color will change dramatically. Amethyst (purple), rose quartz (pink), milky quartz (white), and citrine (yellow) are all quartz with very small amounts of impurities in them to give them the different colors. Minerals like magnetite, biotite, or hornblende have iron in them and are commonly black or green in color. Other minerals, like feldspar, are pink, grey, or almost any color you can imagine.

Another distinctive characteristic of minerals is the way they break, or cleave. Cleavage is the tendency of a given kind of mineral to break in a preferred direction. The directions and smoothness of the cleavages in a mineral are determined by how the building blocks we talked about earlier are put together, and by how strong the bonds between the blocks are. For example, micas such as muscovite and biotite, have one perfect cleavage, which is why they break, or even peel, into flat, sheet-like pieces. There is a very weak bond

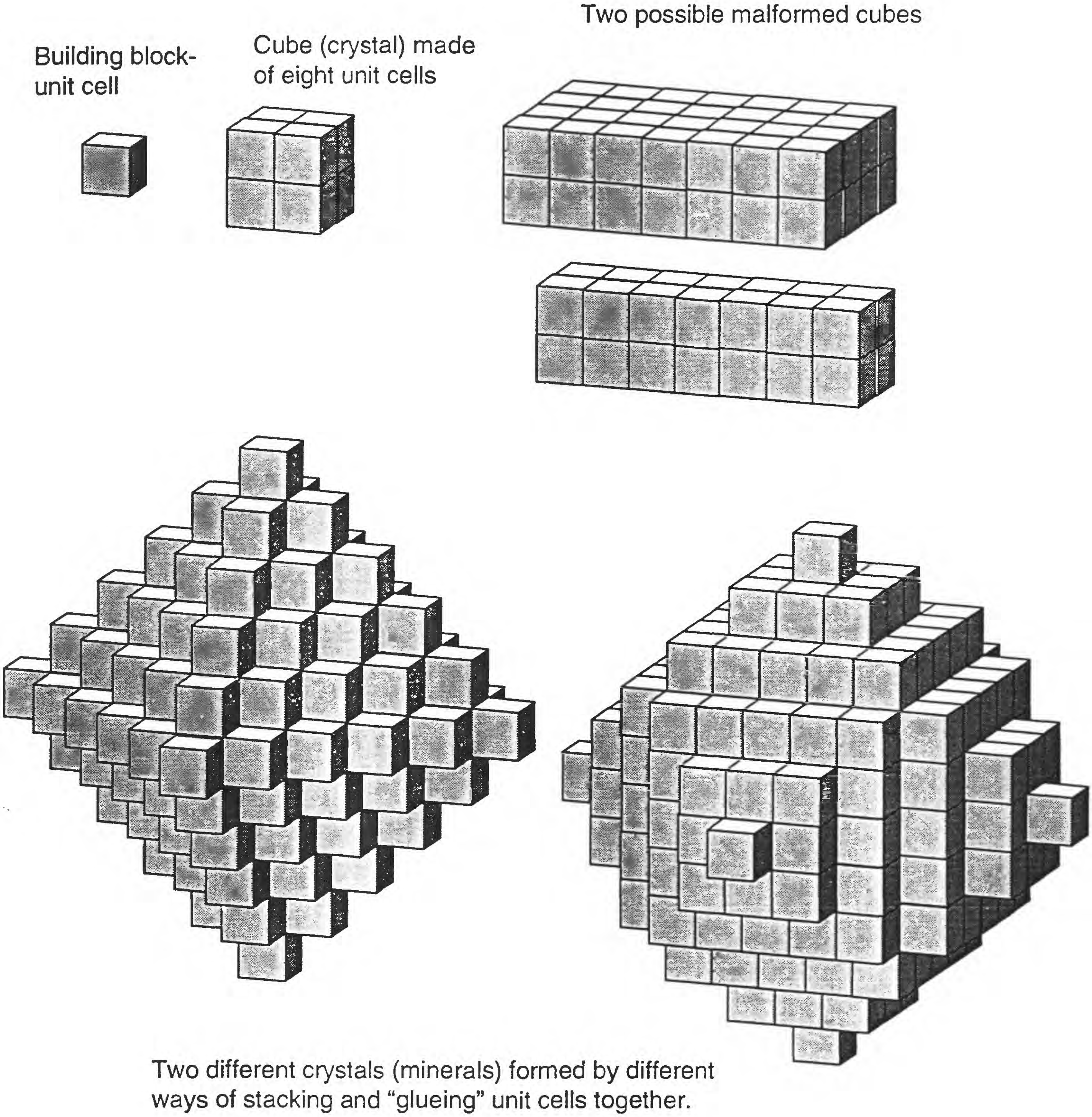


Figure 1. Crystals are made of tiny building blocks, or unit cells, made up of atoms. Different minerals form by different ways of building the crystal from different unit cells. The strength of the bonds between cells determines the way the mineral breaks, or cleaves.

between the building blocks in micas in one direction, which allows it to cleave the way it does. Other minerals have different cleavage directions and qualities, which can be seen when the minerals break into smaller pieces. Some minerals, like quartz, don't have any cleavage, but break into smooth, curved, glass-like fractures. This is because the building blocks in quartz are equally strong in all directions, so that when it breaks, it breaks like glass.

Minerals also have distinct hardnesses. Some are soft enough to be scratched by your fingernail, others are harder, and some, like diamonds, are the hardest known natural minerals. People who study minerals have set up a scale of mineral hardness, and a minerals place in the scale is determined by whether or not it can be scratched or can scratch other minerals. For example, diamond will scratch any other mineral, so it is at the top of the scale. Quartz is pretty hard and will scratch many other common minerals. Clay, talc, and a few other minerals, are very soft and can be scratched by your fingernail.

ROCKS

Rocks are made up of minerals. Some rocks are made of only one kind of mineral, but they are still combinations of minerals. The various kinds of rocks are made up of different kinds of minerals in varying amounts, with different crystal sizes, and different ways the minerals got assembled together into the rock.

There are three basic kinds of rocks— **igneous, metamorphic, and sedimentary.** The kinds are grouped the way they are by the processes by which the minerals that make the rock got together. Igneous rocks are rocks formed from the cooling and crystallization of hot, melted older rocks. Sedimentary rocks are rocks that formed at the surface of the earth, usually as layers of worn-down older rocks that were deposited by streams, or in lakes, oceans, or rivers. Metamorphic rocks form by heating other rocks but without melting them so that new minerals form in the rock.

Igneous Rocks

The rocks that erupt as lava or magma from volcanoes are called igneous rocks. Deep inside the earth there are places where it is hot enough to melt rocks! A melted rock is called a magma, and when it erupts on the surface, the result is a lava flow. Enough lava flows in one place will make a volcano. Magmas, or hot lava, are not on fire, but the melted rock is actually so hot that it gives off light, which is why hot lava is reddish or orange in color. When the magma or lava cools off and turns hard again, or crystallizes, it is called an igneous rock. Magmas can cool off and crystallize deep within the earth, or they may move upwards through cracks in the earth and be erupted as volcanic rocks.

Because they cooled and crystallized from a magma, igneous rocks are made up of interlocking crystals. There are many different grain sizes present in igneous rocks that cooled in different environments. Volcanic rocks tend to have fine grain sizes, because they cooled quickly at or near the earth's surface. Some volcanic rocks cool quickly enough that the chemicals in the magma do not have time to organize themselves into crystals, and the resulting rock is actually a glass called obsidian. It is obsidian that makes the best arrowheads, because it when it fractures, it does so like glass and makes very sharp edges. Other kinds of igneous rocks cool slowly from the molten state, deep under the earth's surface. These rocks are called plutonic igneous rocks and tend to have coarse grain sizes, or they may have both coarse and fine grain sizes in one rock, possibly because of changes in the cooling rate at different times during the crystallization of the magma from which the rock formed.

We can do an experiment in which we can observe the crystallization and growth of crystals in a simulation of what happens when an igneous rock crystallizes. We will use a single chemical, thymol, instead of the very complicated chemical solutions that form real magmas. So although we will only have one type of crystal growing in our "magma", we can think about what would happen if more than one kind of mineral was growing in the magma.

Experiment

Materials required: hot plate, thymol (available from chemical supply houses, or it is possible to do the experiment with alum), petrie or other flat, clear glass dish, magnifying glass or overhead projector.

Procedure: Carefully melt some thymol crystals in a petrie dish on a hot plate. There is some odor and the melted liquid will burn the skin, so be careful! It would be best to do the experiment outside or have the windows open, as the melted thymol smells like mothballs. As soon as the thymol melts, remove the petrie dish from the hot plate and let it cool. Have the kids watch the crystallization as it proceeds. A bright overhead projector in a dark room should allow for observation of what happens as crystallization proceeds.

Questions:
What happens as the material cools?

(Crystals form from the liquid)

Do the crystals have distinct forms? Draw a picture of the typical crystal form.

(Yes- most are somewhat diamond-shaped. Have the kids notice the ridges that form at the growing crystal faces as the crystal grows.)

Why do you think the substance orders itself in this fashion?

(we see the result of the ordering of the "building blocks" of atoms that form the crystal as it grows)

As they grow, the crystals are enlarged by additions to their outer surfaces; perhaps you can see the growth ridges parallel to the growing faces. When the liquid is completely crystallized, what is the actual shape of the individual grains? Why is it different than the initial growth forms?

(the faces of the growing crystals run into, or interlock with, each other, making the crystal shape less perfect than when the crystals are surrounded by melt)

Note the difference in crystal size from the center to the edge of the dish. Why might this pattern develop?

(cooling is more rapid at the edges- When cooling is slow, as at the center of the dish, larger crystals form. When cooling is rapid, as at the edge of the dish, smaller crystals form because there is not enough time for large crystals to grow).

We've done an experiment that helps us understand how igneous rocks form- crystals grow from a melted rock. The kinds and sizes and shapes of the crystals will depend on the chemicals the magma is made of and how quickly it cools.

From what we've seen in our experiment, what can we say about how quickly a lava cools? About how quickly a granite cools?

(lavas have small crystals- they cool quickly at the surface of the earth. Granites cool slowly, deep underground, with lots of time for large crystals to form)

Now we know something about how igneous rocks form. But there is one other thing to think about– why do some volcanic rocks have open cavities in them? Think about this for a minute and try to think about something that you see often that might give you a clue to why. First, what do the holes look like? Are they more or less round? Do they look like anything you've seen before? What happens when you open a bottle of soda pop? Bubbles come out of the soda– and this is exactly the same process that happens in volcanic rocks that are full of bubbles, or vesicles. When a bottle of soda, or a magma, is still in the bottle (or underground), it is under a lot of pressure that keeps the dissolved gases from bubbling out. But when you open the bottle, or erupt the magma, the pressure from the walls of the can, or of the overlying rock, is gone and the gases can come bubbling out. Pretty neat, right? One of the geologist's most important tools is the ability to think about things you are very familiar with and apply what you know to things that are less familiar.

Sedimentary Rocks

Sedimentary rocks are rocks that are made out of bits and pieces of other rocks that have been broken down by erosion. Erosion is the process that happens when weather (rain, snow, wind, and cold) break down rocks at the surface of the earth, and the pieces that result are carried away by streams, rivers, glaciers, or the wind. Eventually the stream or wind slows down enough, so that it cannot carry the pieces of rock it has been carrying and they are deposited. The size of the pieces of rock a particular river, or wind, or glacier can move is determined by how fast the water or wind is moving. A flooding river can carry all sizes of rock from mud to boulders, a fast river can carry pieces up to sand size, and a quiet river can carry only mud or maybe the water will be very clear and clean.

On a windy day, we've all been bothered by dust blowing around. Some of that dust is bits of soil or broken-down rocks being carried by the wind. When the wind stops, there is a thin layer of dust on everything that has been deposited as the wind stopped. That thin layer that is deposited is the result of erosion and deposition, the first step in the process that forms sedimentary rocks. When you go to a river or stream, you see sand, gravel, or mud deposits on the stream bank and bottom. If the water is very high, like after a storm or in the spring time when snow is melting, the water may be brown from all the mud and sand the water is carrying. The size of particles deposited by a particular process can tell us a lot about how energetic the environment was at the time the sediments were deposited.

Glaciers are permanent ice fields that do not melt completely away during the warm summer months. Glaciers deform under their own weight and move downhill under the influence of gravity. As the ice of a glacier moves, it can pick up and carry rock debris from the surface over which it moves. The rocks carried by a glacier can be a very important erosive agent as they are scraped over the underlying bedrock. When a glacier finally does melt, it leaves behind a deposit, called a moraine or till, of the boulders, cobbles, sand, silt, and mud sized particles that it had been carrying.

Just like our example of the layer of dust deposited by a dust storm, most of the sediment that is deposited never turns into a rock. You wash the dust off your car and off your driveway after a dust storm, and the same thing happens to most recently deposited sediments– they are moved again by the same processes that brought them and deposited them before they can turn into a rock.

Sedimentary rocks are deposited in layers. You can imagine this if you take a handful of sand and drop it on the ground. What happens? The sand spreads out in a thin layer. If you then take a handful of pebbles and drop them on top of the sand, another layer will form. If you keep repeating this process, using different sizes or colors of sand, you will build up a series of layers of sediment. In the real world, the layers are deposited on the bottoms of lakes or oceans, or along the banks of streams or rivers, or in sand dunes. If enough time goes by, and enough new layers are deposited on top of the oldest layers, the sediments will be squeezed and will harden and turn to rock. Also, minerals dissolved in water moving through the layers may act like a glue that cements the particles together, making them into a sedimentary rock.

There are many kinds of sedimentary rock, each formed from different kinds of material. When sand is the sediment, the resulting rock is called sandstone. If mud is the sediment, the resulting rock is called shale. When pebbles or boulders are the sediment, the resulting rock is called a conglomerate.

Another kind is of sedimentary rock is formed by the remains of animals or plants. Coal is such a rock, it forms from plants that have been buried and turned to rock. Limestone is made from the shells of dead sea animals, or some limestones form from crystallization of calcite dissolved in water .

Fossils form when the remains of a plant or animal are buried in sand or mud and are preserved along with the rest of the sediment to form a rock. Most limestones and coal deposits can be thought of as a rock that is made up entirely of fossils.

Metamorphic Rocks

Sedimentary, igneous, and metamorphic rocks can be changed, or metamorphosed, into different rocks by heat and pressure. We have all seen changes caused by heat and pressure. If you squeeze modeling clay in your hands, it gradually changes shape, flowing out between your fingers. If you put a piece of bread in the toaster, it is changed by heat into toast. When rocks are buried very deeply, they too can change, or metamorphose, into new rocks, with new minerals and coarser grain size caused by the heat and pressure.

Marble is the rock that results when limestone is metamorphosed: the tiny shells that make up the limestone are changed into the crystals that make marble. Shale is a sedimentary rock formed from mud, if shale is buried deeply, many miles underground, by other sediments being deposited on top of it, the pressure and heat that build up turn the shale into hard slate.

Schist and gneiss (pronounced *nice*) are metamorphic rocks that are coarse grained and may have started as almost any other rock type: granite, sandstone, shales, or limestones. Any rock, whether it started as an igneous, sedimentary, or even a metamorphic rock, can be metamorphosed by heat and pressure to form a new metamorphic rock.

GEOLOGIC TIME AND THE ROCK CYCLE

Now that we know something about rocks, we know that they do change, even if it is very slowly. Weathering and erosion is always happening. Most change that we can see happens during extreme conditions: dust storms moving sediments by air, volcanoes blowing up and distributing volcanic ash, violent storms filling rivers and causing floods that carry and deposit lots of sediment. Rocks are eroded in the mountains and the resulting sediments are carried by rivers to lakes and oceans, where the sediments are deposited as layers. If enough other sediments are deposited, the underlying sediments are turned first into sedimentary rocks. If the rocks are buried deeply enough, heat and pressure change them into metamorphic rocks. If they are buried even deeper, they might start to melt, and form igneous rocks. Uplift and erosion can happen at any point in the cycle, starting it over. Look at the picture that shows the rock cycle (figure 2). The surface of the earth, and its interior, too, are always changing, even if most of the time the change is far too slow for us to see it happen.

Geologists have figured out, through a lot of observations, measurements, and comparisons, that the earth is about 4 1/2 billion years old! This number sounds like a lot, and it is. If the age of the earth were compressed into one day,

The Rock Cycle

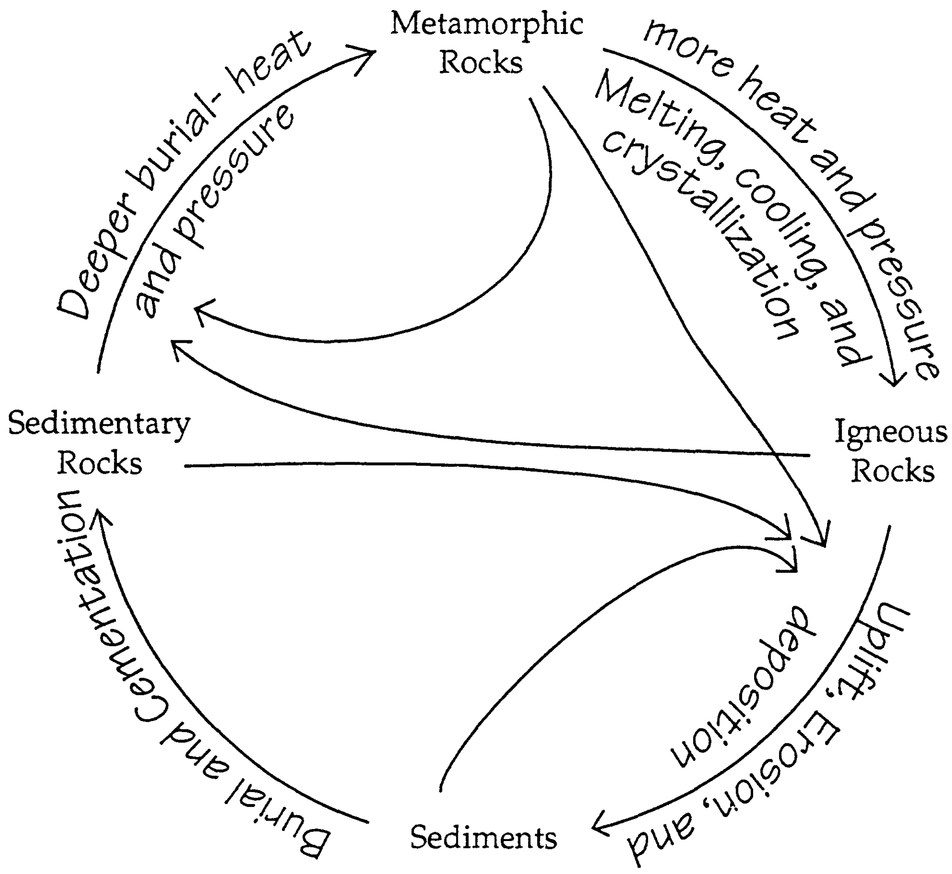


Figure 2. The processes that operate to produce the different kinds of rocks are shown by arrows around the outside of the circle. The processes may be interrupted at any point in the cycle and be replaced by another. For example, an igneous rock can be metamorphosed several times before it reaches the earth's surface where it is subject to erosion and deposition elsewhere as new sediments. Similarly, sediments may be eroded and redeposited many times before they are compacted and cemented into sedimentary rocks.

humans would have been on the earth for only the last one and one-half minutes! The dinosaurs became extinct about 20 minutes before midnight. Until we get to rocks that were deposited at about 9:30 PM, there is no record of life recorded on earth. So the earth is very, very old, and the processes of erosion, sediment transport, and deposition, along with mountain building, melting and metamorphism have been going on for the entire time.

EARTHQUAKES, MOUNTAINS, AND PLATE TECTONICS

Earthquakes are well known to us all, at least through the newspapers and television news. But how many of us who live in eastern Washington have felt an earthquake? Most people who live in California know what an earthquake feels like. Why is that? It's because California has more earthquakes than eastern Washington. Why would one part of the world have more earthquakes than another? We'll explore that in this next section. But first let's learn something about earthquakes themselves with a little experiment.

Take you hands and press them together as hard as you can, palms flat. Now pull one hand towards you and push the other away, all the while keeping the pressure on. What happens? You can feel that your hands would like to slip past one another, but they can't because they are pressed together too hard. Finally, if you keep pulling and pushing harder and harder, your hands will finally slip past another– quickly and all at once. BAM! You've just made an earthquake.

An earthquake is the shaking or shock waves that spread out through the earth when two masses of rock slip past one another, just like our experiment with our hands. Earthquakes may be small, so that the can only be felt by sensitive instruments, or they may be very large, so that buildings and freeways fall down. If we live in an area where there is a lot of pressure between rock masses deep underground, like in our experiment with our hands, then we are likely to feel a lot of earthquakes. Southern California is such a place. There are many others all around the world, as well.

In our experiment with our hands, where we pulled and pushed away and towards ourselves, we modeled one kind of faulting, where rocks slide past each other horizontally. The pressures can also be up and down, or any combination in between. Try the hand experiment again, this time pushing one hand up and the other down. When they slip, what happens? One hand goes up and the other goes down, right? Mountains can form by faulting like this: one mass or block of rock moves up, making mountains, while the other moves down, making a valley. A mountain range can't form from one earthquake, but if you add up the motion of millions of small earthquakes over thousands or millions of years, mountain ranges can form. Don't forget, though, that while the mountain range is moving up because of the motions caused by earthquakes, erosion is wearing the mountains down as they form and carrying the pieces away to form new sediments somewhere else.

Now that we've made a model with our hands of what happens during an earthquake, let's think about what we might be able to see in the rocks themselves that tell us that there have been earthquakes. Let's think back to our experiment– what does it look like where two rocks have slid past one another? There is a break there, right? That break is called a fault– a place where two rock masses have moved past each other. Faults, like earthquakes, can be large or small. Think what you would see if you saw a fault in layered sedimentary rocks. Look at the picture below (figure 3) that shows a block diagram of some sedimentary rocks before and after two different kinds of faults have broken them:

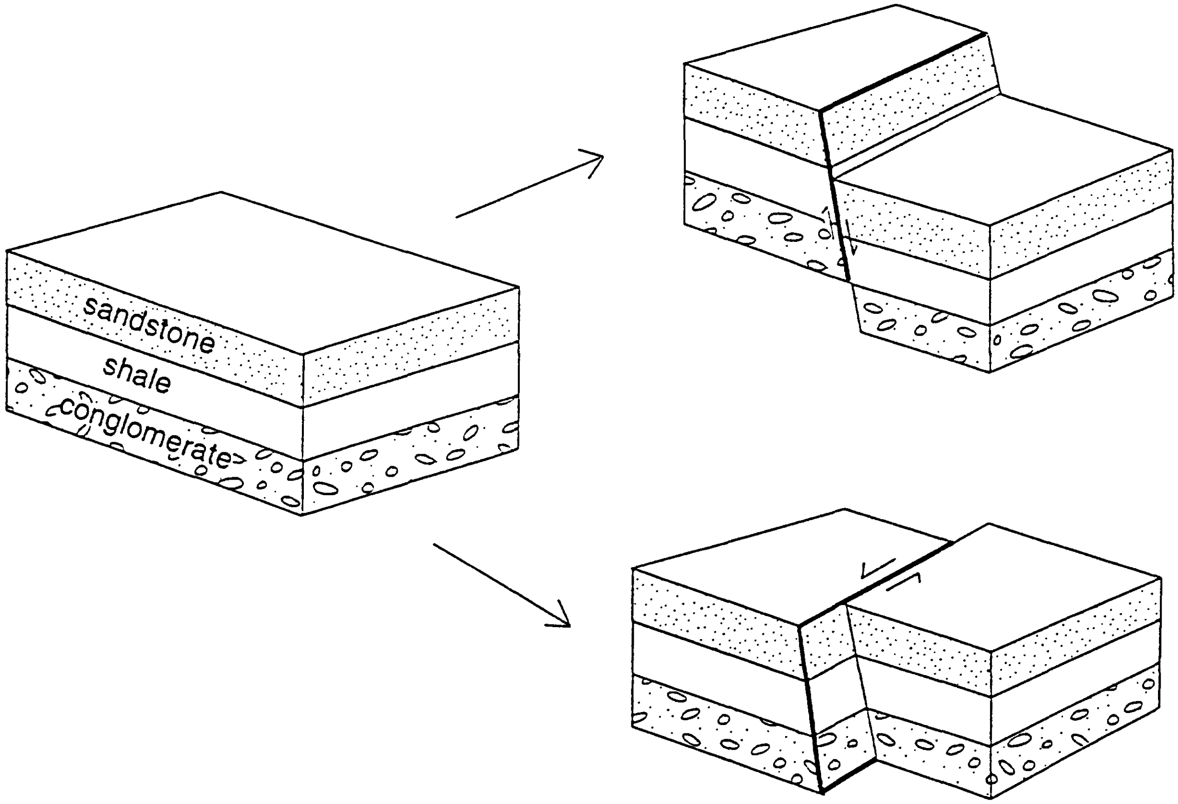


Figure 3. Examples of faults. When layers of sedimentary or other kinds of rock are pushed and broken, like in our experiment with our hands, a fault is the result. The top picture shows a normal, or "dip-slip" fault, where the motion is up-and-down. The bottom picture shows a "strike-slip" fault. The arrows by each fault shows the relative motion of each block past the other. A fault can be oriented in any direction, and the motion may also be any combination of up and down or sideways motion.

You'll notice that in the drawing nothing is shown under the rocks– but there must of course be other, deeper rocks under the rocks at the surface that break during the faulting. The real "push" and "pull" that cause the faulting are in the deeper rocks we can't show in our sketch. We'll talk about this after we discuss another aspect of the deformation of rocks– folding.

When a geologist talks about folded rocks, that is exactly what he or she means. Folds are easiest to see in sedimentary rocks where the layers are bent. What causes folds? The same process that cause faults- rocks pushing and squeezing against one another, but when rocks are folded, instead of breaking in a fault, they gradually bend and buckle. You might imagine that under some conditions, rocks might first bend when pressed, then finally break in a fault. Below is a sketch to help you understand the development of folds in sedimentary rocks (figure 4).

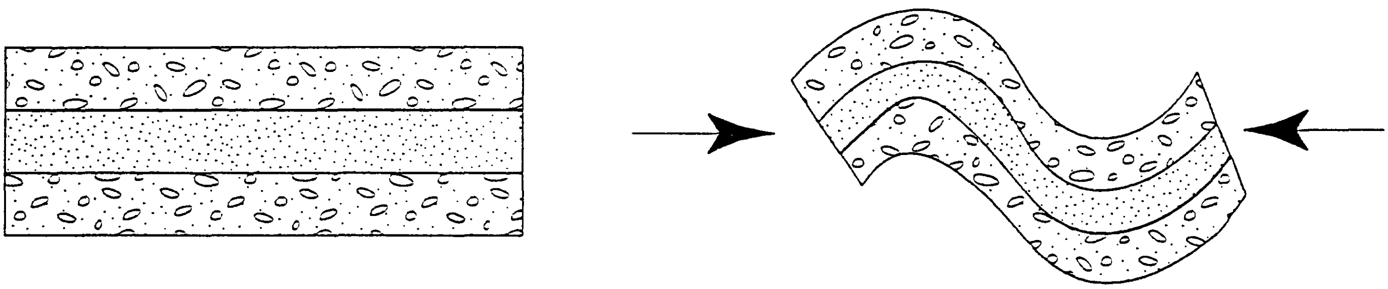


Figure 4. When rocks are squeezed, as shown by the arrows, they may bend or fold instead of breaking. Folds are easiest to see and show in the layers of sedimentary rocks, but they may form in any kind of rock. They may also be of any size, from folds smaller than your fingernail to giant, mountain size folds.

The deeper push and pull that we can't show in our sketches of faults and folds leads us to what geologists call plate tectonics. What causes the deeper pushes and pulls that shape our planet? Many geologists, working over many years have pieced together parts of the puzzle, but there is a lot left to figure out. If you look at a globe, you have probably noticed that South America and Africa, if they were slid across the surface of the globe, would fit together nicely, like pieces of a jigsaw puzzle. You might also notice, if you look at a map that shows where earthquakes and volcanoes are common, that they tend to occur together, near the edges of the continents, as well as in jagged lines that are way out in the middle of the oceans.

The way that South America and Africa fit together is one of the lines of evidence that tell us that the outermost part of the earth, or the crust, is a thin shell that is divided into pieces, or plates, much like the pieces of a jigsaw puzzle. If you look at a globe, you can imagine the plates sliding around on the surface of the earth. Where these plates jostle against one another are the places where most of the earthquakes and volcanoes are today. The movement of theses plates over the surface of the earth is called continental drift. In some places, like in California, the plates are simply moving horizontally past one another along a giant fault system, called the San Andreas fault. The earthquakes in California are caused by the forces that push the plates past each other.

One reason we know these plates of crust are moving on the surface of the earth is from places like Hawaii. If you look at a map that shows the shape, or topography, of the ocean bottom, you can see that there is a line of islands and volcanoes stretching from Hawaii to Midway Island, then a sudden bend in the chain of volcanoes, which then continue all the way to the Aleutian Islands. The volcanoes get older and older as we move northwest from Hawaii, indicating that the source of the magma stayed in one place relative to the oceanic crust that slid over it over millions of years.

If you look at the globe again, though, you will see that the plates cannot slide past each other over the entire surface of the globe. Some places the pieces of crust have to be moving apart, and in others, they have to be moving towards one another. The most common place for them to be moving apart is in the oceans. In the middle of most of the oceans are what are called, logically enough, "mid-ocean ridges." These are the places where the plates are moving apart. As the plates spread apart, new magma moves up from underneath the spreading zone and fills it in. The magma that comes up in these spreading centers forms a rock called basalt that is heavy and dark colored. As this new magma cools and crystallizes, new rocks forms along the ridge, and the previously formed crust gradually moves away from the ridge. One result of this process is that oceanic crust is youngest close to the mid-ocean ridges and the rocks get older as they move away from the ridges.

In other places, like off the coast of Washington, or Japan, or Alaska, or the west side of South America, the plates of oceanic and continental crust are sliding towards each other. You can imagine that something has to give when that happens! Because the continental crust is thick and relatively light, it slides over the thinner, heavier oceanic crust. The oceanic crust goes under the continents, in a process called subduction, but not without causing lots of earthquakes. Another important effect is that behind the places where oceanic crust is subducted there are usually chains of volcanoes– just like Mt. Rainier, Mt. St. Helens, and all the other Cascade volcanoes. If you look at a map again, you can see there are chains of active volcanoes on the continents or islands almost all the way around the edge of the Pacific Ocean.

The next figure (figure 5) shows a block diagram of the coastal region of Washington, looking north. We can imagine that we have cut a giant block of the earth out and are looking at one side and the top. The side we see is called a cross-section, because it shows what we believe happens under the surface of the earth, where we cannot go to actually see what is happening. New oceanic crust is being created at the mid-ocean ridge by upwelling of new basaltic magma from the deeper part of the earth called the mantle. As it forms, the crust moves in both directions away from the ridge. The crust travels slowly over the mantle until it reaches the thicker, lighter continental crust where the oceanic crust slides underneath the continent. There is a trough or trench where the continental and oceanic crust meet, and the area is called a subduction zone, where subduction is the process by which the oceanic crust moves under the continent. Two things that have impacts on our lives result from the subduction process: earthquakes and volcanoes. It is hard to imagine all that oceanic crust moving under the continent without some earthquakes, and indeed, subduction zones are the location of some of the largest known earthquakes. The other important result of subduction is that deep under the continent, melting occurs

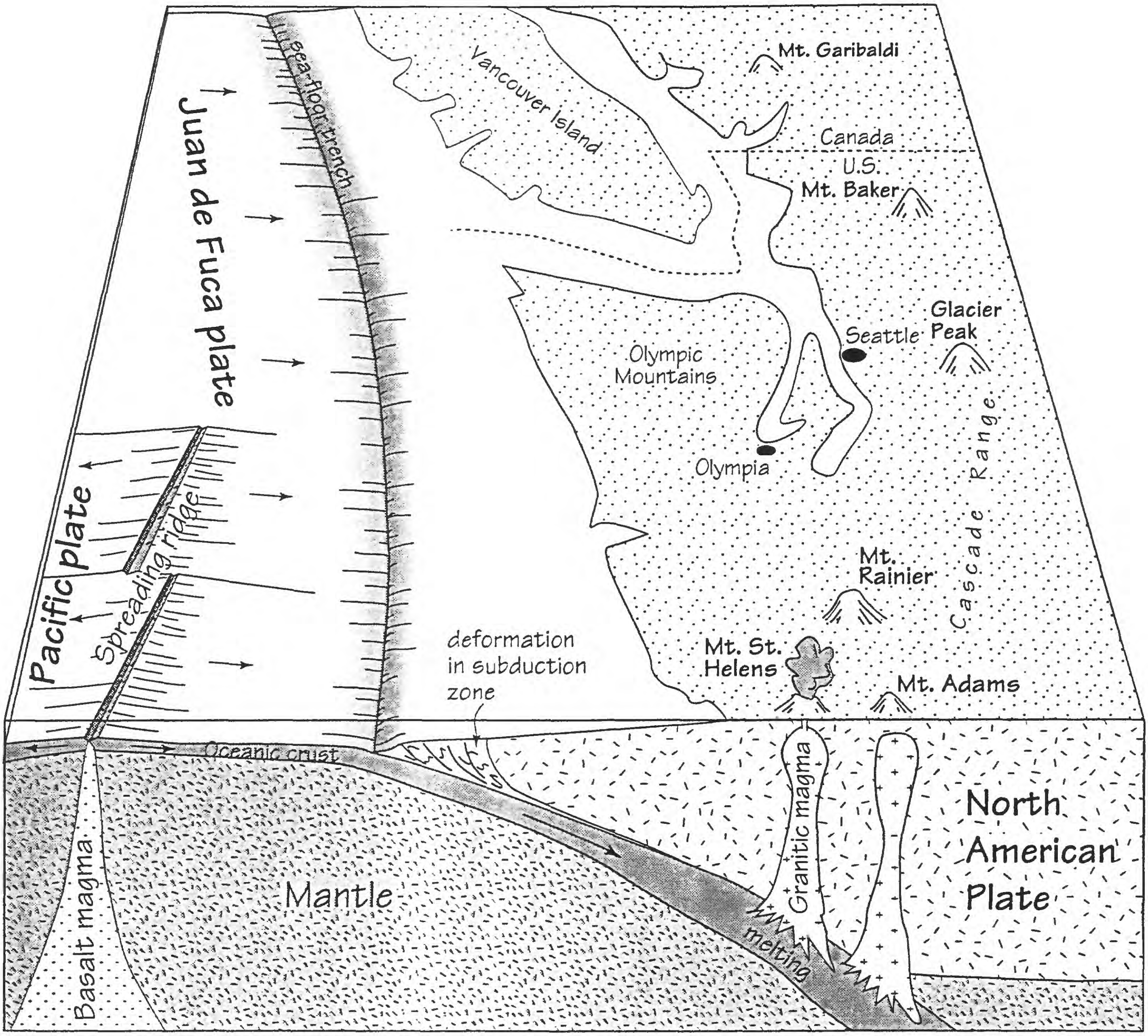


Figure 5. Plate tectonics off of northern Washington. New oceanic crust is created by intrus basaltic magmas at the spreading ridge between the Juan de Fuca and Pacific plates. As the new crust moves away from the spreading ridge, it eventually is subducted, or slides under the continental crust in the sea floor trench. Deep under Washington, new granitic magma forms as the oceanic plate moves under the North American continental crust. This new granitic magma rises through conduits and cracks to form granitic rocks deep under ground or volcanoes like Mt. St. Helens and the other Cascade volcanoes if it reaches the surface. Earthquakes also accompany the subduction of the oceanic crust under the continent.

behind the subduction zone. The magmas that form move upwards through the crust and erupt as volcanoes like Mt. St. Helens, Mt. Rainier, Mt. Adams, Glacier Peak, and all the other volcanoes in northern California, Oregon, Washington, and British Columbia.

Even though we can imagine the process of subduction and continental drift, and see and feel the results today in volcanoes, mountains, and earthquakes, the locations of the plate edges have changed many times over the billions of years of earth history. Entire oceans that are now gone have been present in the past, the continents on each side have drifted together, consumed all the oceanic crust between them through subduction, and ultimately collided. The Himalaya Mountains in Nepal and China are the result of two continents colliding during the past few million years. In other places, there are volcanic rocks like those that are found today at spreading centers far out in the oceans up on the continents. The only way to explain such things is that the world is a constantly changing place, although most of the time the change is too slow for us to see it happen.

MAPS

Maps are wonderful things that can tell us an incredible amount of information. There are many kinds of maps: road maps that help us get around in our cars, maps that show the shape, or topography, of the earth, geologic maps that show where different kinds of rocks are, maps for biology, city planning; maps that show almost anything you can imagine, at any scale. Scale is a way of referring to how much information can be shown on a map. A page-size map may show the entire earth, it may show only the halls and rooms of your school, or it may show anything in between. The difference is one of scale: you simply can't show as much detail on a map that represents a lot of area compared to one that represents a small area.

We will concentrate on two kinds of maps today. Topographic (or "topo") maps are similar to road maps, in that they show all the roads that were present when the map was made and rivers, but they also show the actual shapes of the mountains and valleys as well. Geologic maps show the distribution of different kinds and ages of rocks at the surface. Both kinds of maps are very important tools and products of geologists. We'll start with topo maps.

On a published topo map, water is shown in blue, roads and other man-made features in black, red, and sometimes purple, forested areas in green, and the topography as brown lines. Imagine yourself sitting in a bathtub full of water, and that you drew a line around the tub right at the water's surface. Now imagine letting one inch of water out of the tub, and drawing another line. Keep doing this until the tub is empty, and what do you have? There are lots of lines, equally spaced vertically, that show where the water's surface, or elevation was. A topo map is like that, the brown lines show elevations on the surface of the earth that have the same elevation. Another way to think about it is to imagine yourself walking around a hill. If you start in one spot and keep walking, *without going up or down*, when you get back to your starting place, you will have traced out one topographic contour, which can be shown on your map.

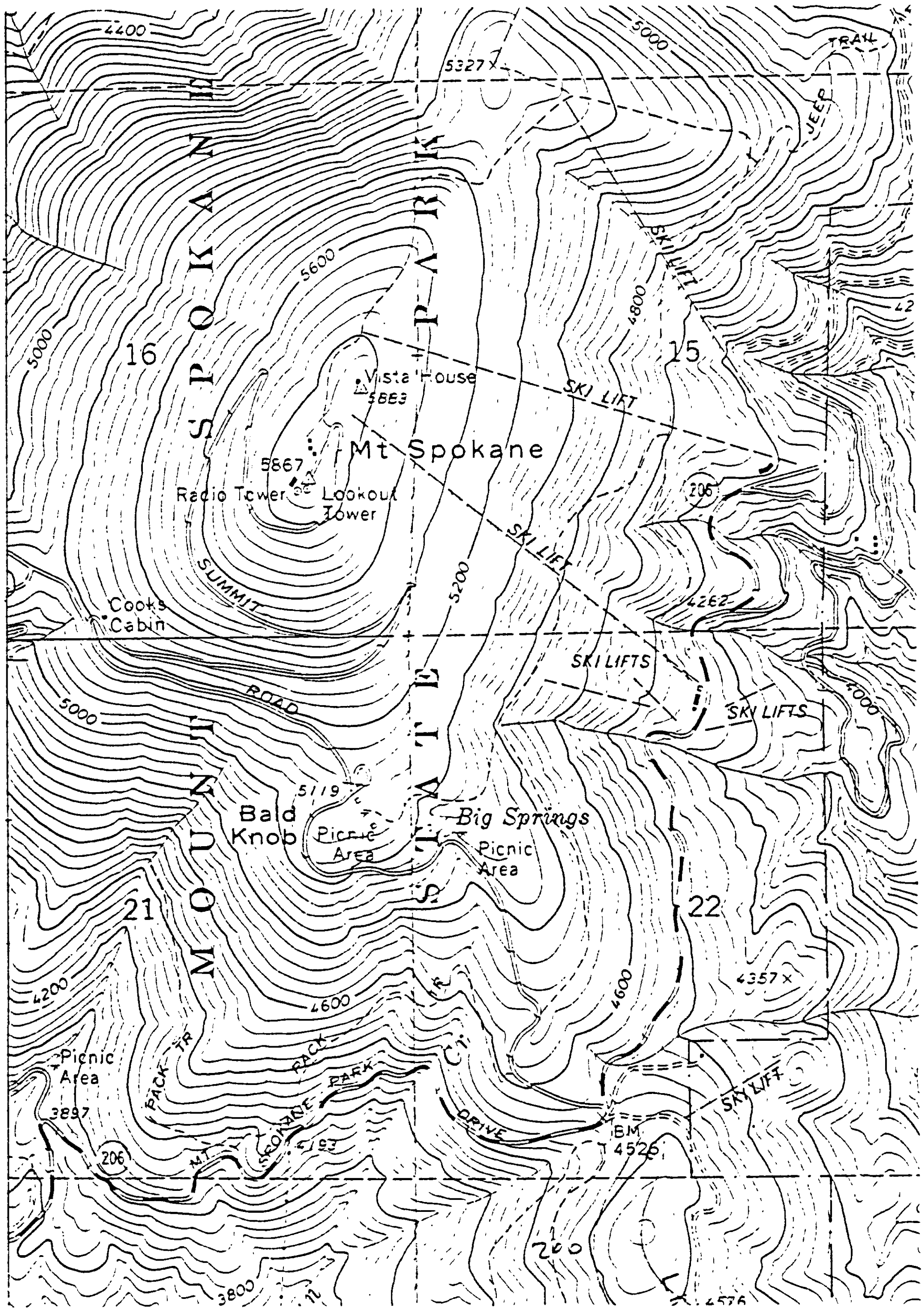


Figure 6. Topographic map of part of the Mt. Spokane quadrangle. The top of the mountain is at the Vista House (elevataion 5883 feet above sea level). The topographic contour lines that form elongate rings around the summit mark points of equal elevation. The elevations of individual contours is also shown on the contour lines that are 200 feet apart. Roads are shown as double dashed or double lines. On the original map, which is in color, the different types of lines on the map are much easier to understand than on this black and white rendering.

There is not really a line on the ground, but you can imagine one being drawn behind you as you walk around the hill. If you move up the hill 40 feet and then walk around the hill again, you will have traced out another contour line. When you have done this as many times as it takes to get to the top of the hill, moving 40 feet up for each walk, you will have traced out the contours on what would be called a topographic map with 40 foot contour interval.

So if you are walking along a contour line, you are not moving up or down, only horizontally. If you are walking straight up or straight down the hill the steepest way you can, you are crossing contour lines at right angles.

On the next page is reproduced a part of the topographic map that shows the top of Mt. Spokane (figure 6). The main road that leads to the ski resort is shown as the black and white double line (on the printed map the road is red to make it show up better). The ski lifts are shown as dotted lines that lead to the top of the mountain. If you look at the lines the ski lifts cross, and follow them around the mountain, they eventually join back up with themselves. Each line traces out on the mountain where an imaginary horizontal plane of a single elevation above sea level intersects the surface.

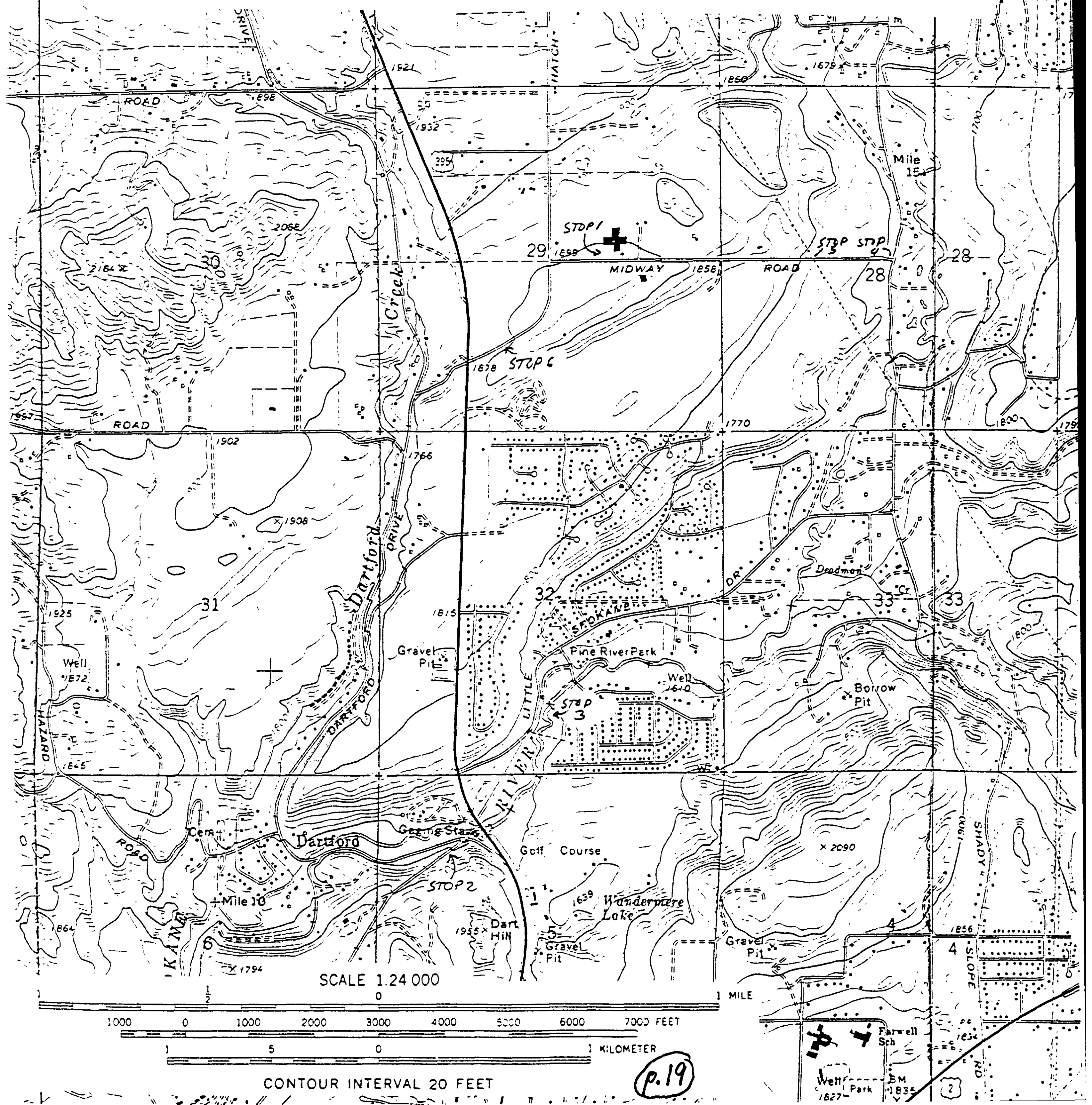
There are important things to recognize about the spacing of contour lines on a topo map. Where the contour lines are closely spaced on the map, the hillside is steep. Where the contour lines are spaced far apart, the ground has a much more gentle slope. We can see this on the map which shows Midway school: out in the playground where the ground is flat, there are almost no contour lines. But as you move down Midway Road towards the Little Spokane River, there are many contour lines, indicating that the hill is much steeper, as we all know from riding our bikes up (or down!) this hill. When you can read topo maps well, you will be able to visualize in your mind the shapes of the hills and valleys from the contour lines. We'll practice with some topo maps of the local area and some of famous topographic landmarks.

Geologic maps show how the rocks that are present in a given area are distributed. Geologic maps are hard to make, because the rocks that are present may be covered with dirt, or trees, or houses! So a geologist who is making a geologic map has to figure out what is under the dirt, trees, and houses by looking at the places where the actual rocks stick out where we can see them.

Imagine you are walking down a hill, and at the top of the hill the rocks that are present are, for instance, gravel and sand. As you walk down the hill, suddenly you notice that the gravel and sand are no longer present, but that granite is the kind of rock that is there: you have crossed a geologic contact. In geology, a contact is the surface where two different kinds of rocks come together. On a map, that surface is shown as a line, on one side is one kind of rock, and on the other side is a different kind. A geologic contact doesn't have to follow contour lines at all, it can go any direction, it can change direction, it can even stop and be replaced by a contact with a different kind of rock.

A geologic cross section is what we would see on the walls if we were to dig a deep trench through the earth. It is one way geologists use to show what is happening with the rocks underground. The front surface of the figure showing

Figure 7. Topographic map of the Dartford area. Full size, full color maps are available from the USGS Earth Science Information Center, located in the Post Office Building in downtown Spokane. This map was made in 1986, so many new roads and buildings have been built since then. Midway School is the large black cross near the center of the picture, other buildings are shown as small black rectangles. Roads are shown as heavy black lines or as thin double lines. See if you can find the little Spokane River at the bottom of the valley near Pine River Park. The topographic contours map out areas with equal elevations, the contour lines are 20 feet apart vertically. The field trip stops are shown.



subduction off the coast of Washington (figure 5) is a simple cross-section that indicates what is happening in a very large slice of the crust.

GEOLOGY OF THE SPOKANE AREA

We've talked about processes and the way geology works, now let's see if we can relate some of this to the geology of our area. The Little Spokane River drains the area from Mt. Spokane to Deer Park, sort of like a giant washbasin tipped slightly so that the water flows out past the lowest spot in the rim. All that water flows out past Dartford in the Little Spokane River. But what about the rocks that are present?

BASEMENT ROCKS

The mountains and hills that mark the edge of the basin are composed of granitic and metamorphic rocks. Right along the Little Spokane River near Midway, all the rocks are granites, but if we look up near Mt. Spokane we can find metamorphic rocks like gneiss and schist. The granite is a coarse-grained rocks composed of interlocking crystals of the minerals quartz, biotite, and muscovite. The metamorphic and granitic rocks can be called "basement", as they represent the surface on which all younger rocks have been laid. All these basement rocks are older than 65 million years old.

COLUMBIA RIVER BASALT AND LATAH FORMATION

Between 5 and 24 million years ago, huge volumes of basaltic lava, known as the Columbia River Basalts, flooded vast regions of the inland northwest, including the Little Spokane River drainage. The basalt forms black to brown exposures of dense, very fine-grained rock. Some basalts are vesicular, that is, they have small bubbles preserved in them. The bubbles formed when gases that had been dissolved in the magma bubbled out when the pressure that kept it dissolved was released during eruption. The same thing happens when a bottle of soda pop is opened: the gas that was dissolved in the pop bubbles out when the pressure is released.

Individual basalt flows in the Spokane area may be as thick as 75 feet. Basalt flows are prominently exposed in the cliffs and benches that flank the Spokane River near the Bowl and Pitcher area. Five Mile Prairie and the Greenbluff area are capped by basalt flows of the Columbia River Group. Basalt outcrops can be seen as far east as the flanks of Mt. Spokane and as far north as Bear Lake. The lava flows blocked the old rivers that drained the Spokane area, which formed lakes against the flanks of the mountains. In the quiet waters of these lakes were deposited silts and clays washed down from the adjacent mountains. These fine-grained lake deposits are called the Latah Formation, after Latah Creek. If you find areas with lots of sticky clay beds, you are probably looking at Latah Formation rocks. The lake-bottom deposits overlie some older basalt flows and underlie some younger flows.

THE SPOKANE FLOODS

During the Ice Ages, between 10,000 and about 2,000,000 years ago, this area was much colder than it is today, and giant glaciers, or ice sheets, flowed south from what is now Canada. The southern edge of the ice sheet frequently blocked the valley now occupied by the Pend d'Oreille River. During the times that the river was blocked, a giant lake formed, backing up well past where Missoula, Montana is now located. When the water got too high, the ice dam broke, sending gigantic floods down the Spokane River and Little Spokane Rivers. It is difficult to imagine how large these floods were. We've all seen little ripple marks on river bottoms or at the beach, caused by currents of water. Such ripples are usually a few inches wide. There are ripple deposits from the glacial floods that are hundreds of feet wide. Imagine the amount and speed of water needed to make such huge ripple marks.

The flood waters carried enormous quantities of very coarse grained sediment. Coarse, unsorted gravel and sand deposits locally are hundreds of feet thick. The gravel pits by Wandermere Golf Course, and the gravels that the Gleneden homes are built on, are in the gravels deposited by the floods.

TODAY

Because the ice age is over and we are not likely to have any more floods of the magnitude of the Ice Age floods that deposited the widespread flood gravels in the Spokane area does not mean that geologic processes have stopped. Every time there is a big storm, some new material is washed down from Mt. Spokane and the other mountains to become new sediments that will gradually break down further and be carried by rivers and wind to a place where they might ultimately turn back into a sedimentary rock. When it is windy, some of the soil from the Palouse area south of Spokane blows in and is deposited as new sediment. Mt. St. Helens is only the most recent volcano to make its presence felt in the area through an eruption. There is always the possibility of a large earthquake near Seattle that we might feel. The earth is a very dynamic planet, though most times the changes are too slow to see. I hope this experience with geology has been interesting for you, and that you have learned a little about looking and trying to understand the story the rocks have to tell.

FIELD TRIP GUIDE

We start at Midway School and work our way down Midway Road to the Little Spokane River, then downstream along Little Spokane River Drive to Pineriver Park and Dartford. We then cross Highway 395, walk up Mill Road to look at the outcrops of granite and gravel, return to school. Figure 7 is part of the Dartford topograpjhic map and has marked on the field trip stops. We will see many of the rock types we've talked about, and will be able to make observations about processes that have occurred and are occurring today.

Start Midway Parking Lot (Stop 1). Brief look around- think about process. We're going to look at some of the more common rocks in the area. The rocks we will see range from about 100 million years old to things that are changing today, if there is a big enough storm. What we will see are the oldest rocks in the area, the granites down by the Little Spokane River, some of the much younger basalt flows (between about 17 and 5 million years old) that cover them, and some gravel and sand deposits that were laid down relatively recently (between about 50,000 and 10,000 years ago) during the giant floods of the ice ages. The final thing we can see is how these rocks are being modified by the processes that are occurring today: erosion and deposition along the Little Spokane River, and changes that are being made by people as they build new roads, bridges, and houses.

Stop 2. Dart Hill area Granite basement rocks and overlying flood gravels. Park at the intersection by the new bridge abutment, but be careful of traffic! Cross the road and walk up Mill Road on the side with the outcrops.

What kinds of rocks make up the jagged cliff-like exposures that are present near the base of the hill? (granite with pegmatite [very coarse-grained granite with muscovite, quartz, and feldspar crystals]. Note the extreme variation in grain size in the crystals. This tells us there are other variables than just how long the rocks had to cool off, like water content of the magma, that control crystal size).

How can you explain the different kinds of granites present? There are at least two kinds of granite present in the cliff. (It is easier to see the relationships around the corner to the east, but the road is too dangerous. There are many dikes of pegmatite which cut the older, finer-grained, darker colored granite. The dikes formed when cracks opened up in the granite while it was solid but still far underground. The magma that formed the pegmatites was injected into the cracks, and then crystallized to form the dikes.)

How many different kinds of minerals can you find in the granites and pegmatites? (Both the even-grained older granite and the younger pegmatite have similar mineralogies, just in different proportions and grain sizes. Muscovite, a kind of mica, forms the translucent, sheet-like soft mineral with one perfect cleavage. The crystals in the pegmatite may be as large as 3 cm. Feldspars of two types are present in both the granite and pegmatite. The crystals are white, pink, or light gray in color. They tend to be in blocky crystals which in some examples have good crystal form. The feldspars may also exhibit cleavage. Quartz is the glassy-looking transparent mineral which has no cleavage, but instead breaks with conchoidal fracture [a fancy way to say the broken surfaces curve like broken glass]. Garnets may be found in the pegmatite, and are easiest to see on freshly broken surfaces. The garnets are nearly spherical, small, pin-head size, and wine-red in color. Other minerals the children might find include biotite, a black mica (due to iron), hornblende (a black to green amphibole), and chlorite (an alteration product of biotite and hornblende, usually a scaly, greenish coating on rock surfaces or other minerals. There are many rocks here that were brought in from elsewhere during the road building. These include basalts, other granites, quartzites and other metamorphic rocks.)

Where did the granite form? Has it always been here? How did it get here? (The granite cooled and crystallized from a magma far underground– we can tell that from the coarse grain size. The texture is typically igneous, like in our thymol experiment– interlocking crystals of different minerals. No, it hasn't always been here. Radiometric dating techniques tell us these rocks are at least 65 million years old. Mountain building [uplift] has brought them up from the deep in the earth where they crystallized, and erosion has removed and carried away the overlying rocks as sediments so we can see the granites today, here at the surface of the earth).

What do we see near the left edge of the outcrop where the rocks are scaly and brownish-gray in color? (A fault- although there is no way to tell what the sense of motion is on this fault because we don't see anything that we can match up across the sides of the fault to give us the sense of motion. There are also several other faults scattered through the outcrop that the children can find).

Keep walking up the road until you come to another place the hill has been cut into to make the roadway. What is exposed here?
(These are gravels, probably deposited by the Spokane floods during the Ice Ages.)

What kinds of rocks are present in the gravels (you name it, its in here. Pieces of many kinds of granitic rocks, basalt, and metamorphic rocks, mostly.)

What is their size and shape? (They are variable- from sand to big boulders. The rocks are well-rounded).

What does the shape of the boulders tell us about the energy of the process that they were deposited by? (It tells us it was very energetic–the large sizes required a lot of energy to carry them here, the mixture of types tells us they were gathered from many different places, and the rounding tells us they were knocked around a lot before being deposited- that they traveled a long way before being deposited— compare the rounding of the boulders in the gravel to the angularity of the freshly broken rocks that were blasted to make the new road.)

Can you see any layers present in the gravel deposit? (Yes— at least you could in 1994, one year after the road cut was excavated. There are crude layers defined by the relative abundance and size of boulders. Some layers are mostly sand, especially near the bottom of the outcrop, while other layers are made up mostly of boulders, which may be as large as 35 cm in diameter. These layers tell us that the gravel was not all deposited in one giant dumping event, but that different events, or at least different energy levels were present in a few larger events, deposited the different layers.)

What can you tell about the relative age of the gravel and the granite? (The gravels are topographically higher up the hill than the granite– so they probably sit on top of the granite. We don't actually see the contact here as it is covered with soils, trees, and dirt, but we can use other lines of evidence to tell us that the gravel is indeed younger than the granite. The gravel is really just a sediment, not even a sedimentary rock– the boulders and cobbles are loose, there is no cement to hold them together. If the gravels were older than the granite, we would expect the gravels to be a real rock, perhaps even a metamorphic rock.)

If you have time and erosion hasn't modified the slope too much, you might take note of the soil developed on top of the gravels. The soils are the dark, vegetation-rich layer right at the top of the embankment. The soil is developed where the gravel is being modified by the weather and by plants that grow. There is no soil on the steep road cut because it was cut too recently– it will take hundreds or thousands of years for a soil to develop on this new road cut.

Another place you can see the flood gravels is along Cincinnati Road hill between Lower and Upper Gleneden. Here the gravels have been extensively modified by erosion (little kids playing on the hill, mostly) so that any original layering has been obscured.

Stop 3. Pineriver Park stream processes- erosion, deposition, flood plains- also look over at granite outcrops
Park at the gate to Pineriver Park and walk across the footbridge that crosses the creek. We didn't spend much time talking about stream processes during our class time, but this is a good place to talk about the processes of erosion and deposition of sediments.

Try to look at the stream like a geologist does, not just as a great place to swim or find crawdads.

Where do the rocks and sand at the bottom of the stream come from? (These are sediments that are currently being moved. Maybe not today, but when the water is high enough and the flow is fast enough, the sands and gravels may be moved further downstream to get a little closer to wherever they will finally be deposited to turn into a rock again. They came from further upstream, where they were broken from their original positions by erosion. During the transport, the banging around against other rocks has rounded their corners.)

Why is there a beach here? (Because it is on the inside of the river bend. On the outside of the bend, on the other side of the creek, the water tends to move fastest, so erosion tends to happen there. This is why all the very large rocks have been brought in to control erosion. On the inside of the bend in the river the water moves more slowly, so that if sands or other sediments are being carried by the stream, they will tend to be deposited here, forming the sand bar we are standing on.)

Is the stream carrying any sediment today? Look closely at the sand at the bottom of the stream. (Hopefully you will be able to see sand being moved along the bottom by the current. If not, you should be able to see little stripes of sand deposited behind larger cobbles and boulders along the bottom. The sand is deposited behind the obstacles, because the obstacle slow the water flow enough that the sands can settle out and be deposited. The next high water will probably move the sands, and possibly the cobbles, further downstream.)

Look through the trees and road on the other side of the river and you should be able to see an outcrop of granite like at stop 1, although this one does not have any pegmatite dikes in it. There are also granite outcrops in the field by the parking lot for the park. The granite outcrops shows us that right here the gravel and sand deposits are not very thick.

Stop 4. Midway-LSR Drive intersection (Granite overlain by basalt)
This stop is optional- the granite is very poorly exposed here and may even be covered by recent road-building activities. At the beginning of 1994 this spot still showed the relationship between the granites and the overlying basalts, which were not present at stop 1.

What kind of rock is present right in the road cut on the northwest side of the intersection? (granite)
Is it fresh or has it been changed? (it has been very deeply weathered– so that it almost looks like sand)
What does that tell you? (the deep weathering is one line of evidence that tells us that these rocks were exposed at the surface for a long time). We saw the basalt up the hill from here; it lies on top of the granite. The granite is an igneous rock- it cooled and crystallized from a magma far underground- that's how it got to be so coarse–grained. Uplift and erosion brought it to the surface of the earth. The granite was covered, millions of years after the granite formed, by the basalt, a volcanic rock we saw up the hill at our first stop

Stop 5. Basalt outcrops by power lines across from Legacy Hills on Midway Road. (There are alternative places to see better basalt outcrops than this. About a mile north of Midway Road along Hatch Road are excellent basalt outcrops.)

What kind of rocks are the big brown knobs? (basalt)
Can you describe the rocks? (they are brown, fine grained lavas with white feldspar crystals less than 1 mm in size. Some rocks are vesicular, or full of gas bubbles)
Have we seen them before? In our session on igneous rocks?
Where else around Spokane can you see rocks like this?
Has this area always looked like this?

These basalts are part of what are called the Columbia River basalt. They were erupted as huge lakes of lava between 17 and about 5 million years ago. The area near Spokane is at the edge of what was during the times of eruption, a giant lake of hot lava, which at times may have stretched from Mt. Spokane to the ocean and from Grand Coulee Dam to Oregon. If you go to Bowl and Pitcher Park, or drive down the Columbia River towards Portland, you will see the same kinds of basalt.

Stop 6 Hatch Road bypass. Drive past Midway School and turn south at Hatch Road. Stop at the road cuts for the new offramp for the freeway where they meet Hatch Road.

What kind of sediment is present here? (It is almost pure sand, with a few cobbles mixed in. No layering is visible, but if you dug through the disturbed upper surface you would find thin laminations and other layering).

Why do you think it is different than the coarse gravels of Stop 1? (These sands are of a similar age to the gravels, but were deposited by more slowly moving water, a much less energetic process than the giant floods. These may have been deposited by relatively slow moving streams after most of the glacial age flooding had already occurred. If this is correct, then these sands are younger than the flood gravels and therefore on top of them.)

That is the last stop on our trip. you may find other stops to make in the area where the same rocks are exposed. As you do, try to relate what you see there to what you have seen today. As you do, hopefully a picture, or movie, of the changes that have occurred in the Spokane area over the past few million years will form in your mind.

Well, that's it. I hope you've had a good chance to look at the world and the processes that shape it. I especially hope that this exposure to geology will open your eyes and you will keep looking with curiosity, and try to read the stories the rocks are telling.

REFERENCES

There are excellent resources available at the US Geological Survey offices in the Post Office building downtown on Riverside Avenue. Topographic maps of the area are available (the Midway area is shown on the Dartford quadrangle), as are some excellent general references. One of the best available books on the Spokane floods is USGS Water Supply Paper 2265, *the Spokane Aquifer, Washington: Its geologic origin and water-bearing and water-quality characteristics,* by Dee Molenaar. There are free handouts on reading topo maps, on panning for gold, on minerals, on volcanoes, and on and on.

Experiment

Materials required: hot plate, thymol, petrie dish, magnifying glass or overhead projector.

Procedure: Carefully melt some thymol crystals in a petrie dish on a hot plate. There is some odor and the melted liquid will burn, so be careful! As soon as the thymol melts, remove the petrie dish from the hot plate and let it cool. Have the kids watch the crystallization as it proceeds. A bright overhead projector in a dark room should allow for observation of what happens as crystallization proceeds.

Questions:
What happens as the material cools?

Do the crystals have distinct forms? Draw a picture of the typical crystal form.

Why do you think the substance orders itself in this fashion?

As they grow, the crystals are enlarged by additions to their outer surfaces; perhaps you can see the growth ridges parallel to the growing faces. When the liquid is completely crystallized, what is the actual shape of the individual grains? Why is it different than the initial growth forms?

Note the difference in grain size from the center to the edge of the dish. Why might this pattern develop?

We've done an experiment that helps us understand how igneous rocks form-crystals grow from a melted rock. The kinds and sizes and shapes of the crystals will depend on the chemicals the magma is made of and how quickly it cools.