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The Geology of West Virginia

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Introduction: This is not meant to be a geology textbook but rather a discussion that will help you understand what you see around you every day or if you take a trip around the State. For example, you're on your way to work or to class or you are going shopping. Most likely, you're driving down a wide valley surrounded by hills. What do the hills look like? Why does the topography change as you go from one part of the State to another? In my opinion, of all the states that make up Appalachia, West Virginia is the most interesting geologically. The western portion of the State, say, Monongalia or Marion counties, are characterized by subdued hills with gentle slopes and rounded tops and adjoin broad valleys. On the other hand, the eastern counties such as Pocahontas or Pendleton counties are more mountainous, the elevations of the ridges will be significantly higher than those to the west. The slopes of the hills will be much steeper, in some cases vertical or near vertical and the valleys will be narrow. Why are the two areas so different? You will discover that some of the reasons are quite simple. For one thing, the kind of rocks that underlie the topography in the two regions are different. In the western part of the State, the underlying rocks consist of a combination of soft shales and argillaceous sandstones that succumb rather easily to processes of weathering and erosion. In the east, on the other hand, the ridges are held up by sandstones such as the Tuscarora sandstone that are hard and highly resistant to weathering. Such sandstones cap sharp ridgelines such as North Fork Mountain and support vertical outcrops such as Seneca Rocks while the valleys are underlain by limestones as well as shales that undergo weathering and erosion more readily. It all makes for a different landscape scenario. In order to understand why landscapes of West Virginia change from place to place, we must take a closer look at Earth, the materials that make up Earth and the processes that are responsible for the changes in Earth's surface that are constantly taking place. But where to start? As a geologist and teacher, I have always thought that to truly understand what we see around us we must start at the beginning. I do not mean for the manuscript that follows to be a highly detailed, scientific discussion, but rather a story of the events that have taken place that resulted in the formation of Earth and eventually to the landscape that surrounds you every day.

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In the Beginning: In 1919, a young astronomer by the name of Edwin Hubble arrived at the Mount Wilson Observatory in California just about the time the construction of the 2.5 meter Hooker telescope was being completed. At the time, the Hooker telescope was to be the world's largest. Using the Hooker telescope, Hubble began his studies of what were thought by astronomers of the day to be clouds of interstellar gas or dust called nebulae contained within the confines of the Milky Way Galaxy. We, that is our star the Sun and the solar system to which Earth belongs, are members of the Milky Way Galaxy. The Milky Way Galaxy is a collection of perhaps 200 to 300 billion stars. At the beginning of the last century, the Milky Way Galaxy was considered to represent the entire universe. Hubble soon made several incredible discoveries that completely revolutionized how we pictures space. First, he determined that the nebulae were not clouds of gas and dust at all but were, in fact, galaxies that were so far beyond the confines of the Milky Way Galaxy that the individual stars could not be seen but rather appeared collectively as a glowing source of light. The significance of this discovery was that the Milky Way Galaxy was not the entire universe. With that discovery our picture of the dimensions of the universe increased enormously. His second discovery was equally spectacular. He discovered that the galaxies were all moving away from each other; as huge as the universe was, it was getting bigger as it expanded into space!

Shortly after Hubble's findings of an expanding universe were released, Georges Lemaitre, a Belgian Catholic priest and professor of physics and astronomy at the Catholic University at Leuven, reasoned that if the universe was in fact expanding, it must have begun to expand from a specific point in space. This led him to propose that at some time in the past, every bit of matter in the universe was once compacted into an object of unimaginable high density referred to a "primeval atom" or a "singularity". Obviously, matter as we know it could not have existed in Lemaitre's "primeval atom"; the conditions of temperature and pressure would not allow it to exist. If not matter as we know it, what was in this "primeval atom"? According to the physicists, the "primeval atom" consisted of elementary particles called quarks. There are six types of quarks with strange names such as up, down, strange, charm, top and bottom (I'm not kidding). Of the six types, the up and down quarks are the most stable; the other types eventually decay into the ups and downs. About 13.7 billion years

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ago, the primeval atom exploded (or in the case of a singularity, began to rapidly increased in size) as it underwent an event known as "The Big Bang". Within the smallest fraction of a second, with temperatures at about 10^{10}K, the quarks began to combine to form protons, neutrons and electrons. Within a million years after the Big Bang, when the temperatures had dropped to below 3,000^{O}K, protons began to form hydrogen nuclei (one proton) and helium nuclei (four hydrogen nuclei plus 4 electrons) with a ratio of hydrogen to helium of 3 to 1 by mass; the value presently observed in stars and interstellar matter. This process went on for several millions of years. Within this expanding mass of hydrogen atoms, clumps (that's what they call them) of hydrogen atoms and electrons began to attract and react with each other and form a helium atom and release energy according to the equation:

$$4H^{+1} + 4e^{-1} \rightarrow He + \text{energy}$$

We may have a problem with the above reaction. Each hydrogen atom has a mass of 1.008 g/mol while each helium atom has a mass of 4.003 g/mol. Four hydrogen atoms would therefore contribute a total of 4.032 g/mol while the one atom of helium represents only 4.003 g/mo. What happened to the remaining 0.029 g/mol of mass? Mass cannot be lost nor can it be destroyed. But according to Albert Einstein, it can be converted to energy by his equation:

$$E = mC^2$$

Where E is energy, m is the mass that seemingly is lost and C is the speed of light, 2.998 x 10^8 m/s, a very large number. Even though "m" is a very small amount of mass, when multiplied by the square of the speed of light, it becomes a very large amount of energy. What was been created by this reaction were stars and the energy released is all of the forms of energy that are emitted from the stars ranging from radio waves to gamma radiation.

Stars then began to collect together into galaxies although no one understands exactly how galaxies form. Edwin Hubble classified galaxies based upon how they appear on photographs as spiral (normal or barred) or elliptical. The spiral galaxies have arms that begin as barred spirals that eventually extend outward around the galaxy. Most spiral galaxies are from 50,000 to 2,000,000 LY across and contain from 10^9 to 10^{11} stars. Elliptical galaxies are shaped somewhat like a football, showing the elliptical shape when viewed side-on but round when

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viewed end-on. While most galaxies are ellipticals, most galaxies listed in catalogs are spirals. The reason for this is because although a few elliptical galaxies are larger than any spiral, (100 times more stars than the Milky Way) most are small and dim with one millionth of the stars as in the Milky Way. There were other galaxies that Hubble was unable to classify as either ellipticals or spirals because their odd shapes and sizes. These he called irregulars. Fewer than 20% of all galaxies are irregulars which are all small with fewer than 25% of the stars contained in the Milky Way. While in any given volume of space, there are more elliptical galaxies than there are spiral galaxies, the spiral galaxies accounting for more than 75% of the brighter galaxies. Our galaxy, the Milky Way, is a spiral galaxy.

They say the Milky Way is an average sized galaxy. As a result, the dimensions of the Milky Way Galaxy would hold for most galaxies. The diameter of the Milky Way Galaxy is about 100,000 LY (light years) with a thickness along the rotational axis of 20,000 LY. Our star, the Sun, is located at the outer edge of the galaxy about 30,000 LY from the center. The advantage of being located at the edge of the galaxy is that there are fewer stars in the vicinity of our Sun, allowing us to see beyond our galaxy into deep space. For example, the closest galaxy to the Milky Way is a spiral galaxy, Andromeda, that is located 2.25 million LY from Earth. You might be able to picture the size of an average galaxy in miles by multiplying the number of light years by the number of miles in one light year, which happens to be 5.879×10^{12} miles.

Galaxies group together into clusters that vary in size and numbers. An example of a cluster is the Pleiades Cluster located 410 LY from Earth. The clusters range in diameter from 3 to 15 million LY. Some clusters contain a few galaxies while others may consist of thousands of galaxies, all of which are moving away from each other. Will the expansion go on forever? Some say that it will; after all, it's expanding into space which has no limits. If the expansion does go on forever, eventually all of the stars, that are simply fires of sorts, will go out and what's left of the universe will be nothing more than burned out cinders. Others believe that as the galaxies move away from each other, new stars are created to replace the dead stars, thereby maintaining the same density of mass and energy within the galaxy as it was in the past and will continue to be in the future. This is referred to as the steady state theory. Still others believe that the forces driving the galaxies

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into space will be eventually be counter-balanced by the force of gravity. As a result, the expansion will stop and the universe will begin to collapse; a process referred to as "The Big Crunch". As the universe collapses, galaxy will crash into galaxy; star will crash into star, all planets will be consumed in the fires of their collapsing stars and eventually everything that now exists in the universe will end up – where? Most likely right back in the form of a new primeval atom. And then what will happen? Another explosion, another Big Bang and the birth of another universe that will go through the same cycle of birth and growth and death. All of this implies that our universe is not the only universe present in space. While ours is expanding, others are undergoing the Big Crunch eventually to form new primeval atoms while other primeval atoms undergo the Big Bang.

The Stars

Now that you have an idea of the Big Picture and how stars form, we must return to a discussion of the stars because of the role they play in the formation of planets. Within the expanding universe, new stars are being created. Star form within dark cloud of gas and dust called dark nebulae. A well-known dark nebula is the Horsehead Nebula in Orion. They are dark because the gases and dust block the light coming from stars located behind them. The particles in a dark nebula are about 75% hydrogen and 23% helium with the remaining few percent being heavier atoms with a tiny percent consisting of dust particles the size of smoke particles. While the particles within a dark nebula are kept apart simply because of their random motion, what causes them to coalesce in order to form a star? According to the astronomers, the most likely source of energy would be the energy released during a nearby supernova which forms a shockwave during the death of a large star (we will discuss that later). While the shock wave generated by the supernova initiates the collapse of the dark cloud, gravity eventually takes over to complete the formation of what is called a protostar at the center of the collapsed dark cloud. With time the core of the protostar begins to collapse. As the collapse takes place, some of the gravitational energy converted to heat, the protostar becomes hot, eventually hot enough to initiate hydrogen fusion, creating a star according to the reaction previously shown:

$$4H^{+1} + 4e^{-1} \rightarrow He + energy$$

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Once created, stars spend 90% of their lives in what is called the main sequence during which time they consume hydrogen to create helium and emit all the forms of electromagnetic energy. In order to understand how stars die, we must consider how they are classified. While there are several star classification schemes, I have chosen the simplest one I could find. In this classification scheme, stars are categorized based on their mass compared to the mass of our Sun. Our Sun represents one solar mass (SM). The smallest stars are the fly-weight stars that possess less than 0.4 SM. Next in line are the light-weight stars made up of from 0.4 SM to 4 SM. Note that our Sun with 1 SM is a small light-weight star. If you know anything about boxing, you should be able to predict the last two categories of stars; the middle-weight stars range from 4 SM to 8 SM and the heavy-weight stars have greater than 8 SM. How big do stars get? I've read of stars in the 100 SM to 200 SM range and I recently read an article where an astronomer claims to have detected a 1,000 SM star.

During their main sequence status, all four sizes of stars do the same thing; they burn hydrogen to produce helium and give off energy. But the burning of hydrogen to produce helium is no different from the fire in your fireplace that is consuming the wood of a log as fuel, leaving behind ash and giving off heat. In both cases, when the fuel is exhausted, the fires will go out. Which of the four types of star do think would have the longest lifespan? When asked that question, I picked the heavy weight star. It simply occurred to me that a star more than 100 times the mass of our Sun, let alone 1,000 times the mass, must have an enormous amount of hydrogen fuel that would take a very long time to be consumed. Wrong again! The lifetime of a star is inverse to its mass. The fly weight stars all have lifetimes in excess of 56 B years; which means that with the universe being only 13.7 B years old, any fly weight star that has ever been created is still out there. Light weight stars such as our Sun have average lifetimes ranging up to 28 B years. Our Sun has an expected lifespan of 10 B years, half of which has already been lived. I might point out that nearly all the stars we observe on a clear, moonless night are the fly weight and light weight stars. Middle weight stars have average life expectancies of 235 M years while the average heavy-weight star will survive for less than 60 M years; the giant heavy weight stars may only exist for a few million years after birth.

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But how do the stars die? It depends on the mass of the star. In the case of a fly-weight star, as the helium in the core builds, increased gravitational forces cause the star to collapse. During the collapse, some of the gravitational energy is converted to heat resulting in the temperature of the star to rise, forming what is called a white dwarf; the "white" designating the extremely high temperature of the stars surface (15,000^{O}C) and the "dwarf" the size of the star. A typical white dwarf star is about the diameter of Earth whose diameter is 8,000 miles with a density of 10^6gm/cm^3. Once in the white dwarf stage, the star will continue to live for a very long time until all fuel is consumed and the star becomes b burned-out cinder called a black dwarf. While our galaxy contains billions of white dwarfs, only about 500 have been identified because they are so dim.

What happens to the larger stars is quite different. As the helium content of the core of the more massive stars increases, the cores begin to collapse as the energy generated by the fusion process increases. The combination of fusion energy and the heat generated by the conversion of gravitational forces causes the temperature of the core to increase, perhaps to 100,000^{O}C, causing the shell of hydrogen surrounding the core to begin to undergo fusion and expand, resulting in the formation of what is called a red giant. On the average, a typical red giant star will be as much as 100 times the diameter of the original star and consists mostly of hydrogen. In the case of the light- weight stars, the red giant stage will collapse and the core of the star will eventually end up as a white dwarf. However, it is what happens to the red giant stage of the medium-weight and the heavy-weight stars that is important to our story. As the cores of the middle- and heavy-weight stars continue to collapse, helium begins to fuse into carbon which fuses into heavier elements such as oxygen, silicon and magnesium. In the case of these large stars, the amount of energy being generated is so large that the star explodes creating a supernova during which large amounts of material is thrown off into space to create cosmic dust (nova is the Latin word for *new*). The cosmic dust consists of heavy, dense materials such as metals, minerals and rock particles while the greatest volume of material consists of ices made primarily of frozen hydrogen and helium and other lesser gasses such as oxygen. It is from this cosmic dust that the planets form. Following the supernova, what remains of the cores of middle weight stars collapses to form neutron stars as electrons are forced to combine with protons to form neutrons. A typical neutron star has a diameter of about 12 miles (20 km), a density of 10^{15}gm/cm^3 and a surface temperature of 10,000,000^{0}C..In the case of the largest stars, the collapse forms a black hole which is a star that is so dense that not even light can escape its grips.

While a supernova occurs within our galaxy every few years, interstellar dust clouds prevent our seeing them. Only three supernovae have been observed in the Milky Way Galaxy; in 1054, 1572 and 1604. The remains of the 1054 supernova is the Crab Nebula which, occurred on July 4, 1054. The supernova, was described by Chinese as being so brilliant that it could be seen during the day and used to read by at night. According to their descriptions, the star remained bright for a few weeks then began to fade until it disappeared after about two years. In 1572, Tycho Brahe observed a supernova that was proof for him that the heavens were not unchanging. The most recently observed supernova in the Milky Way Galaxy was Kepler's Supernova in 1604. Statistical observations of supernovae in other galaxies indicates that a supernova should occur about three times per century in the Milky Way. On February 24, 1987, a supernova was observed in the Large Magellanic Cloud located in a galaxy only 170,000 LY from the Milky Way Galaxy. The Magellanic supernova was the first to be seen with the naked-eye since Kepler saw his supernova in 1604.

The Formation of Planets: For our discussion of the formation of planets, the cosmic dust thrown into space is of most importance. The formation of planets begins with the creation of a new star surrounded by a sphere of cosmic dust. All stars rotate and emit a force referred to as the solar wind. A solar wind consisting of high energy protons and electrons that segregates the cosmic sphere by density by driving the low density ice particles within the cosmic sphere away from the star while leaving the heavier particles of metals, minerals and rock nearer the star. Simultaneously, a magnetic field emanates from the star and sweeps through the sphere of cosmic dust, attracting magnetic particles such as iron and sets the sphere rotating. As all spherical bodies rotate, they progressively flatten along the axis of rotation. The rotational axis of Earth, for example, is 27 miles shorter than the equatorial axis. Eventually the sphere of cosmic dust becomes a disk of cosmic dust surrounding the star and extending out from the equitorial axis of the star. In 1796, Pierre Simon de Laplace, a French mathematician proposed that such a rotating disc would break up into rings much like those surrounding most of the outer planets of our solar system. In the 1940s,

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a German physicist, Carl von Weizsacker, showed that eddies would form within the rings of cosmic gas that rotate around the star. As the eddies orbit the star, they attract the cosmic particles in their path which collide to form larger particles called planetesimals. Once formed, the planetesimals are attracted by gravity to the center of the eddies where they combine to form a homogenous protoplanet (proto means "almost"). As the protoplanets grow in size and orbit around the star, they continue to collect particles of cosmic dust and planetesimals. Eventually, a solar system forms with relatively small, dense protoplanets made mostly of metals, minerals and rock located nearest the star while toward the outer portion of the former dust disk, large protoplanets formed made primarily of hydrogen and helium ices with lesser amounts of other gases and whatever rocks materials were originally present in the outer reaches of the dust disk.

As the protoplanets grew in size, some of the gravitational energy was converted to heat which eventually caused the interiors of the protoplanets to melt. The molten materials begin to separate based on density. Within the protoplanets closest to the star, the densest material, molten iron, settled to the center to form a core (iron is the most abundant metal in the universe). In the case of Earth, layers of rock of decreasing density then began to form around the molten iron core, eventually created the mantle with a density of ~6 and finally the crust with a density of ~3 formed the outermost layer, completing the formation of Earth. The same process occurred within the huge outer protoplanets. Because some dense rock materials were originally present in the outer portion of the cosmic dust disk, the cores of the outer planets were made of small amounts of rock. Surrounding the rock cores of the outer planets the gases accumulated in layers of metallic hydrogen, liquid hydrogen and an outermost layer of gaseous hydrogen and helium. This segregation of materials based on density changed the homogenous protoplanets into the layered planets of our solar system.

The inner four planets, Mercury, Venus, Earth and Mars, referred to as the Terrestrial Planets, are made of layers of rock surrounding an iron core while the outer four planets, Jupiter, Saturn, Uranus and Neptune, making up the Jovian Planets, are huge spheres of gas surrounding a small rock core. To give you an indication of the dimensions of the Terrestrial versus the Jovian planets; Venus

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and Earth, the largest of the Terrestrial Planets have diameters of about 7520 miles and 7930 miles respectively (12,100 km and 12,760 km). Jupiter, the largest of the Jovian Planets, has a diameter of 88,900 miles (143,000 km). Pluto was once considered as the ninth planet until 2006 when the International Astronomical Union demoted it to a "dwarf planet". It is now considered a member of the Kuiper Belt that contains other bodies such as comets made of water ice. Its demotion was due to the fact that it did not follow the trends of the other Jovian Planets. While the other planets orbited within or near to the Suns ecliptic, the orbit of Pluto was 17^{O} from the ecliptic. In addition, Pluto was not a large gassy planet but about as large as our Moon (1,400 mi in dia.) and made primarily of rock.

In summary, we have now come to Earth; a small rocky planet orbiting a small light weight star near the outer edge of the Milky Way Galaxy.

Minerals and Rocks

Minerals: Since this is not meant to be a geology course, I want to keep our discussion of rocks and minerals to a minimum. My intent is for you to learn enough about minerals and rocks in order to better understand later discussions that we will have.

There are somewhere between 2,000 and 3,000 named minerals. Fortunately for all concerned, most by far are rare with many being found in only one place on Earth. The one that for some unknown reason has stuck in my mind since I took my first course in mineralogy is **franklinite**, $(Fe,Zn,Mn)(Fe,Mn)_2O_4$, that is only found in a zinc deposit in Franklin, New Jersey. Minerals can be sorted into one of two basic groups, the silicate minerals that are based on the silicate ion building block, SiO_4^{4+} that most often precipitates from molten rock, either magma and lava. All the other minerals are classified based on the anion group and precipitate largely from aqueous solution. It should be obvious that of all the minerals, the most important are the silicates in that they make up most of Earth's rocks. Except for the core that is largely molten iron, the mantle rocks that overlie the core are dominated by the rock peridotite that is dominated by two silicate minerals, olivine, $(Fe.Mg)_2SiO_4$, and pyroxene which is a group of silicate minerals that can be represented by the general formula: $XY(Si_2O_6)$, where X is usually Na^{+1} or Ca^{+2} while Y can be variety of cations including Mg^{+2}, Fe^{+2}, Fe^{+3}, Al,

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Mn^{+2} or Mn^{+3}. When needed, charge balance is accomplished by substituting Al^{+3} for Si^{+4} in the structure. The outermost layer, Earth's crust, is composed of oceanic crust made up of basalt that consists mainly of olivine, $(Fe,Mg)SiO_4$ and plagioclase feldspar, $Ca_2Al_2Si_2O_8$, and the continental crust that consists mainly of granitic rocks dominated by quartz, SiO_2, and orthoclase feldspar, $K(AlSi_3O_8)$.

The common members of the non-silicate group of minerals include minerals such as hematite, Fe_2O_3, the carbonates including calcite, $CaCO_3$ and dolomite,, $(Ca,Mg)CO_3$, sulfates such as gypsum, $CaSO_4 \bullet 2H_2O$, sulfides including galena, PbS and disulfides such as pyrite, FeS_2, phosphates such as apatite, $Ca_5(F,Cl,OH)(PO_4)_3$, halite, NaCl and a variety of native elements (those existing in an uncombined state) including graphite, C, sulfur, S, gold, Au, silver, Ag, and copper, Cu. While none of these minerals are great rock-formers, they are important on their own. Hematite is our source of iron that is converted to steel by adding a small amount of carbon. The carbonates are the main components of limestone used as a flux in the processing of iron ore. Gypsum is used as an insulation in the form of the gypsum board applied to the outer surface of buildings undergoing construction. Gypsum is also fabricated into sheets commonly called plaster board which are used in the interior of buildings in lieu of having to apply plaster. Many of the sulfide minerals are our sources of metals such as lead (galena, PbS) and mercury (cinnabar, HgS). The nervous system of the human body would not function without halite (NaCl); and the native elements such as gold, silver are of obvious importance and without copper, most electronics would not exist. As a geologist, you would learn the use and importance of many more minerals, where to search for them and how to identify them. You would also discover that individual and combinations of minerals record the history of Earth in the locality in which they were being precipitated and accumulated prior to their incorporation into rocks. For a simple example; a layer of limestone in a sequence of rocks tells a geologist that he or she was dealing with some ancient water body that was warm and clear of sediment based upon the fact that calcite dissolves in cold water and precipitates in warm water while clear water is required for most of the animals whose shells are used to make biochemical limestones. In addition, the shells of animals that become Incorporated into biochemical limestones may tell a paleontologist a large part of the history of the locality such as where the animals lived in terms of such as

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water temperature, water depth, predator-prey relationships, water salinity and water turbidity.

Rocks

Rocks fall into three groups; igneous, metamorphic and sedimentary. How many kinds of each of these three basic types of rocks are there? If you would list an example of every rock for which there is a niche in a classification scheme for all igneous, metamorphic and sedimentary rocks, the number would be very large; perhaps even more than the number of minerals that number in the thousands. I am going to solve the problem by listing only those rocks that one would expect to commonly find at the average outcrop within Appalachia.

Igneous Rocks:

Let's begin with a short discussion of igneous rocks. In terms of the volume of rocks making up Earth, igneous rocks are by far the most dominant. In the discussion that follows I have include the formulae for the important minerals, not for you to memorize, but rather to show you the compositional complexity of the silicate minerals.

Igneous rocks form by the cooling and solidifying of molten rock. There are two types of molten rock, magma and lava. Magma is molten rock located below Earth's surface while lava is molten rock (magma) that has been extruded onto Earth's surface as either volcanoes or lava flows. Igneous rocks are categorized as either coarse-grained or fine-grained. Coarse-grained igneous rocks are those that formed by the slow cooling of magma below Earth's surface, allowing the individual mineral grains to be visible and identifiable by the naked eye. Fine-grained igneous rock, on the other hand, form by the rapid cooling of lava extruded onto Earth's surface where it is subjected to the cooling effects of air, water or beneath ice, producing mineral grains that cannot be identified without the use of a magnifying glass or microscope.

Of the various kinds of coarse-grained igneous rocks, the two most important to our discussions are peridotite and granite. Peridotite is the rock that makes up the outer portion of the mantle and consists largely of the mineral olivine, $(Fe,Mg)SiO_4$, and anorthite feldspar, $Ca,Al_2Si_2O_8$. The lower portion of the mantle is thought to be made of a mixture of oxides formed by the thermal

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decomposition of the silicate minerals that make up peridotite. Grainte is the rock that makes up the continental crust and consists largely of quartz, SiO_2, and orthoclase feldspar, $KAlSi_3O_8$, with lesser amounts of iron-rich minerals such as biotite, $K(Mg,Fe)_3(AlSi_3O_{10}(OH)_2$ and hornblende, $Ca_2Na(Mg,Fe^{+2})_4(Al,Fe^{+3},Ti)_3Si_8O_{22}(O,OH)_2$.

The most important fine-grained igneous rocks are basalt and andesite. Basalt has a composition similar to peridotite except that it contains less olivine and more anorthite,$Ca,Al_2Si_2O_8$, and some augite, $(Ca,Na)(Mg,Fe,Al)(Si,Al)_2O$. Basalt covers 70% of Earth's surface in the form of the oceanic crust plus is the major component of all land flows of lava. Andesite is important in that it is the main fine-grained constituent of which the continental arc volcanoes such as the Andes Mountains are made. It consists of plagioclase feldspar which is a series of feldspars varying in their content of sodium, Na, and calcium, Ca, plus biotite, $K(Mg,Fe)_3(Al,Si_3O_{10})(OH)_2$ and hornblende.

While we are discussing igneous rocks, there are a few others that I would like to comment on. The magma from which peridotite forms is very viscous and, as a result, is rarely extruded to the Earth's surface. There is, however, one example where it has been extruded and formed a fine-grained rock called kimberlite in which diamonds were discovered in Kimberly, South Africa. It was there that the 83.5 carat Star of South Africa diamond was discovered in 1869; a discovery that, began the episode of diamond exploration.

Basalt is the most abundant fine-grained rock on Earth's surface. However, there is a coarse-grained equivalent rock called gabbro. As the basaltic magma makes its way into the fracture between divergent tectonic plates and cools rapidly to form the basaltic oceanic ridge and new oceanic crust, some of the magma cools slowly as it rises and forms the gabbro that makes up the upper portion of the Earth's lithosphere.

Granite is usually indicated as the rock of which the continental crust is made. However, because since it is difficult to distinguish granite from granodiorite in which the orthoclase feldspar, has been replaced by plagioclase feldspars (Ca and Na rich), many authors refer to the continental crust being made of granitic rocks. There is a fine-grained equivalent to granite. Again, because of the high viscosity of granitic magma, it rarely erupts to the surface but

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rather cools beneath Earth's surface to form huge masses of granitic rock called batholiths. It is also important to realize that the "basement" that underlies all of the sedimentary rocks within the continent and is exposed within the Canadian Shield is made of igneous rocks that formed billions of years ago. However, there have occurred rare volcanic eruptions in which granitic magma has been blasted into the atmosphere where it rapidly cooled, forming fine-grained materials that rained to Earth's surface, covering hundreds of square miles of the land. Still very hot and tacky, these materials compacted to form a rock called rhyolite. Three such eruptions created the geology that surrounds Yellowstone Park

Metamorphic Rocks:

By definition, a metamorphic rock is one that has recrystallized from a previously existing rock **in the solid state** by the application of heat, pressure and chemically active fluids. I indicated in bold type that the transition must occur in the solid state to eliminate the possibility of melting during the conversion process. Should melting occur, the resultant rock would be an igneous rock, not a metamorphic one. I might also point out that the "chemically active fluids" are for the most part hot (often super-hot) water. Although metamorphic rocks can form at the contact with an intruding mass of molten magma or lava, most metamorphic rocks form within the zones of subduction where all three metamorphic agents are present. Metamorphic rocks are the result of three types of metamorphism.

Contact Metamorphism: Contact metamorphism is primarily associated with magmatic intrusions in which the host rock is literally "baked" where it comes into contact with the hot magma. Metamorphic rocks formed by contact metamorphism are commonly referred as hornfels. The thickness of the metamorphic rock formed by contact metamorphism depends on the mass of intruding magma and its temperature. The layer of metamorphic rock surrounding the intruded granite magma that formed a batholith will be quite thick. On the other hand, the intrusion of a basaltic dike that intersects a coal bed may only produce a thin layer of natural coke.

Dynamo-Thermal Metamorphism: Dynamo-thermal metamorphism involves pressure (dynamo) and heat (thermal). Metamorphic rocks formed by dynamo-

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thermal metamorphism are most commonly found in the cores of fold-belt mountains such as the Appalachians where the rocks have been subjected to intense pressures generated by plate convergence, especially during continent-continent collisions. The metamorphic rocks formed by dynamo-thermal metamorphism are commonly schists. Schists consist of platey minerals such as mica that become oriented parallel to each other and perpendicular to the direction of the major applied force. Another metamorphic rock that forms due to pressure and heat is the mylonite that forms between two moving fault blocks.

Hydrothermal Metamorphism: In most metamorphic processes, there is little or no addition to or loss of material from the rock undergoing metamorphism. In hydrothermal metamorphism, on the other hand, materials may be added to or removed from the original rock by the "chemically active fluids". While the water may originate from the ocean via a zone of subduction or the dehydration of minerals being subducted by the down-going oceanic plate, a major source of water concentrates during the final stages of magmatic crystallization. While water is a component of molten rock, little water is needed during the crystallization of the major silicate minerals. This can be seen by the fact that only a few silicate minerals contain water of hydration ($\bullet n\ H_2O$), or hydroxyl radicals (OH^{1-}). Because no water is needed during the crystallization process, the water concentrates in the remaining magma. Eventually, what began as molten rock gets to the point where what remains is no longer a magma but rather a hot water (hydrothermal) solution containing the remaining elements. This hydrothermal solution then permeates and reacts with the host rock to produce a new assemblage of minerals. An example would be the conversion of olivine into serpentine and brucite:

$$2Mg_2SiO_4 + 3H_2O \rightarrow Mg_3Si_2O_5(OH)_4 + Mg(OH)_2$$

olivine + water → serpentine + brucite

The next time you go to Washington, D.C., you might want to visit the National Gallery of Art where you will see polished columns of serpentine around the rotunda. A special kind of hydrothermal metamorphism is called metasomatism in which the original mineral assemblage of a rock is replaced either partially or completely by permeating hydrothermal solutions, creating a rock of a totally

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different composition. This is a relatively common procedure in the emplacement of ore bodies.

Metamorphic rocks are widely exposed in the Blue Ridge outcrops, reflecting their proximity to the continent-continent collision that occurred during the Allegheny Orogeny, 250 million years ago. Except for as yet unexplained occurrence of basaltic dikes and sills, the surface of West Virginia is dominated by sedimentary rocks.

Sedimentary Rocks:

As was the case with most types of rock, those who specialize in sedimentary rocks have complex classification systems that serve to subdivide sedimentary rocks into numerous categories based largely on composition of major components, particle size of grains and the type of cement. I will keep our discussion as simple as possible. Sedimentary rocks are classified in one of two basic groups. Rocks that are composed of the insoluble products of weathering are called detrital rocks while those that form from minerals that have precipitated from solution are non-detrital

Detrital Sedimentary Rocks: The most abundant products of weathering are the rock fragments created by physical weathering such as cobbles, pebbles and quartz sands and the clay minerals that are the major byproduct of the process of chemical weathering process known as carbonization/hydrolysis. A major agent of physical weathering is the expansion of ice as it freezes in various kinds of rock fractures; in particular, in joints. The forces generated by the penetration and growth of plant roots produces the same wedging effect as growing ice crystals. Another means of rock disintegration are the rock impacts resulting from rock falls that generate many of the rock fragments that accumulate along the base of cliffs or high road cuts. Equally effective is the energy applied by the pounding of waves along high-energy coastlines and the turbulence of mountain streams that tend to round large rocks into cobbles pebbles and sand. The stream weathering process is easy to observe by the roundness of the resultant particles. How often have you seen "stream-worn pebbles" used as decorative materials? The larger particles if deposited, buried and lithified form rocks called conglomerates. Conglomerates are good examples of rocks that exhibit poor sorting. Sorting is a process whereby particles are separated by size. A poorly-sorted rock such as a

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conglomerate, consists of a mixture of particle sizes as opposed to a well-sorted rock that is composed primarily of a single particle size. The finding of a conglomerate usually indicates that the materials were being subjected to high energy environments such as fast moving mountain streams or high energy coastal wave action. The smaller particles, sands, silt particles and grains of clay minerals are not so easily rounded but retain much of their angularity. Because the bedload of most streams consist of sand-sized particles, stream deposits are usually well-sorted.

Quartz sands lithify to form sandstones. The type of sandstone depends on the material that cements the grains together. A common cement is quartz that precipitates out of groundwater solution and forms overgrowths on the original quartz grains. Sandstones in which the grains are most completely and solidly cemented are called quartzose sandstones or quartzites. Quartzites are among the most resistant of all the sedimentary rocks to the processes of weathering. An excellent example of a quartzite is the Tuscarora sandstone that is responsible for most of the ridges within the Appalachian Mountains and spectacular outcrops such as Seneca Rocks. Another common cement is calcite that precipitated out of the groundwater to fill the pores between the grains. Such sandstones are called calcareous sandstones. A common cementing agent are the clay minerals that are deposited along with the sand in the form of a sandy mud. When buried and placed under pressure from the overlying sediments, the water is squeezed out of the clay-rich mud, resulting in the clay mineral cement that holds the sandstone together. Such sandstones are called argillaceous sandstones and because of the ability of water to re-permeate the clay cement, are less resistant to the process of weathering than quartzites. Overall, sandstones make up 20% of all sedimentary rocks.

The most abundant product of the chemical weathering of all but two silicate minerals (olivine and quartz) that make up Earth's crust are the clay minerals. When deposited in a floodplain, swamp or marsh and are finally buried, they are subjected to the pressure from the overlying sediment, the water is forced out from between the flakes. As the mass compacts, the clay mineral flakes begin to orient with their planar surfaces parallel to each other and perpendicular to the direction of the applied force. Finally, when all, or nearly all, of the water has been forced out, the clay mineral platelets adhere to each other

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to form a shale. As a result of the abundance of clay minerals resulting from the chemical weathering of the silicate-rich rocks, shales are the most abundant of all the sedimentary rocks, making up 70% of the total followed by sandstones at 20% with limestones making up the last 10%. While most abundant of all sedimentary rocks, shales are the most prone to the processes of weathering and erosion, explaining why they commonly makeup the rocks underlying valleys.

Regardless of the kind of cement used in the lithification process, all of the pores between the grains are not filled. The empty pore space is what determines the porosity of the rock while the degree to which the pores are interconnected determines the permeability. The percent porosity determines how much water, oil or natural gas a rock may hold while the permeability determines the ease with which it will move through the rock to a well or spring. Of the sedimentary rocks, the type than commonly has the least porosity and permeability are the shales because of the compaction that clay minerals undergo in the transformation to shales, collapses the pores and minimizes the permeability. This explains why shales are the most common "cap rocks" that overly oil, gas and water-bearing rocks and prevent the escape of the fluids. Because of their inherent high porosity and permeability, most water and petroleum-producing rocks are sandstones. Recently, however, by applying the process of fracking to organic-rich shales, they have become the world's most prolific producers of natural gas. A single fracked well drilled into the Marcellus shale near Morgantown produces the city's entire yearly demand for natural gas. When one considers the total volume of gas-producing shales in the world, sandstones and limestones pale in comparison.

Non-Detrital Sedimentary Rocks: The most common non-detrital sedimentary rocks are limestones. Limestones come in two flavors, chemical and biochemical. The one requirement for all limestones is that they only form in warm, clear (sediment-free) water. Why? Warm water is required because the mineral calcite, $CaCO_3$, is soluble in cold water and precipitates in warm water. That's the reason why shells are scarce if at all present on the beaches along the northern Pacific coast of the United States and Canada or along the Atlantic coast of Newfoundland or Nova Scotia. If the water is warm, as it is between the Tropic of Cancer and the Tropic of Capricorn, the calcium and bicarbonate ions will often

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precipitate from solution in the form of fine-grained crystals to make up a carbonate mud which, in turn, will lithify to form a chemical limestone:

$$Ca^{2+} + 2(HCO_3)^{1-} \leftrightarrow CaCO_3 + H^{1+} + (HCO_3)^{1-}$$

The hydrogen ion, H^{1+}, and the bicarbonate ion, HCO_3^{1-}, combine to form un-dissociated carbonic acid, H_2CO_3, that decomposes into water, H_2O, and carbon dioxide, CO_2:

$$H^{1+} + HCO_3^{1-} \leftrightarrow H_2CO_3 \leftrightarrow H_2O + CO_2$$

Note the double-ended arrows in both reactions. This is a way that chemists indicate that the reaction can proceed in both directions. In this case, it depends on the water temperature. In cold water, the reactions proceed from right to left resulting in the dissolution of calcite. In warm water, the reactions proceed from left to right, resulting in the precipitation of $CaCO_3$.

Shelled animals such as clams, snails and coral have mechanisms within their bodies that result in the precipitation of calcite with which they construct their shells. This explains why shelled animals only thrive in warm water. The requirement for clear sediment-free water is that these animals have no way to eject sediment ingested into their bodies and they would choke to death. Another example of a carbonate rock is dolomite. The basic difference between the mineralogy of limestones and dolomites is that limestones are dominated by calcite, $CaCO_3$, while dolomites are dominated by the allied mineral dolomite, $CaMg(CO_3)_2$.

While there are other types of sedimentary rocks such as conglomerates and cherts, shales, sandstones and limestones are the kinds of sedimentary rocks you will most likely see exposed in the topography of West Virginia.

Weathering, Mass Wasting and Erosion

In order to understand how the topography evolves, we must first discus three processes that are involved, weathering, mass wasting and erosion. Because these three processes work hand in hand, I have decided to deal with them together.

Weathering: There are several definitions for weathering. One states that weathering is "*any reaction between the rock surface and the atmosphere*". This

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definition makes two points. First, only the surface of a rock that is exposed to the atmosphere will undergo weathering, not the interior. Think of sucking a cough drop; only the outer surface is being dissolved. It also indicates that weathering will go on anywhere the atmosphere can penetrate from minute cracks and crevasses in rocks to the interior of caves and caverns. Most importantly, it specifies that the agents of weathering are the gases contained within the atmosphere. Although it fails to indicate which gases are involved, that's up to me. What gases do you think are included? Perhaps by the end of this discussion you will be able to name them.

A commonly used definition for weathering and the one I prefer is that weathering is "*any process by which a rock either disintegrates or decomposes*". Disintegration is any process whereby a rock is broken into smaller pieces, explaining why disintegration is commonly referred to as physical weathering. Decomposition, on the other hand implies a chemical change from one assemblage of minerals to another. Note that it does not require that all of the minerals in the original rock be decomposed. Some minerals such as the quartz in granite will survive weathering while the feldspars are converted into the clay minerals and a variety of dissolved products such as potassium bicarbonate or into as a precipitate such as iron oxide. Obviously, such a process is referred to as chemical weathering. Although physical and chemical weathering can and do go on independently, more often they operate simultaneously.

Chemical Weathering: The two most common chemical weathering processes are oxidation and carbonation/hydrolysis. An example of oxidation that is often used in textbooks is the reaction between iron and oxygen gas:

$$4Fe + 3O_2 \rightarrow 2Fe_2O_3$$

As written above, the reaction states that a shiny iron nail exposed to pure oxygen at atmospheric temperatures will eventually turn into rust when, in fact, it will not. At atmospheric temperatures, oxygen gas is not an effective agent of oxidation; oxygen gas is only effective at high temperatures such as that attained in an acetylene torch. However, take the shiny iron nail and expose it out of doors for a relatively short period of time and rust will begin to form on its surface. What is present out of doors that was not present in the first equation? The

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answer: water. In order for oxygen to be an effective agent of oxidation at atmospheric temperatures it must be dissolved in water:

$$4Fe + 3O_2 + 2H_20 \rightarrow FeO(OH)$$

The first reaction between iron and dissolved oxygen gas produces the yellow mineral limonite, $FeO(OH)$. Upon being warmed, even by the sun on a warn summer's day, the reaction continues as the limonite undergoes dehydrarion (loss of water) resulting in the production of the red oxide, hematite, Fe_2O_3, commonly referred to as rust

$$2FeO(OH) \rightarrow Fe_2O_3 + H_2O$$

The combination of yellow limonite and red hematite are important in that they are the major coloring agents in many sedimentary rocks and soils. If you have ever gone on vacation to the tropics or even to the sub-tropics, you may have noticed that the soils were a bright red. This is because in the ever-hot, ever-wet conditions of the tropics or sub-tropics, the iron contained in many of the iron-bearing minerals in the rocks are oxidized, producing the bright red mineral, hematite. In many of the tropical countries of the world, the hematite in the soil becomes so concentrated that it is used as a source of iron ore.

Perhaps the most important process of chemical weathering is carbonation/hydrolysis. The "carbonation" portion of the process refers to the involvement of carbonic acid (H_2CO_3) while hydrolysis is any reaction involving water. Hopefully you are becoming aware of the importance of water. The importance of the carbonation/hydrolysis reaction is that carbonation/hydrolysis is the main agent in the decomposition of the major rock-forming silicate minerals except for olivine and quartz. We will comment later as to why these two minerals are not decomposed by carbonation/hydrolysis. To illustrate the reaction, I will use orthoclase feldspar, $KAlSi_3O_8$. The reactants in the process are orthoclase feldspar, dissociated carbonic acid and water. As an aside, I would like to point out that for any acid to become involved in a reaction, it must undergo what the chemists call dissociation. Dissociation separates the hydrogen ion, H^{1+} from the anion, in this case the bicarbonate ion, HCO_3^{1-}. The hydrogen ion is the acid ion:

$$2KAlSi_3O_8 + 2H^{1+} + 2HCO_3^{1-} + H^{1+} + OH^{1+-} \rightarrow$$

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The combination of $2H^{1+}$ and $2HCO3^{1-}$ is dissociated carbonic acid. The $H^{1+} + OH^{1-}$ is another way to represent water which also dissociates. The products of the reaction are:

$$\rightarrow Al_2Si_2O_5(OH)_4 \; + \; 2K^{1+} + 4H^{1+} + SiO_4^{4-}$$

Note first, that three ions are produced, K^{1+}, $4H^{1+}$ and SiO_4^{4-}; all of which are carried off in solution, eventually to the ocean. What is left behind are the clay minerals represented by the formula $Al_2Si_2O_5(OH)_4$. The clay minerals are the end product of all of the major rock-forming silicate except for olivine and quartz. Olivine, Fe,Mg)SiO_4, will not produce clay minerals because it does not possess the required aluminum. Quartz will not produce the clay minerals. In fact, quartz does not react with either of the two major chemical agents of chemical weathering, dissolved oxygen (it is already fully oxidized) or carbonic acid (there is no such compound as silicon carbonate). As to the importance of the clay minerals, without them you and I would not exist on Earth. The clay minerals are the major component of soil without which plants would not exist to provide much of our food. You will remember that they are also the major component of shales. The super-abundance in which the clay minerals are produced explains why shales make up 70% of all sedimentary rocks. Now for the question I posed at the beginning of this discussion, what components of the atmosphere are involved in chemical weathering?

Mass Wasting: The ultimate product of weathering is a layer of sediment above bedrock called regolith. As soon as regolith forms, the forces of gravity begin to move it downslope to the valley floor. Once the regolith reaches the valley floor, the work of mass wasting is over. In other words, mass wasting operates on slopes. Once the sediments contained in the regolith reach the valley floor, the process of erosion takes over. We will discuss erosion shortly.

There are few important points that I would like to make concerning the force of gravity. First, the force of gravity acts perpendicular to Earth's surface directed toward the center of the core. Here's a question for you. Will particles of regolith move on a horizontal surface? If not, why not? I learned the answer to that question in my first physics course. The answer is that in order for *any* particle to move on *any* surface, there must be a force acting parallel to the surface. Granted, the force of gravity is acting on a horizontal surface but in a direction perpendicular to the surface, not parallel to it. That's why even a perfect spherical ball or a drop of water will not move on a horizontal surface. Now, let's consider a particle resting on a non-horizontal slope. The force of gravity is still acting toward the center of Earth's core but there is another component of gravity operating downslope, the magnitude increasing as the angle of slope increases. This force is called the *"downslope component of gravity"*. Rather than repeating that definition, I choose to simply call it the "Go Force" since its what makes the particles of regolith "go" downslope. Simultaneous with the Go Force, there is another force referred to as the Force of Cohesion and Friction that operates opposite to the Go Force. Cohesion is the force that causes particles to stick together and friction, by definition, is the resistance to motion. As a result, the combination of cohesion and friction serve to keep particles in place. For that reason, I call it the "Stay Force".

Whether or not a particle will move downslope therefore depends on the relative magnitudes of the Go and Stay forces. Both forces vary in magnitude depending on the angle of slope. As the angle increases, the Go Force increases and the Stay Force decreases. As the angle of slope decreases, the opposite is the case. Theoretically, the two forces would be equal at an angle of slope of 45^{0}. However, experiments conducted on solid, irregular shaped particles (such as regolith) demonstrate that the balance is reached at about 40^{0} which implies that particles resting on slopes of less than 40^{0} will not move downslope while those resting on slopes of greater than 40^{0} will move downslope with a rate of movement increasing as the magnitude of the slope angle increases. Consider going backpacking. Hills and valleys await you. The fact that you can climb a hill tells you that the slope angle is less than 40^{0} and the Stay Force acting upon you is greater than the Go Force. Now consider trying to climb another slope where your climb consists of one step forward and two back. This tells you that the slope is just greater than 40^{0}. If you face a slope that is much steeper than 40^{0}, it's obvious that without help such as climbing gear, you are not going to be able to climb it. Consider what you observe on these three slopes. As you climb the first slope, do you see any evidence of regolith moving downslope? Probably not. Rock outcrops are probably absent and the surface is covered with vegetation, both grass and trees. How about the steeper slope? There may be exposed rock outcrops and evidence that rocks have rolled downhill and there may be evidence

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of a slumping or downslope sliding of the regolith. The base of the steep third slope would probably be littered with rock debris that has fallen from ledges of rock exposed in the face of the slope. It appears that everything is as it should be. But, there is a problem; while nothing seems to be moving downslope on the more gentle slope, mass wasting states that all particles resting on any non-horizontal slopes will move downslope. The fact is that for any particle to move downslope, the Go Force must exceed the Stay Force. But on a slope of less than 40^{O}, how could this be? This could only be accomplished on a slope of less than 40^{O} in one of two ways: 1) either increase the Go Force until it exceeds the Stay Force or 2) decrease the Stay Force until it was less than the Go Force. Can the Go Force be increased? In that the Go Force is a component of the force of gravity which, in turn, is determined by the mass of the particle, a property that cannot be increased, the Go Force cannot be increased. Can the Stay Force be decreased? Remembering that the Stay force is determined by cohesion and friction; the question becomes, can cohesion and friction be decreased? Think of your car's engine. What purpose does the oil perform? First, it keeps moving metal parts apart thereby decreasing cohesion and secondly, it reduces the friction between moving parts. If the engine was started without the presence of oil as a lubricant, the moving parts would heat up and seize in a very short period of time. The question then arises, is there a lubricant available in Nature that can be used to decrease the Stay Force? Have you ever gotten out of a shower or tub and slipped on a wet tile floor? Why are lifeguards at the pool always screaming "don't run!"! The reason in both cases is that a film of water between two surfaces will reduce both cohesion and friction. Water contained within the regolith serves as the lubricant that reduces both cohesion and friction and allows particles to move down slopes of less than 40^{O}. While there didn't appear to be any downslope movement on the gentler slope you were climbing, the fact is that over time, there was slow movement due to the presence of periodic rains reducing the Stay Force. Once again, we see the importance of water. In fact, mass wasting processes are classified based on the amount of water involved into flows, slides and falls.

Flows result with the addition of large volumes of water. An excellent example are mudflows in which fine-grained materials are saturated with water. An example is the mudflow that originated at the summit of Mt. St. Helens and flowed down the Toutle River destroying homes, farm buildings and bridges. Another example, perhaps not so violent, are the mudflows generated in slopes that have been clear cut of vegetation or bared by construction. One particular flow called solifluction forms in polar regions when the upper foot or so of a frozen soil thaws during a short summer. With nowhere for the water to drain, it totally saturates the soil which takes on the characteristics of a liquid and begins to flow down slopes with angles as low as 1^{O} to 2^{O}.

Slides require less water and depending on the particle sizes are referred to as rock slides, or debris slides. Such movements are usually restricted in the area involved but can still be highly destructive. A common type of slide that is experienced by many people, but who may be totally unaware of its presence, is a process called creep. As the name implies, creep is a slow movement of the upper layers of the regolith. During the non-freezing months, water permeates the soli and reduces the Stay Force to the point where during each rain event the top surface of the soil can move a short distance downslope, perhaps only a fraction of an inch. During the freezing months, ice crystals grow between the particles, a process called frost wedging. The growth force of the ice crystals lifts the particle perpendicular to the surface a millimeter or two. Then upon thawing, the particles drop straight down to a new position further down on the slope, again perhaps a fraction of an inch. The overall result of the effect of the lubrication by water and the frost wedging by growing ice crystals results in the slow downslope movement of the soil year-round. Where might you have seen the results of creep? The best example I can think of is the tipping over of poorly designed walls, fence posts angled downslope and the curvature of the lower portion of tree trunks.

Rock Falls require the least amount of water; just enough to permeate fractures in a layer of rock exposed in a road cut or cliff face. After perhaps a few decades of frost wedging, a large rock is broken from the exposed rock layer and falls to the base of the road cut of cliff. You have all seen the rock debris that accumulates along the roadway, especially during the Spring of the year when the final effects of perhaps decades of frost wedging take place. These are the places where drivers are warned “Beware of Falling Rocks”. Now to the final process that sculpts the topography you see, erosion and the process of erosion that is the most important, namely running water or streams.

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Erosion: Of the three major agents of erosion; streams, glaciers and the wind, streams are without doubt the most important. In that glaciers never entered West Virginia, we will omit any discussion of their effects as will we omit a discussion of the wind which is mainly effective in desert areas.

To begin our discussion of streams, I would like to introduce a concept referred to as the hydrologic cycle which describes the cyclic movement of water on Earth. The other reason I want to introduce the hydrologic cycle is to point out the effectiveness of streams as an agent of erosion. Everyone knows that most (70%) of Earth's surface is covered with oceans. The oceans are the source of the water that is distributed around Earth's lands. The water evaporates from the ocean surface, especially in the tropical regions, and carried inland by the prevailing winds. Most of the water delivered to North America is brought by the westerly winds coming off the Pacific Ocean with a lesser amount coming from the Gulf of Mexico. Look at a weather map and follow the eastward progress of the climatic highs and lows across the United States. Once over land, the moisture in the air can precipitate either as rain or snow depending upon the location and the season. The climate of a region is primarily determined by the amount of annual precipitation. Most of the United States east of the 100th meridian receives more than 20 inches of precipitation and is classified as humid. The highest precipitation, (>60 in) is in the region of the Mississippi Delta. Most of the rest of the country receives between 10 and 20 inches of precipitation and is classified as semi-arid with the extreme southwest receiving less than 10 inches, making it arid.

Some of the precipitation falls on Earth and freezes to form 5M mi^2 of glacial ice, 4M mi^2 of which covers 90% of Antarctica. A second ice sheet covers 80% of Greenland with an area of about 700,000 mi^2. The remaining 250,000 mi^2 is what is referred to as alpine or mountain glaciers distributed throughout the high mountains of the world. Unbeknownst to most individuals, 80% of all the fresh water on Earth is contained in glacial ice.

Once glaciers melt and when it rains, a significant amount of the water permeates underground and returns to the oceans by passing through porous and permeable rocks, mostly sandstones and limestones, as groundwater. Groundwater accounts for 20% of all the fresh water on Earth. I know, 80% plus

20% equals 100%. What it really means is that very little fresh water actually exists on the surface of Earth. Lakes contain only 0.7% of all the fresh water outside of the ocean basins. The major point that I would like to make is that streams represent only 0.005% of all the fresh water outside the ocean basins; a totally insignificant amount. However, this seemingly insignificant amount of water is responsible for most of the sculpting of the land accomplished by erosion. But, how is the work of erosion accomplished?

The amount of energy made available to a stream for erosion is determined by the combination of water volume and velocity, a parameter referred to as discharge. The energy is made available in the form of two kinds of water flow, laminar and turbulent. In laminar flow, the energy is directed downstream, transporting both the water and the sediments. In turbulent flow, the energy is allocated in two directions, 1) downstream to aid in the downstream transport of water and sediment and 2) vertically upward. The degree of turbulence is determined by the relative magnitude of the horizontal and vertical components; the larger the vertical component, the more turbulent the water. Question, can laminar flow erode? Remember, erosion consists of two steps, 1) picking particles up from the stream bed and 2) moving them laterally downstream after they have been picked up. The answer is, no, laminar flow cannot erode. Why? Because there is no vertical component of energy directed upward to pick particles from the stream bed. Laminar flow can only transport particles that have already been eroded. Can turbulent flow erode? Yes, because it has a component of energy directed upward to pick particles up and a horizontal component to transport them downstream. In summary, the ultimate goal of the combined processes of weathering, mass wasting and erosion is to reduce the land surface down to sealevel, pick up and transport the resultant sediments and deposit them on the clastic wedges that form along the continental margins where they are buried, lithified and re-uplifted to form a new landscape. But how is the uplift of the new landmass achieved? The answer is by a mountain building episode called an orogeny.

Appalachian Orogenies

Before we begin to discuss the evolution of the topography of Appalachia, we need to briefly review the tectonic history of the region. The Appalachian

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region was subjected to three orogenies or mountain building episodes. It was the combined results of these three events that determined the structures that underlie the region and, eventually, will determine the topography that we see today.

About 2 billion years ago, a super-continent formed about which we know very little except that it eventually broke apart to form an unknown number of continents. After surviving for the better part of a billion years, these continents began to converge on each other, collide and formed a second super-continent called Rodinia. Rodinia lasted until about 700 to 800 million years ago when it broke up, creating the lapetus Ocean (the predecessor of the Atlantic) surrounded by a number of continental landmasses. One of the larger continents , Laurentia, consisted of what is now North America and Greenland. Another large continent was Gondwana that consisted of most of the modern southern continents including Africa, South America, Antarctica, Australia and India. Two smaller continents were also involved in our early history, the Piedmont Micro-Continents and Avalonia.

About 425 million years ago, the lapetus Ocean began to close as a zone of subduction formed to the west of one of the Piedmont Micro-Continents. Eventually, the Piedmont Micro-Continents collided with the eastern margin of Laurentia during the Taconic Orogeny, creating a range of mountains along the eastern margin of Laurentia. Over time, the Taconic Mountains were eroded down to near sealevel. During the time the Taconic Mountains were undergoing erosion, another small continent, Avalonia, was making its way toward the eastern margin of Laurentia. The collision of Avalonia occurred during the Acadian Orogeny about 325 million years ago, forming another range of mountains along the eastern margin of Laurentia called the Acadian Mountains. While the Taconic Mountains were completely removed by erosion by the time the Acadian Orogeny began, remnants of the Acadian Mountains still existed when 250 million years ago the huge continent of Gondwana collided with Laurentia during the Alleghenian Orogeny, creating nearly all of the structures we see today throughout Appalachia. In addition to these three orogenies, there were other continent-continent collisions that occurred to form the super-continent of Pangea. One of these was Baltica that consisted of all of Europe from what is now the Atlantic eastward to the Ural Mountains, the unofficial dividing line between

Europe and Asia. East of Baltica, a number of smaller continents collided to form Asia. Pangea survived as a super-continent until it began to breakup about 200 million years ago, creating the continents we see today. What is important to our discussion is that the structures we see in cliffs and roadcuts throughout Appalachia are the result of the Alleghenian Orogeny. But what about the topography? We'll get to that in time.

Mountains and Hills

I'm sure that you've heard West Virginia referred to as "The Mountain State". Certainly, that would be the case if you were in the eastern portion of the State, either within the High Plateau along the easternmost edge of the Appalachian Plateaus, the Appalachian Mountains or the Blue Ridge Mountains. However, the greater portion of the State is not characterized by mountains but rather by hills. But what is the difference between a mountain and a hill? According to the Glossary of Geology, a mountain is *"a part of Earth's crust that is sufficiently elevated above the surrounding surface generally more than 1,000 feet (600 m), to be considered worthy of a distinctive name, characterized by a restricted summit and generally having steep sides and considerable bare-rock surface"*. In comparison, a hill is *"a natural elevation rising rather prominently above the surrounding land , usually of limited extent and having a well-defined rounded outline rather than peaked or rugged, rising to an elevation of less than 1,000 feet (600 m) "*. That being the case, the State would be more accurately called the "The Hill State". But ..... maybe not. Perhaps it should be called "The Valley State". Why? Because between any two hills or ridges there's a valley. Without the valleys, the hills or the mountain ridges would not exist. But the question that now arises is how do ridges, hills and valleys come about?

Davis' Concept of Topographic Evolution:

In the late 1800s and early 190s, William M. Davis, a geomorphologist (a geologist who specializes in the study of landscapes) was studying the landscape of the Appalachian Plateau. As a result of his studies, he formulated a concept that described the evolution of landscapes. While originally widely accepted, it was eventually disputed by the geologic community as newer theories took its place. While Davis' theory is little heard of today, I feel that his basic concepts can still be used to explain the evolution of landscapes.

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Davis considered his concept to be a cycle, in fact, referred to is as a "Humid Cycle of Erosion". He pointed out that there were two types of streams, exterior and interior. Exterior streams are those in which the water eventually flowed into the oceans. Nearly all of Earth's streams are exterior in nature. Interior streams are primarily located in semi-arid and arid regions. Interior streams head up in a highland and flow into a landlocked basin where they end either by having the water percolate into the groundwater, by flowing into temporary playa lakes which contain water only during the rainy season or by feeding permanent salt lakes such as the Great Salt Lake of Utah. An important part of his concept that still applies to the evolution of a landscape is that every stream system has a baselevel down to which the stream was attempting to carve its channel. He went on to specify that there were two types of baselevels, ultimate and temporary. Every stream system has only one ultimate baselevel. For exterior streams, the ultimate baselevel is sealevel. For interior stream systems the ultimate baselevel is the elevation of the basin floor or the level of water in a playa or salt lake. Above the ultimate baselevel a stream system could have any number of temporary baselevels which eventually disappear in time. An example of a temporary baselevel is a waterfall. Over time, the rock ledge that makes up the lip of a waterfall is undercut by erosion, breaks into pieces that fall to the base of the falls, resulting in the waterfall receding upstream and becoming lower. As the waterfall works its way upstream decreasing in height, it eventually becomes a rapids that progressively pass through what white-water enthusiasts refer to by numbers 5, 4, 3, 2, and 1 and finally become a riffles in the stream. With the elimination of each temporary baselevel, the channel will eventually be eroding toward the ultimate baselevel. In our discussion, we will only consider the approach of the stream channel to the ultimate baselevel.

Davis' cycle begins by the land being uplifted far above its ultimate baselevel. One of Davis' problems was that he didn't know exactly how the uplift took place. Remember, his work was done long before we understood plate tectonics and the forces generated by continent-continent collisions. It was such lacks of knowledge that resulted in his ideas to be set aside by the younger generations. While the descriptor "far above" provides little information, with what we now know about tectonics and mountain building, it could be 10,000 or more feet. With the surface of the land located far above the ultimate baselevel, Davis pictured all of the energy made available to the stream for erosion being expended in down-cutting. While

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the downward erosion by the stream would result in the formation of a slot-shaped valley, the combination of weathering and mass wasting acting on the valley walls would change the slot–shaped valley carved by the stream into the "V-shaped" valley Davis regarded as a "youthful" valley; a valley where the walls approximate the angle of repose. With such steep slopes, rock outcrops exposed along the valley walls would undergo physical weathering and fast processes of mass wasting and would contribute large rock particles to the bed load of the stream. Within the valley, the stream would occupying the entire valley floor, would have a steep gradient and would be highly turbulent. Why? Because the particles falling off the steep valley walls are large and require a high concentration of turbulent energy directed upward to pick them off the channel floor. Once contact with the channel floor has been achieved, a lesser amount of energy is needed to move the particles short distances downstream. It should be pointed out that most of the erosion accomplished by streams invariably takes place during floods when the total amount of energy is high. In addition to being highly turbulent, another characteristic of the youthful streams is that they possess numerous waterfalls that constantly work their way upstream, eventually forming rapids that continue to work their way upstream and eventually become riffles in the stream. With all of the streams in the region in the youthful stage, ridges separating the valleys are either flat-topped with sharp edges or merge along sharp crests. What overall descriptor would you give to a region with such a landscape? I think "mountainous" would be appropriate. Thinking again of a trip through West Virginia, the landscape of the Appalachian Mountains or the Blue Ridge would fit very nicely into Davis' "youthful phase" of landscape evolution and justify the descriptor "The Mountain State".

But time passes and as it does, the distance between elevation of the stream channels and the ultimate baselevel is reduced while the combination of weathering and mass wasting begins to modify the mountain ridges. Sharp ridgelines are changed into rounded, more subdued summits while the slopes on the hillsides are reduced to less than the angle of repose. Rock outcrops on the hillsides become fewer with some disappearing beneath increasingly thick layers of regolith. Soil begins to form and vegetation begins to carpet what eventually would be considered hills. In the valley, a very important change begins to take place. Where the streams in the youthful stage followed relatively straight channels, the

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steams in the valleys begin to move back and forth across the valley floor; a process called meandering. The initiation of meandering signals the end of youth and the entry into Davis' mature phase of landscape evolution. No one agrees as to what initiates the process of meandering but the effects become clear. As the meandering continues to develop, a floodplain forms and continues to widen the valley floor. The purpose of the floodplain is to temporarily provide extra space for the water and suspended sediments to accumulate when the stream, now increased in volume, goes overbank during floods. Within the stream, turbulence has decreased along with the sizes of particles being transported in the bedload. Waterfalls have begun to be converted into rapids and finally into riffles before they disappear. Suspended load has increased within the stream as weathering continues to attack and reduce the sizes of the bedload, creating increased volumes of silt- and clay-sized particles. As the clay- and silt-sized particles are taken into suspension, the water of the stream becomes murky. Eventually the bed of the stream can no longer be seen because of the sediment load. The landscape throughout most of the Low Plateau of western West Virginia would be an excellent example of maturity. No longer justified as "The Mountain State", West Virginia now becomes "The Hill State". But we must not forget that valleys separate all of the hills and ridges which would justify the title of "The Valley State".

Ultimately, the stream channels will approach the ultimate baselevel, creating a valley described by Davis as "many times wider" than the stream channel indicating that the valley has entered the "old age" phase of topographic evolution. Meandering is extreme to the point where during flood events, individual meander loops are cut off from the main channel to form ox-bow lakes. Once in class I commented that I didn't know the origin of the term "ox-bow" when a student raised his hand and informed be that the lake formed from the abandoned loop looked like the shape of the harness placed around an oxen's neck to which a plow would be attached. It's never too late to learn. In the Louisiana delta country, these lakes are called bayous. Levees commonly form along the banks of the old age streams in order to provide a deeper channel that serves to keep the water within the channel for longer periods of time. The presence of the levees result in the level of the water in the stream to be higher than the elevation of the adjacent flood plain. The floodplain commonly is the site of marshes and swamps. The hills between adjacent stream valleys are low; sometimes inconspicuous. An example

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of an old age surface would be the coastal plain that borders the Gulf of Mexico and much of the Atlantic shoreline. I don't think it would apply to the Great Valley whose surface is largely due to the fact that it is directly underlain by carbonate rocks that have been dissolved by the percolation of acidic rainwater.

But according to Davis, what he picture happening over time was a cycle of erosion which means that the process is able to return to a more youthful stage and begin another episode of down-cutting, a process referred to as rejuvenation. This could be accomplished by the elimination of a temporary baselevel resulting in the stream lowering its channel to the next lower baselevel as the channel to baselevel distance is increased. The ultimate cause of rejuvenation would, however, be another tectonic event that resulted in the land being uplifted "far above the baselevel". In fact, by Permian time, most of mountains that had been created during the Alleghenian Orogeny had been worn down to a relatively flat surface near sea level. Then about 60 million years ago, the entire eastern portion of North America from the mid-continent to the Atlantic coast was uplifted about 5,000 feet into a broad arch whose axis extended parallel to the NE-SW trend of Appalachia. Streams underwent rejuvenation and slowly carved out the topography we see today. What controlled the sculpting of the landscape was the structure of the underlying bedrock; primarily the folded structures and the reverse faults. The process of stream rejuvenation is still going on and will continue until the present surface of Appalachia is eroded down to near sealevel. So, as you drive across West Virginia and see the deformed rocks exposed in cliffs and road cuts, understand that they were deformed 250 million years ago during the Alleghenian Orogeny but that the topography you see surrounding you is the result of uplift and rejuvenation of the streams over the past 60 million years and the response of the surface rocks to the underlying structures.

In summary, even though Davis' ideas have been set aside by the geologic community, I think you can see around you landscapes that have the characteristics that we described in our sequence of events. Unfortunately, one of the important geologic attributes that Davis failed to include in his concept was the type and degree of deformation of the underlying rocks. It stands to reason that without an understanding of mountain building orogenies and the mechanism of plate tectonics, such an exclusion would be understandable. It was later that geologists considered the underlying rocks and the degree of deformation to which they had

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been subjected and incorportated them into what are called physiographic provinces.

The Physiographic Provinces

As a result of the effects of the Alleghenian Orogeny and the erosion that has gone on over the past 60 million years on the topograohy and structure of Appalachia, the region was subdivided by the geologists into physiographic provinces. By definition, a physiographic province is a *"large area all parts of which are characterized by similar features or by a history significantly different from that of adjacent areas"*. Appalachia, for example, has been subdivided into four physiographic provinces, the Piedmont, the Blue Ridge, the Valley and Ridge and the Appalachian Plateaus. The physiographic provinces extend from New York to Alabama and from the western edge of the Coastal Plain of the Carolinas and Virginia to Ohio, Kentucky and Tennessee. The major difference between the provinces is the deformation experienced by the underlying rocks during the Alleghenian Orogeny that occurred during the formation of the super-continent of Pangea and the effect these structures had upon the processes of weathering, mass wasting and erosion that sculpted the topography we see today.

The Piedmont Physiographic Province: The easternmost physiographic province is the Piedmont Physiographic Province. Although West Virginia does not extend eastward as far as the Piedmont Physiographic Province, I decided to include it in this discussion primarily to illustrate the variation in the degree of rock deformation that occurred across Appalachia from east to west resulting from the Alleghenian Orogeny. The rocks of the Piedmont Physiographic Province were located in the core of a continent-continent collision between Gondwana and what is now North America (Laurentia). The rocks that existed at the time underwent intense deformation in terms of folding, faulting and recrystallization. Because of the high degree of heat and pressure to which these rocks were subjected, little pre-collision history remains preserved in the rocks. Within the Piedmont, the combined effort of weathering, mass wasting and erosion eventually created a flat, featureless surface across which highly meandering streams carry sediments to the Coastal Plain where they are deposited to create the landward edge of the Atlantic clastic wedge. As one progresses from this zone of intense deformation westward across

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Central Appalachia toward West Virginia, the degree of deformation progressively decreases in intensity as the distance from the collision zone increases.

The Blue Ridge Physiographic Province: West of the Piedmont Physiographic Province is the Blue Ridge Physiographic Province that extends from southern Pennsylvania to norther Georgia and includes the easternmost portion of West Virginia. The rocks within the province are primarily igneous, metamorphic and meta-sediments ranging in age from Pre-Cambrian to Paleozoic. High displacement thrust faults (faults with dips less than 45^{0}) and highly overturned and recumbent folds reflect the proximity to the original collision zone. Rocks within the province are well exposed along the Blue Ridge Parkway. While the northern Blue Ridge Mountains average only about 10 miles wide with elevations rarely exceeding 4,000 feet (1,230 m), the southern Blue Ridge Mountains average 75 miles in width with more than 40 peaks having elevations in excess of 6,000 feet (1,829 m). The tallest peak in the Blue Ridge is Mt. Mitchel in North Carolina with a summit elevation of 6,684 feet (2,038 m). Much of the surface of the Blue Ridge Mountains is covered with a mixture of loose rock fragments and thin soils created by physical weathering. This combination of materials is highly prone to mass wasting, especially during episodes of high rainfall. In 1969, for example, 1,000 landslides were recorded when Hurricane Camille dropped 28 inches (70 cm) of rain within an 8 hour period.

The Valley and Ridge Physiographic Province: The next more westerly province is the Valley and Ridge Physiographic Province, located between the Blue Ridge Physiographic Province to the east and the Appalachian Plateaus Physiographic Province to the west. The Valley and Ridge Physiographic Province consists of three parts, the northern Hudson-Champlain Section, the Middle Section crosses parts of New Jersey, Pennsylvania, Maryland, Virginia and West Virginia and the southern Section that begins at the terminus of the Middle Section in southern Virginia and extends to the Gulf Coastal Plain in Alabama. The Middle Section incorporates much of eastern West Virginia and is the site of our most mountainous region.

The Middle Section is subdivided into two regions, an eastern portion known as the Great Valley Section and a western portion referred to as the Appalachian Mountain Section. The Great Valley or, what is commonly referred to locally as the Shenandoah Valley, extends about 1,200 miles from Quebec, Canada to Alabama.

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The Great Valley Section is underlain by Cambro-Ordovician carbonate rocks that have been brought to the surface by high-angle reverse faults (faults with dips in excess of 45^{0}) from deep below. The faults originated as offshoots called splay faults from near-horizontal, high-displacement thrust faults called decollments. The high displacement of these splay faults compensates for the shortening of the underlying basement rocks resulting from the collision of Gondwana and what is now North America. Because of the widespread exposure of water-soluble carbonate rocks within the Great Valley Section, the valley is characterized by surface features typical of karst topography such as solution and collapse sinkholes. In addition, there are underground systems of caves and caverns that have been formed by the dissolution of the carbonate rocks by the groundwater. Because of the soluble character of carbonate rocks, the topography of the valley floor is essentially flat lying except for a few ridges underlain by resistant rocks and the surface features of karst. Another characteristic of the Great Valley, and of most karst terranes, is that they are grasslands. This is due to the fact that the calcium ion released into the groundwater during chemical dissolution of the rocks is one of the primary nutrients of grasses. In fact, most of the plants that we use as food crops like calcium-rich limestone soils. The soils found throughout the Great Plains are examples of calcium-rich soils called mollisols. The presence of these soils plus the availability of abundant groundwater for irrigation has made the interior of North America one of the world's most prolific agricultural regions. Another type of plant that "likes" limestone soils are cypress trees that are abundant throughout the valley and are easily spotted along the Interstate crossing the valley. West Virginia lies within the southern section of the Great Valley which extends from Pennsylvania to Alabama. The southern section is bounded on the east by the Blue Ridge Mountains which includes South Mountain of Pennsylvania and Maryland, the Blue Ridge of Virginia, Holston Mountain in Tennessee, and the Great Smoky Mountains of North Carolina.

Appalachian Mountain Section: The dominant features within the Appalachian Mountain Section are high amplitude, parallel folds that progressively change from overturned to asymmetrical from east to west with high-angle splay faults commonly breaking the western, vertical limb of the folds. Most of the ridges are capped by quartose sandstones and conglomerates of the Tuscarora Formation while the valleys are synclinal structures underlain by weaker shales and water-

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soluble limestones. In many cases, tensional forces that develop along the axis of the folds as they are being exposed result in the formation of fractures running parallel to the ridge. These fractures allow water to enter into the interior of the fold where a combination of physical and chemical weathering remove the resistant cap rocks and expose the softer underlying shales. In time, the entire crest of a fold may be removed or "breached" creating an anticlinal valley. An excellent example of such a valley is Germany Valley located within the breached Wills Mountain Anticline in Pendleton County, West Virginia. On the western flank of the breached anticline, vertical outcrops of the Tuscarora sandstone forms the spectacular Seneca Rocks while on the eastern flank, the Tuscarora crops out along the crest of North Fork Mountain. In some cases where the erosion within the breached anticlinal structure has sculpted the surface down below the elevation of the synclinal valleys on opposite sides of the anticline, weathering, mass wasting and erosion leave behind a synclinal ridge; an example of which, Sideling Hill, can be observed where a gap has been cut through the structure along I68.

The Allegheny Structural Front: The boundary between the Appalachian Mountain Section of the Valley and Ridge and the eastern edge of the Appalachian Plateaus is a two-step escarpment. In Pennsylvania, the upper escarpment is capped at 2,800 feet (854 m) by an outcrop of the Pennsylvanian Pottsville Formation with the lower escarpment being formed by the exposure of the Mississippian Price Formation. To the south, in Virginia and West Virginia, the escarpment is known as the Allegheny Structural Front, named by Dr. Paul Price, then the Director of the West Virginia Geologic and Economic Survey. At this point, the Pottsville scarp rises to elevations of 4,600 feet (1,400 m). The lower scarp, underlain by the Price Formation and capped by the Greenbrier limestone forms a terrace partway down the Front called the Fore Knobs. To the south, at about 39^{0} north latitude the escarpment diminishes as the summits of the westernmost folds of the Appalachian Mountains rise above the elevation of the eastern edge of the adjacent Appalachian Plateaus Province.

Along US 50, you will come to the edge of the Allegheny Structural Front. The rock cropping out at the edge of the Front is the Pottsville sandstone, the major rock unit responsible for the Allegheny Mountains and the ruggedness of the topography of the High Plateau to the west. On a clear day, this is an excellent place

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to stop and view the ridges of the Appalachian Mountains to the east. In the foreground along Wills Mountain Anticline is an excellent example of a wind gap. It is said that Abraham Lincoln's mother was born just to the east of this gap. At this point, US 50 will begin its descent down the Front into the Appalachian Mountains. From the edge of the Front, the surface slopes steeply to the Fore Knobs. From there, the land again slopes steeply to the floor of the westernmost valley of the Appalachian Mountains. It is interesting to note that before the construction of I68/70, the inexperienced drivers of vehicles, especially semi-trailer trucks driving US 50 at night when visibility was limited, would reach the Fore Knobs and would think that they were at the base of the Front while, in fact, they had yet to descend the longest and steepest part. As they crossed the Fore Knobs, they would shift into high gear and begin the final descent. Soon they would realize that their speed was beyond control; it became impossible to downshift in order to reduce their speed. Now out of control, many vehicles would crash before reaching the bottom of the Front, often with disastrous results.

The Allegheny Plateaus Province: West of the Allegheny Structural Front lay the Appalachian Plateaus. As the name implies, there was more than one designated plateau; there are in fact five plateaus that differed in their topography. Of the five, the one that makes up most of West Virginia west of the Allegheny Structural Front is the Un-glaciated Allegheny Plateau that extends from the New York-Pennsylvania border southward to southern West Virginia and eastern Kentucky. Un-glaciated refers to the fact that the Pleistocene glacier never made it as far south as West Virginia. Within the eastern portion of the plateau from north-central Pennsylvania to Monroe County, West Virginia, the amplitudes of the folds within the plateau are high enough to be sculpted into ridges and valleys by the dendritic stream systems that characterize the plateaus. With elevations high enough to be classified as mountains, the folds within the High Plateau were named the Allegheny Mountains by the early settlers. The High Plateau exhibits ridges and valleys underlain by broad, symmetrical folds unlike the high amplitude, asymmetric and overturned folds of the Appalachian Mountain Section to the east. Although they were all formed during the collision zone of Gondwana and North America, the decreased in assymmetry of the folds of the High Plateau is due to the fact that they were formed further from the collision zone. In addition to the increased ruggedness of the topography, elevations within the High Plateau

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decrease from east to west, from a maximum along the eastern edge at the Allegheny Structural Front near where the broad arch reached its maximum elevation of about 5,000 feet to about 2,000 feet along the summit of the westernmost structure, Chestnut Anticline just east of Morgantown. The east-west variation in topographic elevation is due to the location of the axis of the broad NE-SW trending arch previously described that peaks along the eastern edge of the Un-glaciated Allegheny Plateau, making the edge of the plateau higher than any of the ridges of the Appalachian Mountain Section of the Valley and Ridge Physiographic Province. Within the High Plateau, not only are the major ridges capped by the resistant rocks of the Pottsville and Price (Pocono) sandstones, but the scattered outcrops of these rocks that begin to become exposed by erosion at the surface contribute to the ruggedness of the topography.

Along the western portion of the Un-glaciated Plateau, the compressive forces associated with the Allegheny Orogeny has diminished to the point that deformation of the underlying strata was limited to folds that are so broad and of such low amplitude that the strata are essentially flat-lying and have little effect on the appearance of the topography. Within this part of the plateau the topography is largely the result of the erosion due to dendritic streams. Because of the near-horizontal attitude of the rocks within the region, this part of the plateau is commonly referred to as the Appalachian Low Plateau.

Until the up-arching occurred of Appalachia began 60 million years ago, the topography that had been created by the continent-continent collision of the Allegheny Orogeny 250 million years ago had been erased by the combined efforts of weathering, mass wasting and erosion and worn down to near sealevel. As a result of the arched uplift, streams throughout the region were rejuvenated, sculpting a new topography largely controlled by the subsurface folds and faults. As a result, as one crosses the Central Appalachians today along I68/70, the structures one sees in the roadcuts and cliff faces date back 250 million years to the Allegheny Orogeny while the topography one sees is the result of uplift, stream rejuvenation, weathering, mass wasting and stream erosion that began 60 million years ago; a process that is still going on. As you cross West Virginia from east to west, the changes in topography you observe is the result of crossing from the Blue Ridge Province, across the Valley and Ridge Province and the Un-glaciated

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Applachian Plateau, each with its own rock types, underlying structures and resultant topography.

In summary, you now understand why as you travel across western portion of the State, the hills are subdued, round topped with relatively gently slopes. As your trip heads eastward on I68/70 between Chestnut Ridge east of Morgantown and Frostburg, you are within the High Plateau where the hills become more dominant and linear; ridgeline become less subdued and the slopes on the ridges begin to increase. In addition, a number of the anticlinal folds within the High Plateau such as the Blackwater Anticline have been breached, creating the anticlinal Canaan Valley floored by the Greenbrier Limestone. After crossing one of the most dominant structural features in Appalachia, the Allegheny Structural Front, you descend into the Appalachian Mountains with their long, parallel, asymmetric to overturned anticlines capped by the most resistant rock unit in the region, the Tuscarora sandstone. Then on across the broad Great Valley underlain by very old carbonate rocks brought to the surface by steep, high displacement reverse faults and finally end your trip as you cross the Blue Ridge Mountains onto the Piedmont Province. The variation in the effects of weathering and erosion of sedimentary rocks cause the removal of the weaker rocks, leaving behind the more resistant rocks topographically higher than the weaker rocks. Sandstones and conglomerates, being more resistant to erosion than shales and carbonate rocks, result in the formation of conspicuous ridges or mesas while shales and carbonates typically form valleys and lowlands. There is, however, another factor that determines the effects of weathering and erosion on the topography; that factor is the structure of the underlying rocks; in particular, their folding. Within the Low Plateau where the underlying rocks are essentially horizontal, the lack of structural guidance results in the development of dendritic drainage patterns; patters similar to the veins in a leaf. Drainage divides are randomly divided between adjacent dendritic drainage basins. If the amplitudes of the folds within the underlying rocks are sufficiently high, the strike and dip within the sequence of rocks determines the direction of the drainage pattern as high and low resistant rocks are exposed in parallel strips. Ultimately, the excavation of the low resistant rocks within the valleys leaves the resistant rocks standing in relief and results in a topography consisting of parallel ridges and valleys. If a resistant rock layer, most likely a sandstone, is exposed within the

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limbs of an anticlinal fold, the resistant rock layer will stand out as a monoclinal ridge called a hogback. Exposed anticlinal folds will result in the formation of an anticlinal ridge. As erosion attacks these ridges, increased fold amplitudes stimulate more rapid erosion along the axis of the fold until the resistant rock at the crest is breached.

Natural Resources – Fossil Fuels

Early History: While other states may have rich deposits of iron ore, gold and silver, West Virginia's wealth lies in coal, oil and natural gas. Just as certain regions of the world such as the Middle East seem to be endowed with an excess of oil, West Virginia has been endowed with more than its share of coal, oil and natural gas.

The history behind the development of our fossil fuel resources is an interesting one. It began in 1774 when a Shawnee raiding party captured a settler in southern West Virginia. During the time he was imprisoned in their camp, he saw them making salt from water collected from salt-rich springs located along the Kanawha River. The source of the salt were beds of salt at depth that accumulated during Silurian time. The natives would collect the salt water or brine, bring it back to their camp and evaporate the water in kettles over wood fires to acquire the salt that began to precipitate as the water evaporated. Salt is an absolute requirement in our diets; without it our nervous system would not function. You might remember that salt was so valuable that the Roman soldiers were paid in quantities of salt rather than in gold or silver. Eventually, the settler escaped and brought the information about the salt springs back to his fellow settlers. In 1797, the settlers built their first wood-fired salt furnace using the brine from the salt springs. In a short amount of time, the salt furnaces in southern West Virginia was the main supplier for the salt of settlers who were moving west. By the early 1800s, the amount of brine being provided from the springs did not fill the needs of the new industry. As a result, in 1808, wells began to be drilled to intercept the rising brines. By the mid-1800s, more than 50 brine wells were operating along the Kanawha River. By 1846, the production of salt exceeded 5 million bushels. By 1942, brines were being produced by pumping hot water down into the salt-rich strata at depths of 7,000 feet (2,100 m) to dissolve the salt. Today, three salt-producing companies still operate in West Virginia; two in Marshal County and one in Tyler County.

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Coal: It wasn't long before it was recognized that the heat potential provided by burning wood was not enough to maintain all of the salt furnaces. I might add that this was the same problem faced by operators of James Watt's steam engine when burning wood was first used as the source of heat. In both cases, in order to acquire an adequate amount of heat, the source of heat turned to the burning of coal which was plentiful in both regions.

By 1817, coal was being mined in West Virginia in drift mines dug back into outcrops of coal beds exposed along hillsides. At the same time, coal was already being mined along the Ohio River and used to fuel local industries and to heat homes. While the Civil War halted the production of coal within southern West Virginia and Kentucky, it continued to be mined in the north to provide the energy needed to maintain essential industries and for the railroads. Following the end of the war, investments in coal production increased in the north while the building of the C&O railroad opened up the production of coal from southern West Virginia and Kentucky. In the north, the Fairmont Coal Company opened a mine near Fairmont where it mined the Pittsburgh coal. Today, the Pittsburgh coal accounts for 25% of the total coal production of West Virginia. In 1901, the Fairmont Coal Company became Consolidation Coal Company. Today, three state vie for the major producer of coal in the United States; West Virginia, Kentucky and Wyoming.

Oil and Gas: In addition to the brine springs, early settlers in southern West Virginia discovered vents commonly referred to as "burning springs" that released natural gas. In 1775, George Washington was supposed to have visited one such vent along the Kanawha River. As wells began to be drilled for brines, it was not uncommon for the wells to encounter shallow reservoirs of oil and gas in addition to the brine. To the brine drillers, the gas and oil was of no value. The gas was flared off while the oil was separated from the brine and disposed of in some nearby stream – the first example of environmental pollution. While of no value to the brine drillers, there were entrepreneurs who saw value in the oil. Some of the oil was collected and used as a lubricant or, would you believe it, bottled as a patent medicine. Patent medicines were big business of the day, as they still are. A brine driller, Sam Kier, was said to have bottled a distillate from the oil laced with alcohol and sold it as "Kier's Elixir". It was later discovered by a professor of chemistry at Yale University by the name of Silliman that a goodly portion of his elixir consisted of a fast-burning, clean-burning liquid called kerosene. This single discovery was to

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change the world of fossil fuels. At the time, homes were lit by candles, or if one were wealthy, by oil-burning lamps fueled by whale oil; a very expensive commodity that only the wealthy could afford. In the early 1800s, Nantucket, Massachusetts, was the world's center for whaling. The discovery that kerosene could replace whale oil in oil lamps led to the demise of the whaling industry in the United States. By 1870, only a few whaling ships made port in Nantucket. But in the meantime, a new industry was born; the manufacture and sale of kerosene for lamps.

Once it was discovered that the oil could be refined to make kerosene, oil wells began to be drilled everywhere. It is often said that the first well drilled specifically for the production of oil was the Drake Well outside of in Titusville, Pennsylvania. That may be true, but in 1859, the same year the Drake well was completed, a brine well along the Little Kanawha River was already producing 200 barrels of oil per day. Shortly thereafter, another brine well was producing 1,200 barrels of oil per day. West Virginia was soon in the forefront of oil exploration. In the early days of petroleum exploration, little science, if any, was used to locate the most likely place to drill a well that would produce a commercial quantity of oil. Anyone with a rig and the desire could go out and drill a well. Such individuals were called "wildcatters". The name referred to a wildcat well which is the first well to produce oil in any region. The most well-known wildcatter in the Tri-State region was a West Virginian by the name of Mike Benedum. Born near Bridgeport, West Virginia, and with little education, Benedum had a dream of striking it rich. Which, totally without the aid of science he did. He eventually established the Benedum-Trees oil Company and before he died, recognizing the importance of education, he saw to it that a goodly portion of his estate would be used for education. I suspect that there are not many colleges and universities in the Tri-State region that don't benefit from the Benedum Foundation. For those who may be interested, a book entitled "The Great Wildcatter" describes his life as an oil man.

The first introduction of science into the realm of oil exploration came in 1883 when Dr. I. C. White, founder of the West Virginia Geological and Economic Survey and first chairperson of the newly established Department of Geology at West Virginia University published a theory concerning the most likely place for oil and gas to accumulate. Because both oil and gas were of lower density than water, Dr. White proposed that both would collect in the crestal portion of anticlines. His

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"Anticlinal Theory" proved to be correct. Applying his theory, White discovered the Mannington Oil Field and made a fortune. Using his theory other operators became more successful at finding commercial deposits of oil and gas. While more complex reservoirs now exist, most of the oil and gas produced during the early decades of the petroleum industry was from the crests of anticlines.

Largely because of the demand for kerosene, the petroleum industry grew rapidly throughout western Pennsylvania, Ohio and West Virginia. An employee in one of the refineries in Ohio that converted the oil into kerosene recognized that whomever controlled the refineries could control the entire industry. Such a person could dictate the price of oil, the transportation costs to deliver the oil from the wells to the refinery and the cost of the kerosene. So by techniques that were often described as not too kosher, he began buying up refineries. Eventually, he owned the great majority of all the refineries in the Tri-State region. That person was John D. Rockefeller. He was making a fortune making kerosene for oil lamps.

Then in 1895, Thomas Edison invented the light bulb. At the time, Thomas Edison and Nikola Tesla were at odds over the best method for the production of electricity. Edison was a proponent of DC current (direct current) while Tesla believed AC current (alternating current) was by far the better of the two. As it turned out, Tesla was correct. A major problem with Edison's DC current was that it could only be transmitted up to a mile from its source while Tesla's AC current could be transmitted by wires over long distances. When Tesla won his battle with Edison as to whether the source of electricity should be AC or DC, the country began to be electrified with Tesla's AC current and everyone wanted electric lights. The demand for kerosene plummeted. Rockefeller was on the verge of bankruptcy when in 1908, Henry Ford introduced the Model T Ford that ran on a gasoline engine. It was not difficult to switch refineries from producing kerosene to producing gasoline. Rockefeller was spared from financial disaster. He formed Standard Oil of Ohio which as considered a monopoly by the US government and soon broken up. He was allowed to keep a portion, Standard Oil of New Jersey which eventually became ESSO (which still exists outside of the United States) which, in turn, converted to EXXON until they bought out Mobile Oil to become EXXON/MOBILE. The rest is history. It remains to be seen what future lies ahead for the fossil fuels.

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The Future: today, the coal industry is facing difficult times. Since the introduction of the EPA Clean Air Act, coal burned in coal-fired power plants must be what is called "compliance coal" meaning that the total sulfur content must be less than 1.2%. All of the coal mined in southern West Virginia, Kentucky and Wyoming are compliance coals and can be burned without any pre-treatments. Unfortunately, the coals from northern Weast Virginia are not compliance. The Pittsburgh coal that represents 25% of the total production of coal in West Virginia has an average sulfur content of 2.1%. To use such coals in power plants, the coals must either be "cleaned" or the power plant must employ scrubbers or getters to remove the effects of the SO_3 gases that are produced when the coal is burned. The source of sulfur in most non-compliance coal is pyrite, FeS_2. Cleaning entails grinding the coal into a fine powder and subjecting it to a float-sink process which allows coal particles void of pyrite floats while those with dense pyrite grains sink. The cleaned coal is then separated. Those "cleaned" coals that still contain sulfur in excess of 1.2% can be "blended" with high quality coals that are compliant until the sulfur content is reduced to below 1.2%.

The problem with burning non-compliant coals is the generation of SO_3 gas:

$$2S + 3O_2 \rightarrow 2SO_3$$

If allowed to enter the atmosphere, the SO_3 gas reacts with water in the atmosphere to produce sulfuric acid which, in turn along with NO_3 from gasoline powered engines are the major source of acid rain:

$$SO_3 + H_2O \rightarrow H_2SO_4$$

In order to remove SO_3 gas generated in the firebox, a "scrubber is placed between the firebox and the exhaust stack. The gas stream is than "scrubbed with a solution of $Ca(OH)_2$, producing $CaSO_4$, an inert mineral anhydrite and water:

$$SO_3 + Ca(OH)_2 \rightarrow CaSO_4 + H_2O$$

With no SO_3 gases being vented to the atmosphere, acid rain will not form. All coal-burning power plants built since 1985 are required to install scrubbers. The NO_2 that forms nitric acid, HNO_3, when reacted with water is removed from gasoline emissions by catalytic converters.

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The latest technology for the removal of SO_3 from coal-burning power plants gases is the use of "getters". The commonly used getter is powdered limestone, $CaCO_3$, that is added to the firebox along with the fuel in proportion to the sulfur content of the fuel. In the firebox, the $CaCO_3$ decomposes thermally into CaO and CO_2. The CaO interacts with the SO_3 as it is being formed to form $CaSO_4$ which, once again is inert anhydrite that is removed with the ash:

$$CaO + SO_3 \rightarrow CaSO_4$$

Between the use of coal cleaning, scrubber or getters, the air pollution problems involved with coal-burning power plants will be a thing of the past.

The latest development in the production of petroleum products is the production of natural gas from deep, low permeability organic-rich shales. The presence of deep organic-rick shales has been known for quite some time. The problem has been that the shale formations are "tight", meaning that the permeability is very low. Recent developments in the process of fracking has allowed high-pressure liquids to be introduced into these formations to create permeability and allow the release of enormous volumes of natural gas. Because the volume of shale worldwide is far greater than that of sandstones and limestones, they are the logical source of future sources of natural gas. For example, a single fracked Marcellus shale well outside Morgantown produces all the natural gas used by the city in a year. The production of natural gas from fracked wells has elevated the United State to the number one producer of natural gas in the world. For a world once considered to be facing a future without petroleum, the future does not look so bleak. Admittedly, there are still problems that must be solved involving the fracking process, but that is simply a question of time.