Conceptual Understanding Series for West Virginia Teachers

Weathering, Mass Wasting, Erosion, and Landscape Change

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FORWARD

The following is taken directly from page iv of the online version of the West Virginia Department of Education's Policy 2520.3C Next Generation Content Standards and Objectives for Science in West Virginia Schools:

"The Earth and Space Standard is a content standard which spans kindergarten through high school and provides opportunities for students to investigate processes that operate on Earth and also address its place in the solar system and the galaxy. The standard encompasses three core ideas: Earth's Place in the Universe; Earth's Systems; and Earth and Human Activity. Beginning in kindergarten, students make observations, ask questions, and make predictions as they describe patterns in their local Weather and Climate. In later grades, the content progresses to include these topics: Space Systems: Patterns and Functions; Earth Systems: Processes that Shape the Earth; Earth's Systems: Space Systems: Stars and the Solar System; History of Earth; and Human Impacts. Elementary students observe and investigate matter and processes in their own yards and neighborhoods with their own eyes; the content continues in the grades that follow to include investigations of invisibly small phenomena to the unimaginably large and distant. As students investigate the atmosphere, hydrosphere, geosphere, and biosphere, they gain understanding of the differing sources of energy, matter cycles, multiple systems' interconnections, and feedbacks which cause Earth to change over time."

A search of the document itself finds only three standards related to weathering, mass wasting, erosion, and landscape change:

S.4.GS.11 - identify evidence from patterns in rock formations and fossils in rock layers to support an explanation for changes in a landscape over time.

S.4.GS.12 - make observations and/or measurements to provide evidence of the effects of weathering or the rate of erosion by water, ice, wind, or vegetation.

S.9.ESS.10 - plan and conduct an investigation of the properties of water and its effects on Earth materials and surface processes.

To a geological educator, this lack of attention to the dynamic processes of geomorphology that carve and sculpt West Virginia's landscape seems odd. These events occur around us every day. They are observable in both human lifetime and history and provide insights to even older landscapes. They are not as dynamic as extinction level meteorite impacts, volcanic eruptions, or earthquakes, yet they are powerful enough to mute the landscape created by such activity.

It is important that such forces be included in any study of Earth and of the place called West Virginia.

Special note: Due to State budgetary constraints, this product represents one of the last items to be prepared, edited, and placed on this webpage. I would appreciate a note referencing any mistakes made in my haste to complete the work.

Tom Repine
WVGES Education Specialist

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Introduction

To a geologist, Earth’s landscape is an ephemeral surface expression of the more permanent underlying bedrock geology. Look at the towel in Figure 1. This upper part of the towel very much mirrors the rolling and undulating topographic surface etched into the nearly horizontal rocks of West Virginia’s Plateau Province while the bottom resembles the linear ridges found in West Virginia’s Valley and Ridge Province. Can you mentally track the path water would flow over such a surface? Can you see that there are two different flow patterns? And, can you mentally image how weathering, mass wasting, and erosion would operated in such diverse landscapes?

Gravity, flowing water perpetuated by a humid environment, and the orientation of the underlying sedimentary rocks are the driving forces that form our landscape. Wind plays its part in more arid areas and ice shapes the land in areas of sustained cold. But for us, flowing water is the key.

Can you imagine how the underlaying rocks influence their topography? The answer is all about gravity and the preferred flow direction of streams. Surface water trying to traverse the essentially flat bedrocks of the Plateau can find no preferred direction of travel. It roams seeking cracks and fractures in the rock to establish a confined pathway. As a result, the weathered surface becomes one etched by a dendritic valley pattern surrounded by rolling and rounded hills of nearly uniform height. In contrast, the folded and faulted rocks of the Valley and Ridge provide more readily accessible pathways as less resistant shales are weathered and removed to produce long linear valleys. This results in the regions pronounced trellis drainage pattern with water gaps forming where streams erode uphill into their headwaters area until the break through and capture the headwaters of a neighboring stream. Where such action has occurred and water is no longer present, these gaps are referred to as wind gaps, but here, in West Virginia, they were not made by the action of wind. In our modern age, these gaps serve as railway and highway conduits to reduce travel time across local ridges.

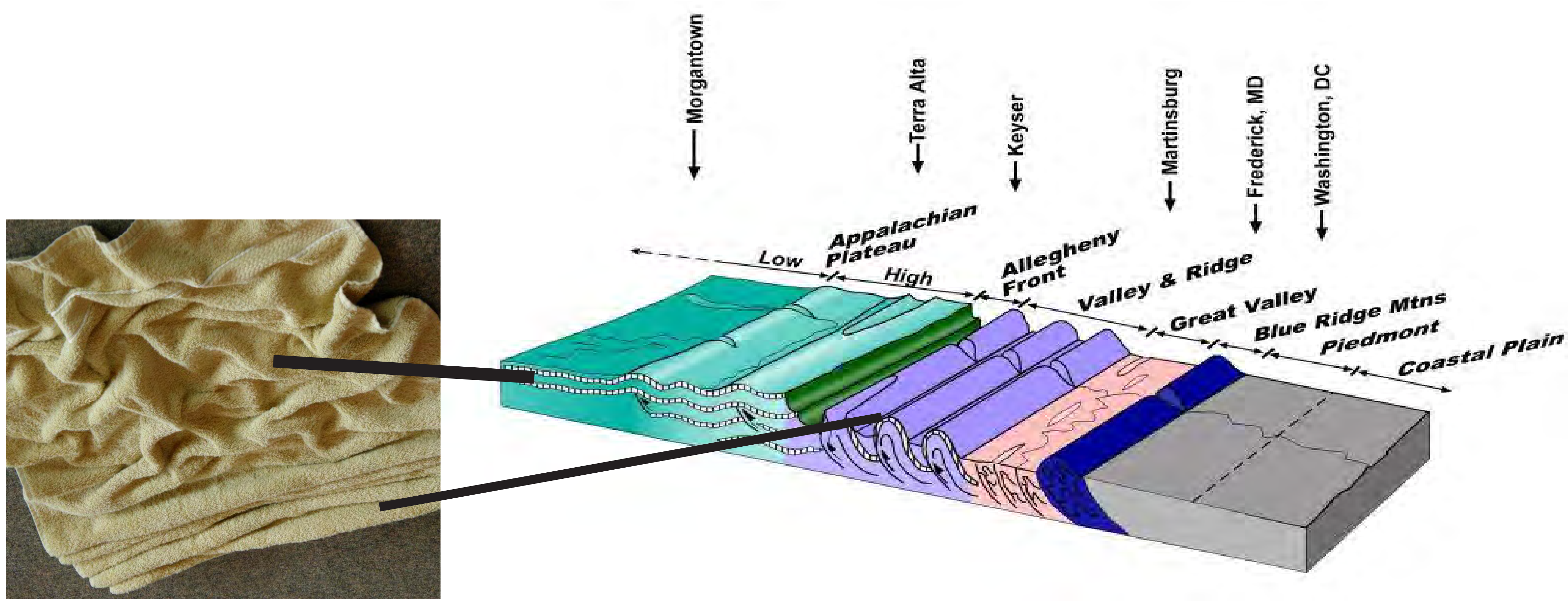


Figure 1.

The best place to begin is for you to assess your own prior knowledge. How does a stream do and accomplish work? How does it generate force and acceleration? If you have ever tried to wade a swiftly moving creek you have most likely experienced the work potential of a mass of gravity-accelerated water. Do the following statements sound familiar: “Work equals force times acceleration” and “Force equals mass times acceleration.” When does a stream actually accomplish the work of weathering? Does weathering by flowing water occur continuously? Do you understand the underlying mechanism of why a flooding stream actually does work more effectively than the same stream on an average day? Will your explanation correctly go beyond water velocity and get to the real heart of the process? These are the topics we wish to examine in the next few pages.

Imagine water flowing downstream from its headwaters to its mouth. Your visualization of the headwaters region most likely includes rushing mountain streams and waterfalls while the distributary system at the stream’s mouth is pictured as a series of sluggish, meandering, sediment clogged, stagnant waters. What does this image, which your student will most likely share with you, suggest about water velocity? Is it higher upstream than downstream?

If you need help, consider the marching band analogy. Can you visualize the chaos that would ensue if the back ranks of the band marched faster than the front ranks? They would start to overrun those in front. Now translate this image to water moving downstream. If the velocity of the water were to decrease as a stream approached its mouth, the water would pile up on itself at some point. In other words, the stream would be in a constant state of flood. Everyday observations tell us this is not the case and observation of raging flash flood waters overflowing their banks clearly implies that not only volume has increased, but that the faster moving flood water is piling up as it encounters slower water downstream. Thus, under normal conditions, water velocity must increase down stream. This is even more important as more water, accumulated from tributaries, increases the streams water volume. That sluggish looking flow you see downstream is deceptive and dangerous.

WEATHERING

In its simplest terms, weathering is any reaction, either physical or chemical, that occurs at the interface between a rock’s surface and the atmosphere such that the rock disintegrates or decomposes. According to the *Glossary of Geology*, disintegration is “any process that breaks down rocks into fragments”. This is commonly referred to as physical or mechanical weathering. The *Glossary* goes on to define decomposition as “any chemical reaction that transforms rocks and minerals into new chemical combinations that are stable under the existing conditions”. This would be chemical weathering. By using definitions we have established that there is a difference between physical (mechanical) weathering and chemical weathering, but we all know that definitions rarely help a learner conceptualize. We are going to try to remedy that as we explore physical weathering.

Quick demonstration: pour some water on a flat table top and observe its preferred direction of travel. Incline the table top ever so slightly and repeat. This time the water has a preferred flow direction. The mimics what happens when surface water flows over flat-laying or tilted and faulted sedimentary rock in West Virginia.

Speed is distance traveled over time. 60 mph is speed. Velocity is a vector quantity requiring direction. Velocity is 60 mph south. When discussing stream flow, the assumed direction is downstream. Thus the direction vector is assumed and stream velocity may be used as a correct descriptor. Besides, stream speed sounds strange!

Pores are the open areas between sediment grains or mineral crystals. Think of it as throwing styrofoam balls into a clear container. There will be naturally occurring spaces between the baseballs, which you can see, because the spherical shape limits the balls abilities to pack tightly together. The porosity of a rock will vary by the shape of its component parts.

PHYSICAL WEATHERING

What natural processes have the potential to break solid rock into smaller pieces? On the microscopic scale, most, but not all, the sedimentary rocks common to West Virginia contain pore spaces. Some pore spaces contain nothing, others may contain water, gas, or oil. If the rock resides in a location where the water can be frozen, disintegration may occur due to ice expansion. On the macroscopic scale consider the daily temperature changes that can occur during winter in places like Spruce Knob (Figure 2). During the day solar energy may partially melt ice and snow laying on a rock. A small portion of this meltwater seeps down into existing fractures in the rock. Some of it enters the pore spaces. Most is contained within the open fracture. As the temperature drops over night, or during a longer period of sub-freezing weather, the water freezes. The expansion associated with the change from liquid water to solid ice produces stress within the rock. To accommodate the stress, the pores and fractures must enlarge. When the water melts the newly enlarged dimensions remain. Each freeze/thaw cycle produces a minute adjustment, making more space for the accumulation of more liquid water, which, when frozen, contributes to a greater cumulative expansion. This cyclic freezing and thawing of water within a rock is called frost wedging. Like most slow geologic features, it is relentless and it will eventually break a fragment of rock loose, eventually producing an area of jagged and broken rock fragments of varying sizes like those seen on Spruce Knob. In West Virginia, frost-wedged sandstones and limestones can produce dramatically larger boulder-sized rocks that occasionally roll into the road. Frost-wedged shales, such as those that proliferate our road cuts, normally break into small prices which fall to form talus (scree) sediment piles (Figure 3).

Figure 2.

Biology also contributes to physical weathering. You've probably seen it so much that it doesn't even register anymore. Or, maybe you never really stopped to question what you were seeing. In either case, we're talking about plant roots and rootlets actively penetrating rock looking for water and nutrient minerals. As the root grows in diameter it generates stress similar to that developed when freezing water expands. In order to give burrowing animals equal press, we would point out that they promote weathering by allowing the atmosphere to penetrate below ground level.

Figure 3.

A quick simulation of physical weathering might be the breaking of a rock with a hammer. A demonstration of chemical weathering is pouring a drop or two of 5% hydrochloric acid on a piece of limestone. Safety first—wear the goggles!

Weathering goes on anywhere the interface between rock and atmosphere is present. Freeze/thaw, frost wedging, and root wedging are physical explanations of the mechanical process that breaks a rock into smaller pieces. Sometimes a large rock just breaks when it falls or moves downslope rapidly. This is known as mass wasting, a term which is both descriptive and scientific. If observed in person and in real time, this movement may be impressively dramatic. A landslide is a type of mass wasting. The rock falls (Figure 4) and hillside slumps and collapses (Figure 5) that plague West Virginia are examples of mass wasting. Not only to these action impose landscape change, they also modify human activity.

Figure 4.

Figure 5.

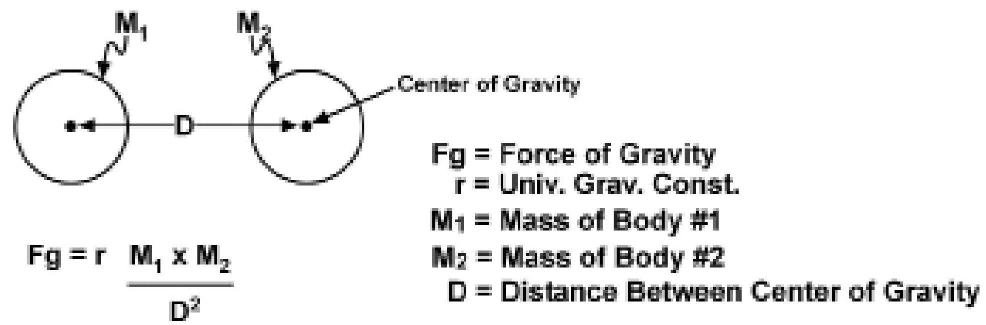
Before we go any further, it might be best if we actually provide you with the reason mass wasting happens. It may not be something you wish to include in your classroom presentation but it will provide you with a more solid understanding of how the weakest of the four basic natural forces modifies landscape.

Frost wedging may work year round in hot desert areas where vegetation is sparse and the rocks are exposed to solar energy. During the day these rock surfaces may become quite hot. Rock is a very good thermal insulator (think bricks). While the rock surface is hot, it stores very little heat energy internally. After sunset, the surface heat quickly radiates out into the atmosphere. Even following a hot summer's day, it is not uncommon for nighttime temperatures in a desert to drop below freezing, forming ice within the rock pores. In many dry areas, the desert landscape is attributed to the power of scouring wind and the action of frost action is overlooked.

PHYSICAL WEATHERING: GRAVITY AND MASS WASTING

An appreciation of what constitutes mass wasting requires a rudimentary understanding of the force that moves material downslope, i.e., gravity. Most students come to your classroom with some prior knowledge of gravity. They may have been exposed to the long perpetuated myth of the apple hitting Isaac Newton on the head. The Newtonian Physics that came out the apple incident became a foundational scientific law mathematically demonstrating that, at the macroscopic level, bodies are attracted to each other by an unseen force (gravity) that functions as an interaction of each bodies mass over the distance between them. Gravity applies to any number of bodies but for our situation we will need to look at what is called the "two-body gravity equation."

The gravitation attraction between two bodies, in our case a rock on the surface of Earth, and Earth itself, is denoted by the equation depicted below:



Since the “G” is a constant, the formula is sometimes simplified to a more understandable word statement that states: “The force of gravity (F_g) is proportional (..) to the mass of body one (M_1) times the mass of body two (m_2) divided by the square of the distance between the center of each object (r^2). This can be represented as follows:

$$F_g \propto \frac{M_1 m_2}{r^2}$$

Breaking this statement and the equation into smaller chunks helps to clarify its true nature.

Chunk #1: Mass is the fractional numerator. This means that the force of gravity is directly related to the mass of the bodies. “Directly” is the key word because any change in mass will produce a similar change in gravitational force. For example, an increase in mass increases the force of gravitational attraction.

Chunk #2: Since the two masses are multiplied together, the equation is telling us that the bigger the combined masses the more powerful the gravitational force. One mass may be small and the other huge but multiplying them together is the important part.

Chunk #3: Distance is the fractional denominator. Thus, an indirect relationship exists between gravitational force and distance. They change in opposite directions, as one increases, the other decreases. For example, increasing distance decreases gravitational force.

Chunk #4: Distance is squared. Any change in distance between the two bodies, because it is squared, must produce a drastic change in gravitational force. Stated another way, gravitation force will decrease dramatically as distance increases while gravitational force will increase rapidly as distance decreases. Have your students use the equation to run some simple mathematical simulations to prove this indirect relationship and to help them see the dramatic change distance makes.

Caution! Remind students that size may not relate to mass. A large gaseous object could have significantly less mass than a smaller rocky object.

The facts do involve a falling apple but Newton was not under the tree. The tree was actually located outside a window at his parent’s home where Newton had gone to escape the bubonic plague ravaging London in the late 1600’s. While sitting at his desk, he noted that every time an apple fell from the tree, it fell straight down. Never at an angle. From his simple observation emerged a profound deduction: there had to be some force (gravity) acting vertically between the apple and Earth’s surface. With time scientists realized the law applied to any two bodies. They could be Earth and the Moon, it could be Earth and you, or Earth and a rock on a slope.

Chunk #5: Earth is not a perfect sphere. It is an oblate spheroid. In order to simplify the situation we will assume Earth is a perfect sphere with a radius of 4,000 miles. Furthermore, given that we are examining gravitational force upon a rock at Earth's surface, let us assume that Earth's center of mass is located at the center of its core.

Chunk #6: The proportionality of the equation illustrates how gravity works between two bodies. The replacement of the equal sign and the gravitational constant removes the ability to derive a precise mathematical answer. But, it also emphasizes what is occurring much better.

Now let's see how this really works by applying all of the above.

Application #1: Imagine a rock on Earth's surface. The distance between the rock's center of mass and Earth's center of mass is 4,000 miles. The rock has a mass of 1000 kg (2200 pounds). Calculate the gravitational force operating between the rock and Earth.

Application #2: Now, imagine the rock has a mass of 1 kg (2.2 pounds). Calculate the gravitational force acting upon this rock. Compare the number to the result obtained in the previous step. Do the different numbers verify the mass relationship in the equation?

Application #3: Repeat either calculation but change the distance. Once again, can you confirm the relationship between gravity and distance?

Application #4: Imagine a 1000 kg rock located at the top of a mountain five miles above sea level. We must now use 4,005 miles in the denominator instead of 4,000 miles. Recalculate the gravitational force. Any significant difference? Not really. For all intents and purposes the same amount of gravitational force attracts all crustal rocks towards Earth's center.

Conclusion #1: On Earth, the mass of the rock is the only variable we need to address when discussing mass wasting. The amount of gravitational force acting on any mass of rock at Earth's surface is essentially the same.

Conclusion #2: Mass wasting is more energetic as the rock mass increases. You knew that already, but now you can explain it if necessary.

A changing center of mass is embedded in the the two-body equation. Earth's mass is about 6.00×10^{24} kg. The discrepancy in mass between Earth and a 1 kg rock is such that the center of mass for the two body system is Earth's core. The mass of the Moon is 7.35×10^{22} kg. In this case, the center of mass for the Earth-Moon two-body system is in Earth's upper mantle.

Complicating Fudge Factor Warning: You innately know, as do your students, that weathering reduces the mass of an individual rock over time. How would you address this dilemma with your students? We'll address this later.

Physical Weathering: The Mechanics of Moving Rocks Downslope

The dominant gravity vector is always directed perpendicular (Figure 6), vertically downward, toward Earth's mass center. A quick demonstration will illustrate the concept. Place a small rock on the flat, horizontal top of a desk or lab table. The rock must be angular so it will not roll. Observe. Any movement? Can you explain your observation?

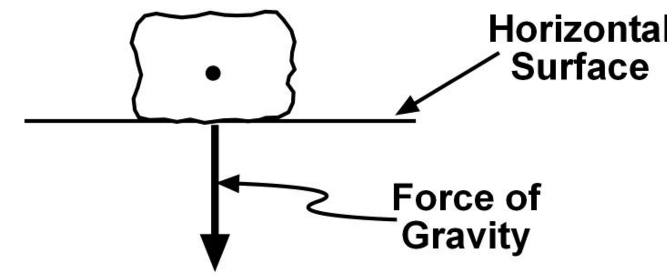


Figure 6.

Under these conditions, the rock on the horizontal table top can, and will, stay put until some non-vertical force acts upon it. What's the easiest way to get the rock to move? You could push it along the table top using your hand. In this instance you have applied a horizontal force to counteract the vertical pull of gravity. Only when the horizontal force becomes greater than the vertical gravitational force will the rock move. You can also try blowing against the rock but chances are that you will not be able to generate enough horizontal force to overcome the vertical gravitational force. In other words, the rock doesn't move.

How can movement be initiated? Here's an east an quick demonstration: produce an inclined surface by gradually lifting one end of the table. At what point do you notice downslope movement? Can you measure this angle? Does it change depending on the surface type and friction? Keep lifting. At what angle does the rock seem to break loose and freely move downslope? If, on Earth, gravity always acts toward Earth's mass center, how do rocks move downslope? Why aren't they pinned in place by the vertical gravitational force? Welcome to introductory vector analysis and another opportunity for science integration!

For mass wasting to operate on a sloped surface the gravitational force must be resolved into two vectors (Figure 7). One must be the downward force acting perpendicular to the sloped surface. This is the "Stay Force" component of the vertical pull of gravity. The other vector becomes a force directed parallel to the sloping surface (Just like your hand or your breath on the table demonstration). This is the "Go Force" component that wants to actually move the object downslope. To determine if a rock will move downslope the Go Force must exceed the Stay Force. While this can be accomplished mathematically, we prefer the more visual technique of determine force by the length of each vector arrow. For example, in Figure 7, the STAY force vector is obviously longer than the GO force vector.

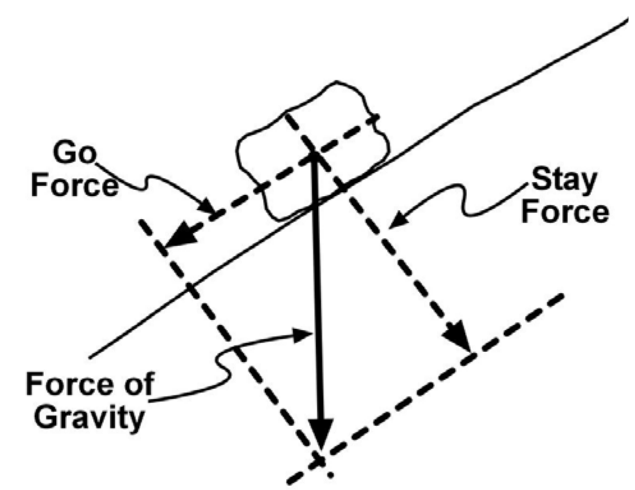


Figure 7.

It is important to remember two things: (a) when added together, the the Go and Stay subset forces may never exceed the value of the total mathematical gravitational force acting between the two bodies, and (b) since we are dealing with rocks on Earth's surface, we have already shown that the distance aspect is moot.

One easy ways to measure student acceptance of this concept is to employ Figure 8. Consider a rock resting on four different surfaces which have slope angles ranging from 0^{o} (horizontal) to 90^{o} (vertical). Can students explain the motion, or lack of motion, of the rock in each scenario? Can you? We'll help by offering the following analysis. On a horizontal surface (a), the Go force is zero while the Stay force equals the full force of gravity. The rock will not move. This is your table top. Slope "d" represents a vertical slope or cliff face. In this setting, the Go force equals the full force of gravity while the Stay force is zero. Mass wasting will be rather energetic! If you measure closely you should determine that the rock will not move on slope "b" but it will move on slope "c".

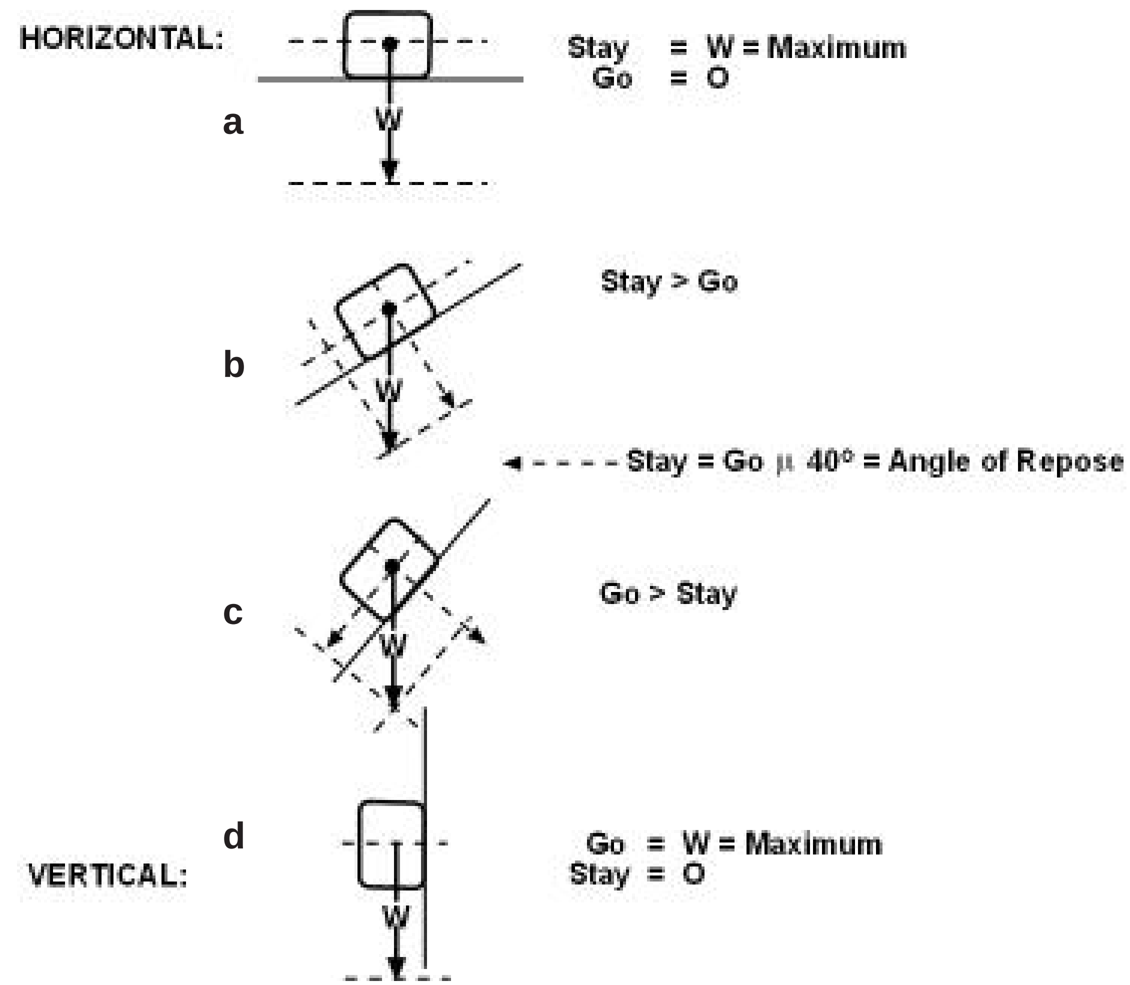


Figure 8.

Three teaching points: (A) when added together, these mathematical value of the two forces may never exceed the value of the total mathematical gravitational force acting between the two bodies, (B) when drawing vector arrows it becomes hard to accomplish this because the vertical gravitational force arrow would be very long, and (C) since we are dealing with rocks on Earth's surface, we have already shown that the distance aspect is moot. Keep this in mind when using these diagrams in class

About now you are most likely speculating on the slope angle that triggers movement. Did 45 degrees pop into your mind? Your students will say the same thing and this means that they have some understanding of the vector issue. However, what is the role of particle friction and cohesion? Well-rounded or spherical rocks have less frictional attachment because they share less amounts of common surface area touching each other. Try piling up some dry beach sand! On the other hand, the increased amount of shared surface area between odd-shaped and angular rocks allows the rocks to remain in place on a slope of about 40 to 42 degrees. This "angle of repose" can serve as a quick determinant of slope stability. Rocks, of any size, resting on slopes of less than 40^{o} will not move downslope of their own accord because Stay > Go. This would be a stable slope. On the other hand, Go >Stay on slopes exceeding 40 degrees. These rocks will move downslope of their own accord, meaning the slope is unstable. Generally speaking, any slope you are able to hike up easily will have a slope less than the angle of repose. You quickly will notice that as the slope approaches the angle of repose your climb will become increasingly more difficult.

Now let's address the decreasing size dilemma mentioned in the sidebar on Page 6. Mass wasting occurs only when Go > Stay. We previously stated that, for our purposes, the only rock variable that influences gravitational attraction is mass. Thus, we intuitively explain why larger rocks move downslope more readily than smaller ones once Go > Stay. However, rocks don't increase in mass as they weather. Common sense dictates that the mass of an individual rock must decrease as it weathers into smaller and smaller pieces of sediment. This implies something else contributes to the Go force. Water! The addition of water to a normally stable sloped surface by a heavy rain or large snow melt can alter inter-particle cohesion (friction). Students will focus on the water reducing friction but you must also point out that the lubricating nature of the water collectively reduces the Stay force to the point that the Go force activates, producing rock flows, slides, slumps, and landslides.

Physical Weathering: Outcomes When Go Force Exceeds Stay Force

Flows

These are mass wasting events in which abundant water essentially converts loose surface rock and soil into a fluid mass. Mud flows (Figure 9) are the most fluid, have the lowest viscosity, transport material furthest, and can occur almost anywhere. The most active, destructive, and dangerous mud flows are volcanic lahars triggered by volcanic eruptions in high elevation mountains with existing snow packs.

Mud flows become high viscosity earth flows or debris flows as the amount of lubricating water decreases and the flow material assumes a more solid state. While the amount of water involved is enough to sustain some movement, earth and debris flows usually do not move far downstream. They normally occur along a valley slope and will often have enough force to partially ride up the opposite valley slope.

Figure 9.

Viscosity describes how a fluid flows. Low viscosity fluids (a very wet pancake mix) flow easily while high viscosity fluids (a not so wet pancake mix) flow poorly.

Lahars are destructive because the viscous mix of mud, water, and rock flows at such a high speed that it scours the slope surface plus carries debris along stream channels for miles before settling into an almost cement-like deposit as the water dissipates. Mount St. Helens in 1894 is the most recent incident of such a flow in the United States.

Solifluction is a type of material flow restricted to permafrost regions. If the upper region of the permaforst melts during warm weather the water lubrication will permit movement even on very low slopes.

Slides and Slumps

Slides are common occurrences in steep slopes possessing high Go force potential. Moderate to heavy rainfalls introduce excess amounts of lubricating ground water that initiate movement. Once movement begins, mass comes into play. As the surface material begins to move a portion of the underlying bed rock often breaks away, facilitating even more movement. Moving as a single large mass with a high Go component the entire mass literally rotates outward leaving behind a distinctive arcurate (curved) detachment surface along the slide's upper vertical face or scarp (Figure 10 and 11). This outward rotation also constructs the slide's characteristic snout mounds produced when water eventually drains from the slump and up slope material continues to move downslope, overrunning the lower margin and building a mound (snout) of material. West Virginia is one of the top states for frequency of slides, slumps, and rock falls (Figures 10, 11, and 12).

Figure 10.

Rock falls and slides occur when bedrock underlying steep slopes succumbs to years of physical weathering. In these cases, the movement is usually a catastrophic failure of large amounts of rock debris over a short period of time. The material that is produced and moved downslope may be seen along the base of over steepened slopes exceeding the angle of repose. This would include roadcuts, natural cliffs, and waterfalls, like the large rocks seen at the base of Blackwater Falls (Figure 12).

Figure 12.

Figure 11.

Creep

This process affects more land surface than all other mass wasting processes combined. It is deceptive because it operates so slowly but tilted poles, tilted retaining walls, and other surface modifications demonstrate the effect of creep (Figure 13).

How does creep actually work and is there a reason it works so slowly? When water freezes it expands in volume. In humid areas, like West Virginia, the soil contains enough water to produce a unique freeze/thaw process called frost heaving. When the temperature drops, the freezing water (frost) heaves surface particles vertically. As we have already demonstrated, gravity is a vertical force. Thus, if the surface is perfectly horizontal, gravity pulls the rock downward into the same spot during the thaw cycle (Figure 14).

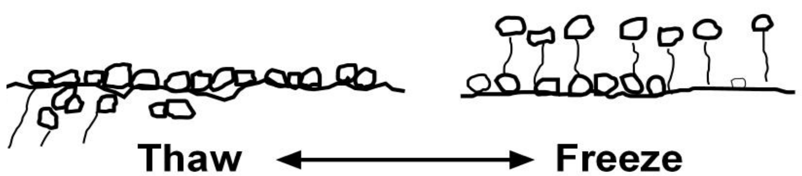


Figure 14.

Figure 13.

Water ice is unique in that its crystal structure rearranges to produce a 10% increase in volume as it changes into is solid phase. Due to this expansion, the ice is less dense than water. Hence it floats. Most liquids contact upon freezing and become more dense in their solid phase.

However, perfectly horizontal surfaces are a rarity in nature. On sloped surfaces, the essentials of the Stay and GO forces come into play. Growing ice crystals lift soil particles perpendicular to the sloped surface, not vertically. As a result, when the ice thaws, gravity asserts itself causing the particle to fall vertically, meaning that it returns to the surface at a point downslope from its original position. As long as the soil is being subjected to frost heaving each and every surface particle is slowly migrating downslope (Figure 15).

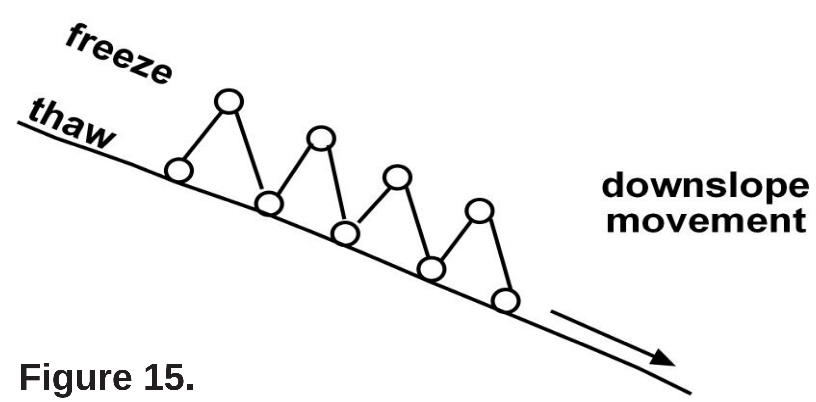


Figure 15.

The stress forces generated by the slowly moving mass of particles in slides and creeps are far beyond the retention capacity of most retaining walls (refer back to Figure 13). It is a given, to geologists, that retaining walls, in time, will fail. Early signs of failure are walls tilted out of their vertically constructed orientation. While the end result is predictable, the result is most often rebuilding of the wall. Large scale structure failure can be postponed by the incorporation of longitudinally and vertically placed “deadmen” that extend back into the slope and planned water drainage (Figure 16). Deadmen can be lengths of strap steel, angle iron or even segments of chain link fencing. These two techniques can help to reduce the downslope GO force by increasing the inter-particle, gravity controlled, cohesive aspect of the Stay force component.

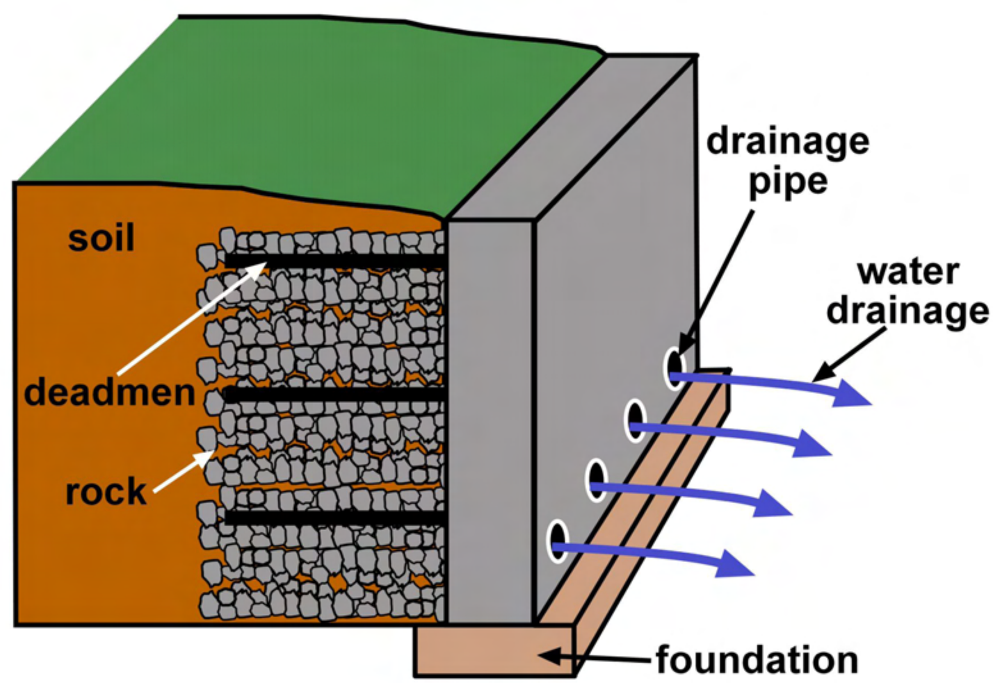


Figure 16.

To some degree, the possibility of a slide may be mitigated by insetting perforated pipes into the slopes to collect and move away excess water.

CHEMICAL WEATHERING

Physical weathering prepares rock for chemical weathering. This is not a commonly taught concept nor a commonly uttered classroom statement. But, it should be. Appreciating how physical weathering prepares a rock for chemical weathering will significantly enhance your, and your students, awareness of the surrounding environment.

A good place to begin student thought is with this question: Which will dissolve better in warm water—a cube of sugar or ground sugar? Everyone knows the answer is ground sugar but can they, or you, explain it? The answer is all about surface area. Sedimentary rocks common to West Virginia contain cracks and crevices due to various formational situations (sediment drys, shrinks, and mud cracks form as the sediment lithifies into rock) and tectonic activity (folded sedimentary rock is often stressed enough to crack it). Physical weathering takes advantage of existing fractures, crevices, breaks, etc. and expands them. This process, as we discussed in the previous section, breaks the original rock into smaller pieces. More rock surface area provides more area for a reaction to occur which means a faster reaction and faster chemical separation of rock forming components, weakening of the rock structure, and increased production of by-products such as sediment and dissolved chemicals.

Look at the top object in Figure 17. Let's pretend this polyhedron is a rock. How many surfaces are available for chemical weathering to attack? Six. Where will the reaction proceed most vigorously? The two sides with the largest surface area. Notice how the number of surfaces tends to increase as the rock is broken into smaller pieces, maybe by frost wedging. Not only is there an increase in the number of surfaces but also a corresponding increase in total surface area. Suddenly, chemicals have a lot more territory to attack.

This is important because most chemical reactions, especially those involving rocks, are surface reactions. The more a rock is weathered physically, the more susceptible it becomes to chemical weathering.

Thus, the rate of the reaction is, in part, dictated by the total surface area exposed to the reactive agent. This reason physical weathering prepares rock for chemical weathering is due to this increasing surface area. Which is what happens to the sugar cube when you grind it into powder.

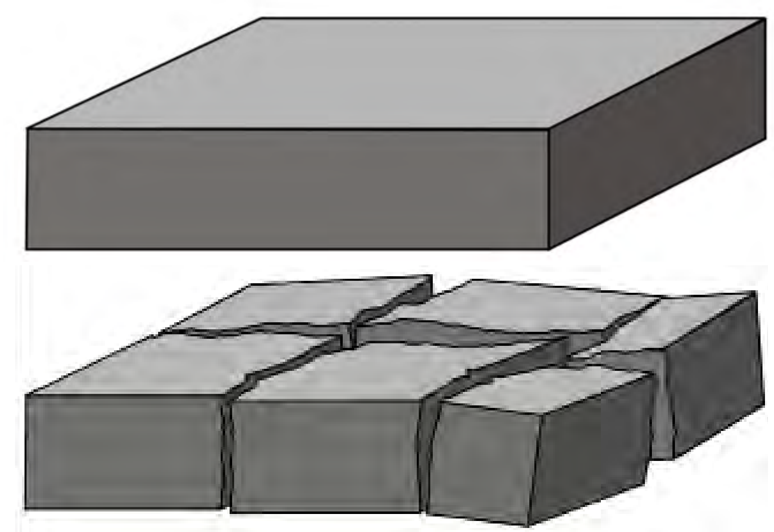


Figure 17.

Physical weathering prepares rock for chemical weathering by creating more surface area for chemical reaction to act on. Make sure your students understand this idea.

A short synopsis of weathering processes may be found at *http://classzone.com/science_book/mls_grade7_FL/231_236.pdf*

Depending on your age group, they may or may not even know what a mortar and pestle is. But, you should and can you provide a reason for their use in the chemistry lab? A short demonstration, or better yet a brief student exploratory activity if enough materials are available, employing a mortar, pestle, and a sugar cube could be the launching point for students to explain what causes ground sugar to dissolve in water faster than a cube of sugar.

Oxygen, carbon dioxide, and water are the major atmospheric reactive agents that contribute to chemical weathering. However, there is a catch to this statement — oxygen and carbon dioxide only become reactive chemical weathering agents when they are dissolved in water. For example, oxygen dissolved in water fuels oxidation. Of the dozen or so elements that make up most of Earth's crust the one that most readily reacts chemically with dissolved oxygen in water is iron. Many minerals contain iron and many of West Virginia's sedimentary rocks contain these iron-rich minerals. If you see red rocks along the interstate or in a local outcrop, we hope your first thought is that the minerals that make up the rock contain chemically oxidized iron, i.e., rust. We hope your second thought is that because the reaction requires water, the red rocks were, at some point in their existence, most likely submerged. This is an example of how geologists build their understanding of rock sequences, ancient environments, and evolving landscapes.

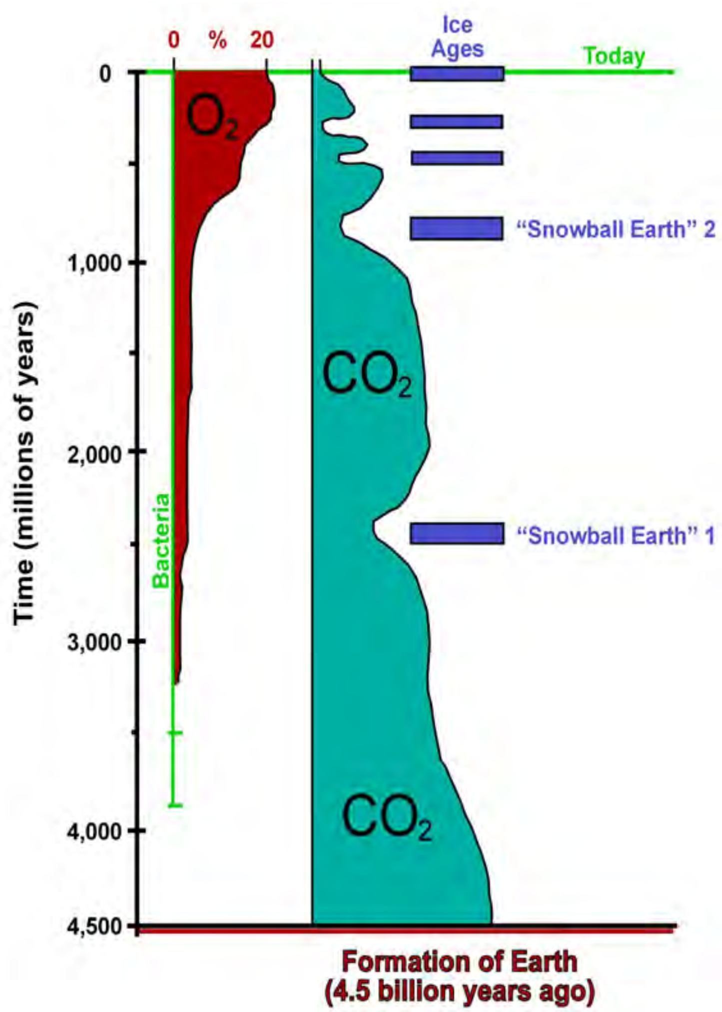


Figure 18. Variations in atmosphere oxygen and carbon dioxide over geologic time. Source: http://www.uwosh.edu/faculty_staff/hiatt/Teaching/102/climate.html

Chemical Weathering: Oxidation

A question that surfaces about this time pertains to Earth's atmosphere. Geologists are used to seeing evidence of climate change in the geologic rock and fossil record. Just like atmospheric oxygen content, atmospheric CO_2 has varied over time (Figure 18). Fossil evidence suggest that, during the Jurassic Period, average CO_2 concentrations were about 4.7 times higher than today. The highest concentrations of CO_2 during all of the Paleozic Era occurred during the Cambrian Period when it was about 18 times higher than present accumulations. High concentrations of CO_2 during the Carboniferous Period (Mississippian and Pennsylvanian time) may account for the prodigious amount of plant growth that became our coal beds. During the Late Ordovician Period there was an Ice Age (Snowball Earth 2 on Figure 18) while CO_2 concentrations were nearly 12 times higher than today.

Our planet did not always posses an oxygen-rich atmosphere, meaning rusting is a relatively common

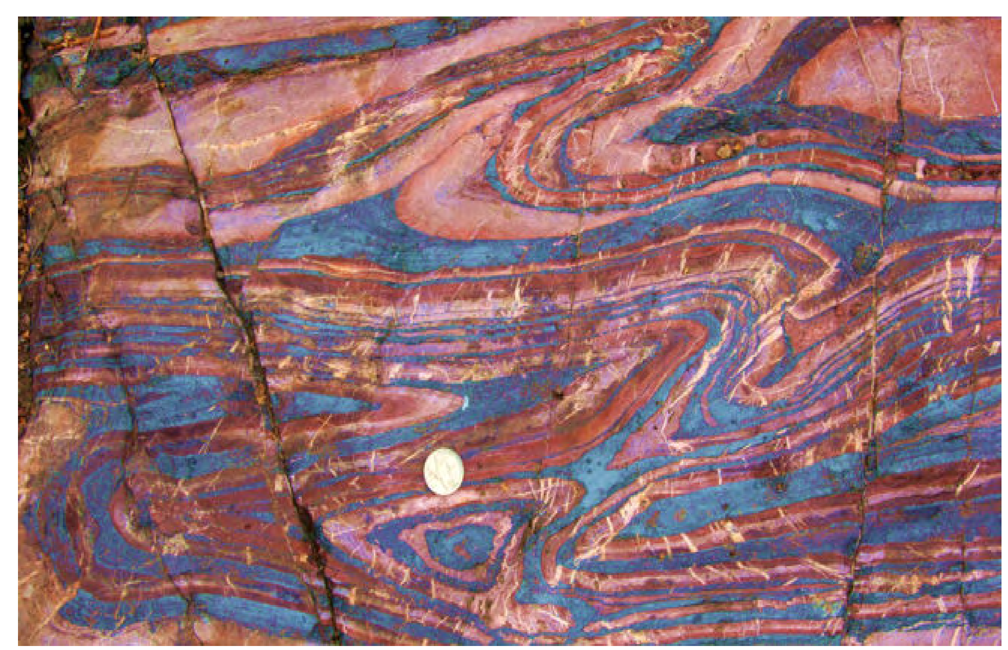


Figure 19.

Rust on rocks usually represents the presence of the marcasite, siderite, pyrite, and other iron rich minerals. Some of these are products of the chemical rusting process while others represent original in-situ minerals the provide the surface area for the chemical reaction. This is mentioned because it is often assumed that pyrite is the only reason for red rocks in West Virginia.

BIF is an acronym for banded iron formation. These rock are about 2-2.5 billion years old and are sedimentary rocks consisting of alternating bands iron-rich sediment (typically hematite, Fe_2O_3, and magnetite, Fe_3O_4) and iron-poor sediment, typically chert. The size of the bands ranges from less than a millimeter to more than a meter in thickness. Figure 19 shows a fairly typical banded iron formation. Locations of BIF rocks occur worldwide. Their variations over time suggest changes to atmospheric oxygen content. The oldest BIF rocks date from 3.5 billion years ago. Most formed about 2.5 billion years ago and none are known found to be younger than 1 billion years in age. The concept of uniformitarianism can not be applied to these rocks because none are forming today. Today, these are important ores mined for their iron content. In the United States, BIFs are found in the region around Lake Superior of the Great Lakes region.

geological event (Figure 19). In fact, such an atmosphere may be only about half the age of the planet. A clue to dating this global environmental change is a rock called banded iron formations or BIF, radioactively dated as being 2-2.5 billion years old (see Figure 18). No such iron-rich specimens exist prior to these rocks. The only way a BIF could form, chemically, is due to chemical weathering and precipitation in an environment rich in water-dissolved oxygen. Prior to this, the water did not contain enough dissolved oxygen to drive the precipitation process.

If you're discussing this in your classroom, we hope a student asks the next logical question: Where did the oxygen come from? This could open the door for you to ask some interesting questions of your own: Have you assumed Earth's oxygen was always a constant 21% of the atmosphere? What kind of global change would be required to alter the amount of atmospheric oxygen? Is it a renewable asset or a fixed commodity? Chances are your students have already been introduced to the concept of oxygen created by photosynthesis or produced as a by-product or waste product of plant photosynthesis. We'd like to clarify these ideas somewhat so you have a more conceptual appreciation of what happened.

Earth's abundant oxygen is the product of evolutionary biological change over geologic time. The multi-step evolution and proliferation of photosynthetic blue-green algae introduced the free oxygen molecule to Earth's atmosphere only when the planetary environment had cooled enough to permit the existence of the bodies of liquid water in which the algae lived. The next hurdle was the time, perhaps a billion years, required for the development of a large biomass of blue-green algae. Only then, did molecular oxygen molecules (O_2) begin to accumulate in the atmosphere. Very importantly, this algae, and today's green plants did not, and do not, "create" the molecular oxygen Earth life-forms breath.

The major purpose of plant photosynthesis, then and now, is to make a simple sugar for food energy. This process is represented by the well-known chemical reaction expressed by:

$$6H_2O + 6CO_2 = C_6H_{12}O_6$$

However, here is where the obvious is often ignored or overlooked. Take a close look at the equation. Do you see any free O_2 wafting about? Using NASA-speak, we seem to have a problem!

The first living organisms neither produced nor consumed oxygen. Indeed, they could not tolerate oxygen. An example of such an organism is the modern bacterium Clostridium botulinum. In the absence of oxygen-producing organisms, the atmosphere would have been very poor in free oxygen (i.e. the molecule O_2). What does all this have to do with BIFs? One of the interesting things about elemental iron (Fe) is that it dissolves in water, whereas the various oxides of iron (as found in banded iron formations) precipitate. The waters of the early Earth would certainly have had sources of iron, such as emissions from submarine volcanoes, and iron liberated from rocks by chemical weathering. It follows that when organisms arose that produced oxygen, iron dissolved in the oceans would combined with dissolved oxygen to form iron oxides which would then have precipitated out, producing the iron oxides that characterize BIFs. The iron would, indeed, form an "oxygen sink"; only after the iron had been used up in this way would O_2 have begun to constitute a large proportion of the atmosphere. The accumulation of oxygen in the atmosphere, which according to geological dating methods started about 2.4 billion years ago, is variously known as the Great Oxygenation Event (GOE), the oxygen catastrophe, and the oxygen crisis.

Ask your students to quantitatively examine the equation by counting the number of atoms of each element on both sides of the equal sign. They should develop the data shown here:

	Left side of equation	Right side of equation
Number of hydrogen atoms	$6H_2$ means 6 times 2 = 12	H_{12} = 12
Number of carbon atoms	6C = 6	C_6 = 6
Number of oxygen atoms	6O and $6O_2$ = 18	O_6 = 6

Conclusion? The formula is not balanced!

The left and right sides have the same number of carbon atoms and hydrogen atoms but the left hand side has 12 more oxygen atoms. The plant can't just ignore surplus oxygen atoms nor can it just throw them away as free oxygen atoms. The plant eliminates the problem by combining 12 individual oxygen atoms (which we can not breathe) into 6 molecules of O_2 (which we do breathe). Green plants don't "create" breathable oxygen--it was already present in the water and carbon dioxide. What green plants do is get rid of the 12 extra atoms of oxygen by bundling them into six oxygen molecules useful to Earth life. This occurs because, chemically, the equation must be balanced. This means that the correct equation for photosynthesis should be presented as:

$$6H_2O + 6CO_2 = C_6H_{12}O_6 + 6O_2$$

For a more indepth chemical discussion of weathering, limestone, how it forms, and how it weathers to form caves and karst topography go to *http://www.wvgs.wvnet.edu/www/geoeduc/AdaptiveEarthScienceActivities/Extras/GeologyForChemistryTeacher.pdf*

The CO_2 content of Earth's atmosphere is 0.035% by volume.

Chemical Weathering: Carbon Dioxide and Carbonation

Water, usually in vapor (steam) form, is the most common gas released into Earth's atmosphere by volcanic eruptions? Do you know what the second most abundant gas is? Carbon dioxide. Since volcanic activity has been present on Earth from Day One, and was much more common billions of years ago, we can assume that CO_2 has been present in Earth's atmosphere and that its amount has varied over time (refer back to Figure 18). Carbon dioxide was present way before photosynthesis. Photosynthesis is much later evolutionary adaptation that green plants used to thrive.

It is not uncommon for a geologist to use the term "carbonate" instead of "limestone."

Like oxygen, carbon dioxide only becomes an effective chemical weathering agent when dissolved in water. And, since cold water can hold more dissolved carbon dioxide, the reaction proceeds more quickly in cooler environments. Unlike oxygen, carbon dioxide (CO_2) chemically reacts with water to create a weak carbonic acid (H_2CO_3) by the following equation:

$$CO_2 + H_2O = H_2CO_3$$

Dilute amounts of carbonic acid is present in the water you drink. It is in the rain and produced the first “acid rain.” It is in the water everywhere and, given enough time, this weak acid can drastically alter a landscape that is composed of rocks chemically susceptible to its acidity. Limestone is a very common rock that occurs everywhere in the State but is especially well represented and visible in many Eastern Panhandle counties. Limestone, the rock, consists primarily of calcite, the mineral ($CaCO_3$). Note the carbonate (CO_3) component of the formula. Rocks containing a high percentage of calcite are called carbonates because of this carbonate component. A chemical rule of thumb is that all carbonates are soluble in water, given time, because of the carbonic acid in the water. To fully appreciate this reaction you must once again factor in the element of geologic time that allows a very dilute carbonic acid, like natural water, to chemically dissolve (weather) a carbonate rock ($CaC0_3$) according to the following reaction.

$$CaCO_3 + H^{1+} + HCO_3^{1-} = Ca_2 + 2HCO_3^{1-}$$

Acids are “acidic” because of the free hydrogen ion content. The higher the free hydrogen ion content the more robust the acid. Carbonic acid, dissolved in water, has few free hydrogen ions so it is a very weak acid.

Chemical Weathering: Hydrolosis

To a geochemist, hydrolysis is any reaction involving water. Carbonation/hydrolysis differs from carbonation in that the water molecule actually disassociates to provide free hydrogen ions. These free ions can be used to make silicic acid, which is more reactive than carbonic acid and is strong enough to weather (dissolve) many of the minerals found in granite. For example, the silicate mineral orthoclase can be chemically weathered to produce the clay mineral kaolinite. After a multistep sequence of reactions, which we are omitting but can be found on the internet, the silicic acid can chemically weather granite into to lumps of various clay minerals, sand-sized quartz particles, and small clay-sized particles. These particles become the sediment which is then eroded (transported) to a new location where it is deposited, accumulates into sediment deposits, and eventually lithified to form new, and younger, sandstones and shales.

Summary of Chemical Weathering Process and Products

Process	Reactant(s)	Notable Product(s)
Oxidation	dissolved oxygen	rust (red coloration)
Carbonation	carbonic acid	dissolved carbonates (limestones)
Hydrolysis	silicic acid	clay minerals, clay and sand sized sediment

EROSION

So far we have discussed how physical weathering mechanically reduces the size of rocks and the forces that control their physical movement down a sloped surface. We have also provided three examples of how chemical weathering contributes to sediment formation. The generic term for the loose weathered material that covers solid bedrock is regolith (Figure 20) and it also composes the sediment material that is transported to a new location by the process of erosion.

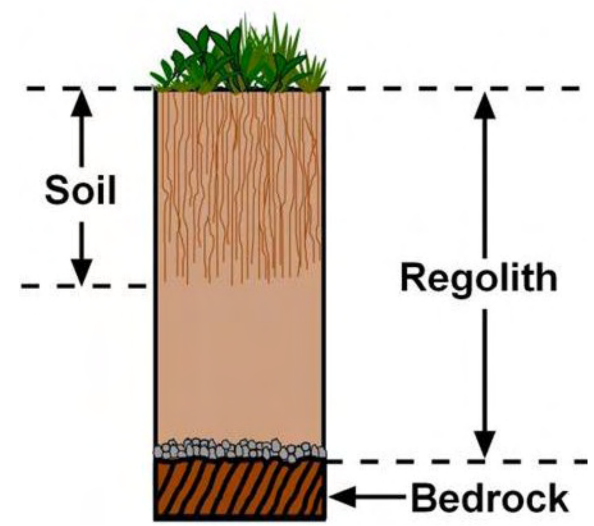


Figure 20.

When, and where, they exist, glaciers are powerful sculpting (weathering) and agents of transport (erosion). The origin of the Great Lakes, the landscape of New England and Long Island, and the fact that much of upper half of North America is still isostatically rebounding upward, are great topics for student exploration of glacial impact. Wind is capable of transporting enormous volumes of material, as can be demonstrated by reading about 1930's Dust Bowl and looking at historical photographs. Even today there are huge dust storms in the American Southwest. Paleo-sand dunes in Zion National Park (Figure 21) are mostly wind blown deposits as indicated by their frosted quartz grains. However, flowing water is the agent most responsible for West Virginia's topographic landscape. For that reason, we encourage you, or your students, to do some personal research on ice and wind erosion while we focus on erosion due to streams. To clarify, we must point out that most landscape sculpting is a result of the combined effect of streams and mass wasting where flowing water shapes the valley floor and mass wasting shapes the valley walls (Figure 22), producing the characteristic V-shaped valley. With this in mind, we need to explore where the energy comes from for water to move sediment particles. The fact that flowing water, moving downhill, carries and transports sediment is not a major revelation. Knowing how this is accomplished by the water might be.

Figure 21.

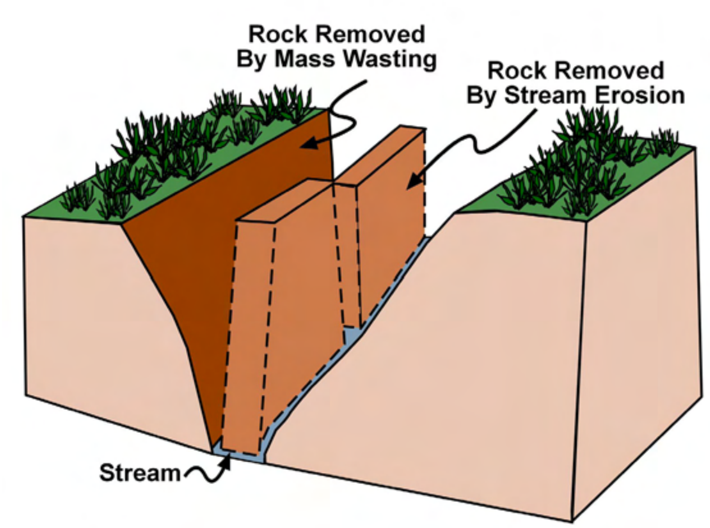


Figure 22.

Isostatic rebound refers to the regional uplift that is currently occurring in those areas once occupied by the last ice sheets. This uplift has influence base levels and the formation of The Great Lakes and Niagara Falls.

Quartz tumbled in water is usually clear because the water acts as a barrier between the individual pieces hitting each other. Wind blown quarts particles lack this protection. As a result, they assume a frosted or "sand blasted" surface appearance.

Geoscientists consider any body of moving water a stream. Size is irrelevant so there are no rivers, creeks, cricks, or brooks in geology. Both the Ohio River and the smallest Laurel Run found in any West Virginia county are streams in geologic terminology.

When does the most weathering occur within a stream system? Did you say: "During floods?" This is absolutely correct. Very little weathering is accomplished during non-flood times because the water contains no abrasive agents to wear away the banks and bottom. On a normal day, a clear mountain stream looks pretty but it is not doing much weathering work.

What about erosion? Same answer! The muddy water associated with a flood is visual evidence of how much more sediment the water is carrying. During floods there is a lot more water and it is moving faster. In other words, the combination of the water speed and volume determines the amount of energy available to move sediment.

We have already established the fact that water velocity must decrease downstream. This leads us to another issue: theoretically, the gradient or slope of the stream channel must approach horizontal at the stream's mouth. Recalling the Go and Stay force discussion of horizontal surfaces we illustrated that nothing moves of its own accord on a horizontal surface. Thus, we should expect that, as the gradient of the stream approaches horizontal at its mouth the water should begin to slow down as the Stay force begins to overcome the Go force. Once again, such an occurrence must produce perpetual flooding. But, everyday observations prove this does not happen. The solution to this dilemma is volumetric distribution. Perpetual flooding is prevented by distributing increasing water volume across the larger, combined volumetric area provided by the delta and distributary system (Figure 23). The ability of distributaries to handle and distribute increasing downstream volume significantly reduces the probability of constant flooding along the stream's lower extremities.

Another natural feature that reduces flooding is the levee commonly found along the lower meandering lengths of the stream channel (Figure 24). During flood events, as sediment laden water rises and goes over the stream bank, the water's ability to carry the sediment (energy) dissipates as water velocity deceases as it spreads out across the flood plain. This reduction in energy allows the larger sediment particles to fall out along and on top of the river bank, forming the levee. Smaller clay-sized mud particles are carried into the flood plain itself. In a natural state, each new flood has the potential of raising the existing levee height. If this occurs, the ability of the channel to handle a higher volume of water increases. This naturally-occurring construction

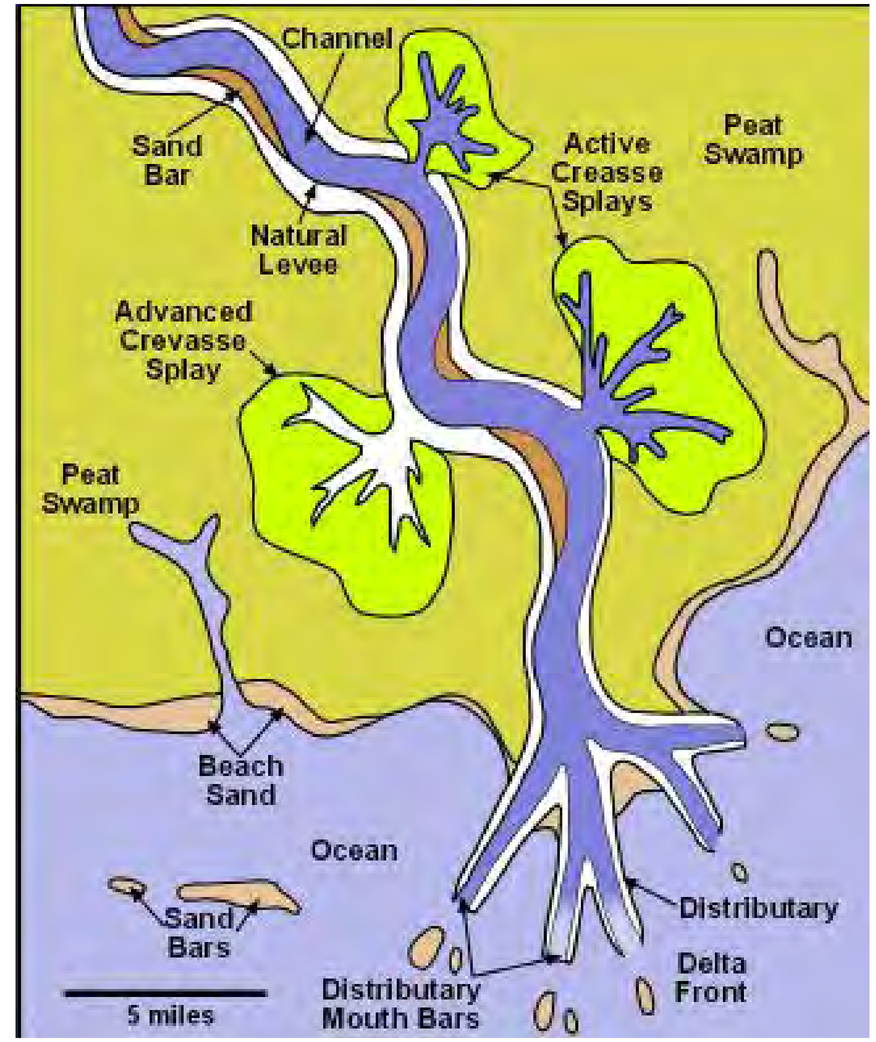


Figure 23.

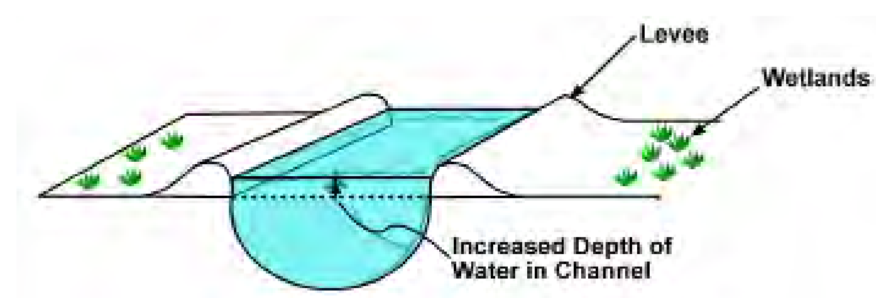
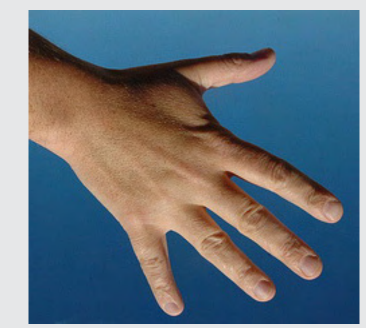


Figure 24.

Activity idea: Lay your hand, with fingers outstretched, on a flat surface. Conceal your arm above the wrist. Imagine that your wrist is the main stream, the back of your hand is the delta, and your fingers are distributaries. The cumulative cross section volume of the distributaries (five fingers) is greater than the cross section volume of the main stream (wrist).



process may produce situations where the contained water level is significantly higher than the surrounding flood plain, which can produce situations where high water events weaken and breech the levee, causing a splay (refer back to Figure 24) that may actually induce a change in stream course or cause more destructive flooding to a part of the flood plain. High levees are a rarity along West Virginia streams, having been mostly lower or leveled by the activity of humans. Most of the levees along the lower reaches of the Mississippi River are man-made structures used to control flow direction and reduce flooding potential. Within the last decades, natural failure and the intentional breaching of portions of these levees to control or lessen urban flooding has contributed to significant destruction of land and housing on the adjacent floodplain.

Erosion: Transport and Sediment Particle Size.

Back at the beginning of this discussion, we mentioned the fact that the mass of rocks decreases as they move downstream. To more correctly state this situation, the size of the rock is decreased by physical and chemical weathering so that many smaller pieces exist where one larger one did previously (Figure 25) Since the rock is not substantially changing composition, it is appropriate to state that rock mass decreases as it moves downstream due to size reduction.

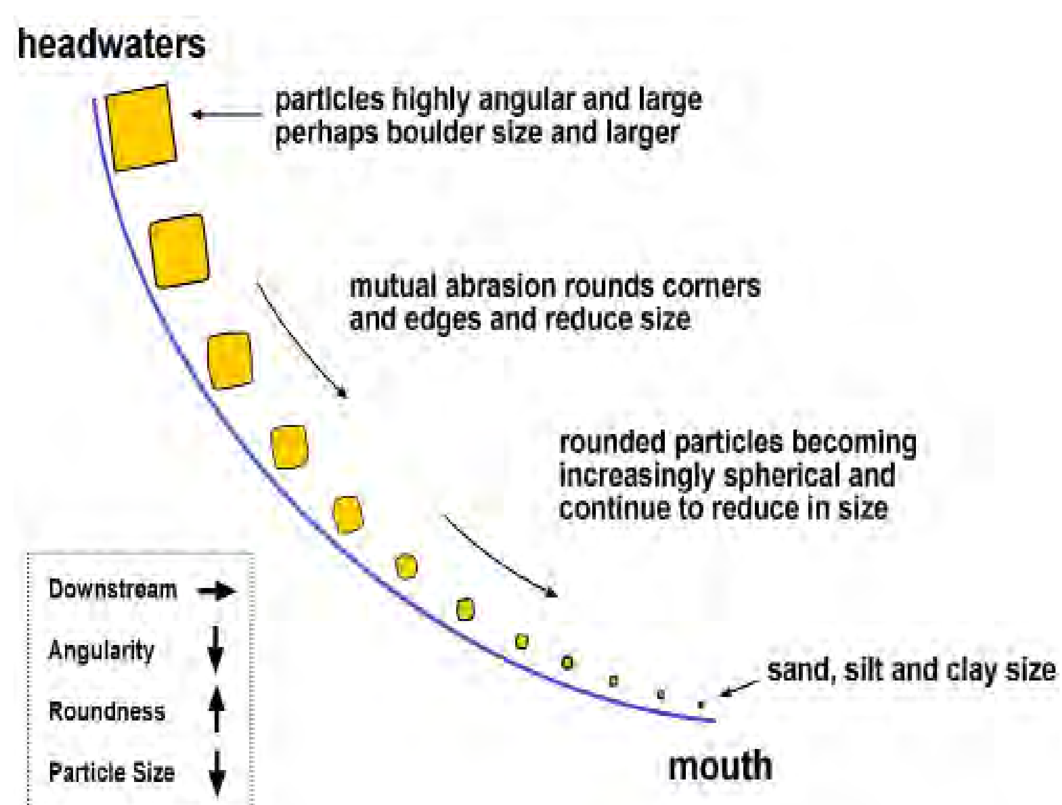


Figure 25.

In Parkersburg, West Virginia, man-made flood walls have taken the place of the Ohio River's natural levels.

The legend in Figure 25 is a code describing how the variables change. As the rock is moved downstream its angularity decreases as sharp edges are broken off. Correspondingly, the rocks roundness increases while particles size decreases. A better word to use in place of roundness is sphericity. Students use these terms interchangeably even though they dimensionally may imply totally mental images. A circle drawn on a piece of pare is round and and two dimensional while a baseball is spherically and three dimensional. Make sure your students, and you, as thinking of three dimensional rocks.

Once regolith (weathered rock pieces) comes into contact with flowing water it either sinks or stays in suspension. As you might have surmised, or already know, this is a function of stream energy versus particle size. However, there is a good chance that your understanding is flawed. For example, ask a student to describe the size of a boulder. and you will most likely invoke something the size of a car or house. Not so, according to Figure 26. In geologic terms, a boulder is anything larger than a soccer ball. Shape is not an issue at this time, even though Figure 26 uses spherical bodies. The longest dimension of a rock or piece of rock is all that matters right now.

Other than the confusion surrounding size terms, the mechanics of how water picks up a particle from the stream bed and then carries it downstream is rarely addressed. To gage their understanding and to use the terminology, ask your students, using the size names on Figure 26 as a reference, which size(s) particles are most readily transported by flowing water. Remind them to think of sediment particles with mass and shape, not soccer balls or baseballs!

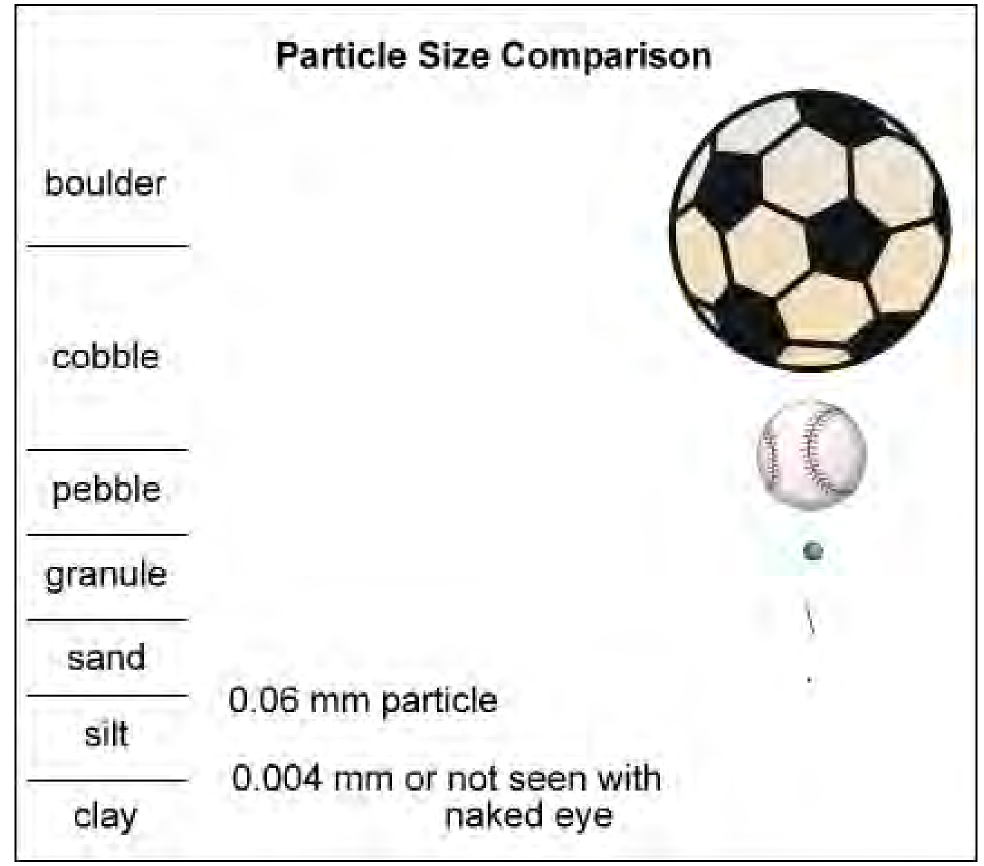


Figure 26.

Hydraulic engineers have been able to answer this question through experimentation and observation using a flume, a high tech version of the homemade classroom stream table (Figure 27 and 28). One of the initial discoveries was that (1) water flows in two very distinctive motions (laminar and turbulent) and (2) these motions are critical to the waters ability to pick up and transport sediment.

Figure 27 (left). Research level flume table. Source: *http://tpapanicolaou.engr.utk.edu/consulting-facilities/*

Figure 28 (right). Homemade K-12 classroom flume table.

In Figure 26 each common item marks the dividing point between sizes. For example, a particle larger than a soccer ball it is called a boulder. If it is larger than a baseball but smaller than a soccer ball then it should be called a cobble. if larger than a pea but smaller than a baseball is is a pebble. In West Virginia, granules are a common component of the sedimentary rock called conglomerate. Sand, silt, and clay-sized particles are the most common in our sedimentary rocks. Remember, these are size terms. A sandstone always contains sand-sized particles but the particles are not always quartz. Silt-sized particles are hard to see but may be detected by gently rubbing the rock over your teeth. A gritty sensation signals the presence of silt-sized particles. Clay-sized particles are so small they can not be seen nor detected using the teeth test.

Activity Idea: As mentioned above, tactile and visual senses go a long way to reinforce sediment size distinctions. Procure the items used in Figure 26. Talcum or baby powder can represent clay size particles if not ingested. Give grouped students to describe and provide names for the relative sizes of the objects. Try to move beyond large, small, tiny, etc. for a comparison to natural materials such as sand, soil, rocks, etc. This can be used to take the next step of actually using Figure 26.

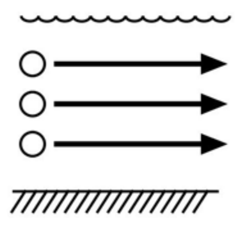


Figure 29.

In laminar flow (Figure 29), individual water molecules flow serenely along, in parallel, non-interfering, pathways. You might assume you are observing laminar flow in the sluggish water found near the river mouth. Not so. Close study revealed laminar flow exists no more than a millimeter or two above the water/stream bottom interface. It was also discovered that the thickness of the laminar layer is indirectly related to water velocity. Thus, as stream velocity increases the laminar layer decreases in thickness, eventually to the point of elimination. In spite of all of these amazing details, this unique, small, and unstable environment is a major determinant of stream erosion.

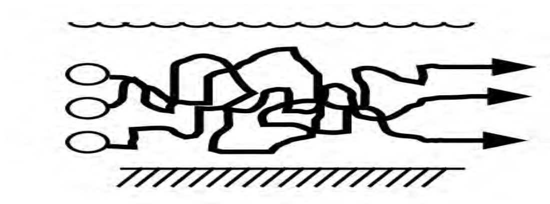


Figure 30.

In contrast, the majority of the motion within the water column is moving in a turbulent flow pattern as it moves downstream (Figure 30). As the term implies, this produces a more or less random movement of water particles that produces extensive interactions and collisions.

Energy allocation within these two flow types may be represented by vector arrows. During laminar flow movement energy distribution and direction for each water molecule is qualitatively demonstrated by parallel horizontal arrows implying that all available mechanical energy is unidirectionally oriented and directed toward moving water downstream (Figure 31). A quick look at the pathway water molecules assume during even minor turbulent flow suggests a portion of the available mechanical energy is directed in directions other than horizontal. If fact, the randomness of the water molecules pathway exhibits the same kind of variable, and unpredictable Brownian gas molecule motion with which you may already be familiar. Turbulent flow, as the squiggling lines in Figure 30 suggest, would require multiple arrows to represent the directional randomness of its energy distribution. Since we are discussing the erosive transport of sediment particles you might already have made the connection between the non-horizontal vectors and water's ability to pick up sediment from the stream bottom. The most important vectors in turbulent flow is the occasional vertical one (Figure 32) because it can actually lift a particle off of the stream bottom and insert it into the water column.

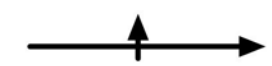


Figure 31.

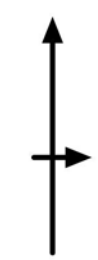


Figure 32.

At this point you might wish to pause and reflect. Are you comfortable with the notion of vertical forces picking up sediment particles and placing them in the water column where the more horizontal forces carry them downstream? Can you explain this to your students? This basic principle is important to answering how silt and clay sediment is picked up by streams.

Laminar flow has the energy to move particles downstream, but, with no vertically allocated energy vector, it is incapable of picking up sediment from the stream bottom. Only turbulent flow can pick up sediment particles from the stream bottom. Once picked up and placed in the water column, the particle is moved along by the horizontal energy vector.

Many pages ago we established that gravity is a function of mass, so a bigger particle (assumed to have more mass) has more downward gravitational force attracting (holding) it in place. This applies to rocks and sediment particles water is flowing over on the stream bottom. Since the act of being "picked up" consists, primarily, of over coming gravity, some vertical (or at least non-horizontal) force is required. Once again we are back to the Go versus STAY forces, but in reverse.

Most people assume that water picks up the smallest particles most readily. And, they rationalize this assumption with the facts that smaller particles are less massive. However, the small size of these particles is not considered and it becomes important because they are smaller than the laminar layer (Figure 33).

The fume experimenters observed and recorded what happened to various sized sediment particles while varying flow rate. The goal was to record the water velocity and turbulence level required to make each particle size break contact with the bottom. The experimental data falsified that hypothesis that the smaller particles were the first picked up.

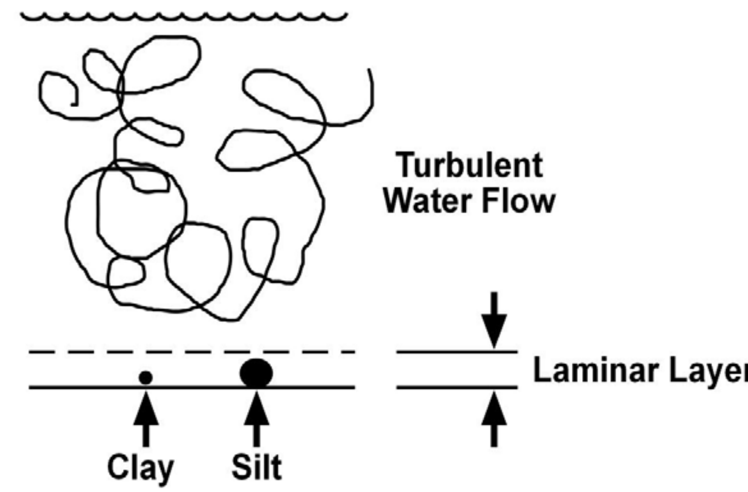


Figure 33.

Being able to interpret graphical data is an important skill and learning objective,

Every notice that sand-sized particles dominate many environments. Figure 34 shows that sand-sized particles require little stream velocity and the least amount of turbulence to be picked up, suspended in the water column, and moved downstream by the horizontal flow vector.

The outcome of the experiment is summarized in Figure 34 in which two different data sets (left and right Y axis) are plotted against particle size (X axis). The relative length of the downward pointing arrows under each particle size (black arrows) graphically suggests the relative amount of gravitational attraction each particle must overcome to be lifted. Thus, a longer arrow suggests high gravitational attraction to be overcome. Looking at this fact alone would suggest that clay particles are lifted form the stream bottom before sand or pebbles. But, this is not the case and it is all due to the laminar layer and the size and shape of the clay and silt particles, not their mass.

Energy (water velocity) actually required to lift each particle size is plotted along the left Y axis. As water velocity increases upward along the Y axis, which particle size is picked up first? This data is plotted on the red line of the graph. Because of its curved shape, the lowest energy expenditure occurs at the lowest part of the curve. Note which particle size this references? Sand sized! The graphed data is clearly telling us that sand-sized particles are lifted off of the stream bottom before silt and clay sized particles. Now, using the same red line, can you determine which particles (that's a hint!) require the highest velocity for pick up? This would be a particle size that is highest along the curve. Are you surprised that a clay sized particle requires almost as much energy to pick up as a pebble? Also note that the energy required to pick up a silt-sized particle is close to that required to lift a granule. What's going on? Particles of wildly different sizes and mass are being pickup up almost simultaneously and yet it takes so much energy to lift the smallest particles?

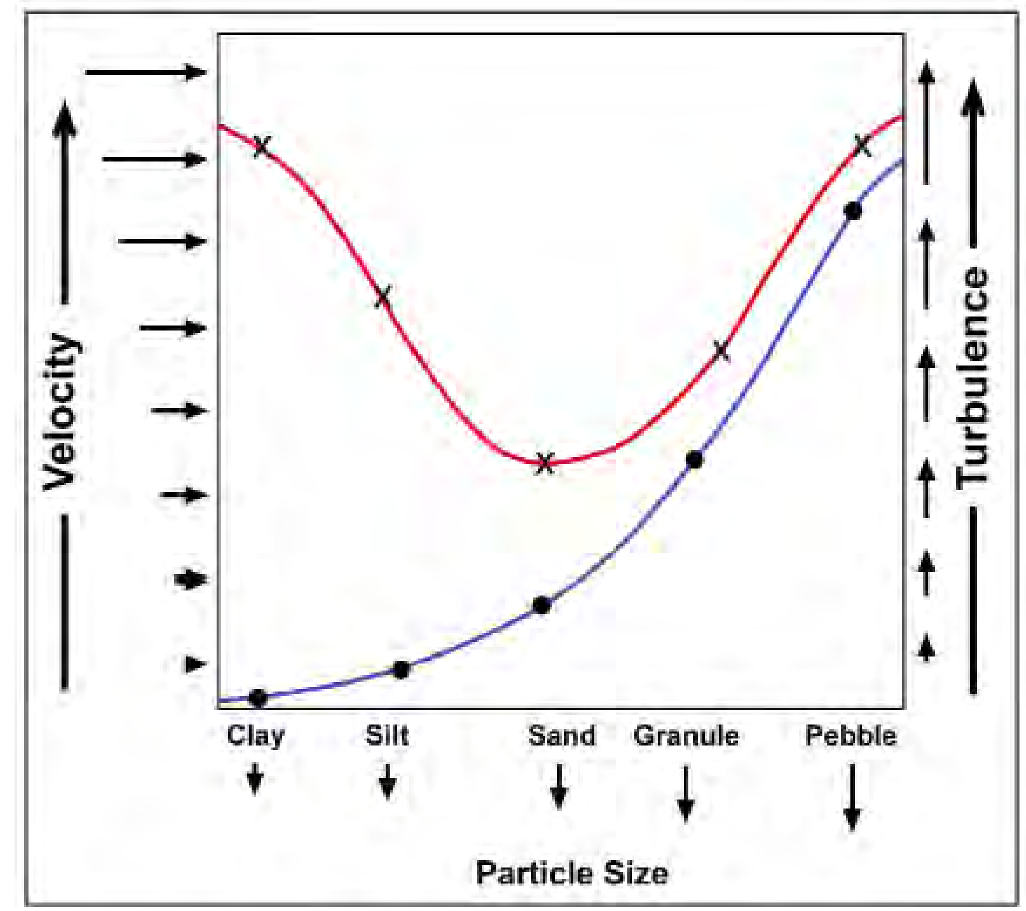


Figure 34.

Turn your attention to the lower curve in Figure 34. This line plots turbulence, or vertical lifting energy (right Y axis) against particle size (X axis). Once again, the differing lengths of arrows under each particle size provide a visual reminder of the relative amount of gravitational force holding each particle in place. Note that, just like water velocity, the smallest particles require the most turbulent water to lift them from the bottom. Puzzled? Remember the dimensions of the laminar flow layer? Even if it is only a millimeter thick, both silt- and clay-sized particles would be totally enclosed within it and the water would just flow over them. Plus, even more importantly, since laminar flow has no vertical energy vector, the water has no energy to lift the particles up and out of the layer.

We know silt and clay sized particles are transported by streams. They make the mess when the flood waters recede. But, the question is not why, but how are these tiny particles ever introduced into the water column? Recall that we previously stated that the thickness of the laminar layer decreases with increasing water velocity. With enough velocity the laminar layer eventually becomes thin enough to allow some of the vertical energy components to pluck silt-sized particles from the bottom and insert them into the water column. To pick up clay-sized particles, velocity must become fast enough to completely eliminate the laminar layer so that access to the clay sized particles can be achieved. Correspondingly, this turbulence level will also lift pebbles, which implies flowing water lifts and move particles of varying sizes at the same time. In terms of rocks, this is helpful when trying to explain a shaly-sandstone or a sandy-shale.

Figure 34 further shows us that deposition is a factor of water velocity, turbulence, and gravity. Since gravity is mass attraction, the more massive (larger) particles will be attracted downward first as vertical vectors associated with turbulence flow weaken. In other words, the bigger particles settle out first because of the gravity and the last material to be deposited are the clay sized particles of mud because the mutual gravitational attraction between Earth and nearly mass-less clay sized particles is extremely small. Flood waters, due to their high velocity and turbulence pick up a enormous amount of mud. When the water carrying the mud enters buildings or flat fields, and becomes stagnant, water velocity and turbulent all but disappear. This helps to explain the muddy mess left behind during most flooding events, even those due to flash floods in narrow valleys.

Stream Capacity and Load

Load is the amount (volume or mass) of sediment carried by a stream and is a function of how much energy (velocity and turbulence) is present. The actual load material is composed of either dissolved chemicals or suspended sediment particles. When discussing dissolved loads, many students are confused by the fact that the most abundant component of a stream's dissolved load consists of chemical solutions that are, for the most part, generically referred to as salt. It is important to clarify this term because it is not referring to saltwater or the table salt students instantly imagine. Instead, in the chemistry of water, almost any element, compound, or mixture is called a salt. Common salts are bicarbonates of sodium, potassium, calcium, and magnesium plus silicic acid produced during the chemical weathering of the silica minerals in igneous rocks and the calcite in sedimentary rocks that accumulates on household faucets. Measured where it enters the Gulf of Mexico, twenty-five percent of the load carried by the Mississippi River consists of dissolved salts. On the other hand, a stream's suspended load is composed of clay, silt and sand particles. The abrasive nature of this suspended material actually does the work of physical weathering by producing cut banks which eventually collapse and insert additional suspended load material into the water.

Capacity is the amount of material carried in the water column.

Load is the actual material being moved downstream (Go>Stay) and may consist of any combination of dissolved chemicals, both natural and man-made, or suspended physical objects such as silt, sand, logs, etc.

Cobbles and boulders commonly make us the stream's bed load, which, due to constant collisions along the bottom is reduced in size to smaller and smaller particles that ultimately wind up in the water column. The bed load, as it is moved along, cuts into the stream bottom and the stream banks, initiating mass wasting as banks and valley walls collapse and widen the valley floor.

If you ever have the chance, listen closely to a mountain stream. You may hear the rocks hitting each other as the bed load migrates downstream. You will also notice there is relatively little accumulating sediment on the stream bottom.

Mountain streams posses a very small suspended load, but contribute to weathering due to the action of the cobbles and boulders in their bed load. The collisions that occur as this material is moved downstream rounds of the angular edges of the mass wasting products, producing a new assortment of less angular or even rounded sand, silt, and clay sized particles. As the suspended load grows, it eventually produces the murky water found further downstream. At its mouth, sixty-eight percent of the entire load of the Mississippi River is carried in suspension. When the stream energy falls below the threshold required to keep this material suspended it begins to settle out. According to public domain government sources (*lacoast.gov/new/About/Basin_data.ml*) the average suspended load at the mouth of the Mississippi River Delta varies from 200,000 to 400,000 tons per day. When this suspended load abruptly interacts with the calm waters of the Gulf of Mexico, turbulence and velocity vectors are reduced to the point were the sediment falls to the bottom. Continual deposition of this material, over the last 5,000 years, has constructed a delta more than 20,000 feet thick that extends 15 to 20 miles into the Gulf of Mexico.

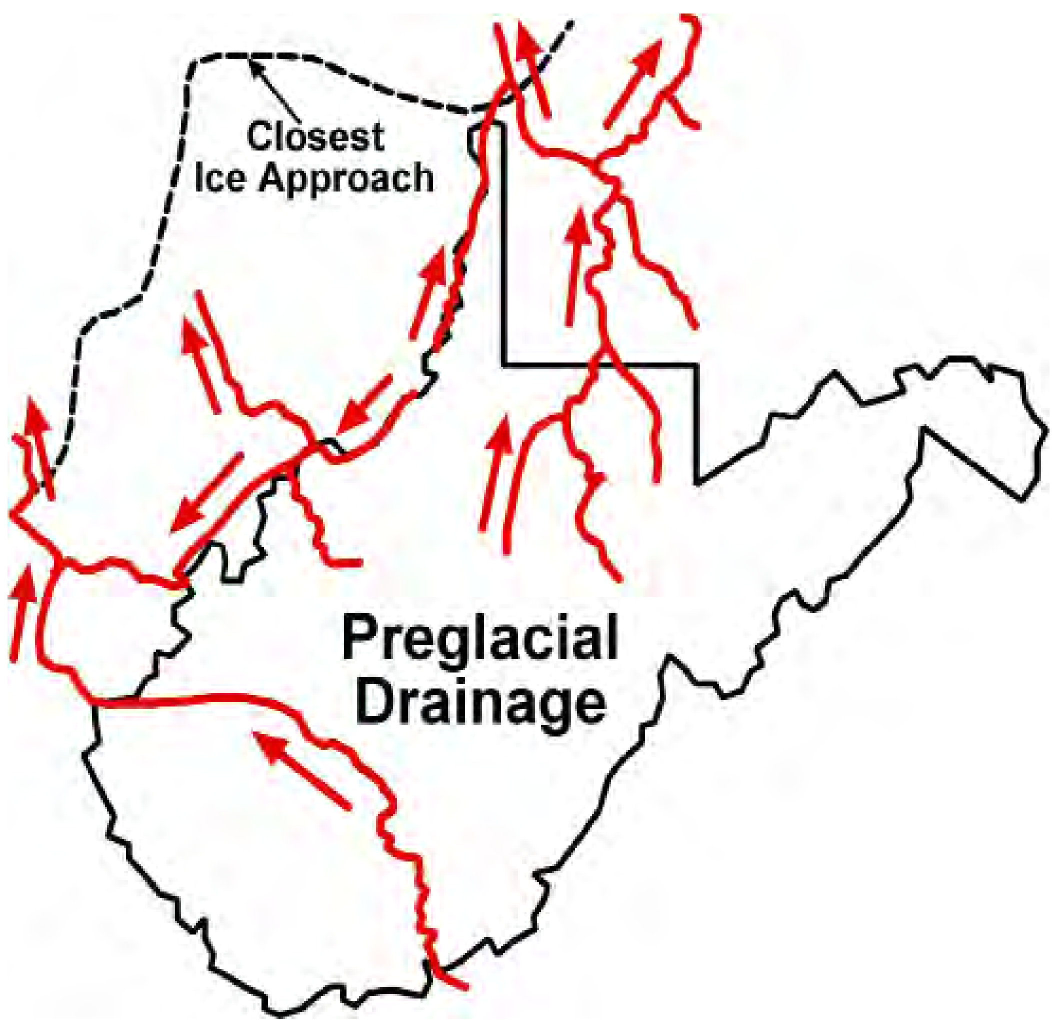


Figure 35.

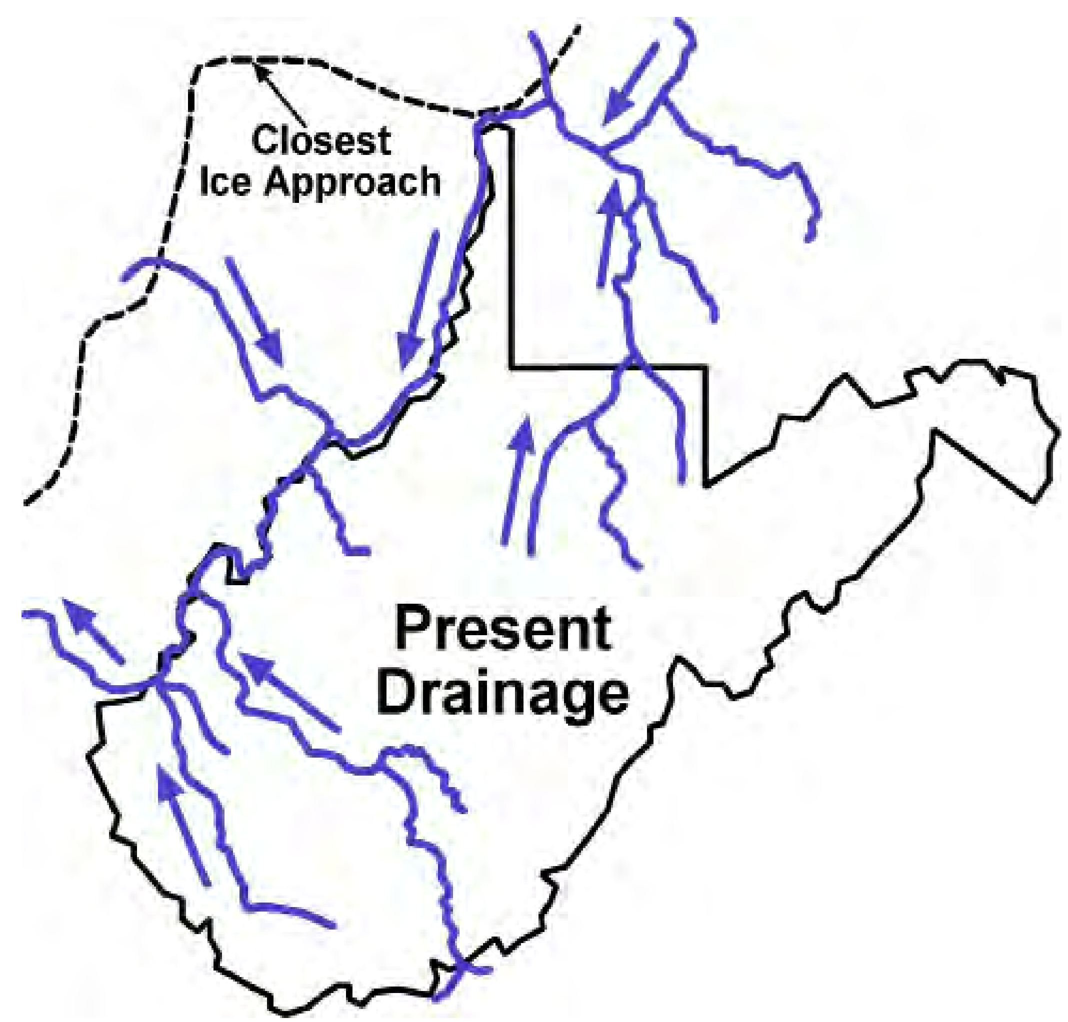


Figure 36.

Interesting factoid: The Mississippi River, as we know it today, is not that old. For many geologic time periods the location was the site of an inland sea that varied in size and depth. What we see today is primarily a product of the melting waters produced by the end of the last Ice Age. The same may be said for the Ohio River. Much of its present course, making the West Virginia border, only came into existence at the end of the most recent Ice Age. As the most recent ice sheet advanced, there was no Ohio River. The smaller stream that did exist in that area flowed north (Figure 35). Most of West Virginia was drained by the stream which carved the wide Taeys River Valley between Charleston and Huntington. Due to ice blockage, the north flowing pre-cursor to the Ohio River was forced to reverse course, becoming the more south flowing Ohio River we see today (Figure 36). Much of the terraced landscape of the Ohio Valley has been formed by massive outflows of meltwater from the retreating ice sheet.

Teachers Note: The Mississippi River and Delta is commonly referred in these kinds of discussions because it is the most studied. It is important to remember that these features may be found on streams of all sizes. There may be one or more streams locally that you can use for a field trip to illustrate delta formation, meandering, cut banks, point bars, etc. You might consider taking photos of local streams to increase student interest.

Deposition and Lithification

This brief discussion about deposition and lithification is included to remind you that these actions are outcomes and products of weathering, erosion, and mass wasting. For a more complete discussion on sediment deposition and how lithification turns loose sediment grains into rock read *Conceptual Understanding Series for West Virginia Teachers: Sedimentary Rocks, ED-16 at http://www.wvgs.wvnet.edu/www/geoeduc/SedimentaryRocksED16a.pdf]*

Figure 37.

As we just highlighted with the Mississippi River, when stream energy can no longer carry its load, gravity takes over and the particles fall downward. The most common place for this to occur is at the distributary or tributary stream mouth (Figure 37) where sudden changed and decreases in energy reduce the upward force vectors associated with turbulent water.

Deposition may also occur further upstream in the stream's meander system (Figure 38), as distance traveled by the water increases or decreases water velocity along one side of the meander versus its opposite bank. These situations (Figures 37 and 39) are responsible for the formation of pronounced areas of sediment deposition where velocity slows, the stream can no longer support its entire suspended load, and a point bar forms (Figure 39). On the opposite bank, the water velocity, because it has less distance to travel, is higher and weathers into the bank forming the characteristic cut bank (Figure 40).

An interesting physics or physical science integration opportunity using meandering: If the water velocity is constant in the middle of the stream but the distance it must travel varies along the banks, its velocity must change. Speed equals distance divided by time. You can use this equation to quantitatively demonstrate a reason for water flowing faster along the cut bank side.

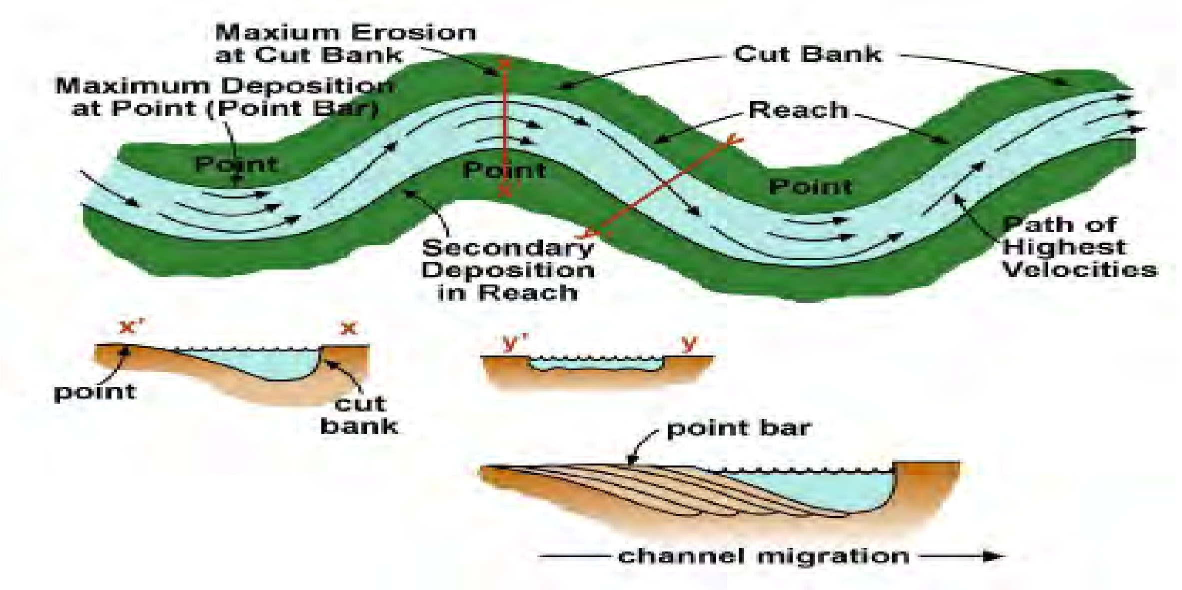


Figure 38.

Figure 39.

Figure 40.

Just like fossilization preserves bones and shells, deposition may, by shear luck, preserve sediment deposits such as ripple marks and mud cracks (Figure 41 and 42). Chances of preservation of such features is only possible if the next depositional event, for example a small flood, does not have sufficient energy to erode traces of earlier deposition. If preserved, the features will be retained as the sediment is lithified. These items offer rare glimpses into ancient environments. Geologists can identify these features applying uniformitarianism. For example. a modern point bar forms by the deposition of thin layers of sediment that slope into the water (Figure 43). Such features are also seen in West Virginia's Pennsylvanian Age sedimentary rocks commonly found in the Plateau Province. Note the inclined bedding shown by the dotted line in the center of Figure 44. This clue tells us that a stream was flowing across the landscape 300,000,000 years ago.

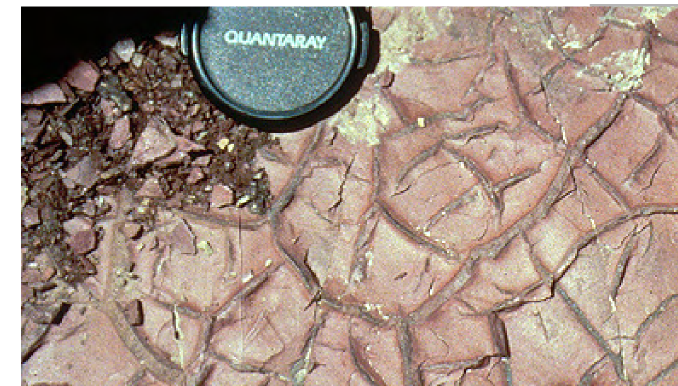


Figure 41.

Figure 42.

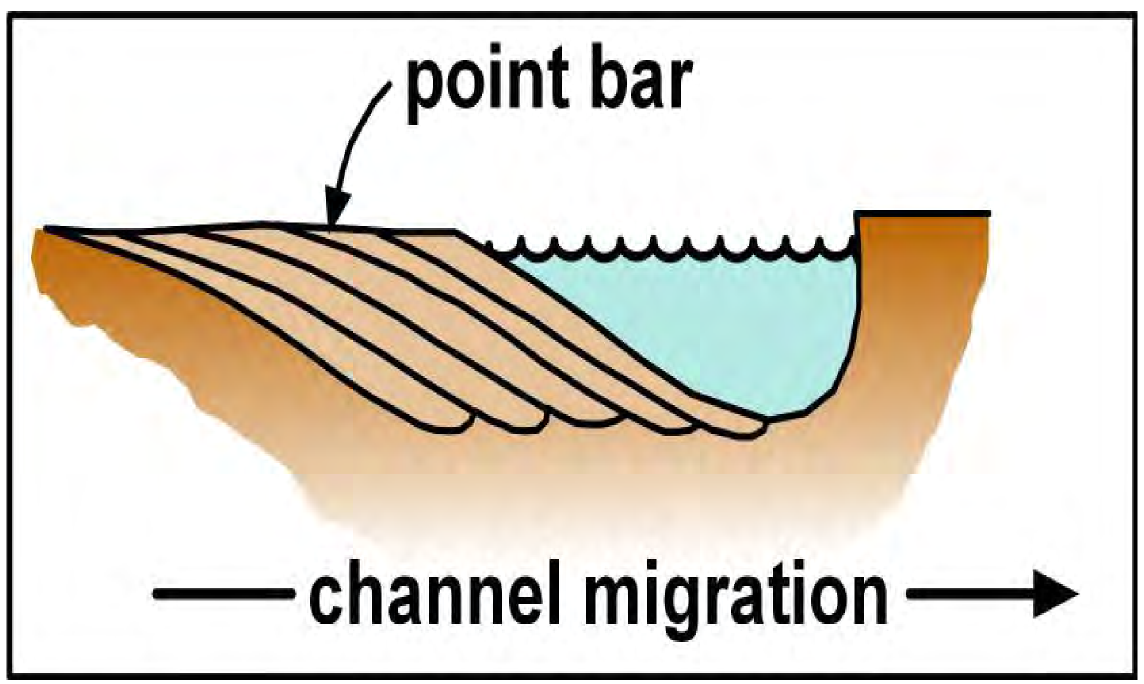


Figure 43.

Figure 44.

Weathering and Erosion Rates

How fast do these processes work? As you might assume, there is no set answer for such a generalized question. Rates will vary with location and climate change and daily/seasonal weather patterns. Most often, the use of an average annual rate will mask the reality of the fact that these process often accomplish most of their work and landscape change during dramatic short term events rather than slow ongoing ones. As we have already stated, in West Virginia flowing water is the most dominant sculptor because of its ability to disintegrate our native sedimentary rocks by physical and chemical weathering. If you feel the need, or a student requests the information, the following statistics provide some measure of response. The first is a quote from an abstract published in 2006 that might provide you, and your students, with some context of erosional rates and change in out part of Appalachia:

We have measured erosion rates...from bare-bedrock surfaces exposed at high elevations at Dolly Sods, West Virginia, a classic Appalachian paleoperiglacial plateau. The mean erosion rate from nine samples is 5.7 m/m.y., (meters per million years) significantly lower than previously estimated...in this region. Measured bare-bedrock erosion rates likely represent the rate at which the highest portions of this broad upland are ***being lowered. Fluvial incision rates (down cutting) measured in the region over similar time scales are ≥2 times faster, suggesting relief is*** *increasing in this portion of the Appalachians. This observation of increasing relief is inconsistent with prior work suggesting that the central Appalachian landscape is in dynamic equilibrium or currently decreasing in relief. We hypothesize that late Cenozoic climate change has accelerated fluvial incision rates, creating a disequilibrium landscape with growing relief with hillslopes undergoing adjustment to increased fluvial* ***incision rates. (Soource: Hanncock and Kirwan, 2006, Summit erosion rates deduced from 10Be: Implications for relief production in the central Appalachians. GEOLOGY, v. 35 no.1 p. 89-92).***

Another source states the following about regional erosion rates:

Sediment samples (n = 27) from eight Great Smoky Mountain drainages...suggest 27 ± 4 m/m.y. (meters per million years) of bedrock erosion... *consistent with [published data suggesting that] the Great Smoky Mountains and the southern Appalachians eroded during the Mesozoic* ***and Cenozoic at about 30 m/m.y. In contrast...rates during the Paleozoic orogenic events that formed the Appalachian Mountains were higher (≥102 m/m.y.). Erosion rates decreased after termination of tectonically driven uplift, enabling the survival of this ancient mountain belt...as an isostatically maintained feature in the contemporary landscape. (2003, Matmon, Bierman, Larsen, Southworth, Pavich, and Caffee. Temporally and spatially uniform rates of erosion in the southern Appalachian Great Smoky Mountains, Geology v. 31 no. 2 p. 155-158).***

These studies suggest an approximate Central and Souther Appalachian regional erosional rate of between 5.7 meters to 27 meters per million years. If you have your students due the math on both of these to convert them to millimeters per year you, and they, will devise some feeling for an annualized pace of change and how it might not be “best use” data. Make sure you also point out that the second reference cites the fact that erosion occurred at a much faster rate during mountain building orogenies. With all that you have read so fat, we hope you understand that landmass uplift is directly related to erosional rate, sedimentation formation, and depositional rate. If you’re looking for a way to apply this data, have your students determine how long it would take to reduce Spruce Knob to sea level? They’ll have to look up the elevation of Spruce Knob, convert it into meters and go from there.

Base Level

Landscape change attributed to flowing water is foundationally based on the principle of base level. For large continent-spanning steams base level is sea level. Most streams encounter temporary base levels at some point. In such cases, the temporary base level may be a lake. Temporary base level for westward flowing West Virginia streams is the Ohio River while many eastern flowing streams encounter multiple temporary base levels due to the unique nature of the tilted and faulted bedrock they must surmount. Even sea level is a changing base level when examined over geologic time. The geologic rock record clearly indicates that 15,000 years ago, near the end of most recent Ice Age and when the present Ohio River Valley was beginning to form, sea level was approximately 300 meters lower. The reason for this can be attributed to the tremendous amount of water tied up in the glacial ice. A great example of this is the Chesapeake Bay story referenced in the sidebar.

Every stream, no matter its width, length, or depth is actively engaged in the attempt to reach base level. For many inland tributaries base level is a larger stream or a lake. As a result, local or temporary base levels exist at various places along the stream's path. Water falls are temporary base levels caused by resistant rock. Upslope base levels are ephemeral landscape features that are constantly being weathered away as the stream attempts to reach sea level. A great example is the lip of Blackwater Falls (Figure 45). If you visit the site, you will notice lots of large rocks at the bottom, indicators of mass wasting events as physical and chemical weathering acting upon the Pennsylvanian age sandstone which forms the falls. Over time, as shown by the large fallen rocks, the lip will literally migrate upstream until the falls are reduced to a series of rapids along a gently sloping stream bed (Figure 46). Upstream falls migration can be a relatively quick geologic event. At Niagara Falls, a surveyed study of the upstream retreat determined ti to be in excess of a meter per year. Of course, this annualized rate hides the reality of dramatic and sudden changes typical of mass wasting events. The development of hydroelectric power stations and the control of water flow has diminished this rate significantly.

Figure 45.

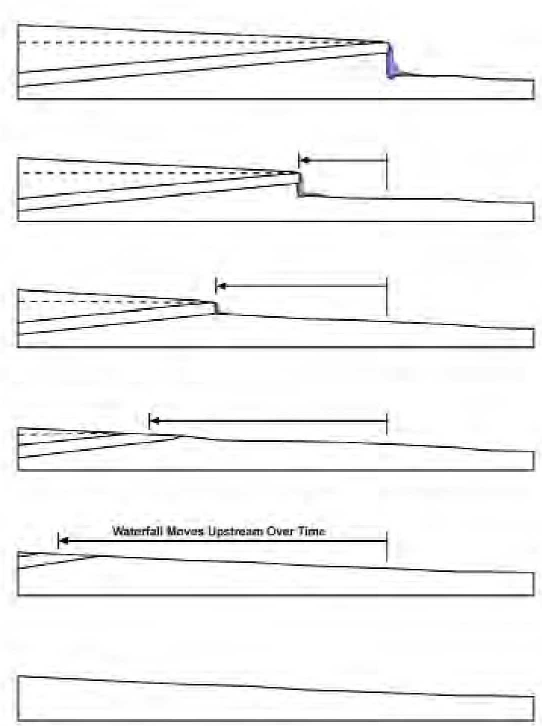


Figure 46.

Consider the landscape change that occurs as lakes evolve into dry land due to infilling by sediment deposition. If you have

Some of West Virginia's earliest underground coal mine maps from the Northern Panhandle counties use Lake Erie as base level and record feet above mean Lake Erie shoreline.

Chesapeake Bay Factoids: About 35 million years ago, a large extraterrestrial object impact what is now the Delmarva Peninsula, forming the Exmore Crater, which has, in turn, contributed to the Bay's geographic shape. During the height of the most recent Ice Age, the Atlantic coastline was about 180 miles farther east. Much of the continental shelf was dry land. As the Ice Age was ending meltwater carved a deep and large valley across the Bay area as it sought base level. Additionally, the melt water contributed to a rising sea level which eventually drowned the stream valley and its tributaries, until, about 3,000 years ago, the present day Chesapeake Bay came into being. Remnants of the ancient Susquehanna River still exist today as a deep channel along much of the Bay's bottom. (Source: Visit *http://www.chesapeakebay.net/discover/bayecosystem/baygeology)*

Terminology note: Notice that we say "resistance" or "resistance to weathering" instead of hardness. Totally different concepts!

every walked about an a wide valley floor and noticed very flat locations covered with lush growths of grasses you may be looking at just such an feature. The water level in the lake represents a temporary base level for the stream draining into the lake. As the flowing water enters the relatively still body of lake water, its energy level dissipates, it can no longer carry is suspended load, and deposition begins. The first landscape to form is the delta. As time passes and more sediment is carried into the lake, the delta will grow progressively further into the lake until it reaches the other edge (top part of Figure 47). The sediment provides a foundation for plant growth that turns the area into a wetland and then a grass-dominated marsh (bottom part of Figure 47). As the amount of water present decreases, or the water table changes, a bog, such as those found a Dolly Sods or Cranesville, form. If layers of additional sediment begin to compact and dewater the lower and older layers (Figure 48), peat might start to form in the bog. In many cases, the original stream will create a new channel into and across the solid land it made as it attempts to overcome the next local base level obstruction.

Figure 47.

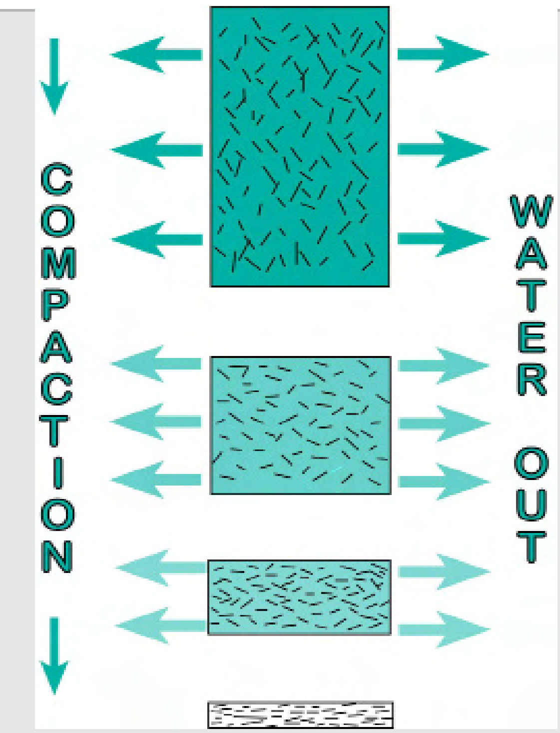


Figure 48.

Dewatering of clay-rich sediment has a tendency to horizontally orient and compress the flat clay particles, eventually forming the sedimentry rock we call shale. The nature of shale reduces its permiability, or the ability of water to vertically move through the shale. However, shale often contains large amounts of organix material that may, over time, decomposed to produce natural gas. In the 1970's and 1980's WVGES geologists were involved in the exploration of natural gas reserves within Devonian black shales such as the Macellus. The technology to free this gas has only become relevant and reliable within the past decade.

Meandering

Those who live along streams are well aware of dynamics of both the lateral (side-to-side) and downstream movement of meanders. In fact, some of the senior members of a community in or near a floodplain might recall actual changes to the landscape during their lifetime. Internet accessible maps and aerial photographs provide images of historical changes in large stream systems such as the Mississippi River and provide good images to use to illustrate various aspects of landscape change such as oxbow lakes, point bar deposition, and cut banks. Figure 49 shows the current path of the Ohio River (dark blue) and the abandoned meander in which Weirton is located.

Figure 49.

All streams meander. Meanders are like syncllines and anticlines—it is hard to have just one. In fact, they can be used as a visual analogy for each other. Find a map of the Greenbrier River and then turn it sideways. The meanders become synclines and anticlines and, what is most interesting, none of them are the same size and shape. This is the reality of the deformed sedimentary rocks of West Virginia's Valley and Ridge Province.

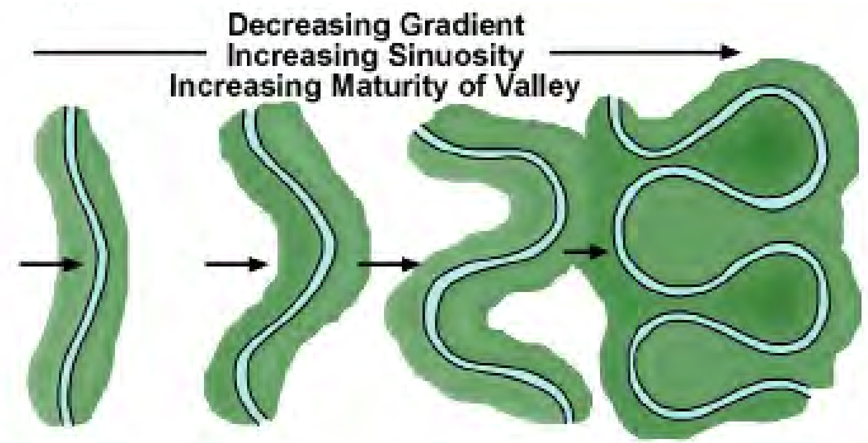


Figure 50.

The degree of meandering (sinuosity) is linked to stream gradient (Figure 50). A stream flowing across relatively flat areas, where there is little of no topographic (landform) or bedrock (geologic) directional influence has a tendency to meander the most. In West Virginia, meandering is not easily recognized due to limited sight lines caused by the hilly topography. A look at our western boundary will illustrate the meandering undetaken by the Ohio River. However, a look at a satellite image, aerial photograph, or topographic map reveals the amount of stream meandering found in West Virginia.

The dynamic process whereby flowing water assumes a sinuous path that meanders laterally (widening the flood plain) and downstream (leveling and moving sediment), is well documented. How the process works, not so much. We know the source of energy driving the stream downslope is the GO force. But what changes the GO vector so that, after a period of time, the meander reverses and erodes laterally back to the opposite side of the valley? Chances are you have heard, or taught your own students, that meandering is simply water taking the path of least resistance. You may assume that stream bed obstructions make flowing water go left or right, initiating the development of a meander. What does your textbook say about meander development? It probably makes a case for the "path of least resistance" and moves on.

The physics of meandering merits some classroom time as it helps build a deeper understanding of how landscape change happens. The whole concept of stream meandering may be turned into a positive discussion on the nature of science by providing you with a topic for open-ended student-center research, debate, and decision making. A first good source is the *The Cause of the Formation of Meanders in the Courses of Rivers and of the So-Called Baer's Law* (http://people.ucalgary.ca/~kmuldrew/river.html). It's only one page long. And, it was written by Albert Einstein. There is a certain satisfaction to boasting that you, or your students, are discussing a paper by Einstein!

A good place to find stream maps, floodplain maps, and other such information is *http://www.mapwv.gov/flood/map/*

Conclusion

The following reference presents a historical review of thinking about how and when meandering and regional and continental scale landscape-altering weathering and erosion occurs: *http://www.geographynotes.com/geomorphology/7-major-geomorphic-theories-of-landform-development/686.* Many of the newer ideas demonstrate the influence of plate tectonic theory. For example, more recent ideas suggest significant landscape change is episodic, occurring only during periods of accelerated weathering associated with regionally active orogenic uplift when a landmass is raised far above base level. This triggers geologically long stretches during which the original landscape is (1) altered, (2) removed by weathering, and (3), altered again by sediment deposition as new landscape is formed from sediment derived from the weathering mountain are transported, deposited, and lithified at lower elevations. Since our observational interval is linked to the human time scale, imposing an average yearly amount of weathering over geologic time is both impractical and creates a misconception.

Ironically, one of earliest landscape change ideas by flowing water was developed in the 1880's but remains one that is commonly found in K-16 descriptive earth science and geology textbooks. The idea was developed by a man named Davis who, as you can clearly tell by the date of his work, knew nothing about plate tectonic theory. According to Davis, when a stream channel sits high above its base level all of its potential energy is converted into down-cutting kinetic energy. In desert regions, this process would probably form a slot canyon. In humid regions, such as the eastern U.S., the valley profile is changed by differing rock structure and type and mass wasting processes such as rock falls, debris slides and rock slides that widen the small area where material is actually removed by the stream, producing the characteristic V-shaped valley with slopes approaching the angle of repose. This is what we see in most of West Virginia. The reason Davis' work is still cited has to do with its simplicity. Unfortunately, his idea is commonly misinterpreted as a qualitative method for determining the age of a stream when, if fact,it has much more to say about the dynamic nature of the landscape of the stream valley. Just for fun, what interesting situations would develop if the Ohio River decided to abandon one of its present meanders and form a new one? Since West Virginia owns the stream bed to the Ohio side, a landscape change created by flowing water could alter the residency of some citizens!

Geological data suggest Earth is currently in an intra-glacial warming period. It should come as no surprise that sea level is rising.

Hilly, as in West Virginia's Plateau Province, is often referred to as "dissected" to imply that it has been formed by weathering and erosion removing existing material to form the current landscape. With this in mind, one might wish to describe West Virginia as the "Valley State."

Again, note our use of the term "resistant to weathering" as opposed to strong or hard. Resistance to weathering and rock strength are two entirely different properties. A very hard limestone used for road construction can be easily destroyed by chemical weathering.

The West Virginia floods of 2016 provide many examples, videos, and photographs illustrating landscape change attributed to moving water erosion and deposition.

A free, online map resource that shows West Virginia streams, their meandering courses, and their flooding potential may be found at http://www.mapwv.gov/flood/map/