Name______________________

ENVI.2030L - Surface and Groundwater

I. Introduction

In this exercise we will investigate various features associated with streams and ground water. We will make extensive use of topographic maps and air photos to study the various landforms that can result from the work of water. The air photos come in pairs so that, coupled with the use of a stereoscope, the land surface will be seen in 3-dimensions. Be careful, there is a sizeable vertical exaggeration.

II. Stream discharge

Water moves downhill until it reaches a *base level* below which it cannot flow. The erosive and transporting potential of a river is dependent upon the amount of flowing water, termed the *discharge*, and its *velocity* which is governed by the channel gradient. A river's discharge is equal to its cross-sectional area multiplied by its velocity:

Discharge = Velocity x Cross-sectional area

Discharge generally increases downstream because water is added by tributaries joining the stream. The above equation suggests that a river should become deeper and wider and flow faster if its discharge is increased. Downstream increases in width and depth are easily noticed but increases in velocity are offset by lower downstream gradients.

The gradient of a river must be balanced with its discharge to produce the velocity required to transport the sediment it is supplied. Ideally, a river's gradient is such that water flows just fast enough to carry the sediment load without deposition or erosion. This condition rarely persists because of seasonal variations in discharge and/or local changes in current velocity which occur because of channel irregularities. As a result, rivers are continually depositing or eroding in an attempt to maintain a balanced state.

Exercise 1. Relationship between discharge, velocity and cross-sectional area.

1. We make observations at two points, *A* and *B*, along a river. *B* is downstream from *A*. At *A* the stream is 30 meters wide, has an average depth of 2 meters and an average velocity of 2 m sec^{-1}. Calculate the discharge of the stream. How much water will flow by point *A* in 1 hour.

2. At B the stream discharge is the same but the width is now 20 meters. The average depth is still 2 meters. Calculate the average velocity. If the stream is carrying a small sand grain in suspension at point *A*, will it be deposited at point *B*? Why or why not?

III. Physiographic characteristics of streams

Differential erosion. Running water is an effective agent of erosion. Different types of rocks show different resistance to erosion. As a result, topographic variations within an area can usually be related to the type of underlying bedrock. The resistance of bedrock to stream erosion is governed by its mineralogy (how susceptible it is to chemical breakdown) and its degree of lithification (how susceptible it is to mechanical breakdown). Unconsolidated or poorly-lithified rocks are easily eroded and usually underlie lower topographic positions than well-lithified rocks. In humid climates rocks which contain abundant quartz (sandstone, conglomerate, and some varieties of igneous rocks) are most resistant to stream erosion. Rocks whose mineral constituents are soluble in water (limestone) or which contain poorly-cemented grains (shale) are more easily eroded and typically underlie lower topographic positions. Finely-layered and better-cemented rocks (slate, phyllite, and most mafic igneous rocks) are of intermediate resistance. Because of tectonic stresses rock units may undergo folding or faulting. Rocks within and adjacent to zones of faulting are typically fragmented during movement along the fault. This reduces their resistance to stream erosion and stream courses are often controlled by fault zones.

Drainage patterns. The geometric distribution of steams within an area is termed the *drainage pattern*. It is controlled by several factors, including relief, the type and distribution of bedrock, and structural features (folds, faults, etc.). Although there is considerable natural variability in these factors, there are only four common drainage patterns.

1. *Dendritic pattern*. This is the most common type of drainage pattern and its form resembles the veins of a leaf (Fig. 1). This stream geometry usually develops in areas where there is no structural control on stream direction and little variation in bedrock. For example dendritic drainage is common in the midwestern United States where large areas are underlain by the same type of rock.

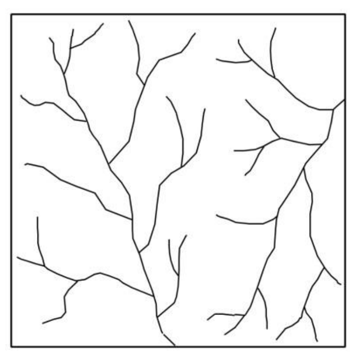

Figure 1. Dendritic drainage pattern.

2. *Rectangular* pattern. Rectangular drainage patterns have a more ordered appearance than dendritic stream patterns. They typically develop in areas where streams flow along zones of weakened rocks adjacent to intersecting faults. Because of fault control, streams generally meet at right angles and have similarly shaped bends. For example New England is a highly faulted terrane and in many places faults can be delineated by stream directions. Hence, at least locally, rectangular stream drainage patterns can be found.

3. *Trellis pattern*. This type of drainage patterns develops in areas where resistant bedrock ridges alternate with valleys underlain by less resistant bedrock. This bedrock distribution directs most major streams into a subparallel orientation. Smaller tributaries frequently converge at nearly right angles to the regional trend, thereby forming a trellis pattern. Typical examples are the drainage patterns developed in the Valley and Ridge Province of the Appalachian Mountains. This province extends from Pennsylvania to northern Georgia and Alabama.

4. *Radial pattern*. Streams which drain isolated topographic highlands usually flow downhill in all directions. This produces a radial drainage pattern which resembles the spokes of a wheel. This type of drainage pattern is common in areas where resistant igneous intrusions form elevated surfaces, for example the Adirondack Mountains of New York state or the various intrusions of the White Mountain magma series of New Hampshire. An area you may be familiar with, the Ossipee Mountains, shows a typical radial drainage pattern.

Stages of river development. A river system is continually lengthened by headward erosion and the stream's longitudinal profile is always changing (Fig. 5). Because of this change, each segment of a river system undergoes an evolutionary development. A segment will occupy a particular developmental stage for only a specific length of time before headward erosion lengthens the river system and moves the segment to a lower position on the longitudinal profile (Fig. 5). The evolutionary stages of river development are discussed below.

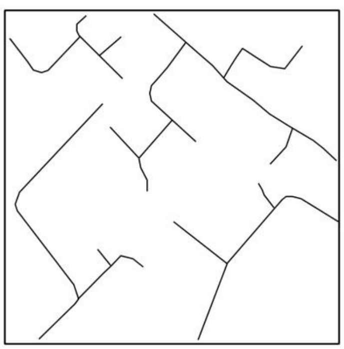

Figure 2. Rectangular drainage pattern.

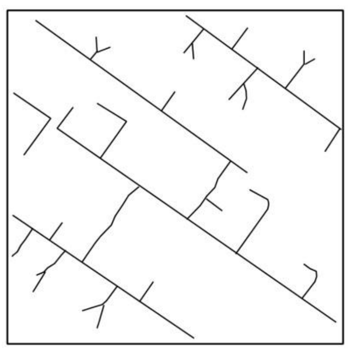

Figure 3. Trellis drainage pattern.

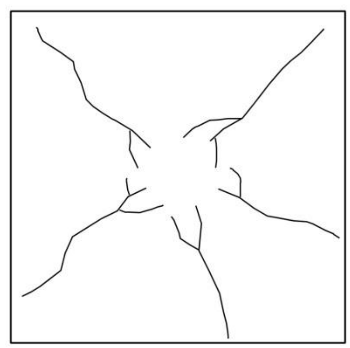

Figure 4. Radial drainage pattern.

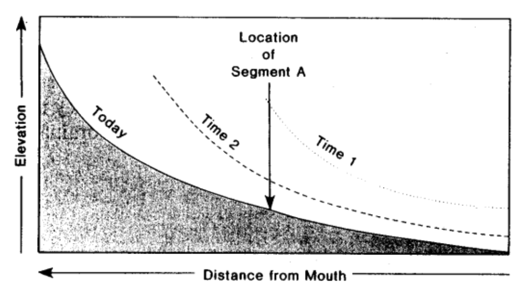

Figure 5. Generalized longitudinal profiles showing the change in stream profile as a result of erosion. From Dallmeyer, R. D., 1978. *Physical Geology Laboratory Text and Manual*. Dubuque: Kendall/Hunt Publishing Company, p. 128.

Degradational stage. The headward segment of a river usually has a steep gradient and actively erodes downward and headward. This river segment typically flows in a steep-sided valley with a characteristic "V" shape. Most of the valley floor is occupied by running water which flows directly over bedrock. Depositional features are not well-developed and waterfalls and rapids are common.

Balanced stage. In the balanced stage most of the energy of the segment is used to transport the sediment load supplied from upstream. Ideally neither deposition nor erosion occurs. However during a flood the river the river velocity increases and the river erodes laterally. Sediment is usually deposited on the floodplain surrounding the river during recession of the flood waters. These deposits are easily eroded and a river segment in this developmental stage commonly meanders across the entire width of the floodplain.

Aggradational stage. An aggradational river segment occurs in the downstream reaches of a river system and has a very low gradient. This segment is characterized by an extensive floodplain, but the channel is restricted and meanders over only a portion of the floodplain. Sediment supplied from tributaries generally exceeds the transport capacity of the aggradational river segment, and excess sediment is deposited within and along the channel.

Terminal stage. When a river reaches its base level (whether a large lake or the sea) its velocity suddenly decreases and it loses its capacity to transport sediment. Most of the sediment is deposited at the channel mouth as a delta. As a river flows across older delta deposits it commonly splays into a network of channels, termed distributaries.

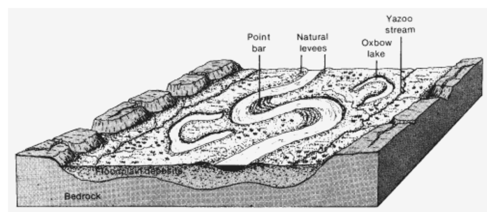

Figure 6. Features found on a floodplain.From Dallmeyer, R. D., 1978. *Physical Geology Laboratory Text and Manual*. Dubuque: Kendall/Hunt Publishing Company, p. 136.

Rivers in the first three stages of development are sometimes referred to as *youthful* (degradational stage), *mature* (balanced stage) or *old age* (aggradational stage). Note that any river can show all three stages of development along its course from youthful in the headwaters to old age at its end.

Depositional features of river floodplains. A floodplain is the land area adjacent to a river which is covered by floodwaters. Most are underlain by fine-grained sediment deposited during recession of the floodwaters. Coarser-grained sediment may locally occur as deposits which accumulated within migrating river channels and during overflow of the banks. The various features found on a floodplain are illustrated in Figure 6.

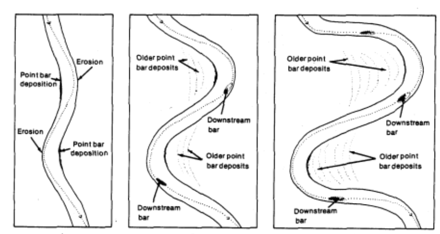

Figure 7. The development of meanders. Position of maximum current velocity is indicated with dotted lines. Arrows show flow directions. (A) Original channel course. Continued erosive undercutting (B) and (C) on outside of each bend produces lateral migrations and “tightening” of meanders. From Dallmeyer, R. D., 1978. *Physical Geology Laboratory Text and Manual*. Dubuque: Kendall/Hunt Publishing Company, p. 136.

Meanders. Moving water flows in a sinuous pattern because channel irregularities deflect moving water towards nearby banks. This results in local increases in velocity and causes erosive undercutting of channel banks. Meanders form in this manner and migrate across river floodplains (Figs. 6 and 7). Meanders do not develop at uniform rates, and straight segments between meander bends are reduced in length as meanders “tighten” (Fig. 7). Rivers eventually erode across meander loops by forming *cut-offs*. Abandoned bends form oxbow lakes (Fig. 6). In Australia these are called billabongs. With time these oxbow lakes fill with sediment and are overgrown with vegetation.

On the outside of each meander bend there is an increase in water velocity which causes undercutting of the channel banks. Velocity rapidly decreases around a meander bend, and some of the material eroded from the undercut channel bank is immediately deposited to form a *downstream bar* (Fig. 7). Water velocity is less on the inside of meander bends than elsewhere in a river and sediment are deposited in these areas as *point bars* (Figs. 6 and 7). Curved topographic irregularities along old point bar deposits usually preserve a record of meander migrations. These irregularities are termed *meander scrolls*.

Natural levees. The current velocity of floodwater rapidly decreases when it leaves the confines of a river channel. This reduces the carrying capacity of the water, and coarser-grained sediment is deposited in a narrow strip along the edge of the river channel. After several floods this material accumulates to form a ridge of coarse-grained sediment termed a *natural levee*.

Bayous. Natural levees are elevated above surrounding areas of a river floodplain and become barriers to merging tributaries. Tributaries often must run parallel to a major river for many miles before finding a breach in a natural levee through which they can flow. These deflected tributaries are called *yazoo streams* (Fig. 6). Many floodplains are poorly-drained and swampy because of the disruption of drainage systems caused by natural levees. These poorly-drained areas are known as *backswamps* or *bayous*.

Stream capture. Streams flowing down foreslope areas have steeper gradients than those flowing down backslopes (Fig. 8). If the difference in gradient is extreme, foreslope streams may be more effective in headward erosion. As a result they can intersect backslope streams and divert them into the foreslope drainage system. This process is called *stream capture* (or *stream piracy*). It is most likely to occur where a foreslope is underlain by less resistant bedrock than a backslope.

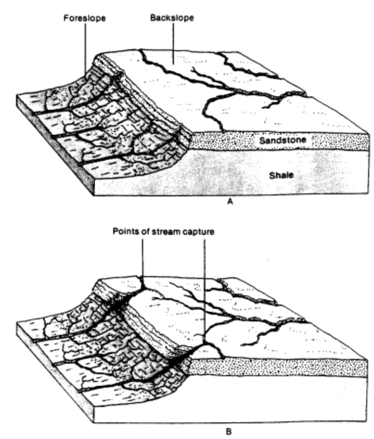

Figure 8. Sequential block diagrams illustrating stream capture. (A) Foreslope streams have steeper gradients and flow over less resistant bedrock than backslope streams. Thus they erode headward at a faster rate. (B) Foreslope streams have "captured" backslope streams and diverted them into the foreslope drainage system. From Dallmeyer, R. D., 1978. *Physical Geology Laboratory Text and Manual*. Dubuque: Kendall/Hunt Publishing Company, p. 138.

Fluvial erosion cycle. Base level controls the final result of the fluvial erosional cycle. Base level approximately coincides with sea level in regions with integrated and through-flowing drainage networks, and stream erosion will attempt to reduce the landscape to this elevation. In areas which are internally drained, local base levels at elevations above sea level control the lowest point to which erosion may progress. The exception are regions of internal drainage (such as Death Valley) where the floor of the basin is below sea level.

Initial stage of erosion. Landscapes in an initial stage of stream erosion are relatively flat and have a low drainage density. Most streams are degradational. They usually have rather steep gradients and actively erode downward. Streams typically have little or no floodplain and flow in narrow, steep-sided valleys with "V"-shaped profiles.

Intermediate stage of erosion. Interstream areas are progressively eroded and stream valleys become wider as denudation proceeds. In the process, landscapes pass from an initial to an intermediate stage of development where more of the land surface is represented by slopes. Drainage systems typically become more integrated and there is also a general increase in drainage density. Most major streams are balanced and are characterized by gentle gradients. Lateral erosion dominates over downcutting and streams commonly meander across well-defined floodplains. Stream valleys have much less pronounced "V"-shapes than those in the initial stages of stream denudation.

Terminal stage of erosion. Extensive denudation of a landscape will occur if base level remains constant for a prolonged period. Interstream divides will be reduced to broad hills and river floodplains will be developed over large areas. River segments within such regions are commonly in an aggradational or a terminal stage of development. They typically have very low gradients and are actively depositing rather than eroding downward or laterally. Rocks which are particularly resistant to stream erosion may locally remain as isolated hills which are termed *monadnocks*.

Rejuvenation**.** A region may be uplifted at any stage of the fluvial erosional cycle. This lowers base level and streams begin active downward erosion. This process is termed *rejuvenation*. Rejuvenated terrains usually have complex landscapes because remnants of older landforms are locally preserved between drainage courses. For example, parts of previous floodplains may be preserved as *terraces* along downcutting stream channels. Also, meandering streams often become entrenched in their previous courses as a result of renewed downward erosion towards a newly-established base level. This produces meandering streams with pronounced "V"-shaped valleys. These streams are termed *entrenched meanders* and are distinctive of rejuvenated areas.

Exercise 2. Use the Strasburg, Virginia topographic map to answer the following questions.

1. What is the name given to the drainage pattern in the vicinity of the Massanutten and Green Mountains?

2. The Shenandoah River is a meandering stream but has virtually no floodplain. How might you explain this?

Exercise 3. Use the Menan Buttes, Idaho topographic map to answer the following questions.

1. What is the age, in terms of stream development, of Henry's Fork?

2. What is the average gradient of Henry's Fork?

3. How might the features marked “levees” been formed?

4. What is the feature located just SW of the section 20 number (near Henry’s Fork)?

5. What may happen in the near future to the bends in Henry’s Fork located in section 1?

Exercise 4. Use the air photos in *Aerial Stereo Photographs* to answer the following questions.

1. Plate 34 - Horseshoe Lake. Find the oxbow lake in the photo. Give its location in terms of the coordinate system on the air photographs.

2. Plate 40 - Bear Creek. Observe the headward erosion of the streams in this area.

3. Plate 44 - The Loop. What does this feature indicate?

IV. Ground water systems

Precipitation that is absorbed into the ground migrates downward through soil and bedrock until it reaches a depth below which all void spaces are saturated. This level marks the upper surface of the local *water table*. The position of this surface is variable and its depth changes with surface topographic irregularities; being slightly elevated under hills and somewhat depressed under valleys. Water within the saturated zone is not stagnant, but slowly migrates through soil and bedrock by following local gradients in the water table surface. When this slowly moving ground water reaches an intersection of the water table with the land surface it forms a spring or is added to a lake or stream. Answer the following questions using the geologic cross-section (Fig. 9) below.

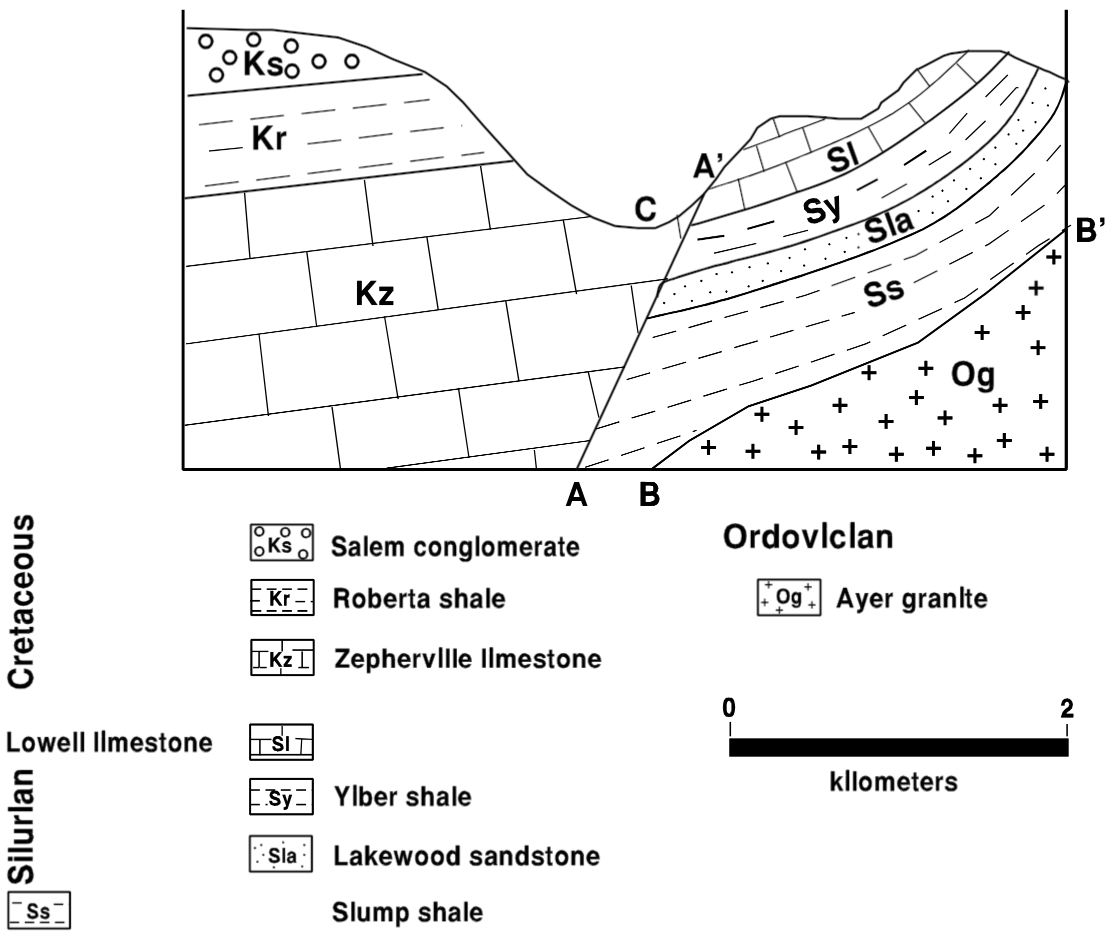

Figure 9. Geologic cross-section for ground water questions.

Exercise 5. Water in the subsurface.

1. Indicate on the cross-section places where you might expect to find a spring.

2. Name the formation that could act as an artesian aquifer.

3. Indicate where you might expect to find an artesian spring.

4. Indicate where you would drill a well so that water would not have to be pumped to the surface.

5. Would you expect to find a stream at point C? Why or why not? You may find information in the next section useful in answering these questions.

6. Draw on the cross-section a dashed line representing the water table.

7. What is surface A-A'?

8. What is the name of surface B-B'?

V. Erosion by ground water

Subsurface erosion may occur during ground water movement. Areas which are underlain by calcareous bedrock are particularly susceptible to this type of erosion because calcite is slightly soluble. Ground water erosion produces unique landscapes.

Mechanism of ground water erosion. The rate of ground water movement through soil and bedrock is slow and does not generate the turbulent action which characterizes surface stream flow. However, if ground water moves through calcareous bedrock it can dissolve and remove a considerable quantity of rock by solution transport. Solution begins along joints or fractures and leads to formation of underground caves. As individual caves are enlarged they join to form a network of subterranean caverns. Caverns eventually expand to a size where overlying rocks may no longer be supported and roofs collapse. This produces circular surface depressions which are termed *sink holes*. In advanced stages of ground water erosion, solution enlarges individual sink holes which join to form *solution valleys*.

Stages of ground water erosion. Humid areas underlain by calcareous bedrock are typically characterized by numerous solution features and have what is termed a *karst topography*. These terrains are pitted with sink holes and have poorly developed surface drainage systems. Only major streams flow in well-defined valleys, and tributaries may suddenly disappear into sink holes or solution valleys. Surface springs are usually abundant. Formation of a karst topography is an evolutionary process and three intergradational erosional stages may be recognized. Each stage represents a greater extent of subsurface ground water solution.

Preliminary stage of erosion. A karst topography will develop when ground water migrates through soluble bedrock. If calcareous bedrock is overlain by relatively impermeable rock layers such as shale, subsurface erosion will not occur. Underground solution will begin when surface streams locally erode downward through the impermeable bedrock cover. With time, sink holes will form and surface drainage will be disrupted.

Intermediate stage of erosion. Calcareous bedrock terrains pass into an intermediate stage of karst development when individual sink holes are enlarged and join to form solution valleys. Surface drainage is modified with development of springs and disappearing streams. Although maximum topographic relief is attained in this stage of karst development, it rarely exceeds several hundred feet.

Terminal stage of erosion. Impermeable rock layers which underlie a calcareous bedrock section define a lower limit for subsurface ground water solution. In a sense they represent a "base level" for ground water erosion. Areas where such layers have been exposed are in a terminal stage of karst development. Isolated hills are usually all that remain of original calcareous bedrock sections and integrated surface drainage systems have usually been reestablished.

Exercise 6. Use the Mammoth Cave, Kentucky, topographic map to answer the following questions.

1. In the southern portion of the map, what is the name given to the small depressions?

2. Why do many of the streams in the southern portion of the map come to an abrupt end?

3. What is the name given to this type of topography?

4. What type of rock underlies the southern portion of the map?

Exercise 7. Use the air photos in *Aerial Stereo Photographs* to answer the following questions.

1. Plate 4 - Sink Hole. Find the solution valley and give its location in terms of the coordinates of the air photo.

2. Plate 5 - Haystacks. Compare this plate to Plate 4. What are the topographical similarities and differences between these two plates? What is the reason for the differences?