GEOG 274 /4A – Review - Part II. (Ch.14-18)
Earth exogenic system: weathering and mass movement, fluvial processes and landforms, glacial and periglacial landscapes, soils.

Overview
This Part II explores the solid Earth's exogenic system. The endogenic system builds and creates initial landscapes, while the exogenic system works towards low relief, little gradual change, and the stability of sequential landscapes. The exogenic system is an open system. As the landscape is formed, a variety of exogenic processes simultaneously operate to wear it down. The exogenic processes at work on Earth's landscapes include weathering, erosion, transportation, and deposition of materials; namely: weathering and mass movement processes, river systems and their landforms, landscapes shaped by waves and wind, landforms worked by ice and glaciers, and, eventually, soils. All of these are the essential subjects of geomorphology - the science of the origin, development, and spatial distribution of landforms.

We examine types of mass movements and discuss the processes that cause them. Weathering is the process that breaks down rock by disintegrating it into mineral particles or dissolving it into water. Weathering produces an overall weakening of surface rock, which makes it more susceptible to other exogenic processes. The difference between weathering and erosion is important: weathering is the breakdown of materials, whereas erosion includes the transport of (weathered) materials to different locations.

Physical (mechanical) and chemical weathering processes break up, dissolve, and generally reduce the landscape. Such weathering releases essential minerals from bedrock for soil formation and enrichment. In limestone regions, chemical weathering produces sinkholes, caves, and caverns (karst environments), in which water has dissolved substantial underground areas.

Earth's waterways both shape and drain the continents, transporting the by-products of weathering, mass movement, and erosion. Rivers and streams produce fluvial landforms and redistribute mineral nutrients important for soil formation and plant growth. There is some overlap in usage between the terms 'river' and 'stream'. Specifically, the term river is applied to the trunk, or main stream of the network of tributaries forming a river system. Stream is a more general term for water flowing in a channel and is not necessarily related to size. We examine the organization of river systems into drainage basins and the types of drainage patterns, examine (stream) gradient, base level, and stream discharge. We then discuss factors that affect flow characteristics and the work performed by flowing water, including erosion and transport. We also look at coastal processes and landforms, discussing coastal erosion and deposition, further noting that coastal environments are vulnerable to storm damage, flooding, rising sea level, pollution.

Over 75% of freshwater on Earth is frozen. Earth's cryosphere consists of the portions of the hydrosphere and lithosphere that are perennially frozen. These cold regions are generally found at high latitudes and, worldwide, at high elevations. Currently, a volume of more than 32.7 million km^3 of water is tied up as ice in Greenland, Antarctica, and ice caps and mountain glaciers worldwide. The bulk of that snow and ice sits in just two places - Greenland (2.4 million km^3) and Antarctica (30.1 million km^3). The remaining snow and ice (180 000 km^3) covers other near-polar regions, and various mountains and alpine valleys. Permanent (formed over many years) snow forms glacial ice. We then look at Earth's extensive ice deposits - formation, movement, and the ways in which various erosional and depositional landforms are produced. Glaciers, transient landforms themselves, leave a variety of landscape features in their wake. Glacial processes are intricately tied to changes in global temperature and rising or falling sea level. We also examine the freezing conditions that create permafrost, and the periglacial processes such as frost action that shape landscapes. With rising temperatures causing worldwide glacial ice melts and permafrost thaw, the cryosphere today is in a state of dramatic change.

Wind is an important geomorphic agent that can move significant quantities of rock material and shape landforms. The ability of wind processes to erode, transport, and deposit sediments is limited to the environments with an ample supply of small and dry particles. We explore wind erosion, the resulting landforms, wind deposition and sand dunes. Wind may fill the atmosphere with dust that crosses the oceans between continents, and also spreads living organisms and contributes to soil formation.

Soils develop over long periods of time; in fact, many soils bear the legacy of climates and geological processes over the last 15 000 years or more. Soils do not reproduce, nor can they be re-created within any reasonable for human life time span - they are a non-renewable natural resource. This fact implies that human use (and abuse) of soils is happening at rates much faster than soils form or can be replaced. Soil is a complex substance whose characteristics vary from kilometre to kilometre - and sometimes even centimetre to centimetre. Physical geographers are interested in the spatial distributions of soil types and the physical factors that interact to produce them. Knowledge of soils is also critical for agriculture and food production. Soil science is the interdisciplinary study of soil as a natural resource on Earth's surface; the field that draws on aspects of physics, chemistry, biology, mineralogy, hydrology, taxonomy, climatology, and cartography. Pedology deals with the origin, classification, distribution, and description of soils (ped is from the Greek pedon, meaning "soil" or "earth"). We examine soil development and the soil horizons of a typical soil profile. We look at the properties that affect soil fertility and determine soil classification, including texture, structure, consistence, porosity, moisture, colour, and chemistry. We also note human impacts on soils, and desertification. We conclude with a brief examination of the Canadian System of Soil Classification, the 10 principal soil orders and their spatial distribution.

Key learning concepts

After reading the appropriate sections of Chs.14 –18 in the Geosystems textbook (see the course outline and/or lecture notes for details on book pages), the lecture notes, and this study guide you should be able to:

• *Describe the dynamic equilibrium approach to the study of landforms, and illustrate the forces at work on materials residing on a slope.*
• *Categorize the various types of mass movements, and identify examples of each by moisture content and speed of movement.*
• *Define weathering, and explain the importance of parent rock and joints and fractures in rock.*
• *Describe the physical weathering processes of frost action, salt-crystal growth, and pressure-release jointing.*
• *Explain the chemical weathering processes of hydration, hydrolysis, oxidation, carbonation, and dissolution.*
• *Review the processes and features associated with karst topography.*
• *Understand a basic drainage basin model, and identify some types of drainage patterns by visual examination.*

• Explain the concepts of stream gradient and base level, and understand the relationship between stream velocity, depth, width, and discharge.
• Explain the processes involved in fluvial erosion and fluvial sediment transport.
• Describe the depositional landforms associated with floodplains and alluvial fan environments.
• Briefly describe the coastal environment, explain coastal straightening and coastal landforms.
• Differentiate between continental ice sheets, alpine glaciers, ice caps and ice fields.
• Describe some characteristic erosional and depositional landforms created by glaciation.
• Discuss the distribution of permafrost and explain major periglacial processes, landscapes, and changes occurring today in the polar regions.
• Describe eolian transport of dust and sand, discuss eolian erosion and the resultant landforms, formation of sand dunes.
• Describe loess deposits and their origins.
• Define soil and soil science, and list four components of soil.
• Describe the principal soil-formation factors, and describe the horizons of a typical soil profile, discuss human impacts on soils.
• Describe the physical properties used to classify soils: colour, texture, structure, consistence, porosity, and soil moisture.
• Explain basic soil chemistry, and relate these concepts to soil fertility.
• Identify the 10 soil orders of the Canadian System of Soil Classification, the principal pedogenic processes that lead to the formation of soils under different environmental conditions, and the general occurrence of these orders.

Review Questions

1. Define landmass denudation. What processes are included in the concept?
Denudation is a general term referring to all processes that cause reduction or rearrangement of landforms. The principal denudation processes affecting surface materials include weathering, mass movement, erosion, transportation, and deposition.

2. What are the principal considerations in the dynamic equilibrium model?
The balancing act between tectonic uplift and reduction by weathering and erosion, between the resistance of rocks and the continuous weathering and erosion, is summarized in the dynamic equilibrium model. A dynamic equilibrium demonstrates a trend over time. According to current thinking, landscapes in a dynamic equilibrium show ongoing adaptations to the ever-changing conditions of rock structure, climate, local relief, and elevation. Endogenic events (including earthquakes and volcanic eruptions) or exogenic events (including heavy rainfall or forest fire) may provide new sets of relationships for the landscape within the geomorphic cycle.

3. Given all the interacting variables, do you think a landscape ever reaches a stable, old-age condition?
In reality, a landscape behaves as an open system, with highly variable inputs of energy and materials. In response to this input of energy and materials, landforms constantly adjust toward a condition of equilibrium. As physical factors fluctuate, the surface constantly responds in search of an equilibrium condition, with every change producing compensating actions and reactions. The balancing act between tectonic uplift and the reduction rates of weathering and erosion, and between the resistance of crust materials and the denudation processes, is summarized in the dynamic equilibrium model. A dynamic equilibrium is

different from a steady-state equilibrium, which fluctuates around an average. Instead, according to current thinking, landscapes adapt to the ever-changing conditions of rock structure, climate, local relief, and elevation.

As conditions change, a system eventually arrives at a geomorphic threshold, or the point at which the system breaks through to a new set of equilibrium relationships and rapidly realigns landscape materials accordingly. A geomorphic threshold (change point) is altered when any of the conditions in the balance is altered.

Taking a hillslope as an example: a slope is an open system seeking an angle of equilibrium (angle of repose). Gravity (the weight of rock) contributes to both, a shear stress load acting to move materials downslope, and the shear strength (resistance) of the material to this movement, including inertia, cohesion, and friction acting to keep materials in place. The slope is in a constant state of adjustment due to the conflicting forces acting upon each other, causing the slope to exist as a balance between these forces (effectively, between the normal stress and the shear stress). Many factors could alter the hillside's equilibrium, such as an earthquake, saturation of the regolith, or the building of a house or dam (adding mass and/or undercutting slope). All the forces on the slope then compensate by adjusting to a new dynamic equilibrium.

4. What events or processes could reduce the degree of cohesion of particles on a slope?
The forces keeping material in place on a slope are inertia, friction, and cohesion. All processes that can induce movement of material (e.g. earthquakes, erosion), and water, act to reduce cohesion and lubricate materials.

5. What will eventually happen to the coarse materials on the debris slope?
Coarse materials on the debris slope will be transported to the waning surface until the slope reaches its angle of repose.

6. What are the general components of an ideal slope?
Slopes generally feature an upper waxing slope near the top. The convex surface curves downward and grades into the free face below. The presence of a free face indicates an outcrop of resistant rock that forms a steep scarp or cliff. Downslope from the free face is a debris slope, which receives rock fragments and materials from above. The debris slope grades into a waning slope, with a concave surface along the base of the slope. This surface of erosional materials gently slopes at a continuously decreasing angle to the valley floor. (See lecture notes on 'Anatomy of a slope' for more details).

7. Define the role of slopes in mass movements, using the terms angle of repose, driving force, resisting force, and geomorphic threshold.
All mass movements occur on slopes. The steepness of a slope determines where loose material comes to rest, depending on the size and texture of the grains; this is called the angle of repose. This angle represents a balance of driving and resisting forces. The driving force in mass movements is gravity, which balances the weight, size, and shape of the grains or surface material, the degree to which the slope is over-steepened, and the amount and form of moisture available - whether frozen or liquid. The greater the slope angle, the more susceptible the surface material is to (mass) movement. The resisting force is the *shearing strength* of slope material, that is, its cohesiveness and internal friction working against movement (*shear stress*). To reduce shearing strength is to increase shearing stress, which eventually reaches the point at which shear gravity load overcomes friction.

8. What are the classes of mass movement? Describe each briefly and differentiate among these classes.
Four basic classifications of mass movement are used: fall, slide, flow, and creep. Each involves the pull of gravity working on a mass until the critical shearing strength is reduced to the point that the mass falls, slides, flows, or creeps downward. A rockfall is simply a quantity of rock that falls through the air and hits a surface. During a rockfall, individual pieces fall independently, and characteristically form a pile of irregular broken rocks called a talus cone at the base of a steep cliff. Creep is the slow downslope movement of material. A debris avalanche is a mass of falling and tumbling rock, debris, and soil. It is differentiated from a debris slide or landslide by the tremendous velocity achieved by the onrushing materials. These speeds often result from ice and water that fluidize the debris (solifluction). The extreme danger of a debris avalanche results from the tremendous speeds and lack of warning. (Please, refer to the lecture notes for more details on classification of mass movement depending on material, velocity of down-motion, and water content).

9. Differentiate between stable and unstable landscapes.
A landscape is stable if its shear strength (resistance to motion) exceeds the weathering and erosion processes (e.g., gentle slope, vegetated soil).
A landscape is unstable if the shear strength (resistance to motion) of its materials is weaker than the weathering and erosion processes (e.g., steep slope, sand soil).

10. What is the interplay between the resistance of rock structures and weathering?
Weathering is greatly influenced by the character of the bedrock: hard or soft, soluble or insoluble, broken or unbroken. The differing resistances of rock, coupled with these variations in the intensity of weathering, result in differential weathering.

Interactions between the structural elements of the land and denudation processes are complex and represent a constant struggle between internal and external processes. An important question to ask is whether or not this dynamic interplay is progressive, evolving and building landforms in an orderly manner through stages. Do landscapes initially form and subsequently age in graceful stages until they are flat? Or does the interplay of forces fluctuate back and forth without ever achieving steady-state equilibrium? The debates in geomorphology are fuelled by the fact that landscapes evolve on a much longer time span than does a human life. Modern geomorphology has moved away from simple descriptive classifications.

11. Describe weathering processes operating on an open expanse of bedrock.
Rocks at or near Earth's surface are exposed to both physical and chemical weathering processes. Weathering encompasses a group of processes by which surface and subsurface rock disintegrates into mineral particles or dissolves into minerals in solution. Weathering does not transport the weathered materials; it simply generates these raw materials for transport by the agents of wind, water, and gravity. Physical and chemical weathering weaken materials on the waxing slope, causing gravity to overcome inertia and cohesion. Gravity pulls these materials down past the free face onto the debris slope, where they are transported farther downslope. In most areas, the upper surface of bedrock is partially weathered to broken-up rock called regolith. In some areas, regolith may be missing or undeveloped, thus exposing an outcrop of unweathered bedrock.

12. What role do joints play in the weathering process?
Joints are fractures or separations in rock that occur without displacement of the sides (as would be the case in faulting). The presence of these usually planar (flat) surfaces greatly increases the surface area of rock exposed to both physical and chemical weathering. (See lecture notes for examples of joint-block separation, a form of physical weathering). When rock is broken and disintegrated without any chemical alteration, the process is called physical weathering or mechanical weathering. By breaking up rock, physical weathering greatly increases the surface area on which chemical weathering may operate. Chemical weathering refers to actual decomposition and decay of the constituent minerals in rock due to chemical alteration of those minerals. A familiar example of chemical weathering is the eating away of cathedral facades and etchings on tombstones caused by increasingly acid precipitation. Water is essential to chemical weathering and the chemical breakdown becomes more intense as both temperature and precipitation increase.

13. What is physical weathering?
Physical, or mechanical, weathering is the term used when rock is broken and disintegrated without any chemical alteration. By breaking up rock, physical weathering greatly increases the surface area on which chemical weathering can take place. An example of physical weathering is frost action. When water freezes, its volume expands. This creates a powerful mechanical force, which can exceed the tensional strength of rock. Repeated freezing and thawing of water break rocks apart. The work of ice begins in small openings, such as existing joints and fractures, gradually expanding until rocks are split apart.

14. Why is freezing water such an effective physical weathering agent?
Water expands by about 9% of its volume as it freezes. This expansion creates a powerful mechanical force that can exceed the tensional strength of rock. In a weathering action called frost-wedging, ice crystals grow in pre-existing cracks in rock and push the sides apart along joints or fractures. The work of ice probably begins in small openings, gradually expanding until rocks are cleaved. Softer supporting rock underneath the slabs already has weathered physically - an example of differential weathering.

15. What is chemical weathering? Contrast this set of processes to physical weathering.
Chemical weathering is the actual decomposition of minerals in rock. Chemical weathering involves reactions between air and water and minerals in rock. Minerals may combine with water in chemical reactions, or carbon dioxide and oxygen from the atmosphere (such as carbonation and oxidation). Although physical weathering may create greater surface area for further weathering to take place, chemical weathering can dissolve minerals in the rock.
An example that demonstrates the difference between physical and chemical weathering is the absorption of water in rocks. In cold climates dominated by physical weathering, the process of rock hydration takes place. In rock hydration water present in the rock expands with freezing, and cracks the rock into smaller pieces. In humid climates, where chemical weathering occurs, water percolates into the rock by dissolving it, a process called hydrolysis, and primarily breaks down the silicate minerals in rock. Hydrolysis dissolves silicate and carbonate materials, leaving behind resistant minerals, such as quartz.

16. What is meant by the term spheroidal weathering? How does spheroidal weathering occur?

Spheroidal weathering is an example of the way chemical weathering attacks rock. The sharp edges and corners of rock are rounded as the alteration of minerals progresses through the rock. Joints in the rock offer more surfaces of opportunity for weathering. Water penetrates joints and fractures and dissolves the rock's weaker minerals or cementing materials. The resulting rounded edges are the basis for the name spheroidal weathering.

17. What is hydration? What is hydrolysis? Differentiate between these processes. How does it affect rocks?

The basic types of chemical reactions that cause chemical weathering of rocks are hydration, hydrolysis, and dissolution. Although these processes are different, three of them involve water and all work to decompose rock.

Hydration, meaning "combination with water," involves little chemical change. Hydration is the absorption of water. Water becomes part of the chemical composition of the mineral (such a hydrate is gypsum, which is hydrous calcium sulphate: $CaSO_4 \cdot 2H_2O$). When some minerals hydrate, they expand, creating a strong mechanical effect, a wedging pressure that stresses the rock, forcing grains apart.

Dissolution and hydrolysis are caused by reactions with acids. In hydrolysis, silicate and carbonate minerals transform into new minerals, principally clay minerals, which have a sheet-like structure (similar to mica). Both the chemical composition and crystalline structure become completely different. Acids add more H+ ions when dissolved in water. The stronger the acid, the more H+ ions they produce. Acids can react with any rock mineral that has other positive ions, like Ca^{++}, Na^{+}, or K^{+}, by taking their place, which changes the chemical composition of the mineral and disrupts its atomic structure. The most important natural acid is carbonic acid (H_2CO_3), which forms from carbon dioxide and water (CO_2 and H_2O). Others include sulphuric acid (H_2SO_4) and hydrofluoric acid (HF), which mainly come from volcanic eruptions.

In dissolution, the acid completely dissolves the original rock, leaving nothing solid behind. For example, the gradual action of carbonic acid on limestone (mainly calcite, $CaCO_3$) over a very long time span results in the formation of caves (a limestone cave or cavern is a natural cavity that is formed underneath the Earth's surface that can range from a few metres to many kilometres in length and depth. Over millions of years, acidic groundwater or underground rivers completely dissolve the limestone, and the cavities grow over time. Limestone is so abundant on Earth that many landscapes are composed of it. Their weathering creates a specific landscape of pitted, bumpy surface topography, poor surface drainage, and well-developed solution channels underground. These are the hallmarks of karst topography, originally named for the Kras Plateau in Slovenia, where these processes were first studied. Approximately 15% of Earth's land area has some developed karst.

18. Explain and differentiate among the formation of sinkholes, karst valleys, cockpit karst and tower karst.

Sinkholes are circular depressions that form by the slow subsidence of surface materials along joints or at an intersection between joints. Karst valleys form when many sinkholes coalesce and may be up to several kilometres long. Cockpit karst is a complex topography of weathered, deeply jointed limestone that forms in the tropics. Isolated resistant limestone blocks can also form in the tropics. These are known as tower karst.

19. What is carbonation?
Carbonic acid is created when water vapour dissolves carbon dioxide. Carbonic acid is strong enough to react with many minerals, and this specific type of weathering known as carbonation.

20. Iron minerals in rock are susceptible to which form of chemical weathering? What characteristic colour is associated with this type of weathering?
Iron minerals in rock are susceptible to <u>oxidation</u>. Oxidation is an example of chemical weathering that occurs when oxygen combines with certain metallic minerals to form oxides. The 'rusting' of iron in rocks or soils produces a reddish-brown stain of iron oxide.

21. What are the main factors influencing weathering processes?
Rock composition and structure, jointing (increases both physical and chemical weathering by surface exposure); vegetative cover, which can protect rock by shielding it from raindrop impact, yet roots can do both, stabilize soil and produce organic acids and enhance chemical weathering. Large plant roots can also break up rocks.

22. Describe the relationship between climate, water and weathering.
Most important in determining weathering rates are atmospheric and hydrologic elements, including climate, the amount of precipitation, overall temperature patterns, and freeze-thaw cycles. Generally, physical weathering dominates in cooler climates, whereas chemical weathering dominates in wetter, warmer climates. Extreme dryness reduces most weathering to a minimum, as is experienced in desert climates. In the hot, wet-tropical, and equatorial rainforest climates, most rocks weather rapidly, and the weathering tends to be deep below the surface.

23. What is hydraulic action?
Several types of erosional processes are operative. Hydraulic action is the mechanical work of turbulence in the water - the eddies of motion. Running water causes friction in the joints of the rocks in a stream channel. A hydraulic squeeze-and-release action works to loosen and lift rocks. As this debris moves along, it mechanically erodes the streambed further through the process of <u>abrasion</u>, with rock particles grinding and carving the streambed.

24. Define the term fluvial. What is a fluvial process?
Stream-related processes are termed fluvial (from the Latin *fluvius*, meaning river). Insolation (sun related energy) is the driving force of fluvial systems, operating through the hydrologic cycle and working under the influence of gravity. Denudation by water dislodges, dissolves, or removes surface material as erosional fluvial processes. Thus, streams supply weathered and wasted sediments for transport to new locations, where they are laid down in a process known as deposition.

25. What is the sequence of events that takes place as a stream dislodges material?
Water dislodges, dissolves, or removes surface material in the process of erosion. Streams produce fluvial erosion, in which weathered sediment is picked up for transport to new locations. Thus, a stream is a mixture of water and solids; the solids are carried by solution, suspension, and mechanical transport. Materials are then laid down by another process, deposition.

26. How does a stream transport its sediment load?
Four processes transport eroded materials: solution, suspension, saltation, and traction. Solution refers to the dissolved load of a stream, especially the chemical solution derived from minerals such as limestone or dolomite or from soluble salts. The suspended load consists of fine particles physically held aloft in the stream, with the finest particles not deposited until the stream velocity slows to near zero. The bed load refers to those coarser materials that are dragged along the bed of the stream by traction or are rolled and bounced along by saltation (from the Latin *saltim*, which means “by leaps or jumps”).

27. What is the basic organizational unit of a river system? How is it identified on the landscape? Define the relevant terms used.
Streams are organized into areas or regions called drainage basins. Every stream drains an area of land called a drainage basin - an area from which all precipitation flows to a single stream or set of streams at a lower elevation. A drainage basin is the spatial geomorphic unit occupied by a river system (a main stream with all its tributaries). River's headwaters, which are a subset of the drainage basin, are the source of a stream.

Due to the different processes occurring at the headwaters and the mouth, different features develop in the respective locations for stream. Landforms at the headwaters are often carved by erosion. Upstream, where erosion is more prominent, water level is low and channels are rougher. A stream typically flows from its headwaters, characterized by steep or rugged slopes, high erosion, high velocity, and low discharge (the amount of water passing a point at a given time), to its mouth. The mouth of a river is characterized by gentle to almost flat terrain, high deposition, low velocity, and high discharge. Landforms at the mouth are more depositional.

Different landscapes form distinctive drainage patterns, including:

- The trellis drainage pattern, which is characteristic of dipping or folded topography.
- A radial drainage pattern results when streams flow off a central peak of dome.
- A rectangular pattern is formed by a faulted and jointed landscape, which directs stream courses in patterns of right-angle turns.
- A parallel drainage is associated with steep slopes.
- A pattern of stream flow in which the stream tends to form a circular path around the hill. It happens when there is a layer of less resistant rock in the hill.
- Dendritic patterns, in which the energy, expanded by this drainage system, is efficient because the overall length of the branches is minimized, and
- Deranged drainage patterns, often found in the areas with disrupted surface patterns, such as the glaciated shield regions of Canada.

A drainage basin is usually delimited by ridges that form drainage divides, i.e. the ridges are the dividing lines that control into which basin precipitation drains. Drainage divides define watersheds, the catchment areas of the drainage basin.

Drainage basins are open systems whose inputs include precipitation, the minerals and rocks of the regional geology, and both the uplift and subsidence provided by tectonic activities. System outputs of water and sediment leave through the mouth of the river. Change that occurs in any portion of a drainage basin can affect the entire system as the stream adjusts to carry the appropriate load relative to discharge and velocity.

28. Erosion, deposition, sediment load, and a meandering stream.
As the stream carries more sediments along its channel, the load of sediments begins to weigh negatively on the velocity of the stream, causing it to take on an S-shaped movement called a meander. A meandering channel pattern is common for a stream that slopes gradually, a sinuous form weaving across the landscape. The outer portion of each meandering curve is subject to the greatest erosive action (called cut bank), while the inner portion of a meander receives sediment fill and forms a deposit (called a point bar). Meander bends are formed because of high-velocity flow on the cut bank causing erosion, at the same time low-velocity flows are causing deposition on the point bar. Any given stretch of a river will have many different velocities. As meanders develop, these scour-and-fill features gradually work their way downstream. As rivers flow, they remove material along the outer bank and deposit material along the inner bank. This process acts to increase the sinuosity of the river. As the river continues to flow, the process of increasing the sinuosity continues and the river will become more sinuous. If the load in a stream exceeds the capacity of the stream, sediments accumulate as an aggradation in the stream channel (the opposite of degradation) as the channel builds up through deposition. With excess sediment, a stream becomes a maze of interconnected channels laced with sediments that form a braided pattern.

29. Describe the formation of a floodplain. How are natural levees produced?
A meandering river has sufficient energy to keep sediments afloat. Meandering widens the stream valley through lateral erosion, resulting in a broad flat valley floor covered with alluvium. This is called a floodplain, which is easily inundated during flooding.
The low-lying area near a stream channel that is subjected to recurrent flooding is a floodplain. It is formed when the river leaves its channel during times of high flow. Thus, when the river channel changes course or when floods occur, the floodplain is inundated with water. When the water recedes, alluvial deposits generally mask the underlying rock. The former meander scars become water-filled (often ephemeral) loops on the floodplain called oxbow lakes (known as a billabong in Australia, an aboriginal term meaning *dead river* that is only intermittently filled with water).

On either bank of the river are natural levees, which are by-products of flooding. When flood waters arrive, the river overflows its banks, loses velocity as it spreads out, and drops a portion of its sediment load to form the levees. Larger sand-sized particles drop out first, forming the principal component of the levees, with finer silts and clays deposited farther from the river. Successive floods increase the height of the levees and may even raise the overall elevation of the channel bed so that it is perched above the surrounding floodplain.

30. What processes are involved in the formation of an alluvial fan?
Alluvial fans are prominent cone-shaped, or fan-shaped, deposits of fluvial sediments. They commonly occur at the mouth of a canyon where an ephemeral stream channel exits the mountains into a flatter valley. Alluvial fans are produced when flowing water (such as a flash flood) abruptly loses velocity as it leaves the constricted channel of a canyon and therefore drops layer upon layer of sediment along the base of the mountain block. Water then flows over the surface of the fan and produces a braided drainage pattern, sometimes shifting from channel to channel. The sediment composing alluvial fans is naturally sorted by size. The coarsest materials (gravels) are deposited near the mouth of the canyon at the apex of the fan, grading slowly to pebbles and finer gravels, then to sands and silts, with the finest clays and dissolved salts carried in suspension and solution all the way to the valley floor.

31. What is a river delta?
The mouth of a river marks the point where the river reaches a base level. Its forward velocity rapidly decelerates as it enters a larger body of standing water, with the reduced velocity causing its transported load to be in excess of its capacity. Coarse sediments drop out first, with finer clays being carried to the extreme end of the deposit. This depositional plain formed at the mouth of a river is called a delta (named after the triangular shape of the Greek letter delta, which was perceived by Herodotus in ancient times to be similar to the shape of the Nile River delta).

32. What is a littoral zone?
Littoral zone is a coastal area and shallow offshore environment, limited by the highest storm waterline on the coast, and the imaginary line in open body of water where sediments unaffected by wave action (in the oceans it is typically ~60 m depth). A line of land-water contact, shaped by tides and waves is called a shoreline. Littoral zone is a subject to continuous erosion and deposition, predominantly by hydraulic action.

33. Describe the refraction process that occurs when waves reach an irregular coastline. Why is the coastline straightened?
Generally, wave action is a process that results in coastal straightening. As waves approach an irregular coast, they bend and focus around headlands, or protruding landforms generally composed of more resistant rocks. Thus, headlands represent a specific point of wave attack along a coastline. Waves tend to disperse their energy in coves and bays on either side of the headlands. This wave refraction (wave bending) along a coastline redistributes wave energy so that different sections of the coastline are subjected to variations in erosion potential.

34. What is meant by an erosional coast? What are the expected features of such a coast?
Erosional coastlines tend to be rugged, of high relief, and tectonically active, as expected from their association with the leading edge of a drifting lithospheric plate. Sea cliffs are formed along a coastline by the undercutting action of the sea. As indentations are produced at water level, such a cliff becomes notched, leading to subsequent collapse and retreat of the cliff. Other erosional forms evolve along cliff-dominated coastlines, including sea caves, sea arches, and sea stacks. As erosion continues, arches may collapse, leaving isolated stacks out in the water.

35. What is meant by a depositional coast?
Depositional coasts generally are located near onshore plains of gentle relief, where sediments are available from many sources. Such is the case with the Atlantic and Gulf coastal plains of North America, which lie along the relatively passive, trailing edge of the North American lithospheric plate, and made up of materials that have been eroded and transported by littoral drift (note: for much sand to accumulate, offshore currents must also be weak).

36. Describe the location of most of the freshwater on Earth today.
A large measure of the freshwater on Earth is frozen, with the bulk of that ice sitting restlessly in just two places - Greenland and Antarctica. The remaining ice covers various mountains and fills alpine valleys. More than 29 million km^3 of water, or about 77% of all freshwater, is tied up as ice. Snow that survives the summer, into the following winter begins a slow (years

to millennia) transformation into glacial ice (analogous to that of formation of a metamorphic rock, i.e. recrystallizing under pressure).

37. What is a glacier?

A glacier is a large mass of perennial ice, resting on land or floating shelf-like in the sea adjacent to land. Glaciers form by the accumulation and recrystallization of snow. They move under the pressure of their own mass and the pull of gravity. Today, about 11% of Earth's land area is dominated by these slowly flowing ice streams. During colder episodes in the past, as much as 30% of continental land was covered by glacial ice because below-freezing temperatures prevailed at lower latitudes, allowing snow to accumulate. Relative to elevation, in equatorial mountains, the snowline is around 5000 m; on midlatitude mountains, such as the European Alps, snowlines average 2700 m; and in southern Greenland snowlines are down to 600 m.

Worldwide, glacial ice is in retreat now, melting at rates exceeding anything previously recorded by scientists. The European Alps have lost more than 50% of their ice mass over the past century, with accelerating melt rates since 1980, losing nearly 20% of their ice during the past 20 years. In Alaska, 98% of surveyed glaciers are in what scientists describe as a "swift retreat." Similar ice losses and reduced snowpacks are reported for the Rockies, Sierra Nevada, Himalayas, and Andes. The USGS is capturing these dramatic changes in a Repeat Photography Project (see nrmsc.usgs.gov/repeatphoto/).

38. Differentiate between an alpine glacier, an ice sheet, an ice cap, and an ice field.

With few exceptions, a glacier in a mountain range that is controlled by the topography is called an alpine glacier, or mountain glacier. It occurs in several subtypes. One prominent type is a valley glacier, an ice mass constricted within the confines of a valley. Such glaciers range in length from only 100 m to over 100 km. The snowfield that feeds the glacier with new snow is at a higher elevation. As a valley glacier flows slowly downhill, the mountains, canyons, and river valleys beneath its mass are profoundly altered by its passage.

The three types of continental glaciers are ice sheet, ice cap, and ice field. These are not constrained by the topography. Both ice caps and ice sheets are capable to completely bury the underlying landscape, although an ice cap is somewhat circular and covers an area of less than 50 000 km^2. Antarctica alone has 91% of all the glacial ice on the planet as an enormous ice sheet, or more accurately several ice sheets acting in concert. Most glacial ice exists in the snow-covered ice sheets that blanket 80% of Greenland (1.8 million km^3) and 90% of Antarctica (13.9 million km^3).

39. How does a glacier accomplish erosion?

Glacial erosion is similar to a large excavation project, with the glacier hauling debris from one site to another for deposition. As rock fails along joint planes, the passing glacier mechanically plucks the material and carries it away. There is evidence that rock pieces actually freeze to the basal layers of the glacier and, once embedded, allow the glacier to scour and sandpaper the landscape as it moves, a process called abrasion. This abrasion and gouging produces a smooth surface on exposed rock, which shines with glacial polish when the glacier retreats. Larger rocks in the glacier act much like chisels, working the underlying surface to produce glacial striations parallel to the flow direction. One of a typical erosional landforms associated to glacial movement is a <u>roche moutonnée</u> - an asymmetrical hill of exposed bedrock. Its gently sloping upstream side (stoss side) has been polished smooth by glacial action, whereas its downstream side (lee side) is abrupt and steep where rock was plucked by the glacier.

40. Differentiate between two forms of glacial drift - till and outwash.

Where the glacier melts, debris accumulates to mark the former margins of the glacier - the end and sides. Glacial drift is the general term for all glacial deposits. Direct deposits appear unstratified and unsorted and are called till. In contrast, sorted and stratified glacial drift, characteristic of stream-deposited material, is called outwash and may form an outwash plain of glacio-fluvial deposits across a large landscape.

41. Describe the evolution of a V-shaped stream valley to a U-shaped glaciated valley. What kinds of features are visible after a glacier retreats?

A typical river valley forms a characteristic V-shape and stream-cut tributary valleys that exist before glaciation. Glacial erosion and transport are actively removing much of the regolith (weathered bedrock) and the soils that covered (often the pre-existing valley) landscape. The glaciated valleys then become U-shaped, greatly changed from their previous stream-cut form. The over-steepened sides, the straightened course of the valley, hanging valleys and waterfalls typically are clearly visible. The physical weathering associated with a freeze-thaw cycle loosens much rock along the steep cliffs, which are falling to form talus cones along the valley sides during the postglacial period.

42. What is a morainal deposit? What specific moraines are created by alpine and continental glaciers?

Glacial till moving downstream in a glacier can form a marginal unsorted deposit known as a moraine. A lateral moraine forms along each side of a glacier. If two glaciers with lateral moraines join, their point of contact becomes a medial moraine. Eroded debris that is dropped at the glacier's farthest extent is called a terminal moraine. However, there also may be end moraines, formed wherever a glacier pauses after reaching a new equilibrium. If a glacier is in retreat, individual deposits are called recessional moraines. A deposition of till generally spread across a surface is called a ground moraine.

43. Where periglacial landscapes occur? Permafrost.

Periglacial regions occupy over 20% of Earth's land surface (40 to 50 % of Canada). The areas are either near (peripheral to) permanent ice or are at high elevation, and have ground that is seasonally snow free. Under these conditions, a unique set of periglacial processes operate, including permafrost, frost action, and ground ice.

When soil or rock temperatures remain below 0°C for at least two consecutive years, a condition of permafrost develops. An area that has permafrost but is not covered by glaciers is considered periglacial. Note that this criterion is based solely on temperature and not on whether water is present. Other than high latitude and low temperatures, two more factors contribute to permafrost: the presence of fossil permafrost from previous ice-age conditions and the insulating effect of snow cover or vegetation that inhibits heat loss.

Permafrost regions are divided into several categories, ranging between continuous and discontinuous permafrost. Continuous permafrost describes regions of the most severe cold and is perennial. Continuous permafrost affects all surfaces except those beneath deep lakes or rivers. Continuous permafrost may reach ~1000 m in depth, averaging approximately 400 m.

The active layer is the zone of seasonally frozen ground that exists between the (subsurface) permafrost layer and the ground surface. The active layer is subjected to consistent daily and seasonal freeze-thaw cycles. This cyclic melting of the active layer affects as little as 10 cm depth in the north (Ellesmere Island, 78° N), up to ~2 metres in the southern margins (55° N) of the periglacial region, and up to 15 m in some alpine permafrost areas.

44. What is a talik? Where might you expect to find taliks and to what depth do they occur?
A talik (derived from a Russian word for thaw) is an unfrozen portion of the ground that may occur within a body of permafrost, often beneath a body of water deep enough to do not freeze to the bottom in winter (usually just over 2 -3 m, even in the most cold continuous permafrost region). Taliks found beneath deep lakes may extend to bedrock and noncryotic (not-affected by permafrost) soil.

45. Permafrost and ground ice, thermokarst.
In regions of permafrost, subsurface water that is frozen is termed ground ice. The moisture content of areas with ground ice may vary from nearly absent in regions of drier permafrost to almost 100% in saturated soils. The presence of frozen water in the soil initiates various geomorphic processes, e.g. associated with frost action and the expansion of water volume as it freezes (frost heaving, aggradation), or those associated with groundwater melting and ground subsidence (thermokarst). Pingos and thermokarst lakes are typical landforms associated with ice-rich permafrost.

46. Describe the role of frost action in the formation of various landform types in the periglacial region.
The 9% expansion of water as it freezes produces strong mechanical forces that fracture rock and disrupt soil at and below the surface. Frost-action shatters rock, producing angular pieces that form a block field, or felsenmeer (accumulating as part of the arctic and alpine periglacial landscape, particularly on mountain summits and slopes).

From the area of maximum energy loss, freezing progresses through the ground along a freezing front (boundary between frozen and unfrozen soil). If sufficient water undergoes the phase change to ice, the soil and rocks embedded in the water are subjected to frost-heaving (vertical movement) and frost-thrusting (horizontal motions). Soil horizons may appear disrupted as if stirred or churned by frost action, a process termed cryoturbation. Frost action also produces a contraction in soil and rock, opening up cracks for ice wedges to form. Also, there is a tremendous increase in pressure in the soil as ice expands, particularly if there are multiple freezing fronts trapping unfrozen soil and water between them.

47. What are some common depositional features associated to frozen landscapes?
With the retreat of the glaciers, many relatively flat plains of unsorted, coarse till were formed behind terminal moraines. Low, rolling relief and deranged drainage patterns are characteristic of these till plains. As the glacier melts, this unsorted cargo of ablation till is lowered to the ground surface. The rock material is poorly sorted, but the clays and finer particles can provide a basis for soil development. Approximately between 21000 and 7000 years ago, Pleistocene glaciers retreated and left behind till and large glacial outwash (meltwater) deposits of fine-grained clays and silts. These materials were sometimes blown great distances by the wind and re-deposited in unstratified, but relatively homogenous deposits - loess.

48. Characterise the ability of wind to move material: Eolian processes.
Wind-eroded, wind-transported, and wind-deposited materials are called eolian (also spelled aeolian, after Aeolus, the ruler of the winds in Greek mythology). The eolian erosion and deposition are accomplished by the fluid type of motion, similar to that of water (including suspension, saltation, and surface creep). The actual ability of wind to move a wide range of sediment sizes is small compared with that of other transporting agents such as water and ice, because air is so much less dense than these other media. However, the quantity of silt and sand moved by wind globally is very large. Dust storms move the finest particles of silt and clay. Sandstorms move larger sand particles. Only the finest dust particles travel significant distances, since the finer material suspended in a dust storm is lifted much higher than e.g. the coarser particles of a sand storm, which typically may be lifted only about 2 m in the saltation-type of motion. The term saltation is used to describe both movement of particles along stream beds, and to describe the wind transport of grains along the ground (usually those grains larger than 0.2 mm). About 80% of wind transport of particles is accomplished by this skipping and bouncing action. In comparison with fluvial transport, in which saltation is accomplished by hydraulic lift, eolian saltation is executed by aerodynamic lift, elastic bounce, and impact (see the appropriate lectures for graphics and reference). Wind equally exerts a drag or frictional pull on even larger surface particles. A slightly lower wind velocity suffices if the particle already has been set into motion by the impact of a saltating grain. This lesser velocity is termed the <u>impact threshold</u>. Once in motion, particles continue to be transported by lower wind velocities.

49. Wind erosion, abrasion and deflation, desert pavement, eolian landforms.
Two wind erosion processes are dominant: deflation and abrasion. Deflation literally blows away unconsolidated or non-cohesive sediment. Rocks exposed to eolian abrasion appear pitted, grooved, or polished, and usually are aerodynamically shaped in a specific direction, according to the flow of airborne particles.

Rocks that bear such evidence of eolian erosion are called ventifacts. On a larger scale, deflation and abrasion jointly are capable of streamlining rock structures that are aligned parallel to the most effective wind direction, leaving behind distinctive, elongated ridges called yardangs. These can range from metres to kilometres in length and up to many metres in height.

Desert pavement, which resembles a cobblestone street, protects underlying sediment from further wind erosion. Desert pavements are so common that many provincial names have been used for them - for example, gibber plain in Australia, gobi in China, and in Africa, lag gravels or serir (or reg desert if some fine particles remain). After wind deflation work on an arid landscape, a desert pavement may formed from the concentrated pebbles and gravels left behind. However, desert pavements appear to may also be formed as a result of deposition, and water also should be considered, e.g. in the formation of lag gravels (another name for paved desert plains that wind deflation has modified).

50. Wind deposition and landforms.
Only 10% of desert areas are covered with sand. Sand grains generally are blown and deposited as transient ridges or hills - <u>dunes</u>. As wind transports individual grains of sand they roll and bounce along the ground. When they encounter a small obstacle, the energy that was expended in horizontal movement is spend in vertical movement, causing more sand to accumulate. Once the height of the patch reaches 30 cm a slipface forms on the downwind face at an angle of roughly 33°, effectively forming a <u>dune</u>. Individual grains then continue to

be blown up the windward face and tumble down the slipface; thus the overall shape of the dune remains the same, but moves downwind. More particles are blown across the windward slope of the dune and the dune will migrate downwind. If the winds are from a consistent direction, the dunes migrate downwind over time as the sand that makes the dunes is transported. Dominant wind patterns shape the dunes. Generally dune shapes may be fit into three classes - crescentic, linear, and star dunes. However, in response to complicated and changing wind patterns, dunes may have multiple slipfaces and various shapes. With time, similar to sedimentary rocks, dunes may also lithify, forming another depositional landform – lithified dunes. Similarly, loess deposits - the wind-deposited fine-grained clays and silts, originated from outwash plains and till of the retreated glaciers. These landforms cover about 10-15% of the Earth's land area, and are characteristic of Earth's "breadbasket" farming regions, because of the excellent quality of the fertile soils they make.

51. The relationship between parent rock, parent material, regolith, and soil.
Bedrock is the parent rock from which weathered regolith and soils develop. Loose surface material comes from further weathering of regolith and from transported and deposited regolith. This unconsolidated sediment and weathered rock form the parent material from which soil evolves.

52. Soil formation: parent material, climate, vegetation, landforms, time, and humans; soil fertility.
Soil is a mixture of about 50% of weathered rock particles and organic material with about 50% of water and air. Organic matter in soil includes: living microorganisms and plant roots, dead and partially decomposed plant and animal matter, and fully decomposed plant matter (humus). Soil is an open system, and its development is affected equally by natural processes and human activities.

The role of parent material in providing weathered minerals to form soils is important in establishing the basic mineral structure and character of the developing soil. At the bottom of the soil profile is the parent horizon, representing either unconsolidated material or consolidated bedrock of granite, sandstone, limestone, or other rock.

Worldwide, soil types show a close correlation to climate types. The moisture, evaporation, and temperature regimes associated with varying climates determine the chemical reactions, organic activity, and eluviation rates of soils. Not only is the present climate important, but many soils also exhibit the imprint of past climates, sometimes over thousands of years.

The organic content of soil is determined in part by the vegetation growing in that soil, as well as by animal and bacterial activity. E.g. bacteria that live in root nodes biologically fix nitrogen, plant litter is broken down into organic matter, and other microorganisms break down dead organic matter into nutrients that plants can use. Earthworms increase soil porosity by breaking up organic matter and relocating it throughout the soil column. Both mammals and plant roots act to improve soil. Mammals mechanically mix soil, whereas plant roots provide channels within the soil that allow air and water movement. The chemical makeup of vegetation contributes to acidity or alkalinity in the soil solution. For example, broadleaf trees tend to increase alkalinity, whereas needleleaf trees tend to produce higher acidity.

Landforms also affect soil formation, mainly through slope and orientation. Slopes that are too steep do not have full soil development, but slopes that are slight may inhibit soil

drainage. As for orientation, in the Northern Hemisphere, a southern slope exposure is warmest (slope faces the southern Sun), which affects water balance relationships.
All of these identified factors require time to operate. A few centimetres' thickness of prime farmland soil may require 500 years for maturation. Yet these same soils are being lost at a few centimetres per year by human abuse of the soil resource.

Land degradation that occurs in dry regions is known as desertification. This worldwide phenomenon along the margins of semiarid and arid lands is caused in part by human activities that degrade soils, leading to losses of topsoil and declines in food production. Desertification results from a combination of factors: poor agricultural practices, such as overgrazing and activities that abuse soil structure and fertility; improper soil-moisture management; salinization (the accumulation of salts on the soil surface) and nutrient depletion; and deforestation. Global climate change is also a contributor. Desertification is now affecting over a billion people worldwide.

Soil fertility is the ability of soil to sustain plants. Soil is fertile when it contains organic substances and clay mineral that absorb certain elements needed by plants.

53. Characterise soil horizons. Where does the main accumulation of organic material occur? Where does humus form? Which horizons constitute the solum?

Within a soil profile, soils are generally organized into distinct, roughly horizontal layers known as soil horizons. The four 'master' horizons in most agricultural soils are distinguished: the O, A, B, and C horizons.

O Horizon: At the top of the soil profile is the O horizon, named for its organic composition, derived from plant and animal litter that was deposited on the surface and transformed into humus. The O horizon is 20%–30% or more organic matter, which is important because of its ability to retain water and nutrients and because of the way its behaviour complements that of clay minerals.

The A, Ae, B, and C horizons extend below the O horizon to the R horizon, which is composed of sediment or bedrock. These middle layers are composed of sand, silt, clay, and other weathered by-products.

A Horizon: In the A horizon, humus and clay particles are particularly important, as they provide essential chemical links between soil nutrients and plants. This horizon usually is richer in organic content, and hence darker, than lower horizons. This horizon is commonly called topsoil.

Ae Horizon: The A horizon grades downward into the Ae horizon, which is made up mainly of coarse sand, silt, and leaching-resistant minerals. From the lighter-coloured Ae horizon, silicate clays and oxides of aluminum and iron are leached (removed by water) and carried to lower horizons with the water as it percolates through the soil. This process of removing fine particles and minerals by water, leaving behind sand and silt, is eluviation—thus, the Ae designation for this horizon. As precipitation increases, so does the rate of eluviation.

B Horizon: In contrast to the A and Ae horizons, B horizons accumulate clays, aluminum, and iron. B horizons are dominated by illuviation, in which materials leached by water from one layer enter and accumulate in another. B horizons may exhibit reddish or yellowish hues because of the presence of illuviated minerals (silicate clays, iron and aluminum, carbonates, gypsum) and organic oxides. Some materials occurring in the B horizon may have formed in place from weathering processes rather than arriving there by translocation, especially in the humid tropics.

Both eluviation and illuviation are types of translocation, in which material (such as nutrients, salts, clays) is moved downward in the soil. In contrast to eluviation, which is erosional, illuviation is a depositional process.

Together, the A, Ae, and B horizons are designated the solum, considered the true definable soil of the profile. The horizons of the solum experience active soil processes.

C Horizon: The C horizon is made up of weathered bedrock or weathered parent material. This zone is identified as regolith (although the term sometimes is used to include the solum as well). The C horizon is not much affected by soil operations in the solum and lies outside the biological influences experienced in the shallower horizons. In dry climates, calcium carbonate commonly forms the cementing material that causes hardening of this layer.

R Horizon At the bottom of the soil profile is the R (rock) horizon, consisting of either unconsolidated (loose) material or consolidated bedrock. When bedrock physically and chemically weathers into regolith, it may or may not contribute to overlying soil horizons.

54. Soil texture and structure, loam. Why is loam regarded so highly by agriculturalists?

Soil texture is defined by its sand–silt–clay ratio (in % by weight). A diagram in lecture notes shows the common designations of soil textures with sand, silt, and clay concentrations. The figure includes the common designation loam, which is a mixture of sand, silt, and clay in almost equal shares. A sandy loam with clay content below 30% is considered ideal by farmers because of its water-holding characteristics and ease of cultivation.

Soil structure is determined by the arrangement of particles (the size and shape of lumps of particles). The smallest natural lump or cluster of particles is called a ped. The shape of soil peds determines which of the structure types the soil exhibits: crumb or granular, platy, block, prismatic, or columnar.

Soil texture and structure define major soil characteristics, including its hydraulic properties, by controlling the pore size, rates of water infiltration and percolation, aeration (and thus oxygen content), water retention capability, nutrient retention capability, and cation exchange capacity.

55. Soil consistence.

A corollary to texture and structure is soil consistence, which is the cohesion in soil and its resistance to mechanical stress and manipulation under varying moisture conditions. Wet soils are variably sticky when held between the thumb and forefinger, ranging from a little adherence to either finger, to sticking to both fingers, to stretching when the fingers are moved apart. Plasticity, the quality of being molded, is roughly measured by rolling a piece of soil between your fingers and thumb to see whether it rolls into a thin strand. Moist soil implies that it is filled to about half of field capacity, and its consistence grades from loose (noncoherent), to friable (easily pulverized), to firm (not crushable between thumb and forefinger).

56. Soil moisture.

Plants operate most efficiently when the soil is at field capacity, which is the maximum water availability for plant use after large pore spaces have drained of gravitational water. Soil type determines field capacity. The depth to which a plant sends its roots determines the amount of soil moisture to which the plant has access. If soil moisture is below field capacity, plants must exert increased energy to obtain available water. This moisture-removal inefficiency worsens until the plant reaches its wilting point. Beyond this point, plants are unable to extract the water they need, and they die. More than any other factor, soil moisture regimes and their associated climate types shape the biotic and abiotic properties of the soil.

57. How can soil colour be an indication of soil qualities?
Colour is important because it suggests the composition and chemical makeup of a soil. Some examples are the reds found in soils of the Maritimes, especially Prince Edward Island (high in iron oxides), the blacks of prairie soils in western Canada, portions of the U.S. grain-growing regions and in Ukraine (richly organic), and the white to pale hues found in soils containing silicates and aluminum oxides. Colour may be the most obvious trait in an exposed soil. However, colour can be deceptive: Soils with high humus content are often dark, yet clays of warm temperate and tropical regions with less than 3% organic content are some of the world's blackest soils.

58. What are soil colloids? How are they related to cations and anions in the soil? Explain cation-exchange capacity.
Soil colloids are important for retention of ions in soil. These tiny clay and organic particles carry a negative electrical charge and consequently attract any positively charged ions in the soil. Clay colloids and organic colloids exhibit different levels of chemical activity. Individual clay colloids are thin and platelike, with parallel surfaces that are negatively charged. A cation is a positively charged ion and an anion is a negatively charged ion. Colloids can exchange cations between their surfaces and the soil solution - a measured ability called cation-exchange capacity (CEC). A high CEC means that the soil colloids can store or exchange more cations from the soil solution, an indication of good soil fertility (unless there is a complicating factor, such as the soil being too acid). Cations attach to the surfaces of the colloids by adsorption, that is, the metallic cations are adsorbed by the soil colloids.

59. The Canadian System of Soil Classification (CSSC) system.
Canadian efforts at soil classification began in 1914 with the partial mapping of soils in Ontario by A.J. Galbraith. The Canadian System of Soil Classification (CSSC) provides taxa for all soils presently recognized in Canada and is adapted to Canada's expanses of forest, tundra, prairie, frozen ground, and colder climates. As in the U.S. Soil Taxonomy system, the CSSC classifications are based on observable and measurable properties found in real soils rather than idealized soils that may result from the interactions of genetic processes. The system is flexible in that its framework can accept new findings and information in step with progressive developments in the soil sciences. The system is arranged in a nested, hierarchical pattern to allow generalization at several levels of detail. Elements of the horizon suffix descriptions are derived from the Soil Taxonomy although adapted to conditions in the Canadian environment. (see the textbook and the lecture 9 notes for more details).

60. What is soil science, pedology?
Soil science is interdisciplinary, involving physics, chemistry, biology, mineralogy, hydrology, taxonomy, climatology, and cartography. Pedology concerns the origin, classification, distribution, and description of soil. Pedology is at the centre of learning about soils. Pedology gives a general understanding of soils and their classification.

Supplementary materials: Soils: //sis.agr.gc.ca/cansis/index.html