CIE Geography A-level

3: Rocks and Weathering

Detailed Notes

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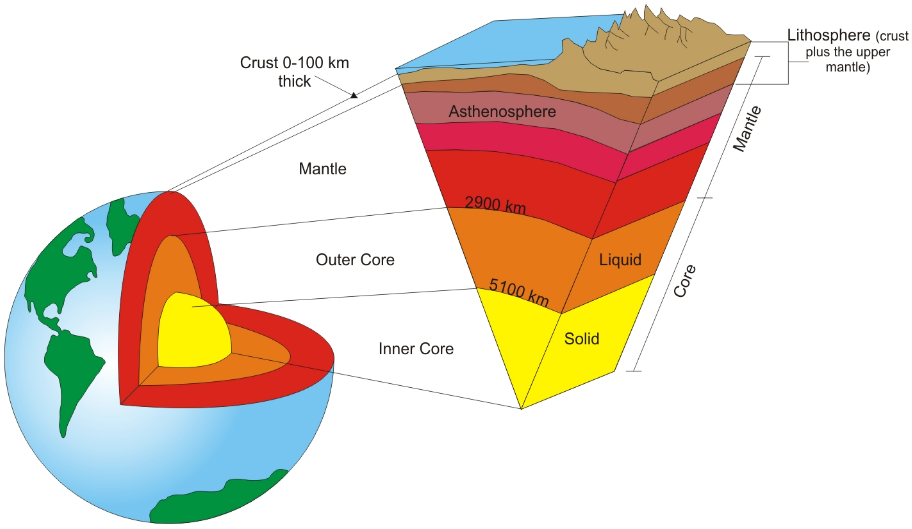
Plate Tectonics

Structure of the Earth

Inner core Solid ball of iron/nickel Very hot due to **pressure** and **radioactive decay** (contains elements such as uranium that give off heat when they decompose) This heat is responsible for **Earth's internal energy**, and it spreads throughout
Outer core • Semi-molten • Iron/nickel



(Source:https://www.leeds.ac.uk/ruskinrocks/Earth%20Structure.html)

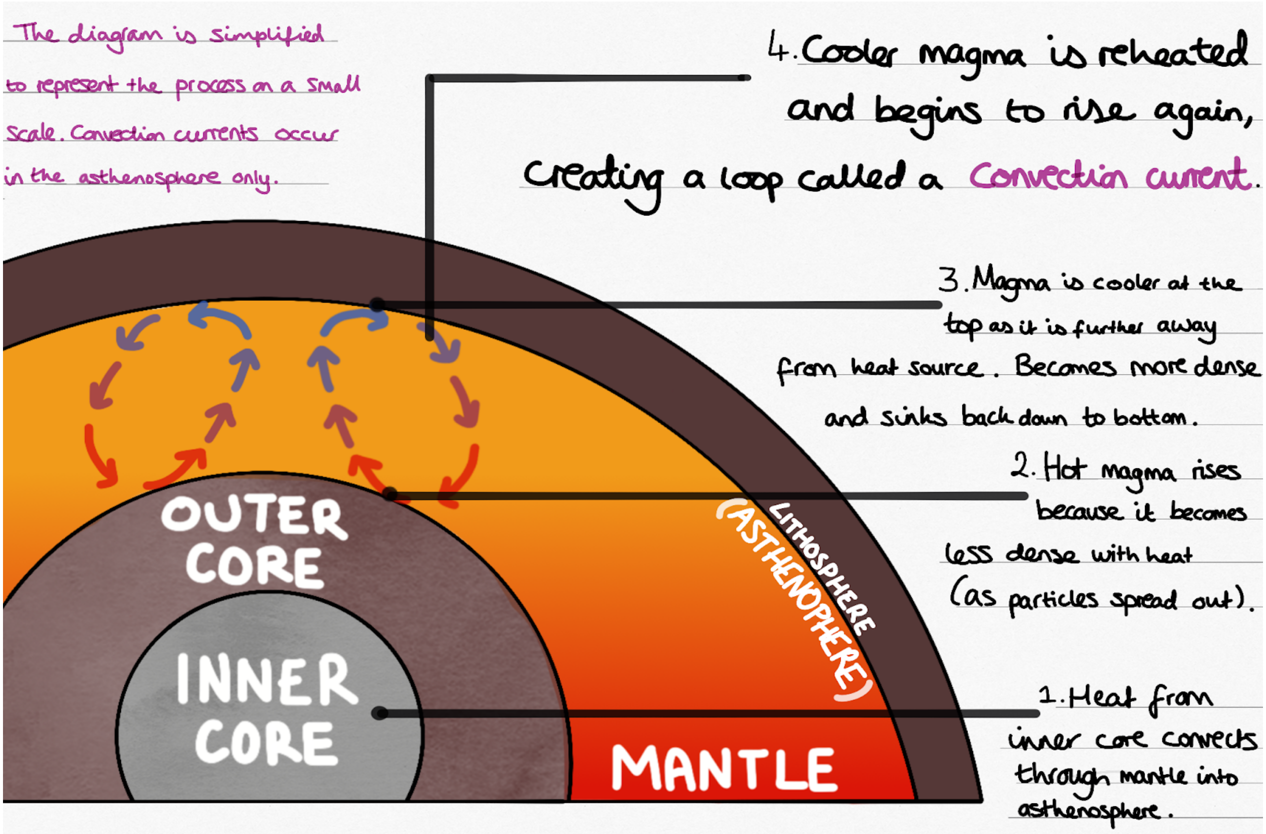
Mantle	Asthenosphere	Lithosphere
Mainly solid rock, and the rocks are high in silicon. However, the very top layer of the mantle is semi-molten magma, which is known as the **asthenosphere**. The **lithosphere** rests on top.	**Semi-molten** layer constantly moves due to flows of heat called **convection currents**. Movements are powered by **heat from core**. **Lithosphere** above.	Broken up into **plates**. Majority of the lithosphere is within mantle. The top of the lithosphere is the **crust** which is the land and sea we live on.

Crust The thin top of the lithosphere **Oceanic crust** is **dense** and is destroyed by **plate movement, continental crust** is **less dense** and is **not destroyed**.

Plate tectonic theory

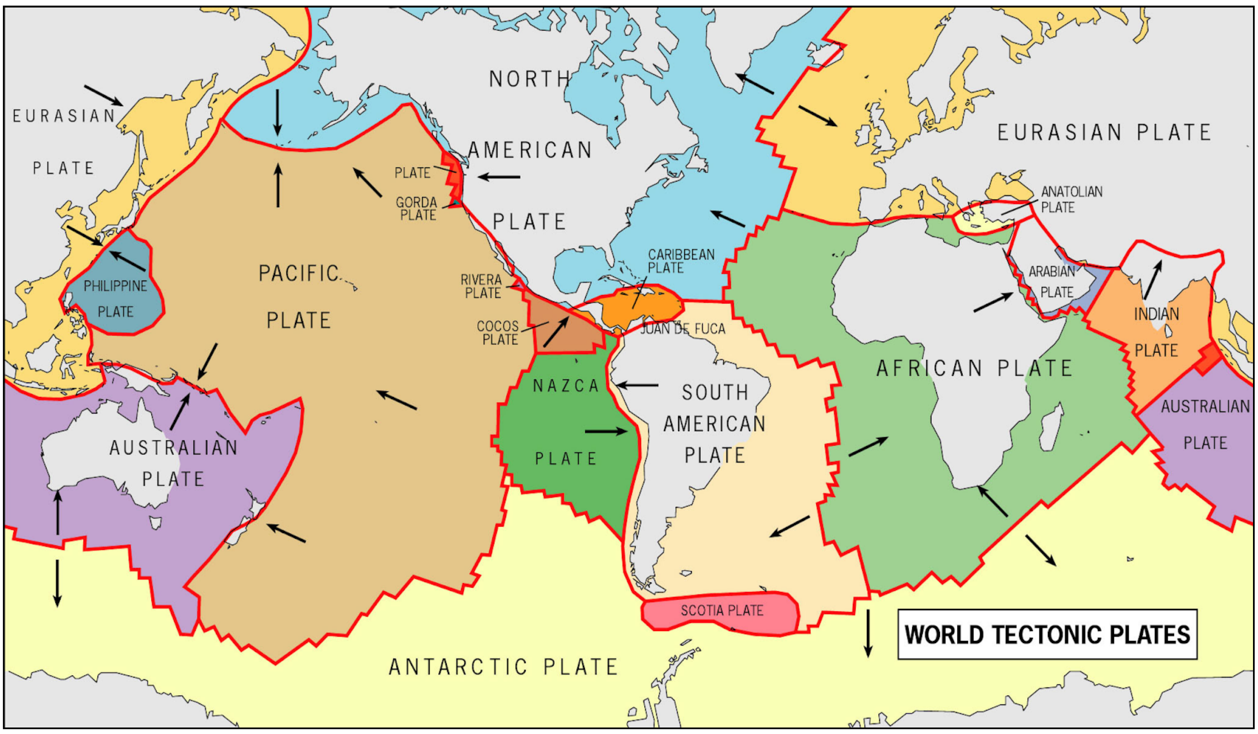
The lithosphere is broken up into **large slabs of rock** called **tectonic plates**.

These plates **move** due to the **convection currents** in the asthenosphere, which push and pull the plates in different directions. Convection currents are caused when the less dense magma rises, cools, then sinks. The edges of where plates meet are called **plate boundaries** (or plate margins).



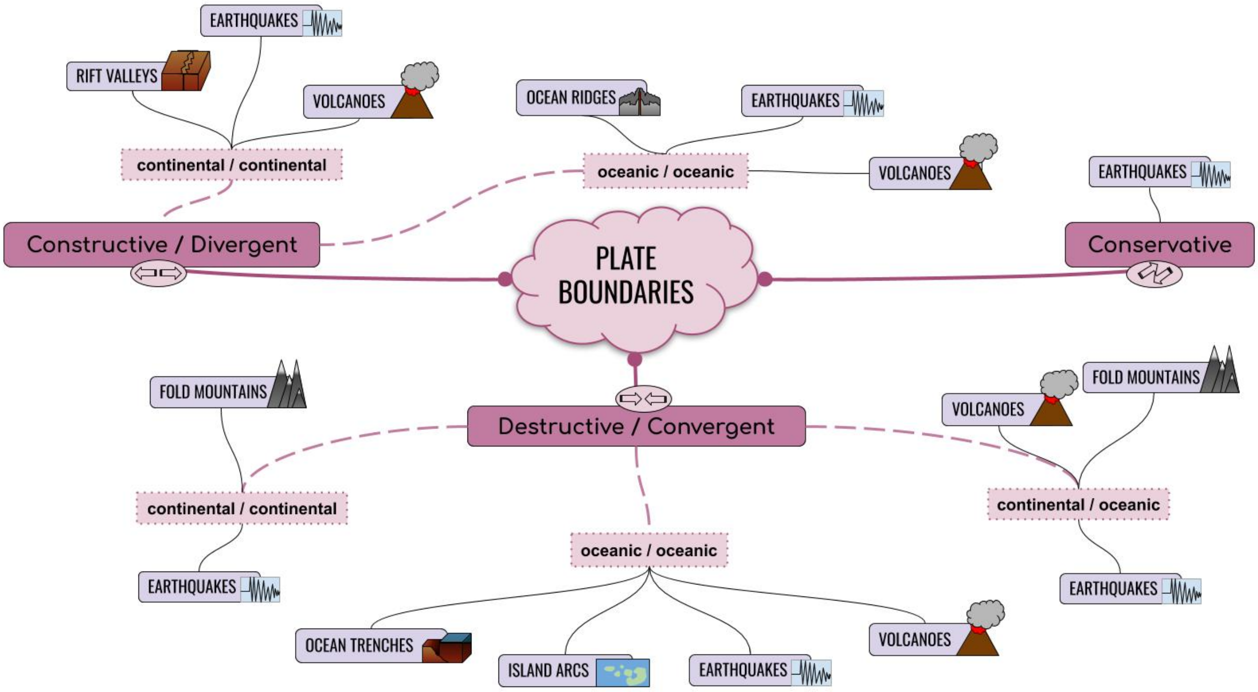
Location of Plates

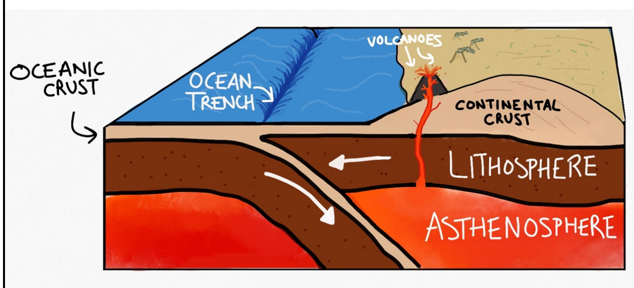
There are **multiple plates** that move **in different directions** around the world.

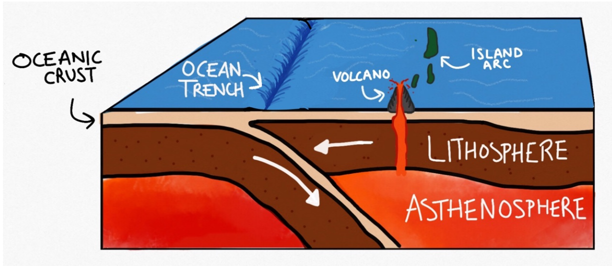
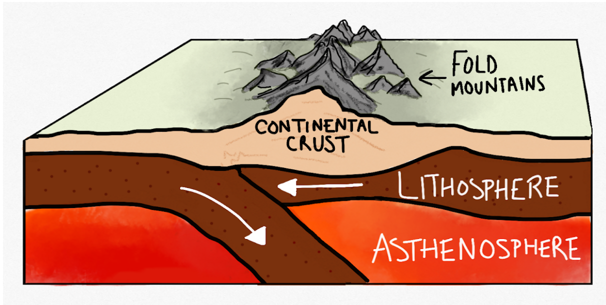


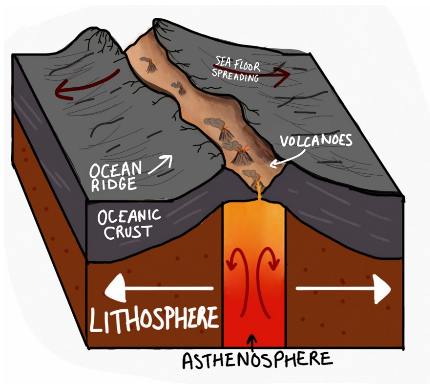
Different Plate Boundaries

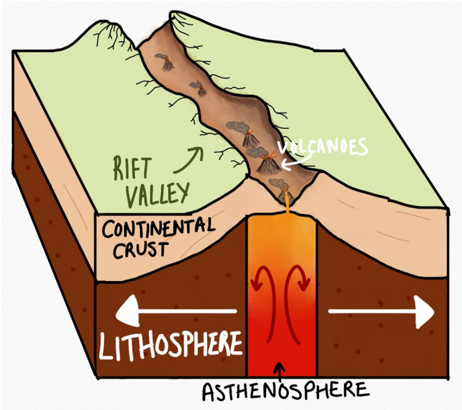
At plate boundaries, different plates can either move **towards each other** (**destructive/ convergent** plate margin), **away from each other** (**constructive/ divergent** plate margin), or **parallel** to each other (**conservative** plate margin). Different landforms are created in these different interactions. This spider diagram outlines what landforms and processes occur at the boundaries.



Destructive/ convergent plate boundaries	
Continental and oceanic: • Denser oceanic plate **subducts** below the continental. • The plate subducting leaves a deep **ocean trench**. • **Fold mountains** occur when sediment is pushed upwards during subduction. • The oceanic crust is melted as it subducts into the asthenosphere. • The extra magma created causes **pressure** to build up. • Pressurised magma forces through weak areas in the continental plate • Explosive, high pressure volcanoes erupt through the continental plate, known as **composite volcanoes**.	

Oceanic and oceanic: ● Heavier plate **subducts** leaving an ocean trench. Fold mountains will also occur. ● Built up pressure causes **underwater volcanoes** bursting through oceanic plate. ● Lava cools and creates new land called **island arcs**.	
Continental and continental: ● Both plates are not as dense as oceanic so lots of **pressure builds.** ● Ancient oceanic crust is subducted slightly, but there is **no subduction of continental crust.** ● **Pile up** of continental crust on top of lithosphere due to pressure between plates. ● **Fold mountains** formed from piles of continental crust.	

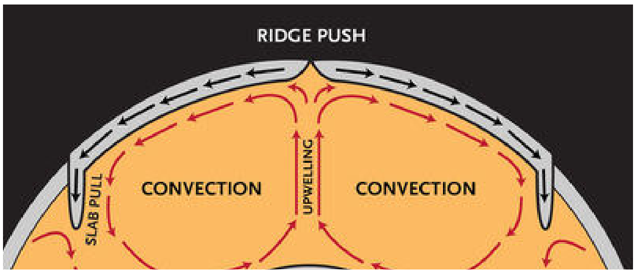
Constructive/ divergent plate boundaries	
Oceanic and oceanic: ● Magma rises in between the **gap left by the two plates separating**, forming new land when it cools. ● Less explosive underwater volcanoes formed as magma rises. ● **New land** forming on the ocean floor by lava filling the gaps is known as **sea floor spreading** (as the floor spreads and gets wider).	
Evidence There is sufficient evidence to prove plate movement, and **sea floor spreading** (theorised by **Harry Hess** in the 1940s) provides some of this proof. **Paleomagnetism** is the study of rocks that show the magnetic fields of the Earth. As new rock is formed and cools the magnetic grains within the rock align with the magnetic poles. Our poles (North and South) **switch** periodically. Each time these switch the new rocks being formed at plate boundaries **align in the opposite direction** to the older rock. On the ocean floor either side of constructive plate boundaries, geologists observed that there are **symmetrical bands** of rock with **alternating bands of magnetic polarity**. This is evidence of sea floor spreading.	

Continental to continental: • Any land in the middle of the separation is forced apart, causing a **rift valley**. • Volcanoes form where the magma rises. • Eventually the gap will most likely fill with water and separate completely from the main island. • The lifted areas of rocks are known as **horsts** whereas the valley itself is known as a **graben**.	

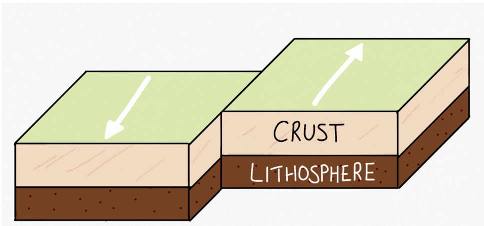
There are further forces influencing how convergent boundaries occur -

Ridge push:
The **slope** created when plates move apart has **gravity acting upon it** as it is at a **higher elevation**. Gravity pushes the plates further away, widening the gap (as this movement is influenced by gravity, it is known as **gravitational sliding**).

Slap pull:
When a plate **subducts**, the plate sinking into the mantle **pulls the rest of the plate** (slab) with it, causing further subduction.



Source: CK-12 Foundation

Conservative plate boundary	
Between any crust, the **parallel plates** move in **different directions** or at **different speeds**. No plates are destroyed so no landforms are created. When these plates move, a lot of pressure is built up. On oceanic crust, this movement can displace a lot of water. On continental crust, **fault lines** can occur where the ground is cracked by the movement.	

Hotspots
Hotspots are areas of volcanic activity that are **not related to plate boundaries**. Hot **magma plumes** from the mantle rise and **burn through** weaker parts of the crust. This can create **volcanoes and islands**. The plume stays in the same place but the **plates continue to move**, which sometimes causes a **chain of islands** (such as Hawaii).

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Weathering

Physical weathering

Physical weathering, or **mechanical weathering**, is weathering that affects **rocks** and **rock formations**.

Freeze-thaw

Freeze-thaw, also known as **frost action**, is weathering **due to freezing temperatures**. Water gets into the cracks of rocks, freezes and then **expands** by around 10%. This repeated action puts pressure on a rock, eventually causing it to shatter and **break off**.

Heating/cooling processes

Repeated **heating and cooling** of rocks can also cause rocks to be **broken down and weathered away**. Rocks can **expand rapidly** when hot and **contract rapidly** when cold, causing the breaking apart of layers of rock.
For example, in hot desert environments when **days are extremely hot** and **nights are extremely cold**, the changes in temperature causes **stress** on the outer layers of rock. This causes the outer layers of rock to **peel off** in a process called **exfoliation**.

Salt weathering

Salt weathering occurs due to **salt crystal growth** inside the cracks and pores in rocks.
When **saline solutions** (i.e. salt water) gets into cracks and evaporates, it leaves behind the salt crystals that were in the solution.

As these salt crystals **accumulate over time**, the build up of **pressure** expands the gap in the **rocks**.

Eventually this can cause the rocks to **break off or disintegrate.**

Honeycomb weathering, which is thought to be caused by **salt crystal growth**.

Pressure release (dilatation)

Pressure release is a type of physical weathering caused when **rocks that are under a great amount of pressure** no longer have to bear a heavy load, causing expansion and fracturing.

When there is a **removal of weight** (e.g. through erosion of the above rocks, melting of a glacier etc.), the underlying rocks will **expand** when the pressure is released, thus causing **fractures** to form on the rock surface.

This occurs, for example, when rocks form **beneath the earth's surface under tremendous pressure**, and when the load above is **eroded away**, the pressure is **removed**, and the rock expands.

Vegetation Root Action

When **vegetation grows**, such as plants and trees, their roots also grow and thus need **more space**.

The growing roots **exert pressure onto the surrounding rock**, eventually causing the rocks to **break apart**.

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Chemical Weathering

Chemical weathering is the **breaking down of rocks** caused by **chemical reactions**.

Hydrolysis

Hydrolysis weathering is the **breaking down of rock** when it reacts with **water** (*hydro-*). Rocks can break down when they are **soluble in water**, for example **chalk** can react and break down in water.

Hydration

Hydration occurs when **water is absorbed** into a substance, causing a new substance to form. For example, **anhydrite** ($CaSO_4$) reacts with water to form **gypsum** ($CaSO_4 \cdot 2H_2O$). Hydration causes rocks to **expand in size and volume**, which can make them susceptible to **other forms of weathering**.

Carbonation

Carbonation is when **CO_2** dissolved in water (known as carbonic acid) reacts with rocks and breaks them down. Carbonic acid reacts with many different rocks, including limestone.
CO_2 can **dissolve into rainwater** due to emissions of CO_2 into the atmosphere, or dissolve into **groundwater** and create caves/sinkholes making this a **widespread issue**.

Factors Affecting Weathering

Different factors can affect the **rate**, **type**, and **severity** of weathering.

Climate: **Temperature** and **precipitation** play an important role in weathering. Some climates **accelerate** certain types of weathering, and others make the weathering **impossible to occur**. For example, in **alpine climates** where temperatures fluctuate more rapidly than in **polar environments**, freeze-thaw weathering is more severe. Salt crystal growth favours **dry climates**, allowing the water to **evaporate** to leave the salt crystals.

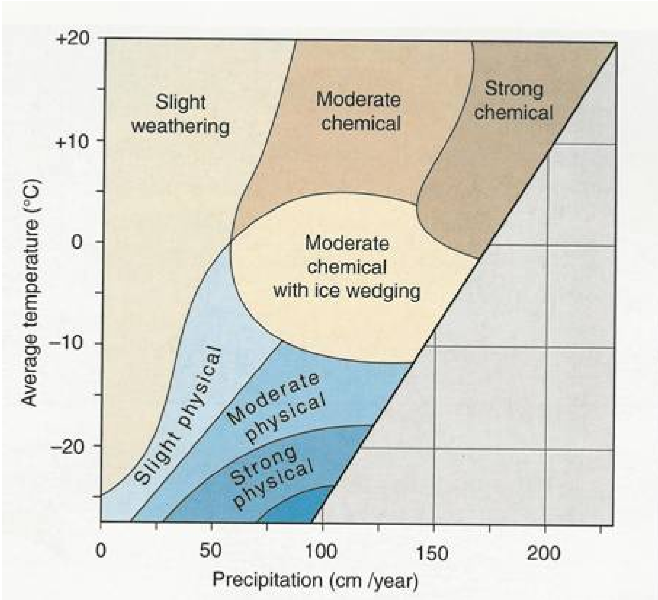
Rock type and structure: The **type** and **structure** of rock dictates the **rate** at which weathering will occur, and also **what type of weathering** (be it physical or chemical, or both) will take place. Some rocks, e.g. water soluble rock types, are more vulnerable to chemical erosion, and therefore will be weathered at a quicker rate. Permeable rock types have pores that can leave it vulnerable to **many types of weathering**. In contrast, hard, impermeable rocks may have **lower rates of weathering** (dependent on other factors) because **more energy is required** to break down the rock. Rocks with **natural weakness areas**, such as **layered sedimentary rocks**, are also more vulnerable to weathering.

Vegetation: The **type** and **amount** of vegetation affects weathering in multiple ways. **Root action weathering** will be at a much **higher rate** in areas with **high vegetation**, especially **large vegetation** such as trees (which have roots capable of breaking apart even hard rocks). Root action is very prevalent in the rainforest, for example, where there is an **abundance** of vegetation.

Relief: Relief can affect the **rate** and **type** of weathering that occurs. Areas of more gentle relief are likely to be subjected to **standing water** and water that infiltrates into **the ground**. In contrast, in areas of **steep relief** it is more common for precipitation to fall as **overland flow**, meaning the multiple types of weathering caused by precipitation may be at a lower prevalence.

The Peltier Diagram

Peltier produced a **diagram** that illustrates the relationship between **temperature** and **rainfall**, and the different **weathering types** that prevail.



The diagram shows how weathering changes in **severity and type** (physical or chemical) when the temperature and precipitation changes. For example, in a climate with high precipitation and high temperatures, there is likely to be **strong chemical weathering**. In contrast, in climates with lower temperatures and lower precipitation (0-90cm/year) there is likely to be **physical weathering**, which becomes more severe as precipitation increases.

This diagram is valuable in analysing how physical factors affect weathering.

Slope Processes

Different processes can occur on slopes that **affect slopes** in different ways, these processes include:

- **Erosion and weathering** on slopes that change the landscape
- The movement of **water and sediment** down a slope
- The **mass movement** of material, which takes place in a variety of **forms.**

Water and Sediment Movement

Due to the **effect of gravity** on slopes, water and sediment **moves downhill**. This happens in several ways:

Rainsplash

When **rain hits** a surface, the **impact** of the rain droplets can be enough to **displace** the soil particles and detach them from the rest of the ground. As the water hits the slope, the force of gravity causes the **water and the displaced soil granules to move downhill**.

Sheetwash

Sheetwash is a type of **overland flow** where a **shallow sheet of water** flows over the surface of the slope, causing the **top layers of the slope** to be transported downhill. This occurs when water cannot **infiltrate into the soil**, therefore flowing over it instead.

Rills

Rills are small streams that develop by **erosive flowing water**. They often develop on **slopes**, as water flows downwards naturally due to gravity. Over time, rills can develop into large ravines known as **gullies**. Huge amounts of **soil** and **nutrients** are washed away through this movement of water.

Mass Movement

Mass movement is the large scale movement of materials on a hillslope, caused when the **stress exerted** exceeds the **internal strength of the hillslope**, causing **instability**.

Mass movement on a slope will always be **downhill** due to the force of gravity. These movements can happen over a **range of timescales**, and also depend on the **moisture in the hillslope material**, which is shown in the diagram below:

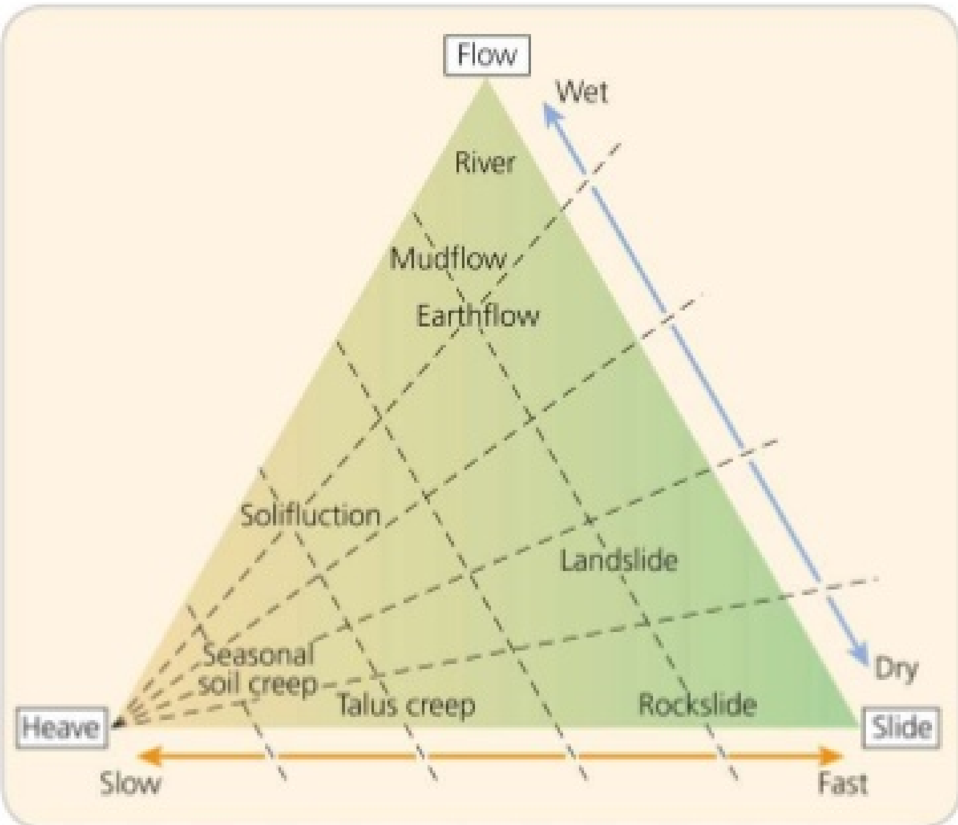


Figure 3.21 A classification of mass movements

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Mass movement processes also depend on the **material the slope is made from**. Different structures have different **internal strength**.

There are several types of mass movement, including: **heaves, flows, slides, and falls**.

Heaves

- Occur on slopes made from **cohesive materials** and **non-cohesive materials.**
- **Frost heave** and **soil creep** are two different types of heaves.
- Heaves are the **slowest** and **most prevalent form** of mass movement.

commons.wikimedia.org/w/index.php?curid=14080343

Heaves occur when soil particles are **pushed**, and then - due to the influence of gravity - the particles move downwards.

On slopes made from **cohesive materials**, this can cause the soil to **ripple**, creating steps called **terracettes** (seen in the picture above).

Frost heave occurs in **colder regions**, where **water in the soil freezes**, and **heaves rocks and soil particles upwards**. The particles then fall downwards under the influence of gravity. When this occurs on a slope, it can create lines of stones, called **stone stripes**.

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Flows

- Occur on slopes made from **cohesive materials** e.g. silts and clays
- **Mudflows** are a type of flow, where a large quantity of wet mud **moves downhill**
- Faster than **heaves**, but not as fast as **slides and falls**

(www.denverpost.com)

Flows are controlled by **moisture** within the slope. When soil becomes **oversaturated**, the **cohesive bonds** within the soil break, causing soil to move downhill like a viscous liquid.

Mudflows often occur under **heavy rainfall conditions**, especially rainfall that falls within short periods of time (leading to less infiltration and percolation into groundwater stores).

Falls

- Occur on slopes made from **rocks**
- Rock falls happen **very suddenly**, and the effects are usually **dramatic**
- Due to the **strong** internal strength of rocks, the slopes can be very steep

(www.geostru.eu/rockfall-analysis/)

Rock falls can be triggered in many ways. They are not as dependent on **rainfall** unlike flows, as the **internal strength of rocks** is not compromised when they become wet to the extent of silts and clays.
Rock falls can be triggered by **freeze-thaw processes, seismic waves, or gravitational stress**, for example.

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Slides

- Landslides are the fast movement of rock, earth or debris down a slope.
- **Rockslides** are a type of landslide that occur on slopes made from **rocks.**
- **Rockslides** occur along **faults** in the rock.

(https://blogs.agu.org/landslideblog/2017/05/15/clinch-mountain-1/)

Similarly to **rock falls**, landslides/ rockslides can be triggered by **seismic waves** or **gravitational stress**. This movement is **large scale**, causing a great deal of material to be moved in a short space of time.

The Human Impact on Slopes

Humans can directly affect slope stability in different ways. Slope stability may **decrease** due to human activities, which can lead to **mass movement** events. Furthermore, humans may **reinforce slope stability**, as increased slope stability **reduces the hazard to the environment and human life**.

Decreasing Stability

Many human activities can **compromise the stability of a slope**. Slope instability is generally caused by either (or a combination of both): an **increase in external stress on the slope**, or a **decrease in the internal strength of a slope**.

Examples of human activities that cause a **decrease in slope stability** include:

Mining

Mass movement as a result of **mining and quarrying** is **frequent**. Mining and quarrying **removes support** from the slope, be that **underlying support** or **lateral support**. This therefore causes **instability** within the slope, often leading to landslides, mudslides, rockfalls, or rockslides.

Furthermore, **mining and quarrying** brings a large amount of **waste**, which is often left on the slope. This adds **stress** onto the slopes due to the weight, leading to mass movement processes.

A rockslide in Aprelevka Gold Mine in Tajikistan, November 2011 (source: www.miningmayhem.com)

Construction

Construction on hillslopes can compromise the stability of these slopes when there is a **change in the topography**. There are many issues caused by construction on hillslopes:

- **Stress** on a hillslope may be added due to construction, e.g. the **weight** of housing or dams.
- Slopes may be **undercut** in order to build, which causes **instability**.
- **Groundwater** is affected due to sewage systems, drainage systems, water demand etc. which can create instabilities in different ways.
- **Water erosion** can affect the **internal strength of a slope**. **Hydraulic engineering** (e.g. the construction of dams) can cause the surrounding slope to become **saturated** if not properly managed, triggering mudslides and other forms of mass movement.

Tourism

Tourism is prevalent in hillslope areas, especially **alpine slopes** where skiing is common. Tourism creates **stress on hillslopes** in a multitude of ways. **Erosion** of the slope is dramatically increased due to the trampling of vegetation, skis, heavy machinery, walking etc. which damages and compacts the soil.

In alpine areas where **seasonal melting is common**, the dramatic increase of water can often trigger mass movement processes such as mudslides when the slope has been degraded.

Construction on an Alpine slope for tourist purposes (source:Jean-Pierre Clatot/AFP/Getty Images)

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Agriculture

Agricultural processes on hillslopes cause **many issues**, which can decrease the stability of slopes.

- Soil can be **compacted** through **heavy machinery** and **animals**. This leaves slopes **vulnerable** to many issues such as soil erosion, changes in **water flows**, and reduced **vegetation cover**.
- The reduction of **vegetation cover** due to **overgrazing** and **trampling** causes the degradation of soil. Vegetation is vital to a **soil's structure**, so without vegetation, mass movement such as landslides are a hazard, and less dramatic mass movement such as **soil creep** are more likely.
- Increased rates of **soil erosion** due to less vegetation. Hillslopes are left **exposed to the elements** when vegetation is removed, causing **erosion and weathering processes to take place**. This can also trigger mass movement.

Forestry

Deforestation can cause **major slope instability** if not properly managed.

Soil strength is enhanced by **roots** of trees so when trees are cut down the strength of the hillslope can be compromised dramatically, especially if the roots die.

Deforestation also decreases the **interception of precipitation**, causing **more water** to flow over the hillslope and **infiltrate into it**. Less water is also being taken **up** by trees roots, increasing the **saturation** of the soil further. This can cause erosion as well as triggering mass movement, especially mudslides.

Clearcutting (the cutting down of the majority of trees/ all trees in an area) can leave the hillslope very **vulnerable**, especially to **wind**.

Forest roads are often constructed for the use of **transporting timber** etc. which interrupts the natural flow of the water. These roads can **create channels for run-off**, which can be highly erosive. This consequently leads to the hillslope becoming unstable.

Increasing Stability

There are certain strategies put in place by humans to **modify slopes** in order to make them more stable. Some of these strategies include:

- **Afforestation:** Afforestation is the process of **planting trees in an area without trees**. Afforestation increases the stability of slopes in several ways:
    - Roots from trees increase the **internal strength** of the soil, meaning the slope can take **more stress** before it fails.
    - More trees reduce the **saturation of the soil**, both from **intercepting precipitation** and **taking up water from roots**. Not only does this reduce the risk of mass movement triggered by **high soil saturation levels** (like mudslides), but it also decreases erosion caused by water which also compromises the internal strength of a slope.

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- **Netting:** Netting or mesh can be placed over a slope in order to stabilise it. This form of reinforcement contains any falling of debris or rock to beneath the netting, which limits the hazard. Furthermore, it prevents falls as there is little room for anything to fall. Netting is particularly effective at increasing the stability of rock slopes, i.e. to prevent rock falls.

Mesh to reinforce soil slope stability(Source: https://www.externalworksindex.co.uk)

Metal netting to secure rock slope. (Source: https://www.externalworksindex.co.uk)

- **Pinning:** Pinning, nailing, and bolting slopes increase the strength of the slope, allowing it to take more stress.
    - Soil nailing is where steel rods are drilled into the soil. The steel rods can carry weight, increasing the stability of the slope and reducing the risk of mass movement.
    - Rock bolting is where bolts are drilled into rock slopes in a specific pattern, which transfers the load from the weaker exterior to the stronger interior of the slope. This reduces the risk of rockfalls and rockslides. Rock bolting works to 'knit' together the rock to make the slope stronger.

Rock bolting and netting used to support a cliff in Thirlmere, Cumbria (Source: www.can.ltd.uk/)

- **Grading:** Grading is the process of **reshaping** the surface of a slope to a **specified slope**. This is done using **heavy machinery**, such as **excavators** and **graders**. The purpose of grading is to provide a more **uniform topography**, e.g. for building, controlling surface runoff, or minimising erosion. Grading can work to **reinforce** a slope so that mass movement processes are less likely to occur.

Excavator grading a slope (source:www.youtube.com/watch?v=FM5w5xOZqn0)