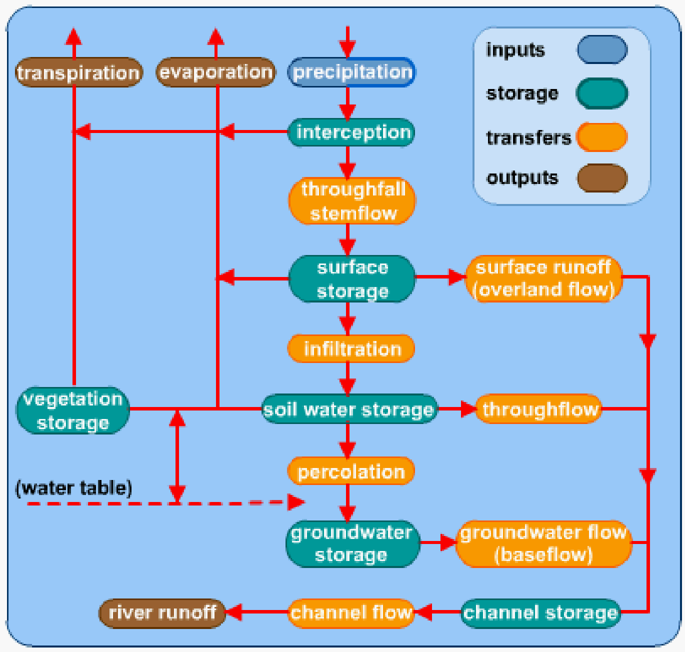
ZNOTES.ORG

UPDATED TO 2021-22 SYLLABUS

CAIE AS LEVEL GEOGRAPHY (9696)

SUMMARIZED NOTES ON THE CORE PHYSICAL GEOGRAPHY SYLLABUS

1. Hydrology and Fluvial Geomorphology



1.2. Drainage Basin System

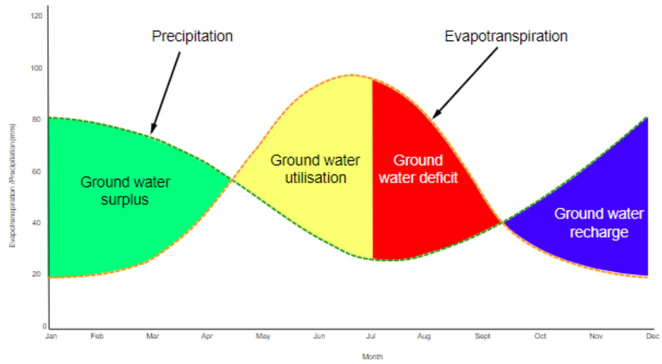
Outputs

- Evapotranspiration
  - **Evaporation:** liquid changes into water vapour, from puddles and streams. Rate of evaporation increases in hot, dry and windy conditions and with larger soil surface area.
  - **Transpiration:** water is drawn from soil by the plant and leaves the plant as water vapour through the stomata.

- **Potential Evapotranspiration:** the amount of evaporation that would occur if an unlimited water source were available.
- **River Discharge:** water that flows into the sea, or that moves in channels (streams/rivers). Water enters the channel as direct channel precipitation or other flows.
  - $\mathbf{Q} = \mathbf{AV}$ (Q = Discharge, A = Cross Sectional Area, V = Velocity). Measured in m^3/second – Cumecs.

1.3. Stores

- **Interception:** precipitation is caught and stored by vegetation before it reaches the ground.
- **Surface Water:** when the infiltration capacity is exceeded, water builds upon the surface.
  - **Temporary stores:** puddles and turloughs.
  - **Permanent stores:** lakes and wetlands.
- **Ground Water:** water that has percolated into bedrock. Is a store of freshwater - wells and boreholes can be dug below water table to access.
  - **Ground Water Recharge:** refilling of rock pores as water moves downwards. Occurs when rate of recharge > rate of abstraction.
- **Channel Storage:** all water stored in rivers streams and drainage channels.
- **Soil Moisture:** water held sub-surface in soil pores. Sandy soils have many large pores, so is permeable, and has quick infiltration rates. Clays are hygroscopic – clay minerals swell when in contact with water, making it impermeable and unstable.
  - **SM Deficit:** available water is being used up.
  - **SM Recharge:** precipitation > potential evaporation. Some dry pores refill.
  - **SM Surplus:** soil is saturated, water cannot enter, so flows over the surface.
  - **SM Utilisation:** evapotranspiration (and other water uses) > precipitation.
  - **Field Capacity:** amount of water held once excess has drained away – saturation point.
  - **Wilting Point:** the range of soil moisture content at which permanent plant wilting occurs.
  - Balance = Precipitation – (run off + evapotranspiration + change in soil moisture).



1.4. Flows

Above Ground

- **Throughfall:** leaves and twigs become saturated so water drips from them. Precipitation can also fall through gaps in vegetation cover.
- **Stemflow:** precipitation is intercepted by vegetation, then runs down the branches and main trunk.
- **Overland Flow:** when soil is saturated, or precipitation exceeds infiltration rate, surface runoff occurs – where water flows over the surface.
- **Hortonian Flow:** shallow, laminar, fast moving water that causes severe soil erosion when precipitation exceeds the infiltration capacity and depression soil capacity.
- **Channel Flow:** movement of water in channels such as streams and rivers.

Below Ground

- **Infiltration:** precipitation soaks/is absorbed into soil.
  - **Infiltration Capacity:** maximum rate that precipitation can be absorbed by soil in given conditions.
  - Infiltration is inversely proportional to overland runoff. Depends on: rainfall duration, antecedent soil moisture, porosity, slope angle, vegetation.
- **Percolation:** slow movement of water downwards through the soil into bedrock under gravity. Fast in Carboniferous Limestone.
  - Rate depends on permeability and porosity of bedrock. Chalk and sandstones are porous, spaces allow water to percolate.
- **Throughflow:** water flows through the soil in natural pipes or percolines. Occurs above bedrock.
- **Groundwater:** water that has infiltrated the ground, entered the **phreatic zone** and discharged into the channel.
  - **Phreatic zone:** part of an aquifer (permeable rocks and sediments that can hold groundwater or allow it to pass through) below the water table where all pores are permanently saturated.
- **Baseflow:** where groundwater seeps into the river's bed and contributes to discharge. Very slow transfer from bedrock and very deep throughflow. Takes months/years.

1.5. Underground Water

- **Water table:** upper layer of the **phreatic zone**. It will rise and fall depending on the amount of rainfall percolating downwards, and the amount of baseflow from lower rocks. The **aeration zone** is seasonally wetted and seasonally dries.
- **Ground water**
  - **Recharge occurs with:**
    - Infiltration (from precipitation)
    - Seepage (through banks/bed of rivers, lakes, puddles and ditches)
    - Leakage and inflow (from adjacent rocks, aquifers)
    - Artificially from irrigation, reservoirs
  - **Loss occurs with:**
    - Evapotranspiration (mainly low areas)
    - Natural discharge (seepage and spring flow)
    - Leakage and outflow (into aquicludes from aquifers)
    - Artificial abstraction
- **Aquifers:** permeable rocks (sandstone, limestone, chalk) that contain significant quantities of water. Water inside moves slowly and maintains streamflow – by absorbing or releasing water in wet/dry periods.
- **Springs:** water flow reaches the surface, making a spring. Might be substantial enough to become a source. Usually where percolating water reaches an impermeable layer or the saturated zone.

Water budget equation: $\mathbf{S = P - Q - E}$

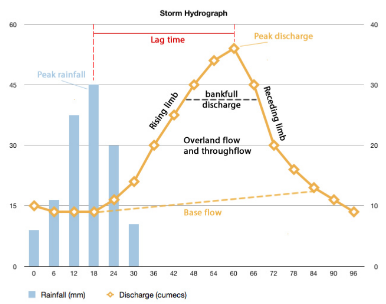
Soil Storage, **P**recipitation, **Q**Channel Flow, **E**vapotranspiration

1.6. Discharge Relationships

Hydrograph Components

A hydrograph plots river discharge against time, and shows the river's regime. Used to understand nature of a drainage basin and factors that affect discharge.

- **Annual Hydrograph (river regime):** to study responses of the river to its environment; highlights seasonal characteristics, therefore biggest influencer is climate.
- **Storm Hydrograph:** shows variations of river discharge over a short time period. Includes both discharge and rainfall on the y-axis.
  - **Cumecs:** cubic metres per second. Unit of discharge.
  - **Approach Segment:** discharge prior to storm.
  - **Rising Limb:** shows quick rise in discharge.
  - **Bank full Discharge:** channel full. Any further increase in discharge = flood.
  - **Peak Discharge:** maximum river discharge.
  - **Lag Time:** time between max rainfall and max discharge.
  - **Receding Limb:** less steep than rising, shows discharge decline after peak discharge.
  - **Stormflow:** stream discharge after rainstorm.
  - **Quickflow:** surface runoff reaches channel quickly.



Storm Process

1. Rain falls on drainage basin in large amounts.
2. Overland flow occurs as precipitation > infiltration rate. Rising limb builds to peak.
3. After a few hours, overland flow reduces and stops. Throughflow then contributes to discharge and stops floodwaters going down as quickly as they rose.
4. Baseflow takes over – back to pre-flood state.

1.7. Drainage Basin Characteristics

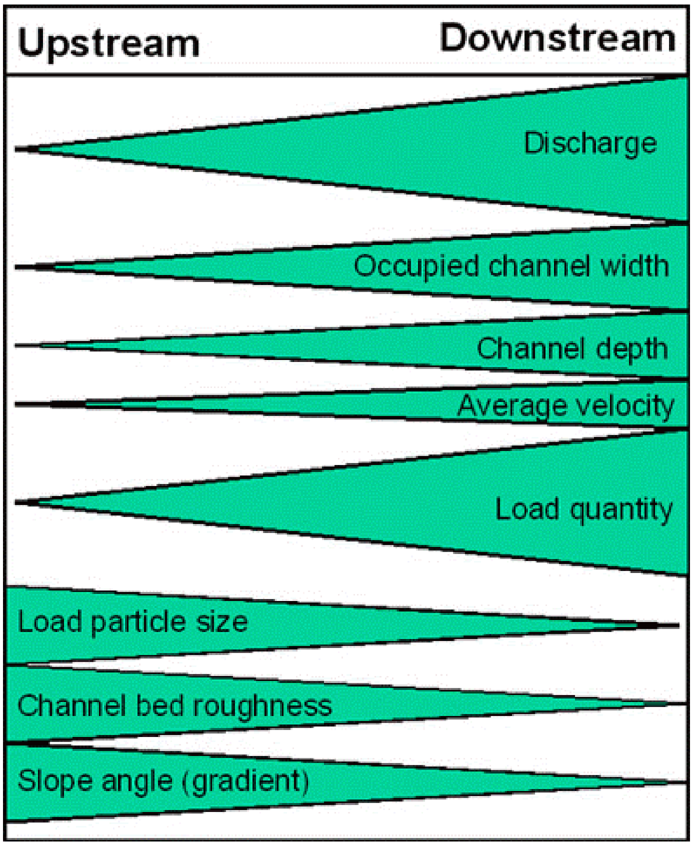
- **Size and Shape:** small basins respond quicker, so lag time is reduced. River channels in circular basins respond quicker than those in linear ones.
- **Drainage Density:** low drainage density causes a long lag time, as water only has a few paths to take.

  - A dendritic (tree like pattern) will have a higher density. Increased discharge response, greater flood risk and reduced lag time.
- **Soil Porosity and Permeability:** impermeable surfaces cause greater peak flows, due to more overland flow. Chalks and gravels allow infiltration and percolation, whereas clay soils do not.
- **Rock Type:** impermeable rocks produce a flashier response, lesser lag times and high peak discharge. Limestone hardly produces a storm hydrograph.
- **Slopes:** steeper = more overland = short lag and higher peak flows.
- **Vegetation Type:** dense forest vegetation intercepts more, so reduced flood response. Opposite in winter.
- **Land Use:** creation of impermeable surfaces (urbanisation) or deforestation increase overland flow. Increasing drainage density (drains) carries water to rivers quicker. Peak flow increases, lag time reduces.

1.8. River Channel Processes and Landforms

Channel Processes

Bradshaw Model



1.9. Erosion

- **Abrasion:** riverbed and bank eroded by the river's load. It is the mechanical impact produced by debris rubbing on the river's sides. Abrasion increases with velocity and effectiveness depends on energy, hardness and concentration of particles.
- **Corrasion:** the erosive action of particles carried by the river.
- **Solution:** the dissolving of rocks (particularly calcium heavy rocks) by removing chemical ions. Maximum rates – fast flowing, undersaturated streams pass over soluble rocks.
- **Hydraulic Action:** direct force of air and water on the rivers banks that causes chunks to break away. Eddies in the water compress water into bank cracks, and the explosion of air bubbles cause the cracks to weaken.
- **Cavitation:** the force of air exploding. With acceleration, pressure drops in fluids, causing air bubbles to form. Cavitation is when these bubbles implode and produce tiny water jets, cutting rock.
- **Attrition:** collision of sediments that wears down both particles. Produces smaller, rounder particles.
- Rate of erosion is affected by: amount and weight of load, velocity, gradient, hardness of geology, pH level and human impacts increasing erosion.

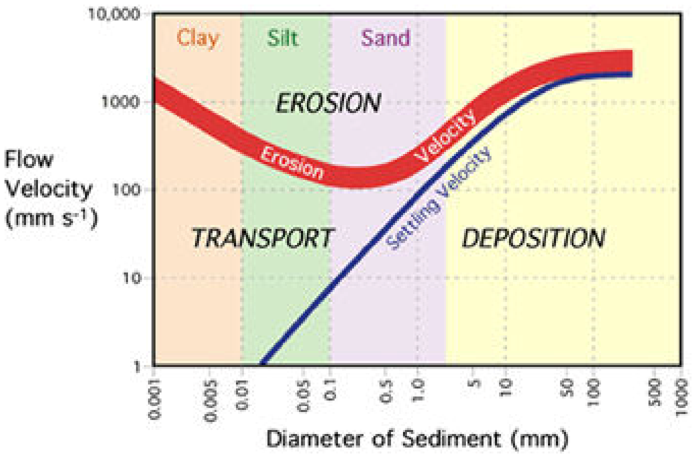
1.10. Load Transport

- **Traction:** large particles that are rolled along the riverbed by the force of water. Spend all/most of time on the riverbed.
- **Saltation:** gravel and small stones hop along the riverbed, as a fast eddy picks them up, and a slower one causes them to fall back down.
- **Suspension:** silts and clays are held up by the water. Gives rivers a cloudy appearance, especially close to the mouth.
- **Solution:** dissolved calcareous rocks.

Load varies with discharge and velocity. Load is calculated at **bank full. Capacity** is the greatest amount of load that can be carried. **Competence** is the diameter of the largest particle that can be transported.

1.11. Hjülstrom Curve

- **Deposition** occurs when there is a reduction in energy, often at river mouths, estuaries and deltas.
  - **Energy reduces when:** gradient reduces, friction increases, load increases, water volume decreases, water flows on the inside of a meander.
- **Sedimentation** occurs when sediment is dropped from still water.
- **Flocculation** is where charged ions in sea water allow clay particles to group and settle. Flocculation leads to development of mudbanks when water becomes brackish close to the sea.



- **Critical erosion velocity:** lowest velocity needed to pick up particle of that size - entrainment.
- **Mean settling velocity:** velocity needed to drop particles from suspension.

Clays have high entrainment value due to their cohesive nature, and gravels due to their weight. Sands are easiest to pick up. Clays remain in suspension if velocity is 0. Velocity for transport is always less than the velocity required to pick up (entrain) the particle.

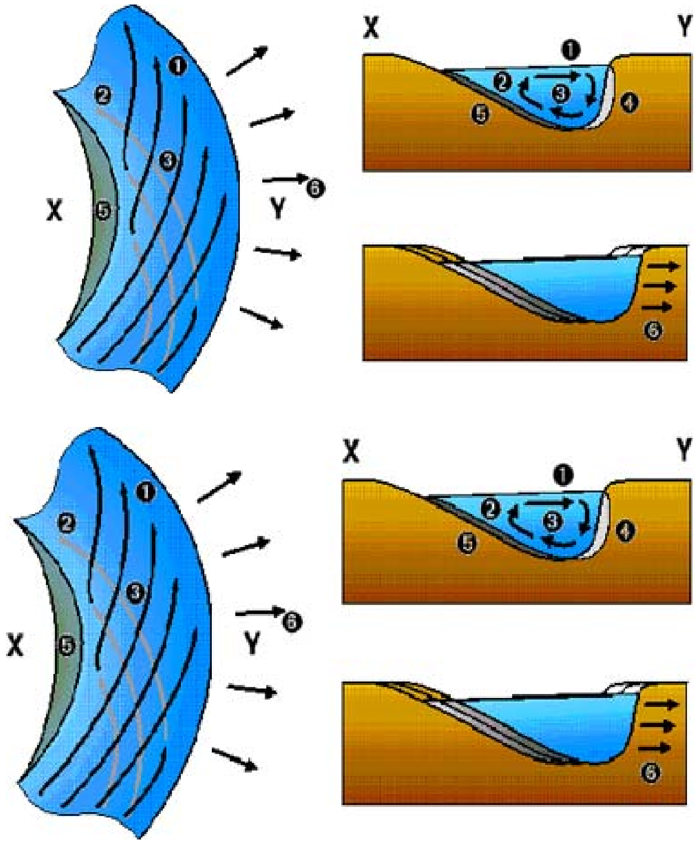
1.12. River Flow

Velocity is affected more by friction than gradient. We can measure friction with:

- **Bed roughness:** $N = \frac{R^{\frac{2}{3}} \times S^{\frac{1}{2}}}{V}$, where **R** is the hydraulic radius, **S** is channel gradient and **V** is velocity. Higher the value of **N**, the rougher the riverbed.
- **Hydraulic Radius:** $\frac{channel\ depth \times width}{(2\ x\ height) + width}$

Thalweg is the imaginary line of fastest water velocity down a stream.

- **Laminar:** water flows in sheets parallel to riverbed. No eddies or meanders. Common on smooth surfaces.
- **Turbulent:** water closest to bed/banks slowed by friction and is overtaken by thalweg. Turbulence created, and water close to banks eddies towards the banks, water close to the bed eddies towards the bed.
- **Helicoidal:** horizontal turbulence produces a corkscrew motion. The thalweg moves both laterally from bank to bank, but also vertically from surface to bed during one rotation.



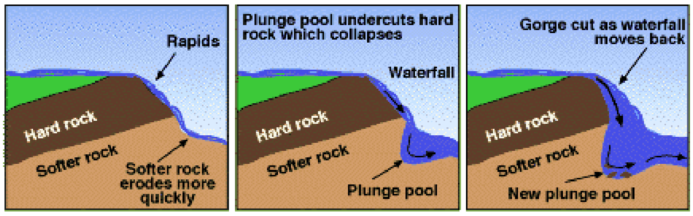
1.13. Channel Types

- **Straight:** channel with sinuosity < 1.5. 1 is perfectly straight. Rare, because thalweg will still move from side to side due to helicoidal flow. Normally artificial.
- **Braided:** channel is divided by islands or bars. Islands are vegetated, whereas bars are not and are unstable. Formed with steep gradient, coarse material, easily erodible bank, highly variable discharge. When discharge is reducing (and hence velocity), sediment is plentiful and bars form (coarse then fine sediment). With reduced discharge, river must split to go around the bar.
- **Meandering:** channel slope, discharge, helicoidal flow and load combine to a situation where lateral erosion causes meandering. NOT a result of obstacles.

1.14. Landforms

- **Meanders:** a pronounced bend in the course of a river. Pools and riffles cause the thalweg to deflect. Where the thalweg is fastest, erosion occurs, and deposition where it is slowest. Over time, this creates a bend in the river.
  - **River Cliffs:** steep side on the outside of a meander bend where erosion is strongest and downwards.
  - **Point Bars:** deposits of sediment on the inside of a meander bend, where thalweg is slowest and rising.
  - **Oxbow Lakes:** erosion with the thalweg causes narrowing of the bend neck, and after a flood event, the neck is breached. Meander cut off with more deposition, creating an oxbow lake.

- **Pools:** deep sections develop where erosion dominates (high velocity, dominant laminar flow).
- **Riffles:** shallower sections of the riverbed where sediment has been deposited (low velocity, turbulent flow). Steep positive relief gradient compared to the negative gradient of the pools.
  - Related to helicoidal flow due to regular spacing.
  - Different gradients creates variations in subcritical and supercritical flow, causing erosion or deposition.
- **Waterfalls:** river spills over gradient change where more resistant rock is on top of less resistant rock, and splashback undercuts rocks by processes of abrasion. Also produced by rejuvenation, where there is a knick point. Plunge pool removes support for overhang, so collapses. Causes upstream migration.
  - **Gorges:** a deep, steep sided valley caused by waterfall retreat.



- **Potholes:** turbulence swirls pebbles around a depression in the river's bed. Sides widened and deepened as pebble erodes the cavity. Initiated by eddying.
- **Rapids:** upper course feature, where gradient is steep, and riverbed is rocky and irregular. Turbulent flow.
- **Bluffs:** old floodplains erode leaving terraces. Meanders erode the edge of the terrace, creating a line of steep slopes called bluffs.
- **Floodplains:** flat land made up of alluvium next to the river, rise during floods, as fine silt is deposited. Backswamps are sometimes created during flood events. Riverbed can raise if discharge is low, and sediment is deposited.
- **Levees:** following a flood event where banks burst, wetted perimeter increases. Increased friction reduces velocity, and coarse material is deposited first around the banks, with finer material moving across the flood plain causing back swamps.
- **Deltas:** sediment is deposited where the river meets a standing body of water, due to a loss of energy. Clay particles flocculate and deposit. Bottomset beds (fine material built out by turbidity currents) form first, then foreset beds (coarse material carried seaward by rolling/saltation), then topset beds (fine material built by distributaries).
  - **Arcuate Delta:** fan shaped. Where longshore drift occurs.
  - **Cuspate Delta:** pointed, formed by two opposing currents.
  - **Bird's Foot Delta:** still sea allows each distributary to build in any direction.

1.15. Human Impact

Catchment Flow Modifications

- **Deforestation:** reduced evapotranspiration, increased surface run off, reduced time lag and less surface storage. Higher peak discharge caused.
- **Afforestation:** once a fully established forest, afforestation has the opposite effect to deforestation.
- **Urbanisation:** creation of impermeable surfaces reduces infiltration and increases overland flow. Sewage systems and storm drains get water to the main channel much quicker than throughflow. Lag times are reduced, and flood peaks are increased. Building on floodplains reduces the available flood space, so flood waters will rise higher.
- **Grazing:** ploughing increases infiltration, heavy machinery causes soil compaction, so reduced infiltration, therefore higher peak discharge. Less evapotranspiration than forested area.
  - Water logging/salination occur with poor drainage.
- **Abstraction:** over abstraction causes the drying up of rivers, falling water tables and saltwater intrusion in coastal areas.
- **Channelisation:** increases the hydraulic radius of a channel, so shorter lag times and higher flood peaks.
- **Reductions in industrial activity:** old springs re-emerge - surface water flooding, basements flood, leakage into tunnels, reduced slope stability.
- **Water storage:** building dams are good for flood/drought control, irrigation, hydroelectric power. However, they can lose water, salinization occurs and ground water changes.

1.16. Causes and Impacts of River Floods

- Physical Causes
  - Heavy, persistent rainfall (deep weather depressions)
  - Rapidly melting snow or ice
  - Impermeable soil and bedrock
  - Coastal storm surges
  - Lack of vegetation
  - Disaster (natural, or dam failure)
- Human Causes
  - Urbanisation (impermeable surfaces, storm drains, channel restrictions from bridges)
  - Floodplain developments increase risk
  - Engineering that obstructs the channel
  - Mechanised farming and poor/inappropriate farming practices.
- Impacts
  - Deaths, damage and disruption
  - Death toll higher in LICs. Cost higher in HICs

1.17. Flood Prediction

- **Recurrence Interval** is how often, on average a flood of a certain size is likely to occur.

  - A 100-year flood is one that is expected to occur every 100 years, on average.
  - Plotting a graph of flood magnitude against recurrence interval can show when a certain size flood is likely to occur, using a best fit line.
  - Or, look at flood history.
- **Flood Risk Maps** show where the river is likely to flood, depending on if flood risk is severe (1-75 years) or moderate (76-200 years).
- Areas most at risk are low-lying parts of active floodplains, small basins subject to flash floods, areas below unsafe dams and low-lying inland shorelines.

1.18. Flood Prevention

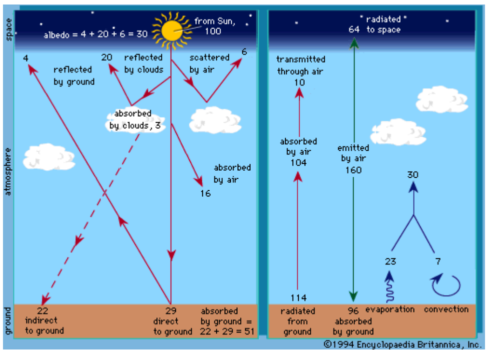
- **Forecasting and Warning:** use of weather satellites, have an emergency plan, radio/internet communication, rain gauges, river discharge gauges. Computer models that compare new data with history
- **Loss Sharing:** disaster aid and insurance.
- **Hard Engineering:** work against natural processes. Construct dams, levees, straighten the channel, reservoirs, build diversion spillways. Normally fixes local problem but causes more up/downstream.
- **Hazard Resistant Design:** adjust buildings to reduce losses. Sandbags, seal doors/windows, move off lower floors.
  - Flood gates installed on individual houses. Eg. Yarm, on the River Tees.
- **Land Use Zoning:** move/avoid building on flood prone areas. Allow flooding to happen on floodplain.
- **Soft Engineering:** working with natural processes. Flood abatement decreases amount of run-off. Afforestation, contour ploughing, remove sediment. Flood diversion allows areas to be flooded, not built upon.
  - **Appropriate Floodplain Use:** working from the channel outwards, appropriate use would be - protected wetlands, rough grazing land (that animals can be removed from), parks and leisure areas, houses, then critical buildings such as hospitals furthest away.

2. Atmosphere and Weather

2.1. Diurnal Energy Budgets

Radiation

- **Incoming Solar Radiation:** shortwave UV insolation is the only energy input. Affected by the amount and type of cloud, the Sun's angle.
  - Around 5% is scattered by atmosphere
  - 24% reflected into space by atmosphere
  - 23% absorbed by atmospheric gasses.
  - 48% absorbed by Earth's surface and heats it.
- **Reflected Solar Radiation:** proportion of energy that is reflected back to the atmosphere is its **albedo**. Lighter materials have a higher albedo value and therefore reflect more radiation energy.
  - **Planetary albedo**: proportion of insolation scattered and returned to space by Earth.
- **Surface/Subsurface Absorption:** since darker surfaces absorb more radiation, the energy has potential to be transferred to lower layers via conduction. If conduction is possible, the surface will remain cool as heat is transferred to the soil/bedrock. Conduction is encouraged when moisture is present. This heat is released back to the surface at night, offsetting night-time cooling.
- **Longwave radiation:** since the Earth is a cold body, it emits longwave radiation back to space. Longwave radiation is easily absorbed by greenhouse gasses (water and CO2) and by clouds, which return the heat to the surface – called the **greenhouse effect**. Heat loss is greatest on cloudless nights.



- **Daytime budget =** insolation – (reflected insolation + surface absorption + sensible heat transfers + latent heat transfers + longwave radiation)
- **Night-time budget =** stored energy – (latent heat transfers + sensible heat transfers + longwave radiation)

2.2. Cloud Effects

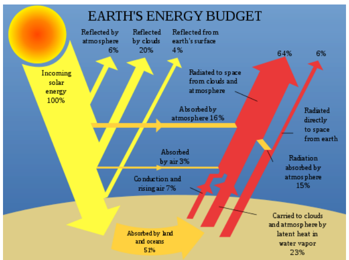
- **Day:** clouds have a net cooling effect due to their albedo value, causing insolation to be reflected to space.
  - Cirrus clouds allow insolation to pass through, but not longwave radiation.
  - Cumulonimbus clouds do not heat or cool well.
  - Low, thick stratus clouds reflect 80% of insolation, keeping Earth's surface cool.
- **Night:** thick clouds acts as an insulating layer, absorbing and reradiating longwave radiation which keeps nights warm. Warm clouds can also emit longwave radiation out to space.

2.3. Heat Transfers

- **Sensible Heat Transfer**
  - **Convection**: thin air layer heated above surface (poor conductor), molecules vibrate more, gas is less dense so rises. Air cools, becomes denser and falls, to replace rising air. At night, air might sink at night in higher latitudes. Some advection may occur.

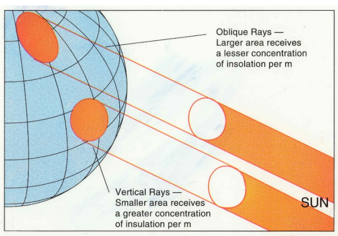
- **Conduction**: heat transfer between the ground and the air when they are in contact.
- **Latent Heat Transfer:** occurs when water evaporates to water vapour, or ice melts into water vapour. Heat required to change state is absorbed from the air, leaving less energy to heat the surface. Latent heat of condensation increases the speed and extent of convection.
  - **Evaporation:** water molecules gain enough energy from surrounding air to change state to a gas, and leave the surface. This leaves overall energy less at the surface, so the surface and air cool.
  - **Dew:** water saturated air comes into contact with an object with a temperature cooler than the airs dew point. Water vapour condenses into liquid form. Latent heat is released during condensation, adding heat to the ground.
  - **Absorbed Energy returned to Earth:** greenhouse gasses absorb reradiated longwave radiation and atmosphere warms.
- **Surface Temperature Changes:** during the day, the surface is heated by radiation, conduction, and convection. Surface air moves slow due to friction, is heated, and rises as a result of convection. At night, ground is cooled by lack of radiation, heat from soil and rocks rises to heat the surface.

2.4. Global Energy Budgets



Latitudinal Radiation Pattern

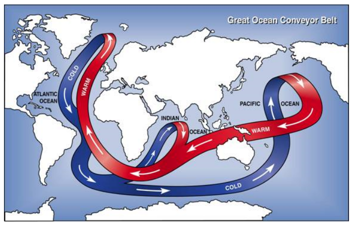
- **Excess:** positive radiation budget in the tropics. Occurs because insolation is so concentrated.
- **Deficit:** negative radiation budget at higher latitudes. Insolation has a larger amount of atmosphere to pass through, there is more chance of reflection back to space, and rays are less concentrated.
- **Balance:** neither regions are getting warmer/colder, horizontal transfer from the tropics to higher latitudes compensate to global insolation differences.



- **Temperature patterns:** little seasonal variation at the equator, but great variation in mid/high latitudes. A lag time exists between overhead sun and maximum insolation, as the atmosphere is heated from below, not above. Coldest period is after winter solstice, as ground continues to lose heat despite resumed insolation. Greater lag time over ocean due to high specific heat capacity compared to land.

2.5. Atmospheric Transfers

- **Pressure variations:** air moves from high to low pressure. Low/declining pressure systems bring poor weather.
- **Surface pressure:** low pressure in equatorial regions, as warm air rises and leaves the surface. Higher pressures seen in polar regions, where cool air descends onto the surface.
- **Surface wind belts:** uneven due to seasonal variation in insolation. Summer in N. Hemisphere causes cooling in southern, hence increasing differences between polar and equatorial air. Creates stronger high-level westerlies in N. Hemisphere.
- **Ocean conveyor belt:** cold, salty water sinks from polar regions and moves towards equator, where warm water gives its heat away to the surface winds. More evaporation in North Atlantic, which leaves saltier water behind – denser so sinks and cools. Water is transported to Pacific, dilutes, less dense so rises.



2.6. Seasonal Variations

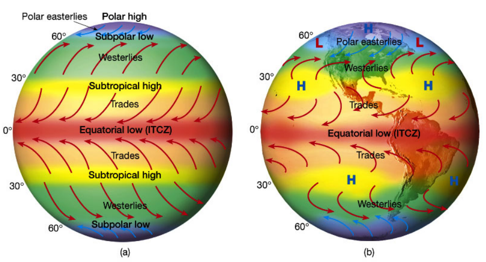
- **Temperature**
  - **Latitude:** between the tropics, the angle of Sun is high, so greater intensity of insolation is received, and hence more heating. Where there is more atmosphere to pass through, a greater proportion of insolation is lost/scattered/reflected by atmosphere. Also, the longer the sun shines, the more insolation is received.
  - **Land/Sea distribution**

Land	Sea
Lower reflectivity, so more absorption of radiation (apart from ice)	Higher reflectivity, so less absorption of radiation (especially with low sun)
Heat confined to near surface as surface has poor conductors	Sun's rays penetrate deep, convection currents distribute heat to great depths

Land	Sea
Low specific heat capacity, so a set amount of energy raises land temp by more	High specific heat capacity, so set amount of energy raises temp by less
Less water, so less energy wasted to evaporation	Large amounts of energy used for evaporation

- **Ocean currents:** surface currents caused by prevailing winds. Clockwise rotation in N.Hemisphere, and anticlockwise in S.Hemisphere. Water piles into domes and due to Earth's rotation, water is piled up on western edge of ocean basins – return flow is a narrow, fast current (gulf stream). Warm currents from equatorial regions raise temps in polar regions. Warm surface causes low pressure, air moves from high to low, so water moves from cold to warm; and winds push warm into warm, exposing cold deep water. Process repeats.

- **Altitude:** air temperature decreases with altitude, as air is thinner, contains less moisture and is therefore less able to absorb longwave radiation.
- **Pressure belts:** link between winds and pressure, as heating of air causes pressure changes, which puts air in motion thus causing the effect of wind.
  - **Pressure changes:** air is driven by the pressure gradient – air moves from high to low pressure. Air moves as per the 3-cell model, where high pressure is caused where air sinks to the ground, leaving space for adjacent air at high altitudes to move over and add to the weight of the sinking air mass. Since earth is spinning, winds blow at angles due to the Coriolis force.



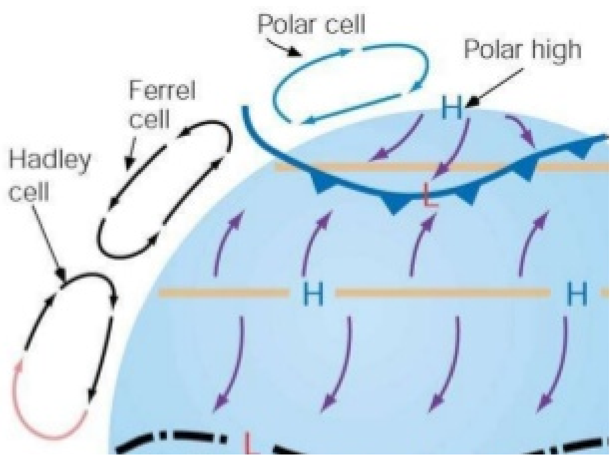
- **Wind belts:** air will move faster closer to the poles, due to the distance between earths axis of rotation and the air.

This fast-moving air produces jet streams. Air closer to the equator will move slower. In addition, faster moving air occurs at high pressure zones, due to centrifugal force – because pressure and Coriolis force work together.

- **Coriolis Force:** air masses are deflected due to Earth's easterly rotation. Air moving from high pressure to low pressure in the N. Hemisphere is deflected to the right, and to the left in the S.Hemisphere acts at right angles to wind direction.
- **Geostrophic balance:** between Coriolis Force and pressure gradient, produces resultant wind – Geostrophic wind. In N. Hemisphere, wind blows anti-clockwise around low pressure and clockwise around high pressure.
- **Friction:** reduces geostrophic force and wind speed, so pressure gradient is no longer balanced by the Coriolis force. Makes air more likely to move to low pressure zones.

2.7. Global Circulation Model

- 3 Cell Model
  - **Hadley Cell:** adjacent to ITCZ, where insolation is most intense. Doldrums created (permanent low-pressure belt) due to constant rising of air, trade winds are drawn in. Air subsides around 30°N/S and is deflected right/left depending on hemisphere.
  - **Ferrel Cell:** not thermally induced, but a result of adjacent cells – creating a 'cog-like' system. Air is forced to rise at the polar front, and forced to sink at the high-pressure zone, where it meets the Hadley cell.
  - **Polar Cell:** cold polar air sinks, creating high pressure. As the air moves towards the equator, it spreads out, pressure reduces, and it rises. Low pressure zone created at 50-60°N/S.



- **Rossby waves:** ridge and trough wave pattern of fast moving 'rivers of air'. 3-6 in each hemisphere, and have their course altered by major barriers such as the Andes mountains. Where there is a trough, air converges (low pressure system) and at a ridge in the wave, air diverges (high pressure system); as the wind rises over pressure ridges, conditions at the surface change.

- **Upper westerlies:** fast moving winds that result from a strong north/south temperature (and therefore pressure) gradient and the Coriolis force. Important for mixing warm and cold air – not included in 3 cell model.
- **Jet streams:** narrow column of fast-moving air through the centre of Rossby waves. 10km above surface, around 250km/h. Two exist in each hemisphere – the polar (30-50°N/S) and subtropical (20-30°N/S) jets; both flowing eastward. Jet streams result from differences in equatorial/sub-tropical air, and sub-tropical/polar air. Greater the difference, stronger the jet stream.

2.8. Weather Processes and Phenomena

Atmospheric Moisture Processes

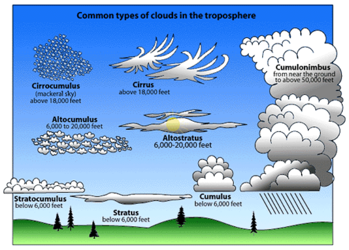
- **Evaporation:** occurs when vapour pressure of a water surface exceeds that in the atmosphere. Sped up by: low initial air humidity, heat and strong wind.
  - **Absolute Humidity:** actual amount of water vapour in a given volume of air.
  - $Relative\ Humidity = \frac{actual\ moisture\ content\ \times 100}{saturation\ moisture\ content\ at\ the\ same\ temp\ press}$
- **Condensation:** further cooling below dew point temperature, or when an air mass reaches saturation – turns water vapour into a liquid water. When **hygroscopic condensation nuclei** are present.
  - **Conduction Cooling:** leads to condensation when moist air contacts a cold object.
  - **Radiation Cooling:** heat lost to space by longwave radiation from clouds and gases in atmosphere.
  - **Expansion Cooling:** air rises and expands due to reduced pressure in atmosphere. Expansion causes a temperature drop.
- **Freezing:** liquid water changes into a solid once temperature falls below 0°C.
- **Melting:** the change of state from solid to liquid above 0°C.
- **Deposition:** transition from water vapour to ice, with no intermediate stage. May deposit on surfaces.
- **Sublimation:** transition from ice to water vapour, with no intermediate stage. Might occur in low humidity.

2.9. Causes of Precipitation

- Requires **hygroscopic condensation nuclei**.
- **Collision Theory:** droplets in clouds collide together (after rising and falling at different rates based on their size) to from a larger droplet.
  - **Coalescence:** two droplets combine to form rain.
  - **Aggregation:** two ice crystals collide to form snow.
  - **Accretion:** ice crystal collects a water droplet, forming hail.
- **Bergeron-Findeisen Theory:** air is saturated with ice before water is added. When air temperature is between -12°C and -30°C, air can only be saturated over ice, so water droplets must evaporate. Ice particles grow when the air has a mix of ice and water, as a result of sublimation. Water vapour deposits on ice crystals. Precipitation occurs once ice crystals have aggregated into a large enough snowflake to fall. When falling, ice may melt into rain.
- **Convectional:** land is heated and so air directly above becomes less dense, rises and cools. As air rises further, latent heat is released, powering the ascent. When condensation occurs, clouds form, precip falls.
  - Result of **unstable air**, where air parcel cools slower than surrounding air, so has to rise.
- **Frontal:** warm air meets cold air. Less dense warm air can't push cool air out of the way, so is forced over the colder air. Warm air rises, cools and condenses, forming a cloud and therefore rain. Centre of low pressure where two air masses intersect.
  - **Warm front:** boundary of advancing warm air mass.
  - **Cold front:** boundary of advancing cold air mass.
  - Result of **conditional instability in air**, where stable air is forced to rise to where it hits dew point.
- **Orographic:** pressure force strong enough to force air to move over a barrier. Air rises, it cools and reaches dew point where cloud forms and precipitation falls. Windward side is called the 'rain slope', lee slope named 'rain shadow' as unsaturated air sinks and warms. Hill fog occurs when the forced ascent produces a thin stratiform cloud. Unstable air (rising temp is warmer than the air rising into) causes continued rising, instead of falling down the lee slope.
  - Result of **conditional instability in air**, where stable air is forced to rise to where it hits dew point.
- **Radiation Cooling:** cloudless night, so ground loses heat rapidly by returning radiation to space. Little wind present, air remains in contact with valley sides to cool by conduction, sinks to bottom of valley. Bottom of valley has a source of moisture. **Ground temperature inversion** occurs and there is warmer air on the sides (heated by morning sun, aided by dry ground) than at the bottom. This causes radiation fog and ice to form.
- **Frontal inversion:** colder, denser air mass descends, forming warmer air above. Barrier created where the two meet that prevents warm air parcels from rising through to the warm air.
- **Subsidence inversion:** air moving upwards experiences adiabatic cooling, due to pressure decrease. This air falls, becomes denser and warms, warm air reaches a cooler layer of unstable air, and a temperature inversion is created.
- A temperature inversion will dissipate once sun has heated the ground long enough to cause cool air above to warm by conduction processes – allowing warm air to rise.

2.10. Types of Precipitation

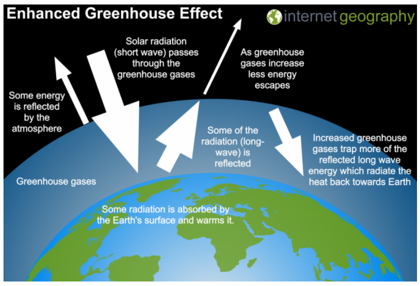
- **Clouds:** if a cloud is tall enough to prevent sunlight reaching its base, it could produce precipitation. The base appears dark – such as nimbostratus and cumulonimbus. The latter stretches from sea level to the tropopause, forming an anvil head, because the cold air cannot rise through the warmer atmosphere.
  - A cloud will not produce precipitation if it is thin enough to allow sunlight through, but may form fog if in contact with valley side/mountain top.



- **Rain:** liquid water droplets heavy enough to fall to the ground. Between 0.5mm and 5mm. Drizzle is rainfall less than 0.5mm. Varies in amount, intensity, duration.
- **Hail:** raindrops carried to freezing level inside a cumulonimbus cloud, and freeze. Hailstones then collide with supercooled water freezing on impact. Rising and falling in the cloud causes repeated melting and freezing until the hailstone is heavy enough to fall.
- **Snow:** snow crystals form when temp is below freezing, and water vapour turns solid. Heaviest snowfall occurs when warm moist air is forced to rise in orthographic or frontal rainfall, as very cold air contains limited moisture.
- **Dew:** deposition of water on a surface that occurs in anticyclonic systems. Rapid radiation cooling causes ground temperature to hit dew point and condensation/direct ground precipitation occur.
- **Fog:** forms as a result of radiation cooling. When sun rises, fog lifts, possibly causing smog to form under an inversion layer (cold air trapped by warm air above it). Fog is common over the sea in autumn and spring.
  - **Steam Fog:** localised when cold air blows over warmer water, and air becomes saturated due to evaporation, resulting condensation causes steam.
- Advection Fog
  - Winds move towards pole over cold sea, so chilled to below dew point, forming advection fog.
  - Winds blow over cold ocean current, advection fog forms over the current.
  - Air passes from sea onto cold land in winter, causing advection fog, or hill fog if the air is forced to rise due to relief. Drizzle may fall if thick enough.

2.11. The Human Impact

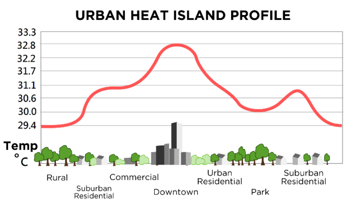
Enhanced Greenhouse Effect



- Greenhouse gasses such as water vapour, carbon dioxide and methane allow shortwave radiation to penetrate, but prevent longwave. This traps radiation inside the atmosphere, causing temperature to rise.
- Evidence
  - **CO_2 (315ppm 1950 400+ppm 2020)** due to increased fossil fuel burning and deforestation – which increases emissions as well as removing trees that reduce emissions. 5 gigatons of fossil fuels were burnt in 1980 – 1 ton burnt = 4 tons CO_2 emitted.
  - **Methane (increases at 0.5-2% per year),** cattle produces 75m tonnes and wetlands 150m tonnes. Methane released as perma-frost melts.
  - **CFCs (increases 6% each year)** are 10,000x more efficient at preventing longwave radiation from penetrating as CO_2 (used as refrigerants aerosol propellants). Also destroys ozone, allowing more insolation to enter the atmosphere.
  - **Nitrous oxides (increased by 8%)** 300x more powerful than CO_2, from fertilisers, burning fossil fuels and vegetation.
  - **Rising sea levels (3.1mm per year)** as a result of thermal expansion and melting glaciers. First 60m of ocean warms by 0.11°C each decade.
  - **Ocean acidity (26% acidity increase since 1750).**
  - **Melting ice and glaciers** around the world are showing signs of decrease, exposing more land and adding to the sea level rise. Arctic ice sheet shrunk by 65% since 1975.
- Causes
  - Scientific consensus is that fossil fuel burning is directly related to the global temperature increase. This includes the emission of the gasses described.
  - **Albedo change:** deforestation and urbanisation has resulted in more, much darker surfaces, so the ground absorbs more radiation, which is released back to the atmosphere – heating it.
  - **Arguments against include:** orbital eccentricity, axial tilt, axial precession, solar output variations, changes in ocean currents, and increased atmospheric dust from volcanoes.
  - **El Niño:** heats the planet as normal westward surface flow of currents reverses and warm water moves east which causes high temperatures and drought in Australia and heavy rainfall in Peru. **La Niña** produces colder years as a result of cool upwellings off the Peruvian coast.
- Atmospheric Impacts

- **Sea Levels:** 200m people could be displaced, 4 million km^2 of land threatened by floods, 200m at risk from flood/droughts. Rise by 2100 is expected to be 26-77cm. 570 cities exposed, contamination of drinking water (salt infiltrates groundwater and aquifers), millions of coastline miles under threat.
- **Warming oceans:** 50% increase in marine heatwaves this decade. 1°C fluctuation causes plankton and coral to stress and bleach (spit out symbiotic algae and die). First 700m of ocean absorbs most heat.
- **Storm Activity:** more frequent and intense hurricanes, tornadoes etc… Floods have causes >500,000 deaths and affected 2.8bn globally, with $8bn in damages in the USA.
- **Agriculture:** USA's grain belt will decrease, China's growing season will increase, Northward shift for timber and crop production. 35% drop in African produce if 3°C temperature rise. $10bn in losses in Texas and Oklahoma in a year due to failed crops.
- **Drought:** reduced rainfall in Europe and USA will expose 4bn to water shortage risks.
- **Disease:** 60 million more people exposed to Malaria, as mosquitos breed faster in the heat.
- **Wildlife:** 40% of species will become extinct at +2°C.
- **Tourism:** previously undesirable areas may become tourist hotspots, and likewise for desirable places becoming undesirable.
- **Cost: 1 tonne** CO_2 causes £45 of damage. Solving the effects could cost 5-20% of each country's GDP, whereas action now may only cost 1% of each GDP.

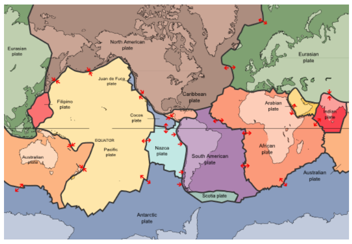
2.12. Urban Climates Theory



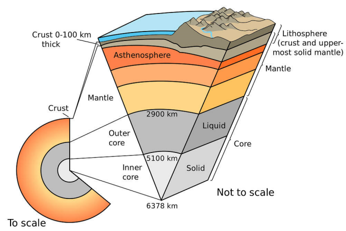
- General impacts and causes
  - **Higher temperature:** greater surface area to absorb heat, low albedo of tarmac (10%) and concrete (20%) so less insolation is reflected (higher specific heat capacity surfaces), high buildings trap insolation and absorb heat, low buildings causes street to collect heat, more heat for atmosphere due to reduced evapotranspiration, pollutants trap heat.
  - **Lower humidity:** lack of vegetation so less transpiration, high drainage density removes water, fewer water bodies so less water available to evaporate.
  - **More intense storms:** greater instability of air, hence stronger convection above urban areas.
  - **Slower winds:** wind scattered by buildings.
  - **Less snowfall:** due to higher temperatures.
  - **Human activity:** radiant heat from heating systems and buildings can contribute up to 50%.
  - **Tiny specific anomalies:** often above canals/rivers.
  - **Insolation:** due to pollution, longwave radiation is trapped, and insolation reduced. Warming occurs by the afternoon and mornings are colder than rural areas.
- **Microclimate Mitigation:** London Plane tree.
  - Installation of urban forest. Reduces ambient temperatures by 3-5°C by shading and increased evapotranspiration. Air quality improves too – so trees added to city schools. 'Living' roofs are popular.

3. Rocks and Weathering

3.1. Plate Tectonics



Nature of Tectonic Plates

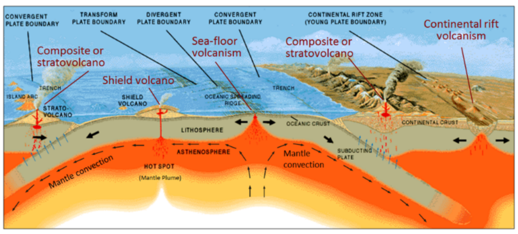


- Evidence
  - Coastline fit of continents (Africa and South America)
  - Orogenic belt fit (Britain, Norway and Newfoundland)
  - Fossil remains in India match Australian ones. Since these animals couldn't swim, plates must have been connected.
  - Glacial deposits (Brazil matches West Africa)
  - Identical sedimentary sequences along Atlantic coastlines (Africa and South America)
- **Continental crust:** 35-70km thick, > 1500m years old, granite composition, rich in Silicon and Aluminium, less dense (2.6kgm^{-3}), light colour.
- **Oceanic crust:** 6-10km thick, < 200m years old, Basalt composition, rich in Iron and Magnesium, denser (2.9kgm^{-3}), dark colour.
- Movement
  - **Convection Theory:** radioactive decay in Earth's core produces heat. Hot magma rises in convection currents, cools at the surface and sinks as denser.
  - **Hotspot:** lava plume through mantle responsible for original crust rifting. Outward flow of viscous magma creates drag force on plates causing movement.

- **Ridge push:** magma intrusion at ocean spreading ridges, which propels the two plates apart.
- **Slab pull:** the force that the sinking (colder and denser) edge of the plate exerts on the rest of the plate.

3.2. Types of Plate Boundaries

- **Oceanic constructive:** rising convection lifts lithosphere creating a ridge. Extensional forces cause stretching and a fissure. Fissure opens and exposed magma fills gap, then cools and solidifies. MAGMA DOES NOT OVERFLOW TO FORM TOPOGRAPHIC HIGH.
  - **Mid-Atlantic ridge:** 0.7-1.4cm per year.
- **Continental constructive:** as above, but less vigorous pull so no clean break. Pulled thin creating fractures, faults develop and central block slides down creating a rift valley which may fill with water.
  - **East-African rift valley:** 2cm per year.
- **Oceanic/Continental destructive:** plates forced together and oceanic plate subducts since denser. In the Benioff zone, crustal melting occurs, and resultant magma forced through cracks – to form volcanoes. Subducting plate drags down crustal material to form an ocean trench.
  - **Juan de Fuca and N.American plate:** 3cm per year.
- **Oceanic destructive:** plates forced together, older plate subducts as is denser. Forced 100 miles below and melts – producing magma chambers. Lower density magma rises through cracks allowing volcanic eruptions.
  - **Japanese Arcs:** 7-11cm per year.
- **Collision:** powerful collision between two continental plates. Both densities are lower than the mantle's, so prevented subduction. Some subduction occurs as lithosphere breaks free. Crust fragments are trapped in collision zone, cause deformation. Intense compression results in folding.
  - **Himalayan Mountain Range:** 5-6cm per year.
- **Conservative:** plates slip past each other with relative horizontal movement (sinistral = left, dextral = right). Lithosphere is neither created nor destroyed. Extensive earthquakes.
  - **Strike-slip:** simple offset.
  - **Transform:** two divergent boundaries push together.
  - **San Andreas Fault:** 3-5cm per year.



3.3. Processes and Associated Landforms

- **Sea floor spreading:** creates oceanic crust, explained by palaeomagnetism – where lava cools and retains the magnetic polarity of Earth at the time of cooling. Slow spreading is a result of the ridge being fed by small, discontinuous magma chambers.
- **Subduction:** where denser plate (density similar to asthenosphere) is pushed into upper mantle. Subduction continues once initiated, driven by the weight of the plate – subducted side remains cooler and therefore denser than surrounding mantle.
  - Rate of subduction matches rate of production.
  - Plate dip of 30° to 70° (older crust = steeper).
  - **Evidence:** surrounding landforms, Beinoff zone, disruption of temperature at depth.
  - **Beinoff Zone:** narrow zone of earthquakes dipping away from deep sea trench. Extends to 680km deep. Deep focus earthquakes occur further from subduction.
- **Fold mountain building (Himalayas)**
  - Indo-Australian plate subducts under Eurasian plate.
  - Same as **collision plate** description. Note that no magma escapes, so there is little volcanic activity.
- **Fold mountain building (Andes)**
  - Nazca oceanic plate subducts under continental South American crust.
  - In addition to normal **collision plate** process, pieces of the Nazca plate scraped off and became part of the accretionary wedge – adding to the mountain range.
  - Partial melting of Nazca plate produces volcanoes.
- **Ocean ridges:** occur at divergent boundaries. Ridges are a series of parallel ridges, with a central double ridge separated by a ridge valley. As a result of tensions and stretching a central block may fall.
- **Ocean trenches:** found at subduction zones. Long, narrow, asymmetric (steep side towards land mass) depressions in the ocean floor (6000-11000m). Found next to land and island arcs – common in Pacific Ocean
- **Volcanic island arcs:** chains of volcanic islands on the continental side of an ocean trench.
  - Subducting plate heats up and melts 75 miles deep.
  - Magma formed begins to rise to surface and meets the overriding plate. Material is added to crust – building volcanoes.
  - If upper plate is oceanic, volcanoes pile up until they poke through the surface – forming an island arc.
  - **Features:** trench outer rise caused by subducting plate, gentle outer slope trench broken by faults, steep inner slope contains fragments of subducting plate.

3.4. Weathering

The breakdown of rocks in situ, whereas erosion is the breakdown of material by movement processes. Limestones and sandstones are least resistant.

Physical Processes

Produces small, angular fragments of the same rock.

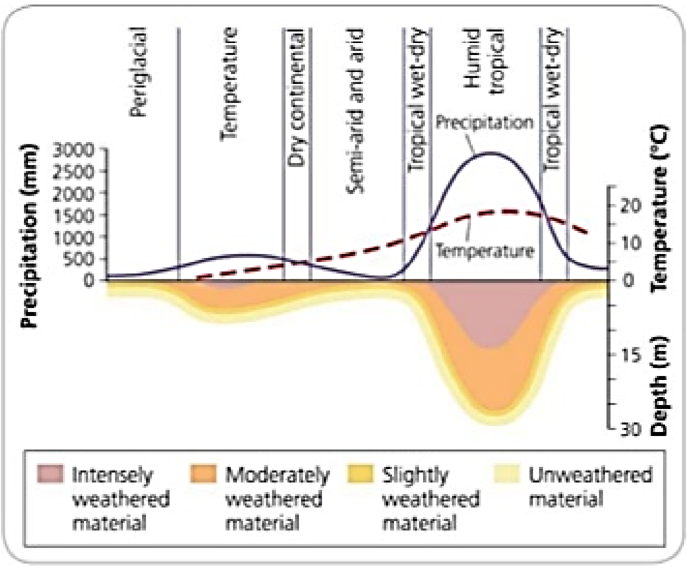
- **Freeze-thaw:** occurs in cold areas where ice forms as water freezes in cracks in rocks.
  - Water that collects in crack freezes and expands 10%
  - Exerts an average pressure of $14kg/cm^2$, crack forced open as this pressure exceeds rock's resistance
  - Ice thaws, parts of the rock breaks free and the water penetrates deeper. Repeats until rock cut through.
- **Exfoliation:** occurs in hot desert with large diurnal energy range (40°C to below freezing).
  - Rocks heat via conduction, only outer layers expand as rock is a poor heat conductor
  - At night outer layers cool and contract more rapidly than inner layers, creating stresses
  - Non-uniform contraction stresses results in outer layers flaking off over time.
- **Salt crystal growth:** physical disintegration due to fretting (saltwater penetrating) rock surfaces.
  - Saline solution evaporates, leaving salt crystals
  - A temperature rises, salt expands – exerting a pressure on the rock, causing disintegration
  - Most effective in areas with temperatures around 27°C, where expansion is 300%, with Sodium Sulphate, Magnesium Sulphate and Calcium Chloride.
  - Rates effected by porosity and permeability.
- **Dilation:** pressure release process.
  - Overlying rocks are removed by erosion (unloading), or if a glacier load is removed
  - Underlying rocks expand as under reduced pressure
  - Fractures form parallel to the surface, producing pseudo-bedding planes. Deeper down, cracks are less prominent. Most broken = close to surface
  - If horizontal pressure is released, vertical faults develop – common on cliff faces.
- **Vegetation root action:** roots can penetrate rocks or prevent rocks from forming/settling in a specific place.

3.5. Chemical Processes

- Creates altered rock substances. Requires water.
- **Hydrolysis:** acid water breaks down rocks with feldspar mineral (such as granite).
  - Acidic water reacts with feldspar in granite, forming kaolin, silicic acid and potassium hydroxyl
  - Acid and hydroxyl are removed, leaving kaolin behind as the product. Hydroxyl is carbonated and removed in solution.
  - **Feldspar + Water Kaolin + Silicic Acid + Potassium Hydroxyl**
- **Hydration:** certain minerals absorb water - allowing them to expand and change, producing mechanical and chemical stresses. Affects shale/mudstones.
  - Clay minerals (such as Anhydrite) expand as they absorb water
  - Anhydrite forms bonds with water to produce hydrates (Gypsum) – causes 0.5% expansion.
  - Extreme cases result in 1600% expansion, which causes cracking and fractures in the rock.
- **Carbonation:** acid rain breaks down limestone/chalk.
  - Carbon dioxide dissolves in rainwater to make a weak carbonic (acid rain)
  - Calcium carbonate in limestone reacts with carbonic acid to form calcium carbonate
  - $CO_2 + H_2O \leftrightharpoons H_2CO_3$
  - Calcium carbonate is soluble and is washed away by percolating water, so limestone is removed.
  - $CaCO_3 + H_2CO_3\ Ca(HCO_3)_2$

3.6. General Factors Affecting Weathering

- Climate

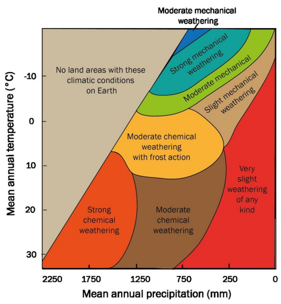


- **Rock Type:** some minerals, cements (in sedimentary rocks) are more resistant to weathering than others.
  - Limestone is susceptible to carbonation ($CaCO_3$).
  - Sandstone contains iron, therefore oxidation prone.
  - Quartz is chemically resistant, cannot be chemically weathered.
- **Rock Structure:** differential resistance along lines of weakness and grains control water movement.
  - Larger grain results in faster weathering, as there is greater void space and high permeability.
  - Natural lines of weakness in rock formations allow water to penetrate – increasing weathering effects.
  - Rocks can be **porous/non-porous** (measure of open space between grains) and **permeable/impermeable** (measure of ease of ability to transmit water). More permeable = more weathering.
- **Vegetation:** increased organic acid production and carbon dioxide increases carbonation. Physical weathering may reduce as temperature are moderated. Roots will increase biological weathering.
- **Relief:** affects temperatures and exposure.
  - Weathered material must be removed to allow the process to continue. If a slope is too steep, water runs

away. If too shallow, no material is removed.
    - Colder temperature occurs higher, so freeze-thaw is dominant at higher altitudes.
- **Human activity:** increased weathering due to increased airborne chemical pollutants and acid rain. Vegetation removal reduces chemical/biological weathering (fewer organic acids).

3.7. Specific Factors Affecting Weathering

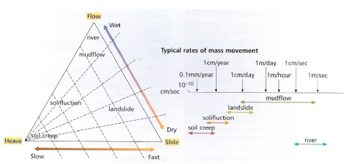
- Temperature
    - **Glacial:** freeze-thaw is dominant, but number and duration of cycles is more important than degree of ice. Likely slow chemical weathering, but common hydration. **Alaska 0.04mm/yr.**
    - **Temperate:** chemical and biological processes are dominant due to abundance of moisture and vegetation. High organic contents, carbonates deposited at dry areas. **Askrigg 0.5-1.6mm/yr.**
    - **Arid/Semi-Arid:** evaporation exceeds precipitation, so mechanical processes are dominant. In semi-arid areas thick organic layers lead to leaching and $CaCO_3$ accumulation. **Egypt 0.0001-2.0mm/yr.**
    - **Humid tropical:** high seasonal rainfall and high temperatures results in significant chemical weathering. **Florida 0.005mm/yr.**
    - **Van't Hoff's Law:** rate of chemical weathering increases 2-3x for each 10°C temperature rise up to 60°C.
- Rainfall



3.8. Slope Processes

Slope Processes

- **Slope:** any inclined surface (hill slope) or a slope angle.
- **Categorising movements**



- **Slope failure causes**
    - **Increased shear stress:** removal of lateral support (undercutting/slope steepening), removal of underlying support, slope loading, lateral pressure, transient stresses.
    - **Decreased shear strength:** weathering effects, changes in pore-water pressure, changes of structure, organic effects.
- **Opposition to movement:** friction, cohesive forces, pivoting, vegetation.

3.9. Mass Movement

- **Heaves (soil creep):** slow movement of material where soil particles are heaved to the surface by wetting, heating and freezing of water. Occurs mainly in winter.
    - Particles move perpendicular to the surface (path of least resistance), and then fall under gravity once particle has dried, cooled or water thawed. Net movement is down the slope.
    - 1-3mm per year in UK. 10mm per year in rainforest.
    - **Evidence:** tension cracks in roads, tilted poles, terracettes, soil piled behind field stone walls.
    - **Talus Creep:** slow movement of fragments along a scree slope.

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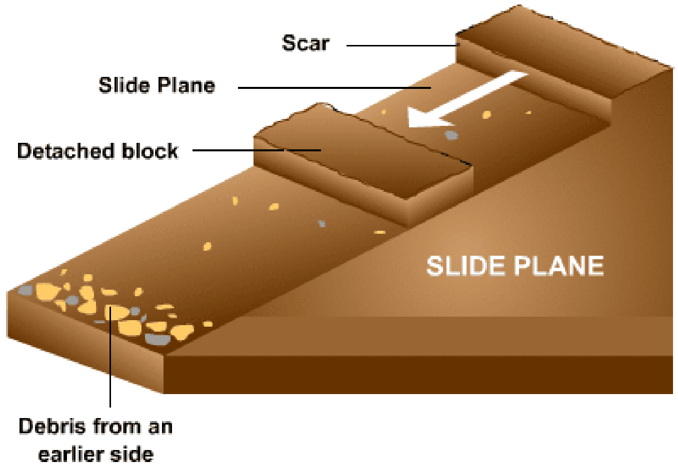
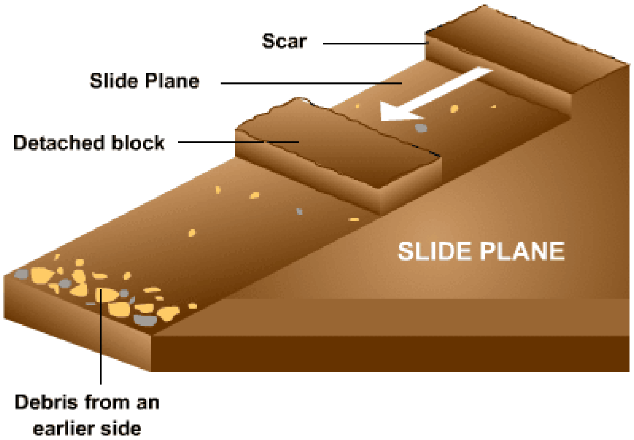


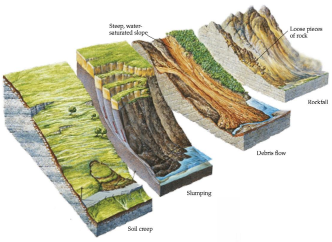
- **Slumps:** weaker rocks such as clays 'slump' with a rotational movement along a curved slip plane.
    - Clay saturates and flows along slip plane. Commonly occurs if the base has been undercut.
    - Produces separate, jerky events.
- **Flows:** more continuous, smoother form of slump. Occurs in deeply weathered clay, and if particle size is the same or smaller than a grain of sand.
    - Mudflows are faster than earthflows (which are deeper and thicker).
    - Higher water content allows flows to occur on shallower slopes.
    - Can occur on saturated toe of a landslide, or as a separate event.
- **Falls:** occurs on steep slopes (>40°), with bare rock faces and exposed joints. Initial cause of rocks falling is erosion or weathering.
    - Rocks detach and fall freely under gravity. If fall is short, a straight scree is produced; otherwise a

concave scree is produced.
- Significantly contribute to the retreat of steep rock faces and providing debris for scree/talus slopes.

- **Slides:** when an entire mass of material moves along a slip plane. Can be rock/landslides, or a rotational slide. Material holds its shape until hitting the slope bottom.



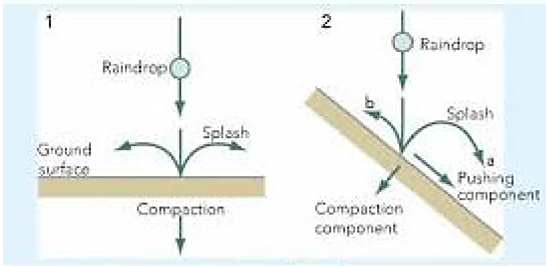
- **Conditions:** weak rocks, steep slope, active undercutting, intensely cold conditions or sudden change in water content.
- **Landslides:** when material moves downslope as a result of shear failure. Downward force > resistance. An increase in water content reduces strength (particles pushed apart) and more mass is added.
- **Rockslides:** large rock mass slides down slip plane.



- **Slip plane:** junction between two layers along a bedding line, or the joint between two rock types. Point beneath the surface where shear stress > shear strength.

3.10. Water and Sediment Movement

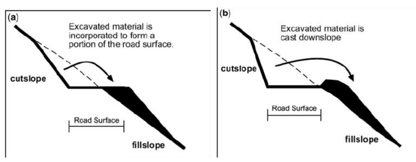
- **Sheetwash:** occurs when the soil's infiltration capacity is exceeded by precipitation rate. Hortonian flow.
- **Surface wash:** unchanneled (sheet like) flow of water over soil's surface. Some high/low velocity sections may develop. Transports material dislodged by rain splash, by eroding a uniform layer of soil. Produces rills.
  - **Rills:** shallow channels that carry water and sediment for a short period of time. Common in agricultural lands after harvesting (bare land) and after compaction of the soil by heavy machinery.
- **Rain splash:** raindrops have an erosive effect. This effect is most prominent on slopes with inclines between 33° and 45° at the start of a rainfall even, when the soil is loose.
  - **5° slope:** 60% of movement is downwards.
  - **25° slope:** 95% of movement is downwards.



3.11. The Human Impact

Impact of Human Activities on Stability

- **Excavations:** cutting into a slope and leaving loose excavated creates a slope too steep to have stability, and is therefore prone to failure. Excavation at the toe of a slope removes the supporting section of the slope.
- **Waste heaps:** highly porous mounds of waste material from quarrying and mining leaves new, unstable steep slopes. Slips occur with soil saturation after rainfall.
- **Loading**
  - **Buildings:** add mass to slope, increase slip likelihood.
  - **Water:** drainage routes disturbed by building foundations - excess water in soil increases mass and will lead to slips (also has lubricating properties). If saturated soils are subjected to an earthquake, liquefaction can occur (pressure between particles makes soil act as a liquid).
- **Vegetation removal:** deforestation leaves land bare (increased surface runoff, more erosion). If roots die/are removed, material is no longer bound together, and stability is compromised.
- **Traffic vibrations:** may trigger mass movements.
- **Footpath trampling:** intensified localised erosion.
- **Construction on slopes:** uses cut-and-fill technique (as described in excavation).

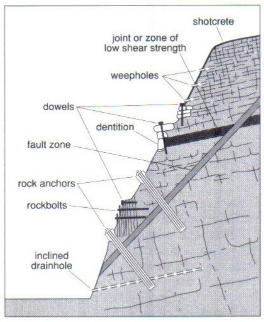


- **EROSION PROCESSES:** can be increased by the removal of vegetation, ploughing up and down slopes (creating water channels and rills) and destruction of the soil structure (through overgrazing/growing, allowing organic deterioration).

3.12. Strategies to Modify Slopes

- **Pinning:** rock bolts, dowel bars and ground anchors installed to hold loose rock into stable rock below. Ground anchors penetrate deeper, through different rock strengths.
- **Netting:** metal mesh nets attached to slope surface, prevents loose rocks falling onto road/rails below.

- **Grading:** process of reducing the slope angle (by excavation) to reduce the risk of movement. Material must be transported away, so costs can be high.
- **Afforestation:** adding vegetation increases the interception, so less surface runoff and erosion occur. Reduces mudflows. More roots hold the soil bound. Reduced infiltration means the slope has less mass.
- **Gabions:** metal mesh boxes used to stabilise the toe of a landslip.
- **Drainage:** excess water adds mass to slope and lubricates it. Trenches dug (filled with permeable aggregate) to quickly remove water from a slope.
- **Grouting:** permeable rocks injected with cement to increase strength and reduce pore water capacity.
- **Shotcrete:** loose surfaces sprayed with concrete to prevent loose rocks from falling.



CAIE AS LEVEL
Geography (9696)

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