Topic: Global carbon stores and changes in magnitude
3.1.1.3 Water and carbon cycles

What you need to know
Global distribution and size of the major carbon stores
Factors driving change in the magnitude of carbon stores over time and space
Changes in the carbon cycle over time, including natural and human factors

Introduction:
Carbon is an essential element to all living things on earth – plants and animals, surface and marine. It also plays a major role in regulating global climate, particularly temperature and in determining the acidity of rain, rivers and oceans.

Carbon cycles, like water cycles, should be thought of as a system. There are inputs, stores, fluxes/flows and outputs that transfer carbon from one environment to another and cause stores to be depleted, or accumulate.

Carbon stores (reservoirs): location

The main stores of carbon are located in, and transferred between the:

- **atmosphere**: mainly as carbon dioxide CO_2 but also shorter-lived methane CH_4
- **biosphere**: all living organisms are composed of carbon occupying various environments
- **cryosphere**: the frozen ground of tundra and arctic regions containing plant material
- **pedosphere**: soil contains much organic carbon and the remains of dead plants & animals
- **lithosphere**: many of the rocks of the earth's crust contain carbon, such as chalk/limestone (calcium carbonate)
- **hydrosphere**: the oceans contain much dissolved CO_2 as well as marine organisms and their remains which form sediments on the sea bed

Carbon stores: magnitude

Location	Total carbon %	Carbon forms
Lithosphere	99.985	Sedimentary rocks Organic carbon Fossil fuels Marine sediments
Hydrosphere	0.0076	Carbonate ions Bicarbonate ions Dissolved CO_2
Pedosphere	0.0031	Soil organisms Plant remains
Cryosphere	0.0018	Frozen mosses
Atmosphere	0.0015	Gaseous carbon
Biosphere	0.0012	Living plants & animals

Factors driving change in the magnitude of carbon stores over time and space

There are two main categories of carbon cycle: the fast carbon cycle (operating on a daily basis as living things breath and digest food and influencing changes to carbon stores over decades and centuries), and the slow carbon cycle which operates over millions of years as a result of lithification (converting organic sediments to solid rock) and tectonic plate movements.

A) **The fast carbon cycle:** some of the key processes are…

- **Photosynthesis**: the absorption of CO_2 from the atmosphere (terrestrial plants) and from oceans (marine plants) to produce organic carbon structures.

- **Respiration**: the release of CO2 into the atmosphere, soil and oceans by animals as they exhale.

- **Digestion**: the release of carbon compounds by terrestrial and marine animals after feeding on carbon-rich material.

- **Decomposition**: the breakdown of animals and plant structures by bacteria and the release of carbon compounds into the atmosphere, soil and to the ocean floor. Where oxygen is present it releases CO_2, where it is absent CH_4 is released.

- **Combustion**: natural fires release carbon compounds from vegetation to the atmosphere.

All these involve living (organic) processes in some way. Additionally, there is an on-going transfer of CO_2 that is non-organic:

- **Ocean-atmosphere exchange**: there is a mutual transfer of CO_2 between the lower atmosphere and ocean surfaces. The flow can go in either direction depending on the balance of CO_2 between the two stores, temperature and conditions of air and water, but the prevailing direction is from the atmosphere to the ocean.

B) **The slow carbon cycle**

This involves five key stages in the movement of carbon around the cycle that takes place over many tens and hundreds of millions of years:

The transfer of carbon into the oceans from the atmosphere and land surface: direct CO_2 absorption as part of the atmosphere-ocean exchange is supplemented by the erosion of carbon-rich terrestrial surfaces as naturally-acidic rainfall dissolves surface rocks and transfers soluble bicarbonate compounds, via rivers, to the sea.

The deposition of carbon compounds on the ocean floor: marine plants (including phytoplankton) absorb CO_2 and marine creatures take in carbon to construct skeletons and shells. Phytoplankton are consumed by zooplankton and their carbon-rich excrement falls to the ocean floor. The skeletal and shell remains of marine creatures also fall the sea bed.

The conversion of ocean sediments into carbon-rich rock: on continental shelves carbon-rich accumulations of deposits may be converted into carbon-rich rocks (such as chalk and limestone) or become contained as concentrations within sandstones and shales to form organic deposits, some of which become fossil-fuel reserves in time. This process of sedimentary rock formation is called lithification.

The transfer of carbon rocks to tectonic margins: as sedimentary rocks are created by heat and pressure over millions of years, they are also moved in the direction their crustal plate is moving. If they eventually become a collision margin, they may be uplifted to become surface mountain ranges (as in the Himalayas). The carbon-rich strata may then be exposed to weathering and erosion to return to the ocean as eroded carbonate rocks.

The return of carbon compounds to the atmosphere in volcanic eruptions: at subduction zones, carbon-rich rocks may be ejected at the surface from volcanic eruptions, usually in the form of gaseous compounds into the atmosphere. Here, CO_2 contributes to the formation of carbonic acid in clouds, which then begins the process of solution of surface rocks and a starting of the terrestrial component again, or being absorbed by ocean surfaces for the marine component.

Changes to the carbon cycle over time

Both natural and human factors can cause a change in the inputs of carbon into the atmosphere, oceans, biosphere and pedosphere. They can also affect the rates at which carbon is removed from one reservoir by transfers to other stores, and this operates over a range of timescales. The table below considers the factors affecting the amount of carbon in the atmospheric store.

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Atmospheric carbon change	Natural factors	Human factors
Increasing atmospheric CO_2 (greater input of carbon)	• Periods of increased volcanicity	• Burning fossil fuels • Causing more wildfires • Increasing meat-based diet (more cattle) • Climate change resulting in melting tundra releasing CO_2 & CH_4
Increasing atmospheric CO2 (reduced removal of carbon)	• Glacial periods (less vegetation) • Interglacial period (warmer oceans absorb less CO_2) • Winter in N. hemisphere (biomass shuts down)	• Clearing natural vegetation for urban / agricultural / industrial uses • Climate change resulting in warmer oceans
Reducing atmospheric CO2 (reduced input of carbon)	• Long-term reduction of volcanic activity	• Carbon-capture schemes (artificial carbon sequestration)
Reducing atmospheric CO2 (increased removal of carbon)	• Glacial periods (cooler oceans absorb more CO2) • Interglacial period (more vegetation) • Summers in N. hemisphere (increased biomass activity)	• Reforestation & Afforestation projects