GEOFILE 761

The role of carbon in earth's life systems

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Synopsis

The carbon cycle is a core geographical topic. Carbon is an important element, central in supporting earth's life systems. It is found in all life forms and in sedimentary rocks (limestones and fossil fuels).

Geographers use a systems approach when studying the carbon cycle. This has inputs, outputs, flows and feedback. Carbon stores and fluxes (flows) involve natural processes that have regulated the carbon cycle, especially atmospheric CO_2 levels, for millions of years. The carbon cycle is split into slow and fast cycles.

Key terms

Systems and feedback, carbon stores and fluxes (flows), carbon budget and balance, sequestration, enhanced greenhouse effect, mitigation

Learning objectives

By the end of this **Geofile** you will have learnt about:

- The basics of the structure and functioning of the carbon system.
- How the carbon cycle operates at different scales: local plant scale to global scale.
- The role carbon plays in supporting life, by affecting climate and ecosystems.
- Negative and positive feedback in the carbon cycle.
- How humans have influenced the carbon cycle and how carbon flows and stores can be re-adjusted to reduce the impacts of climate change.

Links

Exam Board	Link to specification
AQA A Level	Component 1: Physical geography, 3.1.1 Water and carbon cycles, see pages 11–12. Component 2: Human geography, 3.2.5 Resource security, see pages 27–29. Click here
AQA AS Level	Component 1: Physical geography, 3.1.1 Water and carbon cycles, see pages 10–11. Click here
Edexcel A Level	Area of study 3: Physical systems and sustainability, Topic 6 The carbon cycle and energy security see pages 46–50. Click here
Eduqas A Level	Component 2: Global systems and global governance, Section A: Global systems, Theme 2.1 Water and carbon cycles, see pages 20–21. Component 3: Contemporary themes in geography, Section B Contemporary themes in geography, Theme 3.5 Weather and climate, see pages 35–36. Click here
OCR AS	Component 2: Geographical debates, Topic 2.1 Climate change, see pages 19–21, Topic 2.3 Exploring oceans, see pages 25–27. Click here
OCR A Level	Component 1: Physical systems, Topic 1.2 Earth's life-support systems, see pages 15–17. Component 3: Geographical debates, Topic 3.1 Climate change, see pages 31–33, Topic 3.3 Exploring oceans, see pages 37–39. Click here
WJEC	A2 Unit 3: Global systems and global governance, Section A Global systems, Theme 3.1 Water and carbon cycles, see pages 26–27. A2 Unit 4: Contemporary themes in geography, Section B Contemporary themes in geography, Theme 4.5 Weather and climate, see page 40. Click here
IB	Part 2: Geographic perspectives – global change, Unit 2: Global climate – vulnerability and resilience, Topic 2: Consequences of global climate change, see pages 42–43. Click here

The role of carbon in earth's life systems

What is the carbon cycle?

Carbon includes:

- The gases carbon dioxide (CO_2) and methane (CH_4) in the atmosphere, oceans and sedimentary rocks.
- Calcium carbonate ($CaCO_3$), in calcareous rocks (limestone and chalk), oceans and the shells of sea creatures, plus fossil fuels (hydrocarbons).
- Bio-molecules found in living creatures (proteins, carbohydrates, fats and DNA).

The carbon cycle has three main components:

- Long and short-term stores (sinks).
- Flows (fluxes).
- Processes: photosynthesis, respiration, decomposition, combustion, burial, compaction, sequestration, weathering and erosion.

Figure 1 illustrates the International Panel on Climate Change (IPCC) research on the carbon cycle, and human influences since 1750. Carbon stores are so large they are measured in petagrams of carbon (pgC, 10^{15}gC), and annual flows in gC /year^{-1}. One petagram equals 1 gigatonne (gtC), 1 billion tonnes, or a trillion kilograms. About 5 pgC/year is sequestered by the land and the ocean, but the rest remains in the atmosphere (4 pgC/year). Increased CO_2 is the main cause of the enhanced greenhouse effect and climate change.

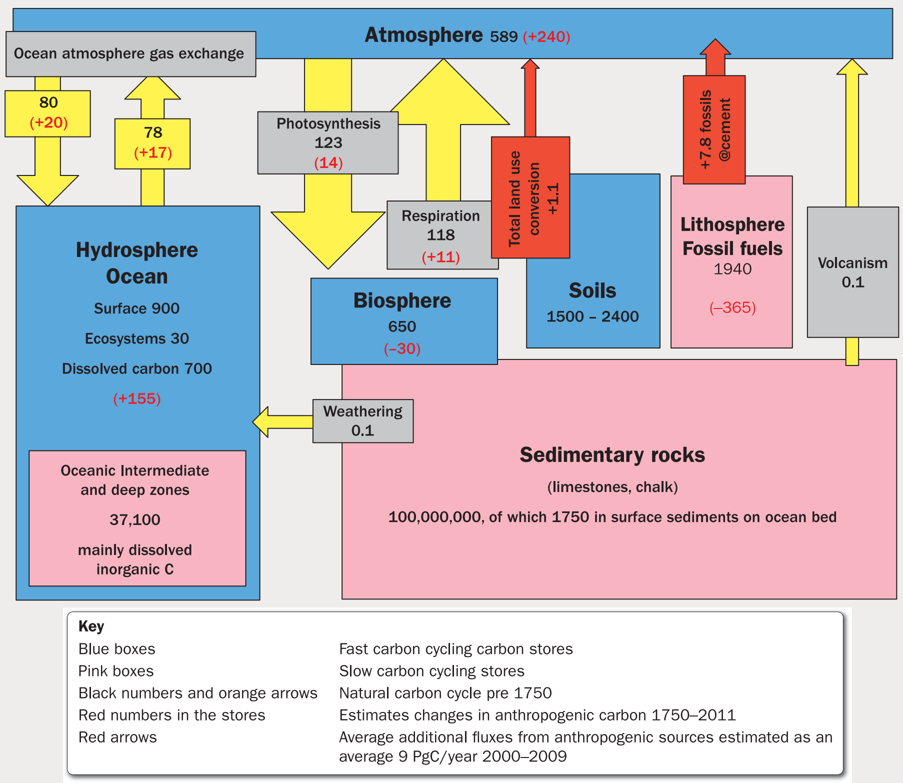

Figure 1 International Panel on Climate Change (IPCC) estimates of the natural carbon cycle and human-induced changes since 1750

Variations in stores and flows

The carbon cycle maintains a balance, keeping temperature, and therefore climate, relatively stable. Most carbon is naturally stored (sequestered) in the lithosphere's rocks and soils. Figure 1 shows the rest is stored in oceans (hydrosphere), then atmosphere and biosphere.

1. Slow cycling

The carbon cycle starts in the earth's mantle, escaping to the faster atmospheric cycle by volcanic activity. It takes millions of years for carbon to circulate as calcareous sediments form on ocean floors and are buried. Carbon is released into oceans by limestones metamorphosed in subduction zones.

2. Fast cycling

- Carbon in the atmosphere, biosphere and upper ocean takes from seconds to thousands of years to flow between stores. These stores vary across earth because of differences in the amounts of land, sea, fossil fuels and plant types.
- Plants capture atmospheric carbon by photosynthesis, forming biomass. As plants respond to changes in solar energy, flows vary seasonally and daily. In extremely cold areas like the Arctic, stores are frozen for months. In tropical areas, rainforests have more

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mobile carbon stores and faster plant growth (net primary production, NPP).

- Carbon moves along the food chain, helped by consumers and decomposers. Decayed plant litter forms carbon-rich humus. Decomposition is fastest in hot, wet tropical climates and slowest in cold, dry conditions and peatbogs (acidic areas with low oxygen availability).
- Eventually carbon returns to the slow rock cycle, as calcareous sediments form on the ocean floors and are buried.

Feedback

The relatively steady concentration of carbon in the atmosphere, land, plants, and ocean is disrupted by:

- Natural variation: short-term decreases of storage resulting from wildfires, volcanic activity, solar variations, disease and predators. Increased storage can result from sudden upwelling of nutrient-bearing cold currents, stimulating plankton growth.
- Human impact: rapid urbanisation, agriculture and resource use have decreased carbon storage in the slow rock cycle and increased flows to the fast atmospheric cycle. People have increased atmospheric CO_2 by hydrocarbon combustion, cement use and by disrupting ecosystems causing an 'enhanced greenhouse effect' (Figure 2).

- Atmospheric carbon exists in two main forms: carbon dioxide (CO_2) and methane (CH_4). Both are greenhouse gases. Together with halocarbons (carbon combined with one or more halogens), they absorb infrared energy (heat) emitted by the earth, and then re-emit it.
- Some of this re-emitted energy returns to earth, where it heats the surface. Without this natural greenhouse effect, the earth would be frozen. However, too many greenhouse gases could cause a 'runaway' effect of irreversible warming.
- Before the beginning of the Industrial Era, the fast carbon cycle was close to a 'steady state'. Ice core data shows little change in atmospheric CO_2 levels over millennia, despite human activity. Pre-industrial revolution, CO_2 was 280ppm. By 1958 it was 317.7 ppm, in 1960 it was 320ppm and by 2016, 400 ppm.
- Scientists such as Keeling have recorded how the rise in CO_2 is increasing average global temperatures, the primary cause of climate change.
- Warming is triggering many worrying positive feedback loops (Figure 3), such as thawing of frozen ground (permafrost) which will release large amounts of CO_2 and CH_4 from swamps and bogs.

Figure 2 Factfile on the greenhouse effect

Disruptions to the carbon cycle

Feedback can cause a 'ripple' effect:

1. Negative feedback: Small-scale disruptions are balanced or cancelled out. For example, volcanic eruptions emit CO_2, raising

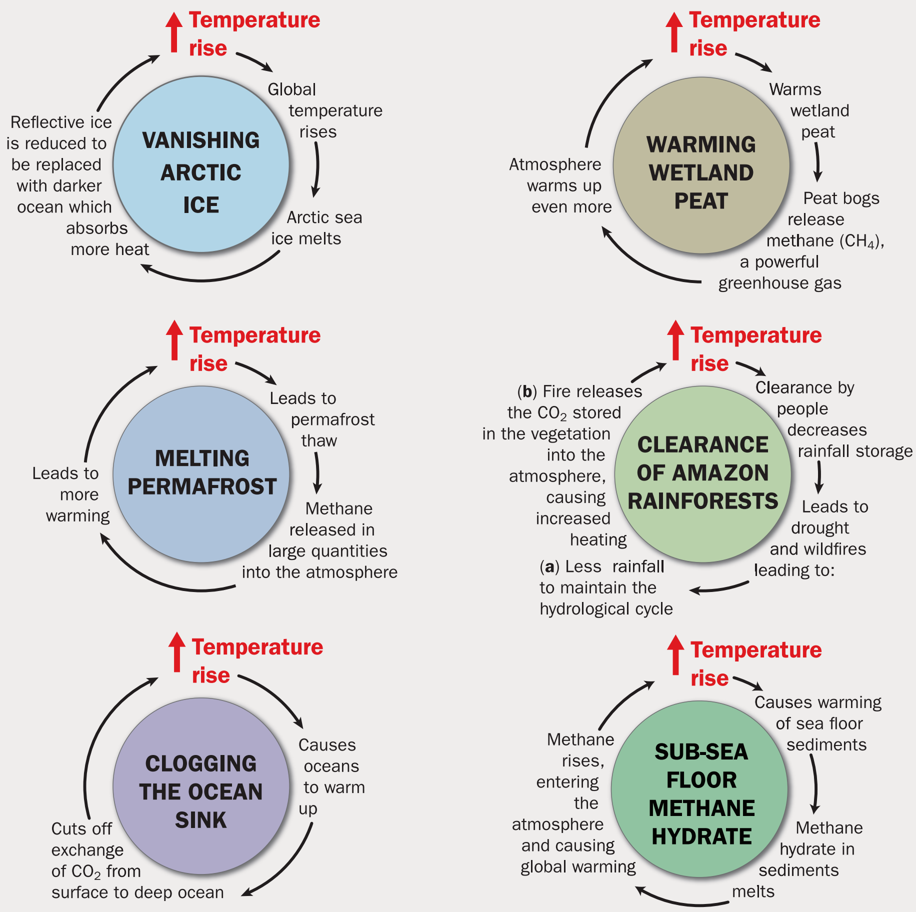

Figure 3 Positive feedback in the carbon cycle

temperatures by the natural greenhouse effect. More air rises, condenses and rainfall increases chemical weathering and dissolving of carbon. More ions are washed into oceans, increasing limestone formation. The excess carbon is stored for millennia, and original stability regained.

2. Positive feedback: Large-scale disruptions to the system may lead to a system 'tipping point' ,with a new balance. Figure 3 shows a range of positive, 'amplifying' feedback loops.

A summary of the effects of changing carbon budgets is shown in Figure 4.

Terrestrial	Oceans	Atmosphere
• Globally important 'bread baskets' of the world are threatened. • Fears of 'food price spikes' and famine. • Melting of permafrost damages Arctic ecosystems: loss of habitats • Polewards shift of species: boreal forests and mangroves. • Possible rise in sea level of 6m by 2200, threatening 375 million people. 10 megacities such as Tokyo and Shanghai are vulnerable.	• Reduced plankton growth reduces CO_2 storage. • Warming melts sea ice. Thermal expansion causes rising sea level. Rising sea levels kill off coral. • Decreased salinity in the Atlantic. Sea ice melt is slowing down deep ocean currents which affect climate (see NAD case study). • Increased acidification. Coral reef weakened and corroded. Coral provides food and livelihood for 500m globally.	• c.20% of the extra CO_2 may remain in atmosphere for many 1000s of years. The fear is irreversible climate change. • Climate change associated with increased extreme weather. 2016 set records for this. • Disruption to the hydrological cycle by deforestation, urbanisation and global warming will lead to water shortages and food supply issues.

Figure 4 Impacts of changing carbon budgets

Case studies

Carbon's significance for earth life systems can be studied at different scales.

Small-scale

1. Tree species: all plants absorb CO_2, but trees process and store more because of their size, extensive roots and woody biomass.

- Trees with large leaves and wide crowns maximize photosynthesis.
- Life-cycle stage plays a part: young trees growing fast store much carbon. Long-lived trees (beech, oak) take hundreds of years to store maximum carbon.
- Some species (willow, poplar, pine) are very efficient carbon stores. Just 1% of Amazonia's 16,000 tree species store half of its total plant carbon. Brazil nut trees may exceed 48m in height and can remove atmospheric carbon for decades or even centuries.

2. Seres (ecosystem succession): new land and water areas are colonised initially by low carbon-storing pioneer plants. Over time, larger plants with higher carbon capacities succeed these. The stages, or seres, create a climax plant community (often trees) with high carbon storage. Humans create artificial stages to maximise biomass (and hence carbon) by planting crops and coppicing trees (Figure 5).

3. Farm-scale carbon budgets: intensive farming reduces carbon stores and increases flows from the biosphere to the atmosphere and hydrosphere. Better land management, including 'carbon farming', aims for carbon neutrality or even a negative budget by:

- lowering CO_2 emissions by greater efficiency and reduced fossil fuel combustion;
- increased CO_2 flows into plants and soil organic material (SOM). Soils are the second biggest carbon store after oceans, but globally, 40% of soils are degraded.

Figure 5 Coppiced woodland. Coppicing is a traditional way of cultivating certain tree species such as hazel
Source: Greenwood Education

Figure 6 illustrates the Farm Carbon Calculator for Shimpling Park, a 645-ha arable and sheep farm in Suffolk. The diagram shows a positive carbon budget, but if improvements in SOM are included (it became organic in 1999), there is actually a carbon balance.

Fieldwork

The Field Studies Council and Forestry Commission provide guidelines to study small scale carbon budgets, stores, fluxes, and links to the water cycle, in peatlands, lakes, rivers and farms (Figure 6).

Continental/global scale

31% of Earth's land is forest, supporting 80% of all terrestrial biodiversity and over 1.6 billion people, mostly society's poorest. Forests are a genetic pool, stabilise soil and regulate climate by naturally sequestering carbon. Deforestation has removed 30% of all former cover. Regionally:

- Temperate forests in Western Europe and North America, heavily deforested by 19th century industrialisation are now more protected and are being replanted (afforestation).
- Tropical and boreal forests in developing and remoter regions show the highest deforestation rates since the mid-20th century. Annually, 13 million ha of tropical trees (36 football fields per minute) are destroyed (WWF). Indonesia has overtaken Africa and South America in rates of deforestation.

Oceanic circulation

Ocean currents are key to carbon circulation, forming the global 'physical pump' of surface and deep water. This drives the 'biological pump' (supporting food chains), and the 'carbonate pump', (limestone sedimentation). However, oceans may be shifting to becoming carbon sources. Ecosystems, especially coral, are threatened by ocean warming and acidification.

Some major currents are showing signs of change. The North Atlantic Drift (NAD) is part of the Gulf Stream, keeping Western Europe's winter climate warmer than places at similar latitudes. Its flow has slowed by 20%, disrupted by rapid Arctic warming and melting ice-cap and permafrost.

Conclusion

The carbon cycle has a major part to play in the earth's functioning and wellbeing, controlling ecosystems, ocean circulation, atmospheric CO_2 concentrations and climate.

Natural processes in the carbon cycle depend on photosynthesis, whilst human processes are dominated by fossil fuel use and land conversion, especially deforestation. People have not created more carbon, but have increased flows into atmospheric and oceanic stores, as well as reducing fossil fuel stores of carbon. Many societies are used to high levels of consumerism and depend on fossil fuels.

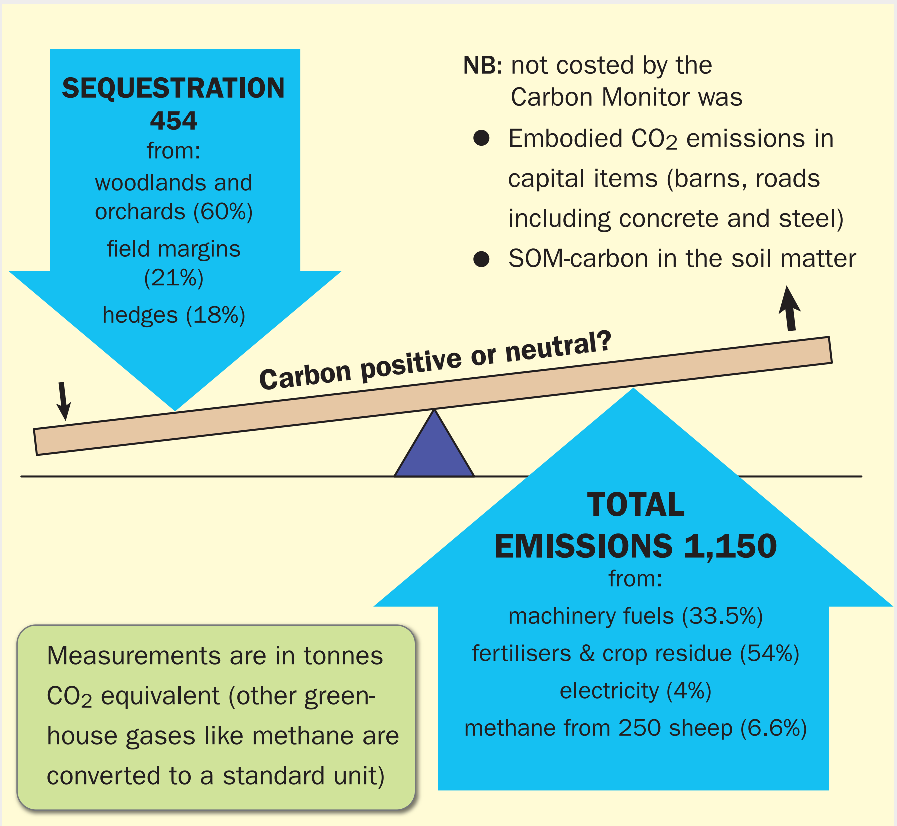

Figure 6 Shimpling Park farm's carbon budget

Focus questions

Short answer questions:

1 Define the term 'carbon sequestration'.

2 Explain the concept of feedback in the carbon cycle.

Essay questions:

3 To what extent do you agree that human activity is the cause of positive feedback in the atmospheric carbon cycle?

4 Assess the role of human change in the functioning of the fast and slow carbon cycles.

5 With reference to a specific tropical rainforest, assess the extent to which changes in the carbon and water cycles are related to global governance.

Learning checkpoint

Whilst reading this **Geofile** summarise the key facts and case studies as follows:

- Use Figure 1 to help summarise the carbon cycle as a natural system and then how humans have affected it. Use the headings: **short-term stores** and **long-term stores, flows**.
- Colour code a copy of Figure 4 into social, economic, environmental, demographic and political impacts.
- Make a copy of Figure 2 on carbon cycle feedback, adding case study facts
- Look online for a GIS map to show changes in a specific tropical forest area.

