Oceans as a store of carbon dioxide

Carbon dioxide in the oceans and the carbon cycle

Earlier in this chapter, we saw that the THC (thermohaline circulation) is a source of adding carbon dioxide into the atmosphere. The relationship between the world's oceans and the atmosphere is important and complex, and to understand this relationship, it is useful to see it in the broader context of the carbon cycle.

The **movement of carbon** across the planet is vital, as all life is composed of carbon compounds of one kind or another. Carbon dioxide is a very minor part of the atmosphere, but this small reservoir is being continually recycled through living things on the earth's surface.

Table 1.2
The Earth's stores of carbon

	Location	Billions of tonnes
ACTIVE	Carbon dioxide in the atmosphere	700
	Held in organisms and dead organic matter on land	3,000
	Dissolved in oceans	37,000
	Held in organisms and dead organic matter in oceans	2,000
	Held in carbonate rocks	20,000,000
	Held in fossil fuel reserves	12,500

Source: Chapman and Codrington (1985), p.236

As table 1.2 shows, a large amount of carbon dioxide is dissolved in the water of the oceans. The amount of carbon stored in fossil fuels is considered to be relatively small compared with the amounts contained in the atmosphere and the oceans. Carbon that is classified as 'active' is available for exchange between the atmosphere, the oceans, the earth and living things through the **carbon cycle** (figure 1.44).

The carbon cycle consists of a network of stores and flows. Major **stores** within the carbon cycle include carbonate rocks, fossil fuel reserves, the oceans, atmosphere, and living organisms and dead organic matter.

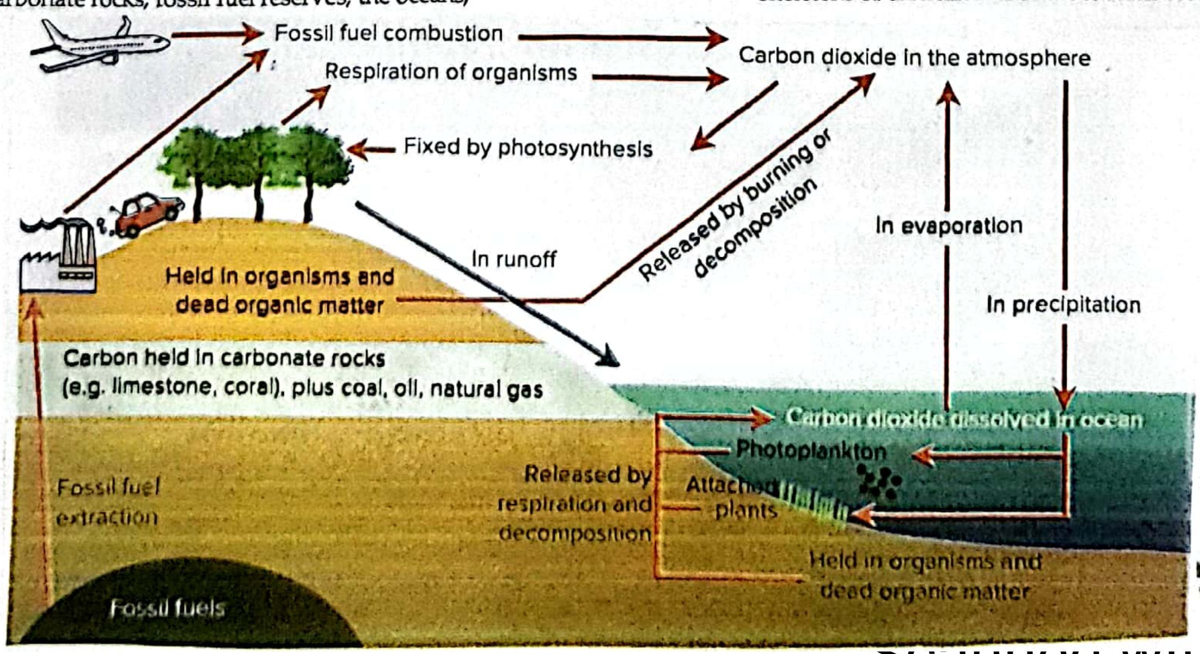
Movement (or **flows**) within the carbon cycle begin with the primary production of carbon by living organisms through photosynthesis. Carbon dioxide is turned into organic carbon compounds, which are ultimately converted back into carbon dioxide by respiration and by the activities of soil bacteria. In addition to this source of carbon, fossil fuel deposits yield carbon through mining and combustion at a rate about equal to one-fifth of the net fixation by land plants.

Since widespread industrialisation began about 200 years ago, the increasingly rapid conversion of carbon from a storage to an active form has produced a **significant increase** in the amount of carbon dioxide in the atmosphere.

The ocean serves as a **carbon sink** because overall it absorbs more carbon from the atmosphere than flows back from the ocean to the atmosphere. In other words, there is a net movement of carbon from the atmosphere to the oceans. This occurs as atmospheric carbon dioxide dissolves in the surface waters of the ocean, especially when the ocean surface is churned up by the wind. Carbon dioxide also flows from the atmosphere to enter the oceans through precipitation.

When carbon enters the ocean waters, some of it is retained as dissolved gas, but most of it is used by marine organisms such as **photoplankton** in the process of photosynthesis. Photoplankton are known as **autotrophs**, which means they can convert light energy or chemical energy into organic matter. Photoplankton are consumed by marine organisms (**heterotrophs**), which are in turn consumed by larger marine organisms in a food chain. At each higher level in the food chain, the concentration of carbon increases.

Photoplankton build skeletal structures composed of calcium carbonate. When photoplankton die, the mineral matter of their skeletons settles down on the ocean floor to build up layers of calcium carbonate as sedimentary strata. Photoplankton also provide food for coral polyps (one example of a marine heterotroph), which in turn secrete skeletons of calcium carbonate to form **coral reefs**.



1.44 The carbon cycle

Living organisms that absorb carbon are an important mechanism for moving carbon around within the oceans. Organisms move carbon from the ocean surface to deeper water, and when the organisms die, the carbon moves again to the ocean floor. The downward movement of carbon in marine organisms is known as a **biological pump**. When the dead organisms decay, carbon dioxide is released into the deep ocean waters.

As shown in table 1.2, the oceans hold over 50 times more carbon than the atmosphere. Oceans can hold much more carbon dioxide than the atmosphere because most of the carbon dioxide that transfers into the oceans reacts with the water to form carbonic acid, bicarbonate and carbonate ions. This process reduces the **gas pressure** of carbon dioxide in the water, thus permitting more and more absorption from the atmosphere.

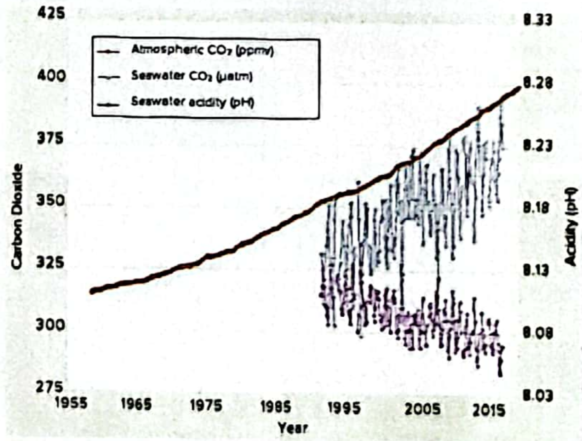
Mixing of water in the oceans occurs at a much slower rate than the mixing of gases in the atmosphere. Consequently, there are large differences in the **concentration** of carbon dioxide within the oceans, both horizontally and vertically. In general, tropical waters **release** more carbon dioxide to the atmosphere than they absorb, whereas oceans near the poles **absorb** more carbon dioxide than they release. Furthermore, the concentration of carbon dioxide is about 10% higher in the depths of the oceans than at the surface.

Human activity is affecting the carbon cycle to a growing degree. Burning fossil fuels releases vast quantities of carbon dioxide into the atmosphere at a rate that is far beyond the rate of any natural processes, bringing carbon into the 'active' part of the carbon cycle that would normally be stored in rocks and soil. About half the carbon that is released by fossil fuel burning remains in the atmosphere, while oceans absorb most of the other half. In addition, a much smaller volume of the carbon produced during fossil fuel burning is absorbed by plants, whose growth is stimulated by the additional carbon. By this process, plants become a sink for carbon dioxide that becomes available for release into the atmosphere when the plant dies and decays, or is burnt.

Despite the ocean's role in absorbing the additional carbon dioxide released by burning fossil fuels and deforestation, the concentration of carbon dioxide in the atmosphere continues to rise. Carbon dioxide is a **greenhouse gas**, which means it prevents heat escaping from the atmosphere into space. Therefore, an increasing amount of carbon dioxide in the atmosphere means more heat is trapped, which results in rising temperatures. It is generally accepted that this increase is a major contributor to **global warming** of the earth.

The carbon that is absorbed from the atmosphere into the oceans **offsets** human-generated global warming because carbon dioxide in water no longer traps heat. The oceans therefore **mask** some of the impact of global warming. Carbon dioxide that is absorbed by the oceans no longer affects the planet's heat balance, so understanding the exchange of carbon dioxide between the atmosphere and the oceans is an important part of understanding our climate system and the potential impact of future carbon dioxide emissions.

However, there is a downside to the ocean's absorption of additional human-generated carbon dioxide. As shown in figure 1.45, as the proportion of carbon dioxide in the ocean increases, chemical reactions cause the ocean's acidity to increase. Known as OA, or **ocean acidification**, the pH (which measures acidity) of the world's surface ocean waters has fallen by 0.1 over the past 200 years. The pH scale is logarithmic, and so a fall of 0.1 represents a 30% increase in surface water acidity. Measurements show that the world's oceans have not been so acidic for more than 20 million years.

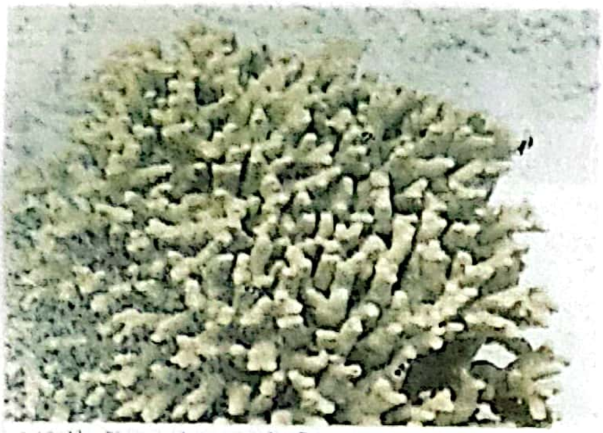


1.45 The relationship between rising levels of carbon dioxide (CO_2) in the atmosphere at Mauna Loa (Hawaii, USA) with rising levels of CO_2 and acidity in the nearby ocean. As CO_2 accumulates in the ocean, the pH of the ocean decreases, indicating that the ocean water is becoming more acidic. Source: modified after Feely (2008)

Although increased levels of carbon dioxide in the oceans benefits some species, such as algae and sea grasses, increasing acidity has a **devastating impact** on species that have skeletons of calcium carbonate, such as oysters, clams, corals and some plankton, because calcium carbonate dissolves in acid.

Impact of ocean acidification on coral reefs

Because of their **slow rates of growth**, coral reefs are vulnerable to damage and destruction. It is estimated that 58% of the world's coral reefs are potentially threatened by human activity, and according to Seaweb (an online organisation that advocates better conservation of ocean environments), coral reefs are threatened in 93 of the 109 countries where they are found. The world has already lost 27% of its coral reefs, and if present rates of destruction continue, 60% of the world's coral reefs will be destroyed over the next 30 years.



1.46 Healthy coral on a reef in Fiji. Compare this with the bleached coral shown in figure 1.47.

1.47 A bleached coral reef effected by Montipora White Syndrome. Note the large swath of white skeleton tissue surrounded by normal (brown) corals.

One of the main threats to coral reefs comes from **coral bleaching**, which is the whitening of the coral polyp due to a reduction of photosynthetic pigment. Bleaching occurs due to a change in the relationship between the coral polyp and microscopic algae known as **zooxanthellae**. Coral and zooxanthellae live in a **symbiotic relationship**, which means that each depends on the other for survival. The coral receives about 90% of its energy requirements from the zooxanthellae.

Bleaching occurs when the coral expels its zooxanthellae. As most of the colour of coral comes from the photosynthetic pigments of the zooxanthellae, the tissue of the coral animal becomes transparent when the zooxanthellae are expelled and the bright white skeleton of the coral is revealed, giving the reef a sickly white colour.

Bleaching is a sign of **stress**, and it can be caused by a variety of factors including changes in the ocean **temperature**, changes in the water chemistry (especially **acidification**), increasing **sedimentation** (especially from soil erosion), and **dilution** of the saline content by freshwater.

Acidification, the decrease in the pH of the Earth's oceans, is a consequence of global climatic change. Acidification occurs when the ocean surface absorbs carbon dioxide from the atmosphere. Measurements suggest that the current rate of pH decline is 100 times faster than the natural rate of decline.

When **ice sheets** in the Arctic and Antarctic collapse as a result of global warming, minerals and nutrients from eroded soil and bedrock are released into the sea that encourage the growth of photosynthetic plankton, which boost the absorption of carbon dioxide from the atmosphere. It is estimated that each year, Antarctic icebergs deposit 120,000 tonnes of iron into the Southern Ocean which promotes enough growth in plankton to sequester (absorb) 2.6 billion tonnes of carbon dioxide — the equivalent combined annual emissions of India and Japan. Although this has a positive effect in reducing the build-up of atmospheric carbon dioxide, it makes the problem of acidification of the oceans worse, and scientists warn that it may make most of the world's oceans inhospitable to coral reefs by 2050.

Once bleaching occurs, corals begin to starve. If conditions return to normal quickly, then the corals can regain their zooxanthellae, return to normal colour and survive. However, the stress of even short-term bleaching usually leads to decreased growth of coral and reduced reproduction as well as less resistance to disease. If the cause of the bleaching lasts more than ten weeks, it usually leads to the **death** of the coral.

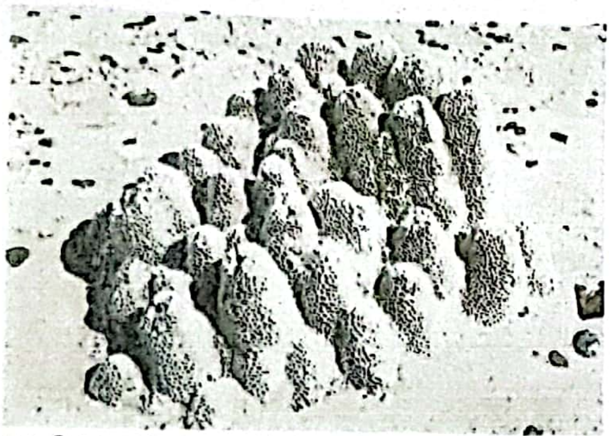
Some of the causes of coral bleaching are natural. For example, strong winds, exposure at low tide and certain weather conditions can all cause bleaching. Annual bleaching of coral each summer is also a normal occurrence as increases in solar radiation affect the reef.

3 A healthy coral reef in Fiji.

Another threat to coral reefs (that also causes bleaching) is destructive **fishing practices**, such the use of poisons. Some large-scale fishing operations deliberately try to reduce coral cover to make fishing easier. They may also remove fish that are important elements in the food chain of the reef. In places where overfishing occurs, the food chain is **disrupted** and there is a decline in zooplankton, which in turn starves the coral.

Once bleaching begins, corals usually continue to bleach even if the stressor is removed. If the coral in a community survives the bleaching, it often takes weeks or months for the food web to re-establish itself, and it is fairly common for a bleaching to result in the **colonisation** of the reef by new species.

Many researchers argue that the greatest threat to coral reefs is **global warming** because corals are so vulnerable to small changes in ocean temperature. Temperature increases of only 1.5C° to 2C° for six to eight weeks are usually sufficient to trigger coral bleaching. If those temperatures continue for more than eight weeks, the coral will almost certainly not



1.49 Dead coral on a beach in Hong Kong.

survive. According to the IPCC (Intergovernmental Panel on Climate Change) 2007 assessment, coral reefs will be highly vulnerable to increased and more frequent bleaching events as a result of global warming, and this negative impact will be magnified by the additional problem of increasing acidity resulting from increased carbon dioxide during the period to 2040.

According to some estimates, about half of the world's coral reefs will die within the next forty years from human causes unless significant measures are taken to save them from the impact of global warming. Mass bleaching has now been seen to affect every reef region in the world, and both the frequency and severity of bleaching events seem to be increasing.

Question Bank 1G

1. *With reference to table 1.2, what percentage of the world's active carbon is in the oceans?*
2. *Briefly describe the carbon cycle, making specific references to components that are (a) stores and (b) flows.*
3. *How is carbon transferred between the atmosphere and the oceans? In which direction is the larger net movement?*
4. *How are human actions affecting (a) oceanic carbon dioxide levels, and (b) oceanic acidity?*
5. *What is the impact of increasing ocean acidity on coral reefs?*
6. *Describe the causes of coral bleaching, and explain why it is a problem.*