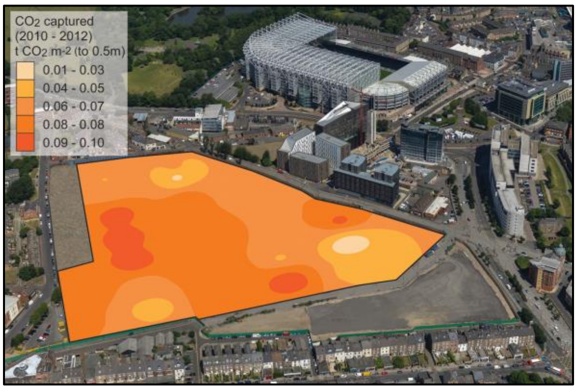
Speeding up nature to trap carbon dioxide
The potential role of enhanced weathering and carbonation in mitigating climate change

Natural Earth processes extract carbon dioxide from the atmosphere and trap it within rocks for millions of years. However this takes a very long time to happen – certainly far too slowly to help in our current concern about climate change.
But recent research has shown that it is possible to speed up the processes, such as weathering, for the removal of carbon. We shall consider two case studies; this first one applies particularly to urban areas.

When old buildings have been demolished, the materials are crushed on site and may be left for several years before redevelopment. This happened at Newcastle University, UK, where an area of crushed brick and concrete rubble was monitored over a period of 18 months (starting about three years after the demolition). Trial pits showed that chemical reactions had occurred between the crushed waste and carbon dioxide from the atmosphere and that new carbonate minerals had been formed in the soil, effectively trapping atmospheric carbon. The first part of the process is the reaction of carbon dioxide with water to form a weak acid, called carbonic acid. $CO_2 + H_2O \leftrightharpoons H_2CO_3$. This then reacts with several of the minerals in the concrete, for example the complex silicate mineral called Jennite:
$Ca_9Si_6O_{18}(OH)_6.8H_2O + 9H_2CO_3 \rightarrow 9CaCO_3 + 6H_4SiO_4.8H_2O$
This process is known as **carbonation.**

The calcium carbonate product (insoluble $CaCO_3$) remains in the soil for as long as the crushed rubble remains undisturbed and open to the atmosphere.
The diagram shows the measured capture of carbon at 23 of the trial pits at the Newcastle University site.



Observed carbon capture at Science Central, Newcastle, in tonnes of CO_2 per square metre, at a depth of 0.5m. (*Washbourne et al 2015).*

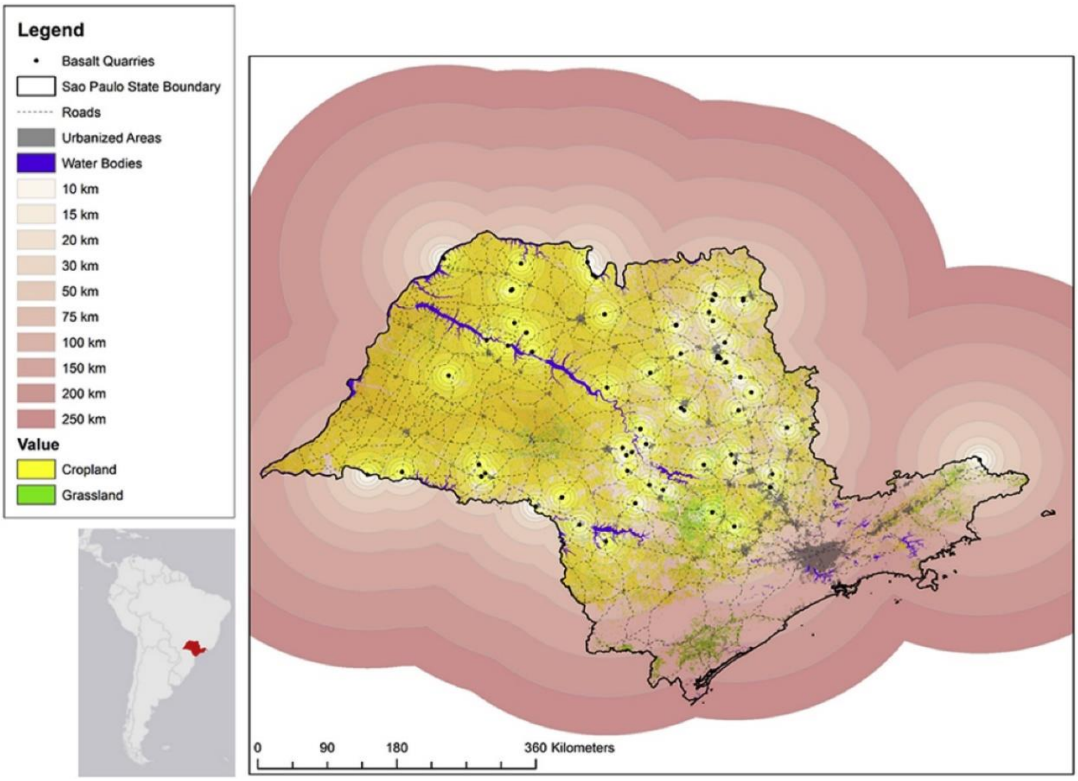
The researchers showed that the carbonation processes were effective to a depth of about one metre. They estimated that the trapping (**sequestration**) corresponds to 85 tonnes of CO_2/hectare (8.5 kg of $CO_2\,m^{-2}$) being removed from the atmosphere annually over much of the area. Speeded up weathering such as this also occurs with other waste materials such as mine waste and the slag from the manufacture of iron and steel.

The second case study looks at the potential for carbon sequestration in the State of Sao Paulo in Brazil. Here, much of the State is underlain by ancient basalt lava flows, and the basalt is widely quarried for construction material. Basalt is mainly composed of silicate minerals containing calcium and magnesium. These minerals can react with carbonic acid derived from atmospheric carbon dioxide, to deposit carbonate minerals in the soil, just as in Newcastle. If basalt is finely crushed, the increase in surface area means that it will react more quickly with the carbonic acid, i.e. natural weathering processes will be speeded up.

Under the Brazilian climate, the silicate minerals may also break down through another process called hydrolysis to produce calcium and magnesium hydrogen carbonates, which are very soluble, and also remove carbon. These are then carried away in rivers to the sea where they become part of new minerals which are deposited. These processes together are called **enhanced weathering**.

Brazilian farmers already spread crushed basalt thinly over many hectares of agricultural land, to improve the quality of the soil. At the same time this will speed up the natural weathering processes, thus removing carbon dioxide from the atmosphere. To be effective, there must be a balance between the carbon input needed to quarry, process and transport the basalt to the farm land, and the amount of CO_2 which can be removed by enhanced weathering.

The map shows the State of Sao Paulo with its basalt quarries. The colours represent distances from the quarries. If the distance from the quarry becomes too great, then more carbon is spent in fuel for the lorry than is gained from its removal from the atmosphere. The maximum road travel distance from the quarry to the field is 540 km for carbonation and 990 km for enhanced weathering, above which the emissions are more than the potential capture.



Sao Paulo State, Brazil showing agricultural land with distances (red shade) around Sao Paulo's basalt quarries (black dots) (*Lefebvre et al, 2019*

It has been calculated that if crushed basalt could be applied at 1 tonne per hectare to all of the Sao Paulo State's 12 million hectares of agricultural land it could capture around 1.3 to 2.4 Mt (million tonnes) of carbon dioxide equivalent through carbonation and enhanced weathering, respectively. This allows for the carbon emissions from the processes of quarrying, processing and transport.

Ask pupils to suggest the stages in quarrying and processing the basalt where carbon emissions might be involved.
How does the "carbon footprint" of the proposals for Sao Paulo State compare with that in the Newcastle study?

Are there any suitable demolition sites near your own home where carbon sequestration might be going on in the soil? How far is the nearest basalt quarry from your home? Could the crushed basalt technique be used on your nearest farmland?

The back up

Title: Speeding up nature to trap carbon dioxide

Subtitle: The potential role of enhanced weathering and carbonation in mitigating climate change

Topic: Two case studies in the sequestration of carbon by promoting enhanced weathering processes.

Age range of pupils: 14 years upwards

Time needed to complete activity: 30 minutes

Pupil learning outcomes: Pupils can:
- state that natural weathering processes are slow on a human timescale;
- explain how natural acids from atmospheric carbon dioxide can speed up the weathering of rocks;
- explain that when silicate rocks are weathered by carbonation or enhanced weathering, carbon is taken from the atmosphere and trapped in the newly-formed minerals in the soil or washed into the sea to form new minerals;
- demonstrate the importance of considering distance between the sources of crushed rock and the areas where it is to be applied;
- show that carbon sequestration from building rubble, crushed and retained on site, involves no additional carbon footprint.

Context: Government 'net-zero' targets will affect many areas across the world. This Earthlearningidea explores how natural weathering processes may be enhanced to speed up carbon sequestration.
(*In Sao Paulo State the main source of carbon emissions is that of diesel lorry transport from quarry to field. However emissions also arise from*

diesel powered machinery at the quarry in drilling the rock face, blasting, loading the basalt and in crushing it to 5mm: also in spreading it on the fields. By contrast, in the Newcastle case, carbon emissions would have been involved at the time of demolition, crushing and spreading the rubble – but this had to be carried out in any case. After that the site absorbs carbon dioxide with no further emissions, until the redevelopment takes place).

Following up the activity: Find local examples of demolition sites where crushed rubble may be sequestering carbon while awaiting development. Use a geological map to find out where your nearest sources of basaltic rocks are. Explore the internet for further examples of carbon sequestration.

Underlying principles:

- Natural processes of weathering can be speeded up artificially within the soil.
- Carbonic acid is produced by atmospheric carbon dioxide and water.
- Carbonic acid reacts with silicate minerals, to produce soluble hydrogen carbonates, which are ultimately carried to the sea, where plant and animal action fixes the carbon for tens of thousands of years.
- Carbonic acid also reacts with silicate minerals to produce insoluble calcium and magnesium carbonates which remain locked up in the soil.
- There is no carbon footprint in the sequestration of carbon in crushed demolition rubble, while the site awaits redevelopment.
- Carbon-intensive methods of extracting, processing and transporting crushed basaltic rocks must be balanced against the amount of carbon sequestration, once it is spread on farmland.
- A recent trial in spreading basalt dust onto agricultural land has taken place in the U.K. The basalt dust produced as a waste product of quarrying for aggregate in Northumberland (approx. 400km away), has already increased crop yields and contributed to the sequestration of CO_2 on the farm.
- The maximum global potential of CO_2 removal from the atmosphere from the production of industrial waste containing calcium and magnesium bearing minerals is estimated at 700 – 1200 Mt (million tonnes) per year.

Thinking skill development: Cognitive conflict may be experienced at the concept of demolition rubble being able to absorb atmospheric carbon dioxide, and metacognition as pupils debate the issues. If local examples can be found then bridging skills are involved.

Resource list:

- paper copies or a screen version of this activity.

Source: Written by Peter Kennett of the Earthlearningidea Team, based on case studies by Washbourne et al 2015. *Rapid Removal of Atmospheric CO_2 by Urban Soils*
https://pubs.acs.org/doi/10.1021/es505476d
and Lefebvre et al, 2019. *Assessing the potential of soil carbonation and enhanced weathering through Life Cycle Assessment: A case study for Sao Paulo State, Brazil*.
https://www.sciencedirect.com/science/article/pii/S0959652619320578
Further information from a lecture by Prof. David Beerling, Sheffield University, Feb 2021:
https://www.youtube.com/watch?v=BNDfs6KpDxo

The ‘How will the ‘net-zero’ target affect your local area?’ series of Earthlearningideas

Topic			**Earthlearningidea title**
Introduction			How will the ‘net-zero’ target affect your local area?
Possible mitigation measures	Use alternative energy sources	Solar	Harnessing the power of the Sun
		Wave	Harnessing the power of waves
		Wind	Farming the wind: through onshore and offshore windfarms
		Tidal	Tidal energy
		Nuclear	Nuclear power - harnessing the energy of the atom
		Nuclear waste	Nuclear waste disposal
		Biofuel	Liquid biofuels: keeping our wheels turning into the future
		‘Blue’ hydrogen	Blue hydrogen: the fuel of the future? *Also:* Hydrogen of many colours
		Geothermal – hot rocks	Deep geothermal power from ‘hot dry rocks’: an option in your area?
		Geothermal – flooded mines	A new use for old coal mines
		Hydro – small scale	Small-scale hydroelectric power schemes
		Heat pumps	Heat from the Earth
		Waste – incineration	Energy from burning waste
		Waste – methane	Energy from buried waste
	Stop fuels releasing greenhouse gases	Carbon capture	Capturing carbon?
	Store energy from sources that give irregular energy supplies	Batteries	Nuclear batteries: the future?
		‘Green’ hydrogen	Green hydrogen used to even out renewable energy supplies? *Also* Hydrogen of many colours
		Hydro – storage	Matching supply and demand using stored water
		Compressed gas	Storing gas underground: What can we store? How can we do it? How will it help?
	Provide raw materials for new technologies	Electric vehicles	Electric vehicles: the way to go?
		Insulation	How do I choose the best insulation?
	Remove carbon form the atmosphere	Enhanced weathering	Speeding up nature to trap carbon dioxide
		Tree planting	Let’s plant some trees
Possible adaptation measures		Coastal flooding	How will rising sea level affect our coastlines?
		Inland flooding	Inland flooding: a Sheffield case study
		Landslides	Landslide danger
		Agriculture	The future for global agriculture