How volcanoes recycle the Earth's crust to uncover rare metals that are vital to green technology

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The Motzfeldt deposit in southern Greenland. Author provided

To understand the resources of the near future, geologists need to understand the volcanoes of the distant past. Exploration of ancient magma chambers in places such as Greenland has the potential to provide new sources of the rare metals that underpin modern green technologies.

Many rare metals—such as neodymium, niobium and dysprosium – essential to the production of wind turbines and electric cars, are mined from fossil volcanoes.

Volcanoes are nature's way of bringing material from deep within the earth up to the surface. Melting processes within the mantle – the interior part of the Earth between the super-heated core and the thin outer crust—produce magma which rises up hundreds of kilometers and eventually erupts on to the surface as volcanoes.

The earth's crust is made up of semi-rigid tectonic plates which move around and collide to form mountains or sink underneath one another at regions called subduction zones. The volume of material brought to the Earth's surface by volcanoes is balanced by similar amounts of material going back into the mantle via sinking tectonic plates.

This points to what we call "element cycles," where material from depth comes up to the surface via volcanoes and then returns again to the mantle via subduction. One of the big questions in Earth Sciences is what happens to this subducted material and how long it resides in the mantle.

Fossil volcanoes

Our recent research studied a group of ancient volcanoes in southern Greenland. Around 1.3 billion years ago, Greenland was a volcanic landscape with deep rift valleys much like modern East Africa. Substantial volcanoes erupted on to the land surface and major river systems similar to the Nile carried minerals from these volcanoes over huge areas.

The rivers and volcanoes in Greenland are now long eroded, but the sediments that the river transported can still be found, and the volcanic "plumbing systems" that operated beneath these ancient volcanoes have preserved samples of the magmas that erupted.

We wanted to understand how element cycling relates to the concentration of critical metals in these ancient volcanoes in Greenland. While it is useful to study the valuable elements themselves, sometimes we can learn more about Earth's element cycles by studying other elements associated with them.

Fentale volcano in the Ethiopian rift has erupted large volumes of chemically evolved magma similar to Greenland. Author provided

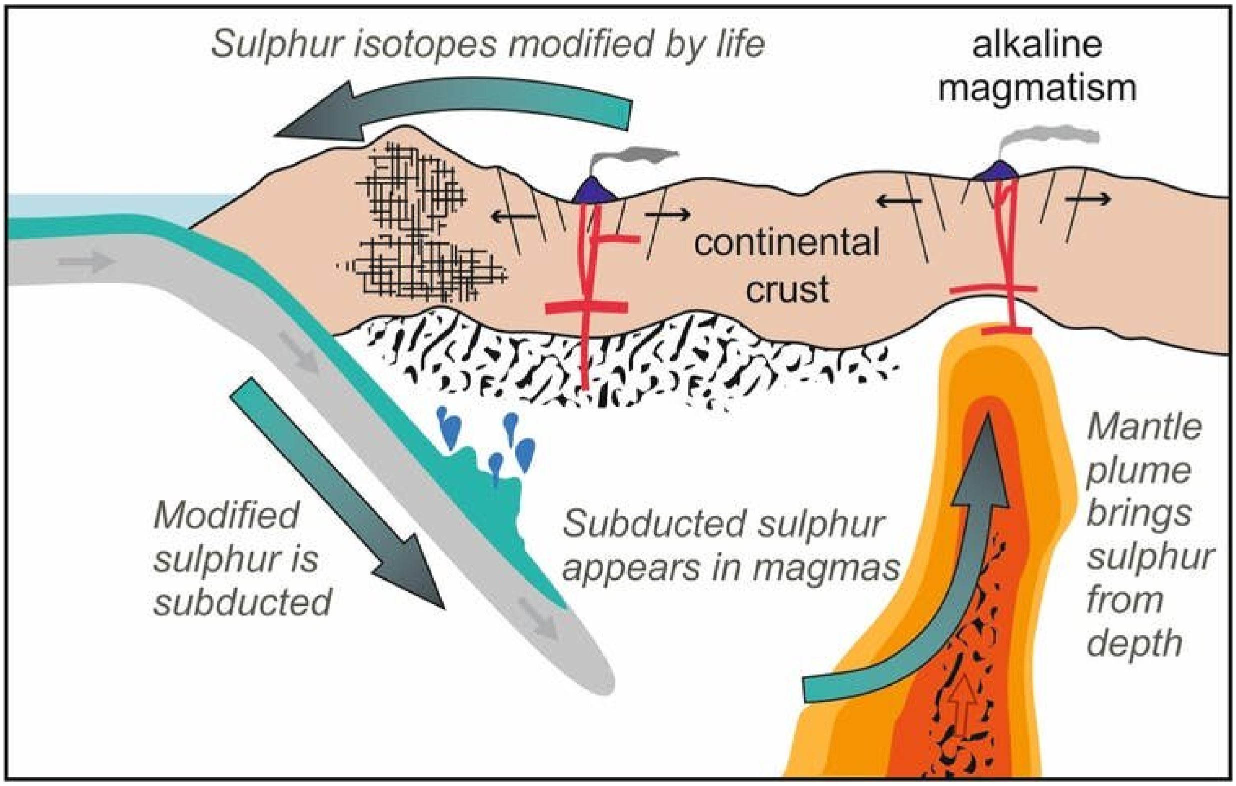
Fingerprinting sulfur

In our study we used the element sulfur of which there are four stable forms (called isotopes). Each has a slightly different mass. This is important because natural processes can selectively separate lighter isotopes from heavier isotopes. Much like snacking on a bag of M&M's where you prefer the red ones and leave behind the brown M&Ms, geological processes lead to variations in the relative abundances of each element in different materials.

By measuring the amount of isotope in rocks, we can learn about the processes that formed them. sulfur isotopes are particularly useful because bio- and geochemical processes on the Earth's surface (at low temperatures) are very efficient at modifying sulfur signatures, whereas magmatic processes (at high temperatures) do not create much variation between light and heavy sulfur.

So the variations in sulfur signatures in magmatic rocks allow us to fingerprint traces of recycled crustal material in the mantle source. By choosing volcanoes that were active at different periods of geological time, we reconstruct how the mantle composition and sulfur cycling have varied over Earth's history.

Geologists have known for a long time that Earth's surface has changed profoundly over the past 4.5 billion years as life emerged and became progressively more complex. The increasing imprint of life on the sulfur cycle has dramatically changed the sulfur isotope ratio of sediments at the surface of the Earth, but this imprint has not previously been documented in rocks from the mantle.



Author provided

Our work shows for the first time that the sulfur signature of the Earth's mantle changed in a manner that broadly matches the changes in sulfur on the Earth's surface. Biological and atmospheric impacts on the surface sulfur signature appear to have been transferred all the way into the Earth's interior.

This means that the Earth's surface and mantle are strongly connected—one responding to changes in the other—although timescales of this recycling remain unknown. Our data show that sulfur that was once on the Earth's surface went back into the mantle through tectonic plate activity and then—1.3 billion years ago—found itself coming back to the surface in the Greenland volcanoes. It's like geological *déjà-vu*.

One cycle or many?

How many times has sulfur been recycled between the Earth's crust and mantle over geological time? We do not currently know the answer to this but our research paints a picture of the Earth as a global element conveyor belt with surface sulfur and mantle closely linked.

The study has many implications. A major question in geology is how rare metal deposits form, particularly the high-tech metals that are essential for the green energy revolution. The story from sulfur seems to be consistent with our work on other isotopes. For example, one of the world's biggest deposits of the element tantalum (used in electronics and also concentrated in one of the ancient volcanoes in Greenland) has isotopic fingerprints that also hint at crustal recycling.

It may be that these global cycles have taken elements from surface to mantle and back again many times, effectively concentrating those elements each time. The global cycle that we have documented in sulfur may be an essential precursor to generate the metal deposits that are crucial to modern technologies. By understanding plate tectonics and magmatic processes that took place billions of years ago, we gain insights into how to identify and understand the mineral resources of the future.

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