

How has weathering affected Earth?

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Abstract

Have you ever wondered why the Grand Canyon is so deep? Weathering of rocks creates features like this. Physical and chemical weathering affect the shape and composition of the continents. They also impact the movement of elements between the continents and the ocean.

We wanted to better understand these weathering processes. We analyzed samples containing marine sediments up to 2,000 million years old. Marine sediments collect particles weathered from the continents. We looked

at the amounts of four elements related to weathering. We saw a shift in weathering about 650 million years ago. Erosion and particle transport dominated weathering processes before that. Afterwards, the chemical weathering of rocks became more important, but not always. The shifting importance of chemical and physical processes related to regular movements of the Earth's crust and mantle. This information helps us understand more about the impact of weathering on geological history.

Introduction

Have you ever watched a heavy rainstorm carry dirt down the street? This is an example of **physical weathering**. Rocks are broken down into smaller pieces in a process called **erosion**. Water, wind, and changes in temperature can contribute to erosion. And rocks that are at higher elevations or in the mountains can erode more quickly. Particles eroded from rocks move from place to place in a process called **particle transport**. Eroded particles can even make their way through rivers to the ocean. There, they become part of **marine sediments**.

Rocks can also change through chemical reactions. **Chemical weathering** happens when rain and soil water interact with the **minerals** in rocks. Some of these minerals dissolve, releasing molecules and elements that plants and animals need to grow.

The shapes of mountains and rivers on the continents are controlled by weathering. Weathering is also responsible for the movement of elements – like carbon – around the



The Grand Canyon formed through millions of years of physical weathering.

Photo: Murray Foubister, CC BY-SA 2.0

Earth. But researchers don't all agree on how weathering has changed over Earth's history. This is because it's hard to find and analyze reliable samples of sediment from billions of years ago.

We wanted to better understand the long-term history of weathering. So, we designed a study to analyze the particles produced by weathering over geologic time. These particles are found as ancient marine sediments within sedimentary rocks.

Methods

We used the Sedimentary Geochemistry and Paleoenvironments Project database to find information about the chemistry of ancient marine sediments. We also looked at 2,000 of our own samples. The samples contained sediments that were up to 2,000 million years old. We looked at the amounts of zirconium (Zr), rubidium (Rb), sodium (Na), and aluminum (Al) in the samples. These elements are related to weathering.

We calculated the ratio of Zr to Al (Zr/Al) to look at physical weathering. Zr is a metal that is fairly stable. Zr/Al in marine sediments is low when chemical weathering is high or when Zr gets trapped on land instead of being transported to the ocean. Zr/Al in marine sediments is high when a large amount of this trapped Zr is transported from the

continents to oceans. This can happen because of intense physical weathering, erosion, and particle transport.

We also calculated the ratios of Rb to Al (Rb/Al) and Na to Al (Na/Al) to look at chemical weathering. Rb and Na are parts of minerals that are removed from rocks easily, although Na is more easily removed than Rb. The Na/Al and Rb/Al ratios in particles transported to the oceans should be small when chemical weathering is intense. This is because more of the Na and Rb have been removed from the rock during chemical weathering.

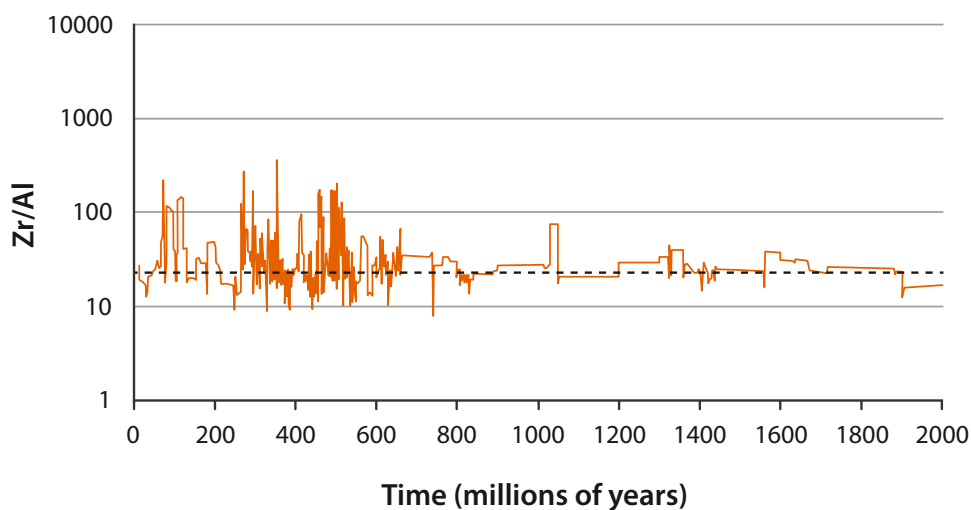
We then looked at Zr/Al and Rb/Al over time. We wanted to see if the values changed at regular intervals – and thus, if their timing matched any known geological processes.

Results

Physical Weathering

We saw that before 650 million years ago, Zr/Al was close to the average in the continental bedrock. This means that physical weathering, erosion, and particle transport were

efficient at moving Zr into the oceans. Chemical weathering was stable but not intense. But around 650 million years ago, Zr/Al became more variable. Values were both higher and lower than in the continental bedrock (Fig. 1).



At what point in Earth's geologic history did the ratio of Zr/Al become more variable?

Figure 1: The ratio of zirconium to aluminum in marine sediments from the past. The dashed line shows the average ratio in the bedrock on land.

Chemical Weathering

We found that Rb/Al decreased around 300 to 400 million years ago. Also, Na/Al was low for all of our samples.

Timing

Our elemental ratios did change at regular time intervals. Zr/Al and Rb/Al both peaked about every 35 million years, 50 million years, and 200 million years.

Discussion

We saw a shift in weathering around 650 million years ago. This timing matches the origin of modern plate tectonics and deep subduction (Fig. 2). Subduction happens when one plate slides under another into the mantle. This can cause high mountains to form, which mainly tend to be eroded by physical weathering. So, when subduction is intense, erosion and particle transport of Zr is high. When subduction is less intense, chemical weathering is more important.

We know that the intensity of subduction and plate

movement changes at regular intervals. For example, it takes the mantle about 200 million years to circulate. And this matches one of the time intervals at which Zr/Al and Rb/Al regularly peaked! Our data shows good evidence that weathering might be related to patterns of subduction.

We think increased chemical weathering 400 million years ago corresponded to the evolution of plants with roots. Roots stabilize the soil and produce acidic chemicals, which can increase chemical weathering.

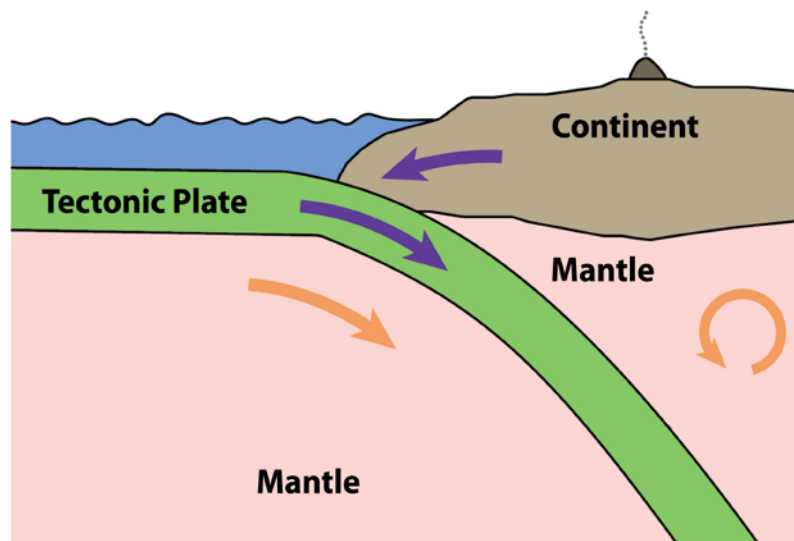


Figure 2: Subduction occurs when a tectonic plate dives under another plate and into the mantle. This illustration shows a tectonic plate subducting under the continent. The tectonic plate eventually melts into the mantle to circulate. This subduction can cause the formation of trenches, volcanoes, and mountain ranges. Arrows show the direction of tectonic plate (darker) and mantle (lighter) movement.

Conclusion

Our research shows that geological processes can have huge impacts on weathering. And you can see the impacts no matter where you live! Take a walk to a nearby park or natural space. Can you see any places that have eroded? Is there a creek or river? Is the water clear, or can you see

sediment? Over a few years you might see the bank of the river start to erode and wash away. Just imagine these processes happening at a continental scale for millions and millions of years. What you see now could change a lot in that much time!