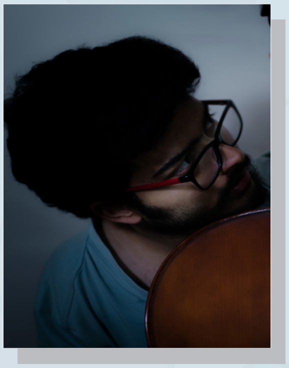
How Did the Oldest Part of the Earth still Survive Today?



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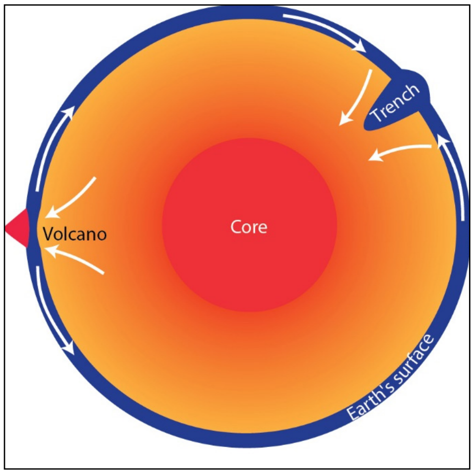
By chemical dating techniques, scientists have now pinpointed that the earth formed about 4.54billion years ago (1 billion = 100 crores). But, it is hard to find such old rocks around us. Let us take a few examples of rocks in different parts of India. If any soil sample from the Ganges plain is dated, it will not be older than a few million years (Myrs; 1 million = 10 lakhs). Further north, rocks from the Himalayas are not more than 55 Myrs old. In the southern part of India, for example, the Deccan plateau would not cross the age of 65 Myrs, while the Western Ghats are as old as 150 Ma. Even the Aravallis and the Vindhiyas are not older than 1700-1800 Myrs. All these comprise a significant landmass of India. Apart from India, if we sample the rocks worldwide, most of them are not older than 2000 Myrs. So, if the earth was formed 4.543 billion years ago, where did all the old rocks go?



Cycle of plate tectonics. Older materials go inside the earth along trenches and the newer materials come up on the surface along volcanoes.

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This question has always challenged earth scientists. The answer did not emerge until the early 1970s when the plate tectonics theory was formulated. The theory states that the upper layer of the earth (~100 km thick) is divided into several rigid "plates" that move past each other. Additionally, the plates are created when hotter materials from the interior of the earth come out on the surface as volcanic eruptions along volcanic ridges in the middle of the ocean (called constructive or divergent plate boundaries) likewise, the old surface of the earth sinks into the earth's interior or gets destroyed along oceanic trenches (called destructive or convergent plate boundaries) due to strong tectonic forces. This continuous recycling of materials along the plate-boundary regions is the sole reason that we do not find rocks that are very old.

Once the first problem was solved, a second-order complexity was added when scientists found rocks older than 3billion years. According to the theory of plate tectonics, any rocks on the earth should not have survived for such a long period. So, the presence of such old rocks seems to contradict the established theory. Geologists call these old rocky regions as "cratons". Some of these old cratons were found inside the Indian landmass in Dharwad and Singhbhum regions and some of them are reported to be 4.2billion years old, which is closer to the age of the earth. Other than India, large parts of North America, Northern Europe, West and South Africa, Antarctica, Australia, Brazil, China and Siberia are covered by such cratons (blue regions in the map).

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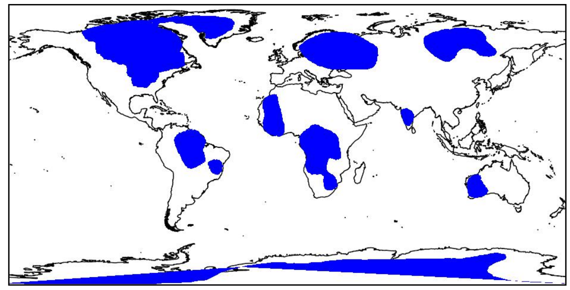

Rocks older than about 3 billion years are marked in blue in the map.

For the last few decades, researchers have been trying to understand how these older cratons survive when all other parts of the earth's surface are recycled or destroyed. Several possible explanations exist to this question. One of the propositions that came during the late-1970s states that cratons are made of lighter rocks that will not sink into the earth. For example, oil drops cannot sink in water because oil is lighter than water. However, this hypothesis was later challenged by mathematical calculations where it showed that cratons made of only lighter materials were unable to survive for a long time. If they reach plate boundary regions, even lighter rocks can be destroyed due to tectonic forces.

A second possible explanation came during the late 1990s, where studies showed that cratonic rocks were stronger than any other non-cratonic rocks. Thus, if cratons reach the trenches (subduction zones), they would be able to with stand the tectonic forces and would not be destroyed.

In early 2000, researchers with more advanced scientific techniques started to investigate what could be the possible strength of the surface of the earth. With mathematical calculations, it was seen that if cratons are sufficiently strong, they can survive for a long time, although, determining the exact strength of cratons has remained a difficult issue. My study at the computational geodynamics laboratory at the Indian Institute of Science, Bengaluru, involves understanding this problem of cratons' survival by estimating the material strength of cratons using computer models. The material strength of rocks is measured in terms of viscosity. Average viscosity of the earth till 3000 km depth is estimated as 10^{21} Pascal-second (for comparison, viscosity of water is 10^{-3} Pa-s, viscosity of honey ~10 Pa-s, viscosity of a glacier ~10^{12} Pa-s). However, the viscosity of cratons is still an open question.

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If we want to know how rocks have behaved for millions of years, it is almost impossible to set up a real-time experiment. Solving mathematical equations with computer simulations is the only way to understand such long-term natural phenomenon. So, at the computational geodynamics laboratory, we use supercomputers to solve such equations. A supercomputer, in simple words, is a computer with multiple central processing units (CPUs) that can work several times faster than a normal computer and can solve complicated mathematical equations much more quickly. In our study, we use a few hundreds of CPUs to develop computer models of cratons' survival.

In our models, we find that cratons are 100-1000 times stronger than the average strength of the earth. They are most likely the strongest material on the earth. Because of their strength, even earthquakes do not occur naturally in these regions. For example, many Indian cities near the Himalayan region, like Delhi, are prone to earthquakes, but southern cities, like Bengaluru and Mysuru, are quite safe as they are situated on the Indian craton. In fact, in the last 500 years of earthquake database, there is no record of a single earthquake from southern India, while northern India has witnessed devastating earthquakes on several occasions.

It is quite interesting to know that unlike most old materials that become more and more fragile with time, older rocks like cratons retain their strength. It is their strength that has helped to form large landmasses and continents over millions of years, where life has thrived.