The Igneous History of Mars

J. Brian Balta

Visiting Professor of Petrology Texas A&M University, MS 3115 TAMU, College Station TX 77845

balta@tamu.edu

Brian Balta has spent more than 10 years conducting research into the chemistry of meteorites and the origin of worlds in our solar system. He uses analyses of rocks from Mars and the asteroid 4 Vesta to understand properties of their magmatic history, and uses computational tools to simulate the properties of magmas generated on these worlds. After finishing his Ph.D. at the California Institute of Technology, he worked as a postdoctoral Research Associate at the University of Tennessee and has served as a Visiting Professor of Petrology at the University of Pittsburgh and Texas A&M University.

Abstract:

Of all the worlds in this solar system, there are currently only 4 where it is possible for a human to pick up and hold a rock known to come from that body: Earth itself, the Moon, asteroid 4 Vesta, and the planet Mars. Samples of rocks, particularly igneous rocks, are important because not only do they let us uncover the history and evolution of a planetary body, but they are also the only rocks that can be dated directly.

Igneous processes on Mars stretch all the way to the planet's formation. Building a rocky planet is an energetic, violent event. Every time debris is accreted to or impacts a growing planetary body, it supplies energy that is partially converted to heat. The energy of impacts is supplemented by energy given off by radioactive decay, which was much more frequent in the early solar system as radioactive elements were more abundant. These energy sources combine to trigger melting, allowing the larger rocky worlds to differentiate into an iron-rich core and a nearly molten, silicate magma ocean. As this magma ocean cools, it separates and crystallizes into distinct components, some of which likely created the planet's first crust and mantle.

Unlike Earth, Mars has never developed plate tectonics, instead remaining as a "Stagnant lid" world. That lid is thought to have grown over time, creating a thick, cold crust that is thought to exist today – thicker than continental crust on Earth. Beneath that crust, heat in the mantle has been dissipated by melting of hot rocks in rising mantle plumes. These molten rocks can then erupt at the surface as lava flows, flood basalts, and eventually individual volcanoes. Eruptions first covered much of the martian southern hemisphere, and then later established multiple, long-lived volcanic centers at the Tharsis, Elysium, and Syrtis Major sites, where volcanism has continued until the most recent geologic era. Impacts onto the surface of Mars have occasionally ejected rocks from these sites out into space, where over 100 of them have fallen to Earth – nearly all of them igneous, formed by these processes. These rocks have given us the story of martian volcanic processes.

As with the ocean crust on Earth, martian magmatism is dominated by basalt, produced by melting of the planet's mantle. The igneous martian meteorites include samples that were likely intrusive and crystallized within Mars's crust, extrusive lava flows, samples emplaced shallowly close to Mars's surface, and brecciated samples that have been broken up and remixed by impacts, showing that volcanic processes on Mars operate much like those on Earth. As those magmas rise towards the surface, it is thought that many are trapped in magma chambers at the base of and within Mars's crust, where certain minerals crystallize from the magma before they are erupted. Sometimes those rocks are trapped in the crust permanently creating intrusive igneous rocks, sometimes those minerals can be picked up magma to the next; similar processes are common in active magmatic systems on Earth. Measurements on and above the surface have similarly located igneous rocks produced in lava flows and in locations affected by impacts, which has expanded our knowledge of martian igneous processes beyond just the samples available in meteorites. Finally, these rovers and orbiters have also found first-generation sedimentary rocks, where the grains from primary igneous rocks have been reworked by water and partially altered but are still present and able to be analyzed.

The youngest martian meteorites are just over 100 million years old, indicating that volcanism on Mars has occurred geologically recently and is very likely to occur again. The chemistry of these meteorites demonstrates that there are distinct chemical reservoirs inside of Mars which may have formed during magma ocean differentiation and which behave very much like similar components on Earth – enduring for billions of years, occasionally being pushed upwards into a melting zone by some geologic process, and then melting to produce basaltic rocks of varying trace element and isotope chemistry. These igneous rocks represent the raw materials that are then reprocessed at the surface by impacts, water, and wind into the brecciated and sedimentary rocks found at the surface by rovers today. Although relative ages and age estimates can be determined using sedimentary rocks, finding igneous rocks on Mars will be required to establish firm ages for any sedimentary sequences observed on Mars or for any returned samples. Although we don't know exactly where the martian meteorites originated, they give us a 4.5-billion-year long record of volcanism and magmatic processes on Mars, and record the foundation on which all other martian geologic processes occurred.