

Worlds in Eruption

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Worlds in Eruption - Volcanoes

Volcanism, in its various guises, is without doubt one of Nature's most spectacular and fearsome displays of power. Volcanic eruptions – like those of Krakatoa, Mount St Helens or Montserrat – destroy huge areas of land and can kill thousands of people.

Volcanic activity is also, arguably, the most important of all geological processes. It makes its presence felt from hundreds of kilometres below the Earth's crust up to the cruising altitudes of commercial airliners. It resurfaces continents, alters climate patterns and – in the long term - may cause mass extinctions of life. For geologists, volcanoes also serve as windows through which they can peer into the heart of the Earth - windows that give invaluable insights into the processes churning away below our feet.

But Earth is far from being the only planet where volcanism has played a salient role.

For over thirty-five years a flotilla of interplanetary spacecraft has set sail for new worlds beyond our own. These intricate robots, bristling with sophisticated instruments, act as our remote senses: seeing, listening, and in some cases touching the surfaces and smelling atmospheres of other distant bodies. They have presented us with conclusive evidence that the effects of volcanism are ubiquitous throughout the Solar System.

Many of these volcanic constructs dwarf anything we find on Earth. And, by studying extraterrestrial volcanoes and the material they throw out, planetary scientists are slowly unravelling the complex geological processes that have sculpted other worlds.

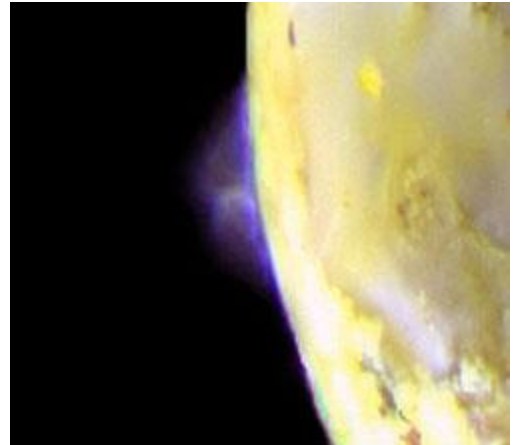
The volcanic power plant

What causes volcanism? There are two basic ingredients needed to make a volcano: heat, and something to melt. The latter is straightforward. Be it rock or ice or a mixture of both, if you add enough heat it will eventually melt. This gives you the molten stuff – magma. When magma escapes to the surface it erupts to form lava flows, which - along with ash and larger boulders - constructs a volcanic cone.

But where does the heat originate? The first source is primordial heat, the energy left over from a planet's formation. It was generated when immeasurable numbers of planetesimals (comets and asteroids of all shapes and sizes) collided at hyper-velocities to build up the planet. The impacts liberated large amounts of energy, mainly in the form of heat.

A second source is important in providing a slow but continuous source of heat. It's the natural decay of radioactive elements such as uranium, thorium and potassium. These elements release subatomic particles, which give up heat energy as they are slowed down by the surrounding rock.

Recently, planetary exploration has led to the identification of a third heat source, unsuspected by Earth-based geologists. It is tidal energy released in moons as they orbit in the powerful gravitational field of their parent planet.



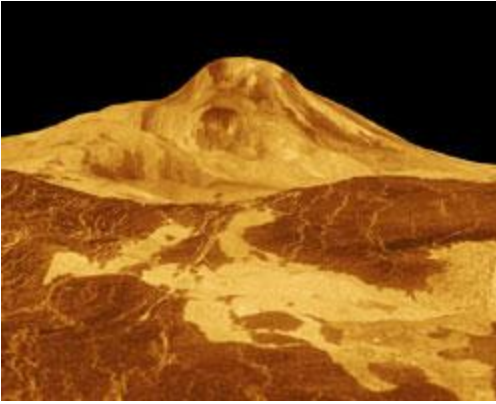
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Hell-planet Venus

By studying the shape, distribution and location of the plethora of volcanic features on other worlds, we can start to piece together their unique geological jigsaw in the same way we do on Earth. Much has been learnt about extraterrestrial volcanism from missions to Earth's siblings, Venus and Mars.

Volcanic plumes spew forth from the surface of Io.

Between 1990 and 1994 NASA's Magellan mission mapped the surface of Earth's nearest planetary neighbour, Venus. The orbiting spacecraft used radar to cut through the all-enveloping clouds that permanently hide a twisted and tormented surface where volcanism has run rife. Over 80% of the planet's surface is covered with volcanic plains called planitia - vast coalescing lava flows, subsequently warped and fractured by movements of the planet's crust. Researchers believe the planitia formed from relatively fluid lava, similar to the Earth's basaltic lavas that form the Deccan Traps in India and the Columbia River Plateau in America.



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The volcano 'Maat Mons' on Venus is 5 miles high and named for an Egyptian goddess of truth and justice.

Magellan mapped huge volcanoes hundreds of kilometres across and thousands of metres high. These are 'shield' volcanoes, so called because their convex-upward shape resembles that of a Roman shield, and they are similar to the volcanoes that make up the Hawaiian Islands. Height measurements from Magellan show that the large volcanoes are generally located on large bulges in Venus's crust. These are thought to represent 'hot spots' - plumes of molten rock and heat which well up from deep within the planet's interior.

Among other volcanic features are coronae, circular blisters on the Venusian surface hundreds of kilometres across which are also formed by up-welling heat from below. And on a smaller scale, 10-20 kilometres across, the surface is peppered with literally millions of cone, dome, and shield volcanoes.

The Magellan radar images also reveal that Venus's crust is fundamentally different from the Earth's, in that it shows no sign of plate tectonics. On our planet, the process of plate tectonics drives large slabs of the crust – plates – in perpetual motion around the Earth, jostling and diving below each other as they go. The action of plate tectonics is fundamental in cooling the Earth's molten interior. First, a vast amount of heat energy is consumed in melting old cold crust that descends into the hot mantle below. Second, heat escapes via volcanic eruptions which are concentrated along the margins of the plates.

Venus appears to be a one-plate planet, so how does it cool off? Presently there are two main theories. Venus may lose its internal heat mainly through hot-spot volcanism, at the large shield volcanoes and coronae, in a controlled gradual process. Or, periodically, Venus may literally boil over like an oven pot with a lid, spilling vast quantities of lava onto its surface and releasing heat in the process. Perhaps this is how the extensive planitia were formed. The jury is still out on this controversy.

Gigantic volcanoes of Mars

Mars has also been the target for numerous robotic Earth emissaries. They have revealed that Mars today is almost volcanically extinct - but that hasn't always been the case. The Mariner 9 spacecraft in 1971 and the two Viking spacecraft in 1976 first returned images that tell a story of more dynamic times. Like Venus, Mars boasts an impressive assortment of volcanic features.

Indeed, the largest volcano in the Solar System is found on Mars - Olympus Mons. Situated in the Tharsis province, a huge bulge in the planet's crust, Olympus Mons towers some 27 km high, three times higher than Mauna Loa, Earth's largest volcano. At least twelve other volcanoes are found within the Tharsis province including Arsia Mons, Pavonis Mons and Ascraeus Mons - three giants in their own right.

The Martian volcanoes are also strikingly similar to the shield volcanoes found on Earth. They are surrounded by numerous lava flows and channels, and have collapsed pits or calderas at their summits. The main difference is size - in every detail the Martian volcanoes are bigger, even though the planet is only half the Earth's diameter. Why?

Again the answer lies with plate tectonics. On Earth, as a crustal plate moves over a hot spot, the rising plume 'burns' a series of holes in the crust - each hole being marked by a volcano. A good analogy is moving a piece of paper over a candle. The candle's heat will burn a path as the paper moves above. The Hawaiian Islands have formed as a chain of volcanoes where the Pacific Plate is moving over a hot spot. Because the crust on Mars is stationary, and has been some time, up-welling plumes simply continued to burn a larger hole in the same area of crust, supplying the resulting volcanoes with more magma that erupted in lava flows. This built up much larger volcanoes with a longer history of activity, including the vast bulk of Olympus Mons.



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Olympus Mons on Mars is the largest volcano in the solar system. It is three times the height of Mauna Loa and its area is as large as the entire Hawaiian archipelago.



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The dark maria on the surface of the moon are not 'seas' of water as once thought but of volcanic basalt flows.

While there is some debate as to whether Venus and Mars are volcanically active today, the general consensus is that the Moon and Mercury are volcanically dead. But this wasn't always so.

Just glance at the Moon, and you can't fail to notice the large blue-grey patches on its surface. These patches were once considered to be oceans of water, hence the name 'maria' (Latin for 'seas'). We know differently today. In truth they are some of the Solar System's largest expanses of basalt, the most common volcanic rock. The lunar basalts were erupted thousands of millions of years ago, at temperatures as great as 1400 C. The very high temperatures meant the lavas were as fluid as engine oil, allowing the flows to cover vast distances.

Mercury also shows evidence for past volcanism, but you'll need to look a lot harder to find it. Masked by craters that pockmark its surface, Mercury hides lava plains similar to the lunar maria. The craters themselves actually give some indirect evidence for past volcanic activity on Mercury. The planet lacks craters less than 50 km in diameter, and the simplest interpretation is that lavas buried them thousands of millions of years ago, when Mercury was a much fierier world.

How long ago did volcanism stop on the Moon and Mercury - and why? Samples of lunar lava returned by the Apollo astronauts have been dated at 3200 million years or older - far more ancient than most rocks on the Earth. The cratering record for both worlds confirms that most volcanic activity ended over 3000 million years ago.

The reason is simple. Both worlds are small, compared to the Earth, Venus and Mars. A golden rule in physics, which applies to volcanic activity on a planet, is that small bodies cool more quickly than larger bodies. The Moon and Mercury have cooled faster than the Earth and Venus, hence their quicker decline in volcanic activity.

Furthermore, because of their smaller size, the Moon and Mercury had less primordial heat leftover from their creation. They also contained a smaller fraction of radioactive elements, the decay of which is all-important in providing planets with a continued source of internal heat. The Moon and Mercury have cooled to form thick solid crusts. While their interiors may be molten, the magma is trapped beneath a deep rigid crust and is sealed in forever.

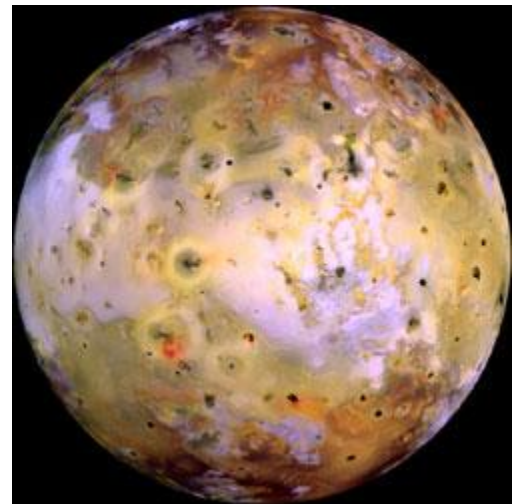
Erupting moons

To the surprise of many scientists, the spacecraft armada has revealed that volcanism is not confined to the rocky planets of the inner Solar System. One of the highlights of the Voyager missions to Jupiter in 1979 and 1980 was the discovery of active volcanism on its moon Io. Navigation engineer Linda Morabito was running a image processing technique to brighten an image returned from the Voyager 1 spacecraft, when she was greeted by a huge semicircular plume extending outward some 280 km above the moon's multicoloured surface. Previously invisible in the raw image, the faint plume represented a huge volcanic eruption, spewing a fountain of molten rock faster than the speed of sound. Further careful processing of other images revealed no less than eight active volcanoes on this world.

Io is about the same size as our Moon, which is now volcanically dead. Why, then, should Io be the most active volcanic world in the Solar System?

The answer comes the third option for internal heat, tidal forces. Io is under constant stress. It orbits Jupiter at approximately the same distance the Moon orbits Earth - but Jupiter is 318 times more massive. As a result, Io is constantly stretched by Jupiter's immense gravitational pull, and - to make matters worse - its sister moons Europa and Ganymede tug on Io in the opposite direction. This repetitive tug-of-war raises and lowers Io's surface by up to 100 metres as it revolves around Jupiter. Such tidal forces produce enormous amounts of energy, in the form of heat in the moon's interior. Although Io contains some radioactive elements, it's the heat liberated in the continuous flexing that has melted the moon's interior, resulting in a surface peppered with over 300 volcanoes, some of which are active today.

Could similar volcanism be found on Jupiter's other large moons, Europa, Ganymede and Callisto? These moons do undergo tidal heating, but to a lesser extent, as they lie at greater distances from Jupiter where gravitational forces are weaker. The answer may lie in recent images from the Galileo spaceprobe, currently in orbit around Jupiter. They show evidence for a bizarre form of icy volcanism on Europa and Ganymede. This 'cryovolcanism' involves slushy, oozing ices and brines driven to the surface by interior heat. These moons might also suffer more dynamic eruptions, with geysers spraying fluid high into a jet-black sky.



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Io - the most volcanically active place in the solar system.

Moving yet further afield, the Cassini spaceprobe, currently en route to the ringed world Saturn, may find volcanism on the many moons which circle this gas giant. Voyager 1 and 2 sped past Saturn with only hours to image the surfaces of the planet's moons. Like Galileo at Jupiter, Cassini will enter orbit around Saturn and repeatedly encounter a selection of satellites. Who knows what volcanic features its sharp-eyed cameras may bring into focus?

Cosmic perspective

The new technology that permits planetary exploration has expanded the science of volcanology far beyond the well-worn terrestrial field localities of Hawaii and Iceland - the cradles of volcanic research. Spacecraft have shown that similar kinds of volcanoes, and also more exotic styles of volcanism, occur throughout the Solar System.

If we are to fully understand the geological processes that have shaped our dynamic planet - and others beyond it - we must be prepared to go looking for the answers. Fortunately we stand at a revolutionary time, a time where rapid advances in technology provide us with the means to search, to unravel and eventually to understand why worlds erupt.