

ICE ON MARS -- SOME EVIDENCE FROM VOLCANOES

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If the interpretations of currently extensive ground ice on Mars are correct and if such conditions represent earlier stages in the planet's climatic evolution as well, the subsurface interaction of magma and ice would appear to have been inescapable. Maars and tuff rings would be predictable landforms, and some prospective martian analogs for the terrestrial features have, in fact, been identified. Other landforms on Mars suggest that volcanism and glaciation may have coincided periodically in time and space during the planet's history and thus imply that surface ice was more extensive in the past than it is today.

Tablemountains in Iceland and elsewhere have been interpreted as products of subglacial eruptions because of their shapes and/or petrologic compositions: they are characterized by steep-sided pedestals of pillow lava and palagonite tuff breccia, surmounted by subaerial basalt flows that commonly formed small shields.

On Mars, features resembling tablemountains, and similar in dimension to the Icelandic structures, appear to be localized primarily in the plains north of lat 40°N; if a subglacial analogy for them applies, an expanded polar ice cap could have hosted magmatic intrusions and subsequent eruptions.

One of the persistent conundrums on Mars has been an explanation for the continuous basal escarpment around the enormous shield volcano Olympus Mons. There is no apparent counterpart around subaerial shields on Earth. However, oceanic-island shields do have breaks in slope near sea level comparable to, though not as sharp as, those at the top margin of the tablemountains, and similar developmental stages have been ascribed to both the subaqueous and subglacial volcanic processes.

We propose that the basal scarp of Olympus Mons is analogous to the steep flank of tablemountain pedestals and indicates existence of a 1-4-km thickness of surface ice in the Olympus Mons region at the time eruptions began. The platform on which the martian shield is built thus would consist of 8x10⁵ km² of pillow lava and palagonite breccia, with attendant dikes and sills.

Rates of Magma Supply and Ages of Volcanic Systems

VOLUME AND STRATIGRAPHIC VARIATION OF PLEISTOCENE VOLCANICS SOUTH OF LASSEN PEAK, CALIFORNIA

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Volcanism in the last .6my in the region south of Lassen Peak produced predominantly andesite and dacite, with minor basalt and rhyolite. Major and trace element abundances and mineral analyses are organized according to stratigraphic succession based on geologic field mapping of 180 km². Eruptive temperatures vary from 828-1061°C according to FeTi oxide calculations. 0.8km³ of dacite forms the base of the section in Mt. Tehama, an eroded stratocone in the western and central part of the area; 1.2km³ of andesite under 2.2km³ of dacite are at the base of a platform to the east that accumulated 14km³ of andesite (and minor dacite) between .6-.4my ago. These flows were gently folded along NW axes and 3 dacite domes (1.8km³) protruded through. A 3km³ dome covers the vent that produced the plagioclase flows. Meanwhile, Mt. Tehama erupted 20km³ of early andesite flows and pyroclastics, culminating in an explosive episode producing only .15km³ of debris that marks the end of early stratocone activity. The youngest group of flows that issued from Mt. Tehama consists of 11km³ of andesite, basalt, basaltic andesite, andesite, and dacite erupted in that order. After .25my ago domes extruded on the SW flanks of the dissected volcano and along its NE quadrant contributed another 8km³ of dacite, minor andesite and rhyolite. Finally, 5km³ of rhyolite flows were extruded from a vent now covered by Lassen Peak, and a shield volcano 8km to the SE was built of 7km³ of high Al basalt and andesite. Sr varies from 200-800 ppm, V from 65-247 ppm, and Y from 14-25 ppm. All 3 elements tend to increase slightly in early flows of Mt. Tehama while Sr and Y but not V reach a high value and then decrease in younger flows, with lowest values in dacite domes and rhyolite flows. Maximum Y value is in dacite flows of Mt. Tehama.

ERUPTION RATE IN CENTRAL AMERICA ESTIMATED FROM VOLUMES OF PUMICE DEPOSITS

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Dacite pumice deposits in the Nicaraguan volcanic chain are easily identified in the field and lend themselves to fairly accurate volume calculations; this suggests a simple method for calculating total magma eruption rates. Using an estimate for average mafic to silicic magma production (8:1, based on field observations), the total material erupted equivalent to each dacite deposit can be calculated. Such figures, combined with radiometric dates, have been used to estimate the recent rate of eruption for a 100-km. length of the chain.

For the last 21,000 years the number of large pumice eruptions is well known, and yields variable and high estimated total eruption rates of 13 to 46 km³ per million years per kilometer of arc. Extending the time back to 400,000 years better averages fluctuations, but increases the probability of missing significant deposits; for that period the (minimum) estimated rate is 7 km³/km.

The lower range of these figures compares reasonably with other workers' estimates for the central Andes and for island arcs. If a rough figure of 10 km³/my/km is accepted for Nicaragua, the visible volume of all the present volcanoes is insufficient to account for material erupted in even the last 100,000 years; either the present edifices are extremely young, or most of the erupted material resides in thick windblown deposits filling the Nicaraguan Depression.

THE HISTORIC ACTIVITY OF FUEGO VOLCANO, GUATEMALA: CONSTRAINTS ON THE SUBSURFACE MAGMA BODIES AND PROCESSES THEREIN

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The times of activity at Fuego (one of the most active volcanoes in the world) since 1800 correlate with the activity of other Central American volcanoes. Approximately 0.7 km³ of olivine-bearing, high-Al₂O₃ basalt has been erupted since 1932, and about 1.7 km³ has been produced during 450 years of historic records. A minimum of 13,000 years and a maximum of 100,000 years were required to build Fuego's cone of 50 km³. Within the recent cluster of activity since 1932, rates of magma production have increased to 0.5m³/a¹ and the trend has been toward more eruptions (shorter repose) of progressively more mafic basalt. 47% of the eruptions occurred within 2 days of the fortnightly tidal maximum and 36% occurred within 2 hours of the semi-diurnal minimum of the vertical tidal gravity acceleration. Thus the maximum compressional component of the tidal cycles can trigger an eruption at Fuego. Eruptions with higher effusion rates produce larger volumes of materials, although they only last a few hours. A threshold volume of 10³m³ is involved in a vulcanian event. It also appears that less than 700 m depth of magma is expelled from Fuego's fissure vent during one vulcanian episode. The 20-70 year clusters of activity beginning at 80-170 year intervals are interpreted as the ascent of primary batches of magma ascending to the secondary chamber and erupting. The mode of ascent (viscous sphere vs. dike-like body) from the deeper (8-16 km), large (1 km³) primary chamber into the shallower (2-5 km), smaller (.1 km³), dike-like secondary chamber may be a critical factor in determining the composition of the lavas. It may also explain the andesite-basalt transition at Fuego and the basalt-andesite polarity of Fuego to its twin, Acatanaco.

RECENT RATE OF MAGMA SUPPLY TO KILAUEA VOLCANO, HAWAII

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The rate of magma supply to Kilauea Volcano during four long-lived eruptions since 1952 was reported by Swanson (1972) to be nearly constant at 9 x 10⁵ m³/mo. Swanson argued from several lines of evidence that this supply rate applies to noneruptive periods as well and therefore represents the steady-state supply to Kilauea, at least over time scales of a few decades during periods of quiescence at neighboring Mauna Loa. Results of high-precision gravity surveys and related geophysical observations at Kilauea during 1975-1977 indicate that, after a local M=7.2 earthquake in November 1975, magma was delivered to the summit region at a mean rate of 9.3 x 10⁵ m³/mo until June 1976. Magma then gained access to the east rift zone, where it accumulated at roughly the same rate until an eruption there in September 1977. These results support the conclusion that magma has been delivered to Kilauea at a nearly constant rate during the past 25 years. However, it is clear from the historic record that only a small fraction of the implied magma supply has been extruded subaerially since the beginning of the 19th century. A possible source of this discrepancy is

the unknown volume of magma involved in subaqueous eruptions or shallow intrusions. At least four discrete intrusions into Kilauea's east rift zone occurred during 1975-1977, and summit inflation remains intermittent and relatively weak. Therefore, most magma delivered to Kilauea during the past 44 months probably resides in shallow storage within the east rift zone, providing a significant potential for future eruptions in the area.

Swanson, D.A., 1972, Magma supply rate to Kilauea Volcano, 1952-1971, *Science*, 175, 169-170.

RECENT GEOLOGIC INVESTIGATIONS ON HUALALAI VOLCANO, HAWAII

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Hualalai Volcano, on the island of Hawaii, covers an area of 900 km² and has a subaerial volume of 100 x 10³ m³. Its last major eruption occurred in 1821. Vents are concentrated along two rift zones that strike N 45° W and N 10° W and have a total length of 40 km. Vent deposits are commonly rhyolite and spatter cones but also include silicic shields, suggesting relatively long-lived eruptions, and phreatic debris. Recent geologic mapping and ¹⁴C dating indicate that 1) most of the surface vents and flows are Holocene; 2) approximately 20 x 10³ m³ of basalt have been erupted in the last 10³ years; 3) at least 6 major eruptions have occurred in the last 500 years, extruding about 10³ m³ of basalt. The rate of magma supply from the mantle source volume to the surface during Holocene time has been about 2 x 10⁵ m³/yr, 24 of that calculated for Kilauea Volcano (Swanson, 1972). Petrochemical variations among alkalic basaltic rocks and the development of trachytic suggest that low-pressure fractionation, possibly in a shallow magma chamber, is occurring.

RECOVERY OF DATABLE CHARCOAL FROM BENEATH YOUNG LAVA FLOWS -- GUIDELINES FROM HAWAII

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An understanding of long-term eruptive rates of particular volcanoes requires that the absolute age of prehistoric lava flows be determined. For young flows, this means that material must be recovered for carbon-14 dating. Techniques for the recovery of charcoal from beneath young lava flows have been developed during studies in Hawaii aimed at understanding the prehistoric (pre-1800) eruptive history of Mauna Loa and Kilauea Volcanoes. Studies by workers in the fire prevention and investigation field have shown that charcoal formation is a rate-dependent process controlled primarily by temperature and duration of heating, as well as by the moisture content, density, and size of the original wood. Excavations beneath historic flows show that charcoal forms wherever wood is quickly buried by lava but generally burns to ash soon after formation. Charcoal, once formed, is preserved only where circulation of oxygen is restricted, or where temperatures remain below that required for charcoal ignition. With an understanding (and application) of these factors, carbonized material, especially roots, can be routinely obtained from beneath all parts of pahoehoe flows and from under margins of aa flows wherever lava has covered brush or forest-covered soil.

RATES OF VOLCANIC ACTIVITY ALONG THE SOUTHWEST RIFT ZONE OF MAUNA LOA VOLCANO, HAWAII

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Flow-by-flow mapping of the 65-km-long southwest rift zone and adjacent flanks of Mauna Loa Volcano, Hawaii, and about 50 new ¹⁴C dates on charcoal from beneath these flows permit estimates of rates of lava accumulation and volcanic growth over the past 10,000 years.

The sequence of historic eruption along the southwest rift zone, beginning in 1868, shows a general pattern of uplift migration and increasing eruptive frequency and volume, culminating in the great 1950 eruption. No event comparable to 1950, in terms of volume or vent length, is evident for at least the previous 1,000 years. Rates of lava accumulation during the historic period were several times higher than average rates for the preceding several thousand years along the southwest rift zone and adjacent flanks. Rates of lava accumulation along the zone have been unequal to those of active Kilauea Volcano, during the historic period but were much lower in prehistoric time (Kilauea data by R. T.