GEOLOGIC ALTERATION AND LIFE IN AN EXTREME ENVIRONMENT PU'U WAIAU, MAUNA KEA, HAWAII.
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We are investigating Pu'u Waiau, a cinder cone located near the summit of Mauna Kea volcano. Lake Waiau occupies a portion of the crater. Volcanic ash and lapilli which form the cone have been hydrothermally altered to a material with a reflectance spectrum close to that of the martian bright regions. An extremely limited ecosystem, consisting mainly of bacteria, is found in the water and the rocks. Pu'u Waiau provides an opportunity to study geologic alteration and life in an environment approaching that on early Mars.

Geology and Environment: Pu'u Waiau is located one km southwest of the summit of Mauna Kea, at an altitude of approximately 4,000 m. The cone was formed by eruptions of ash and lapilli. A hawaiite-mugearite lava flow from Pu'u Waiau has produced a K-Ar date of 107+/-13 ka [1].

Mauna Kea (White Mountain) has been glaciated at least four times, most recently around 12,000 years ago. Several of the summit cones and flows are characterized by hyaloclastites and pillow lavas indicative of eruption into glacial meltwater. *Porter* [2] contends that Pu'u Waiau was erupted subglacially, while *Wolfe et al*.[1] argue for subariel eruption during an intergalcial period.

The summit of Mauna Kea is a semi-arid, alpine desert tundra. Nighttime temperatures fall below freezing throughout the year [3]. The upper slopes are snow covered each winter but the snow completely melts and ablates in the spring. *Woodcock* [4] described a 10 m thick permafrost layer beneath the south wall of the Mauna Kea summit cone. The present investigation located interstitial ice within a few cm of the surface in the outward facing east slope of Pu'u Waiau.

Lake Waiau, located in the Pu'u Waiau crater, is the only permanent body of water on Mauna Kea. The lake is fed by the melting of snow and subsurface ice, and the level is maintained by a small outflow channel. The lake is perched on a layer of relatively impermeable pyroclasts [2].

Alteration: Portions of the vesicular ash and lapilli which form Pu'u Waiau have been extensively altered. The major secondary mineral is clay, identified as montmorillonite mixed with saponite [3]. Minor alteration components include the zeolites phillipsite and possibly gismondine [1]. This suite of minerals is indicative of hydrothermal alteration at moderate temperatures, probably due to the percolation of warm water or steam through the cinders [1,3]. Alternatively, alteration could have been contemporaneous with eruption into subglacial meltwater [2].

Material on other portions of the upper slopes of Mauna Kea is much less altered. Fine ash and clay particles have been winnowed from much of the surface, leaving a lag deposit of mm to cm scale lapilli and rock fragments. The material below approximately 10 cm is finer grained than that at the surface and contains considerably more x-ray amorphous colloidal material (palagonite) than clay. The surface ash is extremely dry, while the palagonitic material below a depth of approximately 5 cm is distinctly moist. Much of this moisture evaporates within a few minutes upon exposure to the air.

Life: The summit of Mauna Kea is nearly devoid of life. The exception is the relative oasis created by Lake Waiau. The shoreline, particularly around short stream channels, is thinly fringed by grasses. Droppings from small mammals were observed near some of the grassy areas.

The lake also contains a limited population of microorganisms. We cultured lake water in three agar media for 30 hrs at 37°C. We also examined solids filtered from the lake water using optical and scanning electron microscopy. The lake sample contains 1-2 µm bacilli and submicrometer coccoid forms.

We also collected material from a suspected bacterial mat at the shoreline, which was producing bubbles of an unidentified gas. This samples contain culturable bacteria in much higher concentrations than the lake water, as well as numerous sausage-shaped microorganisms resembling diatoms.

The rim of Pu'u Waiau crater, approximately 100 m above lake level, consists of dry ash partially altered to smectite. A sample of this material yielded extremely small amounts of culturable bacteria. This result suggests that bacteria can survive at the surface anywhere on the mountain.

We also tested a sample of mixed volcanic ash and ice from the interstitial ice deposit on the outer slope of the cone. This material produced large colonies of micrometer-scale bacilli. The culture pattern resembled that from the dry ash sample, but was orders of magnitude more vigorous. These bacteria are apparently adapted to existence near the freezing point at the interface between ash and ice. However, they thrive when exposed to elevated temperatures and abundant nutrients.

Mars: Hydrothermally altered volcanic ash has been proposed as a spectral analog to the fine-grained, aeolian surface material which dominates the soil of Mars [5]. We measured the visible and near-infrared spectrum of altered, clay-bearing ash from the rim of Pu'u Waiau and compared it to a composite spectrum of martian bright regions [6]. Both spectra contain a relatively featureless ferric absorption edge through the visible and show essentially flat absorption in the near-infrared. Bands at 1400 and 1900 nm in the Pu'u Waiau spectrum result from higher levels of H_2O and OH in the ash than on Mars. The presence of ferric absorption features near 600, 750 and 860 nm in the martian spectrum implies higher levels of red (well-crystalline and pigmentary) hematite on Mars [7] than in the Pu'u Waiau material.

Bacteria can exist in a range of environments at the 4,000 m elevation on Mauna Kea. These microorganisms survive in water, at the interface of ice and volcanic ash and even in the dry ash itself. Bacteria on a warmer, wetter early Mars might likewise survive in isolated bodies of water, within permafrost layers or perhaps even in the near-surface regolith.

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