Scientists propose time-lapse continental drilling to monitor microbial, mineralogical, and hydrothermal processes in a young rift zone volcano

New Proposed Drilling at Surtsey Volcano, Iceland

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SUSTAIN workshop;
Heimaey Island, Iceland, September 30-October 4, 2014

Surtsey, an isolated oceanic island and a World Heritage Site of the United Nations Educational, Scientific, and Cultural Organization, is a uniquely well-documented natural laboratory for investigating processes of rift zone volcanism, hydrothermal alteration of basaltic tephra, and biological colonization and succession in surface and subsurface pyroclastic deposits. Deposits from Surtsey's eruptions from 1963 to 1967 were first explored via a 181-meter hole drilled in 1979 by the U.S. Geological Survey and Icelandic Museum of Natural History, which described petrologic characteristics of the basaltic tephra, partially altered to lithified tuff, thermal conditions, nature of hydrothermal alteration, and growth of a rare calcium-silicate and zeolite assemblage above and below sealevel [*Jakobsson and Moore*, 1986].

A workshop convened on Heimaey Island, Iceland, developed the scientific rationale and logistical strategies for a forthcoming proposal to fund a new drilling program at Surtsey. Twenty-four scientists from 10 countries, including representatives from the Surtsey Research Society and the Environment Agency of Iceland, attended the Surtsey Underwater Volcanic System for Thermophiles, Alteration Processes and Innovative Concretes (SUSTAIN) drilling program workshop, funded by the International Continental Drilling Program (ICDP). The collaborative investigations proposed by SUSTAIN's scientific team focus on three ICDP research themes: volcanic systems and geothermal regimes, the geobiosphere, and natural resources—as applied to environmentally sustainable pyroclastic rock concretes.

The synergistic approach agreed upon by the workshop participants aims to integrate new interdisciplinary findings about original constructive and eruptive processes at Surtsey with new studies of mineralogical processes in the 50-year-old deposits and new monitoring and exploration of the active hydrothermal system and subterrestrial microbial colonization. The workshop participants came to the decision that questions about the active evolution of thermal conditions and the role of abiotic and biotic processes in the progressive lithification of basaltic tephra, the nature of hydrothermal alteration, and the growth of a rare calcium silicate and zeolite assemblage above and below sea level over the past 35 years could be answered only by drilling near the site of the previous hole in the eastern crater of the volcano.

Through discussion and collaboration, the SUSTAIN workshop participants developed a proposed drilling program based on two cored holes, designed to protect the sensitive wildlife and vegetative habitats of the Surtsey Natural Reserve. A clean 200-meter-deep vertical hole with anodized aluminum casing would allow scientists to explore pore water chemistry, microbiota-water-rock interactions, and seawater compositional modifications over time in a future "observatory" with packer experiments. A 300-meter-long hole with steel casing inclined west toward the eastern volcanic vent axis would intersect dike intrusions beneath the crater, enabling researchers to gain additional information on deep stratigraphy and structure, and investigate the higher temperature zones of the hydrothermal system.

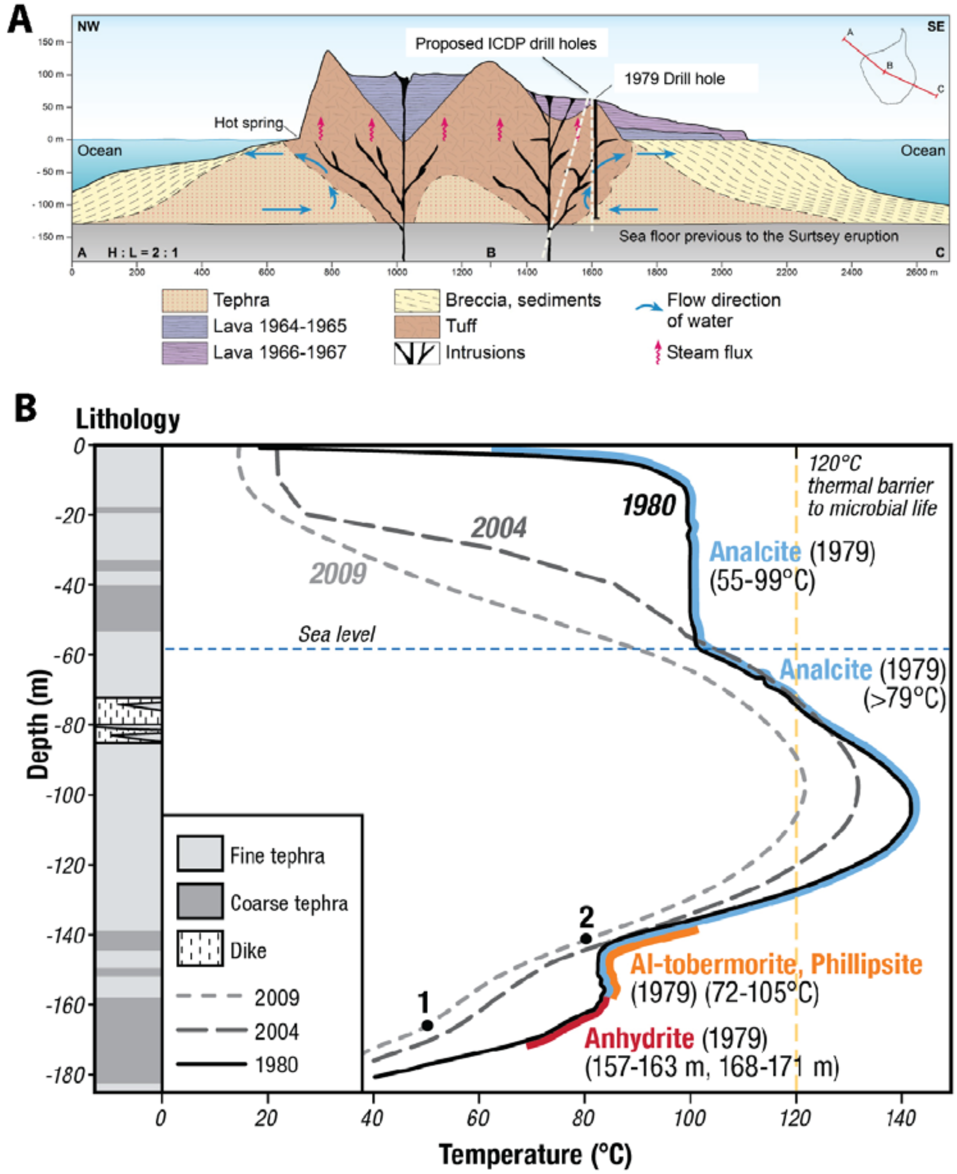

Figure 1. The internal structure of Surtsey volcano, a UNESCO world heritage site. A, Schematic cross-section of Surtsey (after *Jakobsson et al.*, 2013) showing inferred palagonitization of basaltic tuff in 2004, the 1979 drill hole, and the two proposed ICDP drill holes. B, Temperatures within the 1979 hole, measured in 1980, 2004, and 2009 (*Jakobsson and Moore*,1986; *Jakobsson et al*., 2013; *Marteinsson et al.*, 2014). Lines adjacent to the 1980 curve show the greatest abundance of authigenic analcite (blue), Al-tobermorite and phillipsite (orange), and anhydrite (red). Downhole water sampling in 2009 and microbiological analyses revealed an archaeal community dominated by *Archaeoglobus*-like 16S rRNA sequences at 145 m (80°C) (site **1**) and diverse subterrestrial bacterial sequences and *Methanobacteriales*-like archaeal sequences 172 m (54°C) (site **2**) (*Marteinsson et al.*, 2014).

Indigenous subterrestrial microbiota have been detected below a 130°C thermal barrier, disseminated in fluids from the underlying seafloor from faults and cracks of the underlying seafloor into permeable overlying tephras (*Marteinsson et al.*, 2014). Quantifying the subseafloor biosphere has become an important scientific goal of research programs, including the International Ocean Discovery Program, yet it is exceedingly difficult and costly to investigate these processes at depths of oceanic ridge systems. Meeting participants designed an experimental observatory within the proposed vertical hole that would provide quantifications of microbial alteration in seafloor basalt and rates of reaction in an evolving hydrothermal system. The proposed drilling program will be the first to sample microbial colonization of an isolated neo-volcanic island at successive depths from the surface to the seafloor with all possible precautions taken to avoid contamination from the surroundings to answer classical questions in geobiology of "Who are they"? "What do they do"? and "How do they do it"?.

Monitoring of the evolution of Surtsey's live hydrothermal system and its temperature, fluid geochemistry, permeability and microbial activity will provide invaluable information for understanding the formation, microstructures and macroscopic rock physics properties of lithified tuffs, as sustainable concrete prototypes and industrial resources with long term societal benefits for human and earth ecology. The authigenic calcium-silicate (Al-tobermorite) and zeolite minerals in Surtsey tephra have proven cation exchange capabilities for radionucleides and heavy metals. They are also the predominant crystalline binding phases of Roman pyroclastic rock concrete that has remained stable in seawater for 2000 years (*Jackson et al.*, 2013). Determination of rates of reaction and phase-stability relationships in the evolving Surtsey system as a function of time, temperature, and fluid interactions would provide an exceptionally well-constrained geological analog for innovative concrete encapsulations of hazardous wastes.

After development of a comprehensive data management system and an education outreach program for the global public the SUSTAIN workshop participants will submit a full drilling proposal to ICDP. More information about the proposed drill site can be found at http://surtsey.icdp-online.org.

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