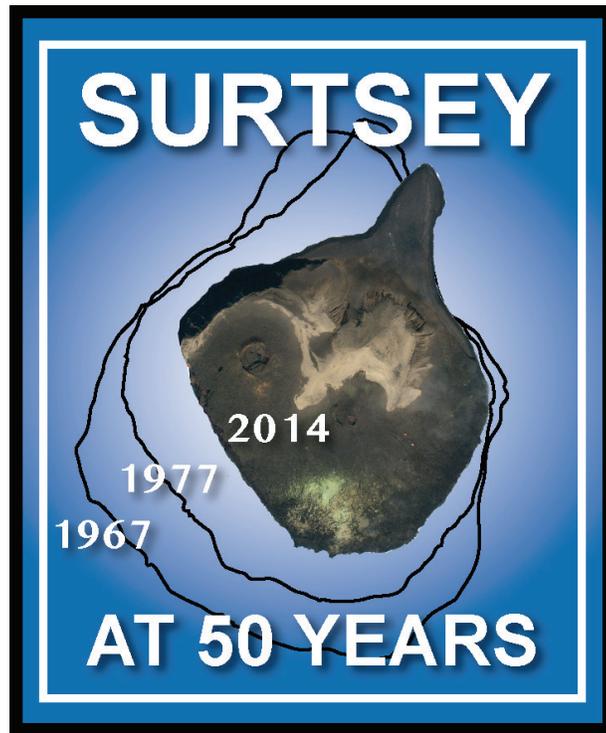




International Continental Drilling Program



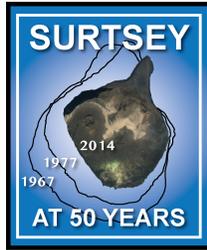
SURTSEY AT 50 YEARS - 2014 ICDP Workshop

Hótel Vestmannaeyjar and Conference Center

Vestmannabraut 28 900 Vestmannaeyjar ICELAND

September 30 to October 4, 2014

Program and Abstracts



SURTSEY AT 50 YEARS - 2014 ICDP Workshop

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September 30 to October 4, 2014

Program

Tuesday, September 30th 2014

- Afternoon Arrival, check in, and room assignments.
6:30 PM Welcome "Icebreaker"
7.00 – 9.00 PM Light Dinner

Wednesday, October 1st 2014

7.30 – 8.30 AM **Breakfast, Hótel Vestmannaeyjar**

8.40 – 9.10 **Welcoming Address, Conference Center**

Hallgrímur Jónasson, Director of RANNÍS, The Icelandic Centre for Research, Chairman of the Surtsey Research Society, "Research and environmental priorities at the Surtsey Protected Area."

Orientation

Marie Jackson, UC Berkeley, "What we will learn about changes at Surtsey over the past 50 years?"

9.10 – 10.20 **I. Surtsey Overview**

1. James G. Moore & Sveinn Jakobsson (USGS, USA; Iceland Institute Natural History, Iceland) "1979 Surtsey Drilling Project." 30 minutes
2. Sveinn Jakobsson, James G. Moore & *Ingunn Thorseth** (Iceland Institute Natural History, Iceland; USGS, USA; *Univ Bergen, Norway*) "Palagonitization of the Surtsey tephra, Iceland." 20 minutes
3. James White (Univ Otago, New Zealand) "Some new observations from Surtsey, and from the partly palagonitized Surtseyan volcano Pahvant Butte (Utah, USA)." 20 minutes

Posters

4. Páll Einarsson (or student) (Univ Iceland, Iceland) "Deformation of the Surtsey edifice."

10.20 **Coffee Break**

10.30 – 11.45 **II. Eruptive, Constructive and Hydrothermal Processes**

5. *Martin Jutzeler & Jocelyn McPhie (Univ Southampton, UK; Univ Tasmania, Australia)* "Characteristics of Oligocene, lithified and diagenetically altered "surtseyan" facies; Ohanapecosh Formation, Washington." 20 minutes
- 6, 7. *Magnús Tumi Guðmundsson, Bernd Zimanowski & Ralf Büttner (Univ Iceland, Iceland; U Wuerzberg, Germany)* "The importance of water-rock interactions in Icelandic subglacial and submarine volcanism." (See also *Zimanowski & Büttner, "Experimental Studies on Formation and Thermal History of Surtsey Deposits."*) 20 minutes
8. J. Michael Rhodes (Univ Massachusetts Amherst, USA) "Geochemical stratigraphy of the Hawaii scientific drilling project." 15 minutes
9. *Andri Stefánsson¹, Hanna Kaasalainen¹, Nicole S. Keller¹, Ingvi Gunnasson² & Bergur Sigfússon³* (¹Univ Iceland, ²*Reykjavík Energy, Iceland*, ³*Joint Research Centre, Holland*) "Disequilibrium aqueous speciation and chemical energy in hydrothermal systems." 15 minutes

10. Robert Zierenberg (UC Davis, USA) "Sulfur sources and sinks in submarine hydrothermal systems." 15 minutes
- 11.45 – 12.15 **Open Discussion:** What are the major factors to be resolved in understanding the eruptive processes, constructive processes and hydrothermal system at Surtsey recorded in deposits above and below sealevel over the past 50 years? Moderators: Magnús Tumi Guðmundsson, Andri Stefánsson, & Robert Zierenberg
- 12.15 – 14.00 PM **Lunch and Posters**
- 14.00 – 14.50 **III. Biotic and Abiotic Processes in Basaltic Glass Alteration**
11. Peter Schiffman, *Bruce Pauly* & Robert Zierenberg (UC Davis, USA) "Abiotic alteration of basaltic hyaloclastites: What we know (or think we know) about the process of palagonitization." 20 minutes
12. Steffen Leth Jørgensen (Univ Bergen, Norway) "Biotic processes in palagonite formation." 15 minutes
13. Viggó Þór Marteinsson^{1,3}, *Alexandra Klonowski*¹, *Eyjólfur Reynisson*¹, *Pauline Vannier*¹, *Magnús Ólafsson*² (¹Matís Research Institute, Iceland; ²ÍSOR, Iceland; ³Agricultural Univ of Iceland) "Microbial colonisation in diverse surface soil types in Surtsey and diversity analysis of its subsurface microbiota." 15 minutes
- Posters**
14. Magnus Ivarsson (Swedish Museum Natural History, Sweden) "Fossilized microorganisms in subseafloor basalts."
15. Andreas Türke & *Wolfgang Bach* (Univ Bremen, Germany) "Microbial life at the glass-palagonite interface."
- 14.50– 16:00 **IV. The Ancient Roman Concrete Connection: Applied Mineralogy**
16. Marie Jackson¹, James G. Moore², *Sean Mulcahy*¹, *Martin Kunz*³ (¹UC Berkeley, USA, ²USGS, USA; ³Lawrence Berkeley Lab, USA) "Authigenic crystalline cementitious fabrics in Surtsey tephra and Roman seawater concrete." 20 minutes
17. Piergiulio Cappelletti¹, *Diego Gatta*² & *David Bish*³ (¹Univ Naples, Italy; ²Univ Milan, Italy; ³Indiana Univ, USA) "Crystal chemistry and cation exchange in zeolite systems." 20 minutes
18. Nichola Coleman (Univ Greenwich, UK) "Interrelationships between synthesis conditions, structure and ion-exchange behaviour of aluminous tobermorite." 15 minutes
19. Tiziana Vanorio¹, *Anthony Clark*¹ & *Waruntorn Kanitpanyacharoen*² (¹Stanford Univ, USA; ²Univ Chulalongkorn, Thailand) "Rock physics characterization of rock-fluid interactions under HT-HP conditions." 15 minutes
- Posters**
20. Concetta Rispoli, Piergiulio Cappelletti, *Vincenzo Morra* & *Corrado Stanislao* (Univ Naples, Italy) "Mineral assemblages and material properties of ancient Roman harbor concretes."
21. Tobias Björn Weisenberger¹, *Rune S. Selbekk*² & *Hannes B. Mattsson*³ (¹Univ Oulu, Finland; ²Univ Oslo, Norway; ³Swiss Federal Institute Technology, Switzerland) "Basaltic glass devitrification and formation of zeolites."
- 16:00 – 16:30 **Open Discussion:** What are the major factors to be resolved in understanding the authigenic alteration processes in the Surtsey deposits ... and how these can be applied to innovative industrial and cementitious materials? Moderators: Piergiulio Cappelletti, Marie Jackson, Peter Schiffman, & Steffen Leth Jørgensen
- 16.30 **Coffee Break**
22. Dennis Nielson (DOSECC, USA) "ICDP: Funding and logistical support." 15 minutes
- 16:45 – 17.30 **Organized Discussion:** Descriptions of work sessions leading to writing the full drilling proposal; Leader and notetaker of focus groups determined; ICDP Funding and logistical support; Other potential funding agencies; Open Forum for discussion of proposed work by individual researchers. Moderators: Marie Jackson, Dennis Nielson

Wednesday, October 1st 2014 , continued

18.30 PM **Reception**

19.00 – 20.30 PM **Dinner**

Thursday, October 2nd 2014

7.30 – 8.30 AM **Breakfast, Hótel Vestmannaeyjar**

8.40 – 8.50 **Introduction to the day's activities, Conference Center**

8:50 – 10:20 **V. Zero Impact Drilling Program**

23. Þórdís V. Bragadóttir (Environment Agency, Iceland) "Vegetation and wildlife description, environmental status and protection measures within Surtsey." 30 minutes

24. Þórdís V. Bragadóttir, Aðalbjörg Birna Guttormsdóttir (Environment Agency, Iceland) "Environment Agency of Iceland, permitting process and information needed for an application to drill on Surtsey." 30 minutes

25. Dennis Nielson (DOSECC, USA) "Best practices for a zero impact drilling program through the Surtsey hydrothermal system." 15 minutes

Dennis Nielson (DOSECC, USA) "Downhole geophysical logging and imaging." 15 minutes

10.20 – 10:50 **Open Discussion:** What are the major factors involved in siting the Surtsey drill hole?

10.50 **Coffee Break**

11.00 – 17.00 **VI. Vestmannaeyjar Field Trip**

26. James G. Moore (USGS, USA) "The 1973 eruption of Eldfell volcano, Heimaey, Iceland." 20 minutes

Ingvar Atli Sigurðsson (Iceland Institute Natural History, Iceland) "Introduction to the afternoon field trip."

11:45 **Pick up bag lunches**

Group photo

12:00 **Board bus for afternoon field trip**

17:00 **Return to Hotel Vestmannaeyjar**

18.30 PM **Reception**

19.00 – 20.30 PM **Dinner**

Friday, October 3rd 2014

7.30 – 8.30 AM **Breakfast, Hótel Vestmannaeyjar**

8.40 – 8.50 **Introduction to the day's activities, Conference Center**

8.50 – 9.00 **Organization of focus group work sessions to write the full drilling proposal**

9.00 – 11.00 **Focus group work sessions to develop realistic, achievable scientific goals for the Surtsey drilling project** (Session leaders and notetakers to be determined on Thursday afternoon).

11.00 **Coffee Break**

11.15 – 12.30 **Focus group works sessions reconvene, with option to change groups**

12.30 – 1.30 PM **Lunch**

1.30 – 3.15 **Focus groups present their wish lists** (~10 minutes), followed by discussion about what is feasible and what is not from technical, budgetary and environmental perspectives.

3.15 – 4.15 **Focus groups write a detailed outline for proposed research projects**, a 2-3 page of points that can easily be worked into proposal text.

4.15 **Coffee Break**

4.30 – 5.30 **Open Discussion: The Road Ahead.** Completing the full drilling proposal and individual contributions to the Supporting Appendix**.

18.30 PM **Reception**

19.00 – 20.30 PM **Dinner**

Saturday – October 4th 2013

7.30 – 8.30 AM **Breakfast, Hótel Vestmannaeyjar**
8.50 – 9.00 **Wrap up, Conference Center**, and assignments with due dates for proposal components
9:00 – 10:30 **Writing session**, for group collaborations on components of the drilling proposal and individual contributions to the Supporting Appendix of the drilling proposal.
10.30 **Coffee Break**, and room check out

Hiking or a possible fishing boat trip around Surtsey (in good weather) in the afternoon.
Departures on the 11:30, 17:30 or 20:30 ferry to Landeyjahöfn (good weather) or the 15:30 ferry to Þorlákshöfn (bad weather)

Notes

* italics designate research collaborators not present at the workshop

**Individual contributions (1-3 pages) to the Supporting Appendix of the drilling proposal: If the drilling program at Surtsey were successfully implemented, and you had the opportunity to work on Surtsey material, then what specific research investigations would you undertake? What analytical, experimental, or theoretical methods would you employ? With whom would you collaborate? Where would you seek funding? Your contribution is due to Marie Jackson by October 20th, 2014, the same date that travel reimbursements must be received.

Vegetation and Wildlife Description, Environmental Status and Protection Measures within Surtsey

Pórdís Vilhelmína Bragadóttir¹

¹ Environment Agency of Iceland, Suðurlandsbraut 24, 108 Reykjavík, Iceland,
thordis.bragadottir@umhverfisstofnun.is

Scientists maintain an annual watch on the plant and animal colonisation in Surtsey. The first colonists were diatoms in 1964 but the first vascular plant, the sea rocket (*Cakile artica*), was found in 1964. Today 73 vascular plant species have been found in four main vegetation communities on Surtsey. The plant cover is relatively thin except in the gull colony. The first fungi was found in 1965, bryophyte in 1968 and lichen in 1970. The first birds to breed in Surtsey were black guillemots (*Cepphus grille*) and fulmar (*Fulmarus glacialis*) in 1970. Since then 15 species have tried to nest in the island and 11 breed there on annual basis. In 2004 a total of 336 species of invertebrates had been recorded in Surtsey. Since 1980 grey seals (*Halichoerus grypus*) have breed on the peninsula.

The objective of declaring Surtsey a protected area was to ensure that development of the island would be in keeping with the principles of nature itself. The purpose of conservation is to ensure that colonisation by plant and animals, biotic succession and shaping of geological formation will be as natural as possible, and that human disruption will be minimized. When Surtsey was protected in 1965 human visits to the island were restricted. These restrictions are first and foremost to prevent biological contamination and to protect Surtsey's delicate environment. Permission must be obtained from the Environment Agency of Iceland before going onshore and dive inside the reserve. Visits to Surtsey are limited to research purposes. Photographers and film crews have been allowed to go onshore to make documentary material about the island.

According to article 6 in regulation no. 50/2006 on Surtsey nature reserve it is prohibited to disturb vegetation, animal life or geological formations or other natural features within the reserve. Construction work should cause minimum disturbance and have little environmental affect.

In order to minimum the environmental affect number of expeditions to Surtsey is limited each summer. The Environment Agency has listed guidelines for restrictions on expeditions to Surtsey in the management plan for Surtsey. These restrictions pertain to number of people in each expeditions, length of stay and number of expeditions each year. Expeditions during nesting season are not allowed except when it is not possible to conduct the work at other times.

Transportation of animals, plants, seeds, organisms, minerals and soil to the island is prohibited.

References:

Surtsey Research Progress Reports online http://surtsey.is/pp_ens/write_ref_2.htm

The nomination report for Surtsey for the UNESCO world heritage list
http://surtsey.is/SRS_publ/WHL/Surtsey_Nomination_Report_2007_72dpi.pdf

Environment Agency of Iceland, permitting process and information needed for an application to drill on Surtsey

Þórdís Vilhelmína Bragadóttir¹ and Aðalbjörg Birna Guttormsdóttir²

¹ Environment Agency of Iceland, Suðurlandsbraut 24, 108 Reykjavík, Iceland, thordis.bragadottir@umhverfisstofnun.is

² Environment Agency of Iceland, Suðurlandsbraut 24, 108 Reykjavík, Iceland, birnag@umhverfisstofnun.is

The Environment Agency of Iceland manages over 100 protected areas in Iceland. According to article 38. law no. 44/1999, on nature protection an authorization of the Environmental Agency is required for projects where there is a risk of damage to sites of natural interest. Electronic application form is located on the Agencies web page, www.ust.is. The Environment Agency has set its own timeframe of 15 working days after the application submission and complete data gathering from the applicant. With larger projects and projects that may significantly affect the conservation value of the area this work can take up to 40 working days while the application is sent to stakeholders and research institutions for review.

Construction, disturbing the earth, extracting materials and otherwise altering the land or the sea floor within the reserve is prohibited according to article 7. in regulation no. 50/2006 on Surtsey nature reserve except by permission of the Environment Agency and Vestmannaeyjabær municipal council, upon their receiving the opinion of the Surtsey Research Society's.

Assessing whether a project needs to go through the environmental impact assessment is carried out by the Icelandic National Planning Agency. Environmental impact assessment is carried out before applying to the Environmental Agency and the information gathered throughout the environmental impact assessment is used within the decision making process at the Environmental Agency.

The application to Environmental Agency must include a detailed action plan, time schedule, environmental impact evaluation of the project should be described, mitigation measures and how to prevent pollution of the area in case of accidents. If further construction work is needed to prepare the area for the drilling it should also be included in the permit application.

In addition to the Environment Agency's permit, the applicant must also, according to article 5. in the reserve regulation, apply for permit to go to shore in Surtsey and if needed dive inside the nature reserve for those who will perform the drilling if it will be allowed. This application is an addition to the previous permit given out by the Environment Agency and is applied for after the operational permit. Permission to go to shore in Surtsey applies to individuals and only those who are implementing the project.

The Environment Agency controls all expeditions to Surtsey and sends a guide with them for inspection. Payment for the guide is according to the Agency's tariff which is displayed on the Agency's website.

Crystal chemistry and cation exchange in zeolite systems

Piergiulio Cappelletti¹, G. Diego Gatta² and David L. Bish³

¹ Dipartimento di Scienze della Terra, dell' Ambiente e delle Risorse, *FEDERICO II* University, Naples, Italy, piergiulio.cappelletti@unina.it

² Dipartimento di Scienze della Terra "A. Desio", Milan University, Milan, Italy, diego.gatta@unimi.it

³ Department of Geological Sciences, Indiana University, Bloomington, USA, bish@indiana.edu

Zeolite minerals are, along with clay minerals, among the most common authigenic minerals in volcanoclastic and sedimentary rocks. Their paragenesis in tuffaceous rocks, together with the above-mentioned clays, can be useful indicators of syn- and post-depositional diagenetic processes that affected the parent rocks. Furthermore, the importance of natural zeolites as industrial minerals suitable for several technological applications has promoted research on worldwide volcanoclastic deposits, particularly those with high grades of zeolites (Passaglia and Vezzalini, 1985; de Gennaro and Langella, 1996; Cappelletti et al, 1999; de Gennaro et al., 2000; Cerri et al., 2001; Cappelletti et al., 2003; Langella et al., 2013; Machiels et al., 2014), although they generally lack the purity of their synthetic counterparts.

Smith's (1963) requirements for a zeolite include: 1) a 3-D framework of tetrahedra occupied more than 50% by Si and Al; 2) an "open" structure with a framework density (FD, number of tetrahedral atoms per 1000 Å) lower than 20 (Passaglia and Sheppard, 2001); and 3) an extraframework population represented by cations and H₂O molecules. These features govern the properties of zeolites (e.g., molecular sieve, reversible dehydration, cation exchange) (Passaglia and Sheppard, 2001). The general formula for a zeolite is M_xD_y[Al_{x+2y}Si_{n-(x+2y)}O_{2n}].mH₂O (Gottardi and Galli, 1985), where M are monovalent and D are divalent cations; in this formula the tetrahedral part, negatively charged due to Al-for-Si substitution, is balanced by the exchangeable extraframework cations, coordinating H₂O molecules. The theoretical cation-exchange capacity (CEC) of zeolites is primarily a function of the amount of Al³⁺-for-Si⁴⁺ substitution; the higher the substitution, the higher the CEC (Pabalan and Bertetti, 2001).

The favorable ion-exchange selectivity of natural zeolites for some cations such as Cs⁺, Sr²⁺ and NH₄⁺ paved the way for studies on the potential uses of these minerals in the treatment of radioactive wastes and contaminated wastewaters (Robinson et al, 1995; Pansini, 1996) and siting of nuclear waste repositories (e.g., Yucca Mountain Project, Broxton et al., 1987).

Given both the technological and geological importance of zeolites, samples from the drill core will be particularly interesting. Studies on similar deposits, such as the Campi Flegrei volcanic district (Italy), showed that zeolite crystallization took place in a relatively short time, likely due to the presence of juvenile water at condensation temperature, and no evidence of interaction with seawater was found. Comparison with previous experimental results on phillipsite crystals from Surtsey (Jakobsson and Moore, 1986) should clarify whether any cation-exchange processes have occurred or whether phase transitions may have occurred in the unusual chemical environment sampled in this drill hole. In this study, analyses of drill core samples will be performed using scanning electron microscopy (SEM-EDS) (both on crystalline phases and on residual/altered glass fraction) and by quantitative X-ray powder diffraction, using both lab and synchrotron data to supply accurate quantitative analyses of the mineral assemblages present in the drill core samples.

References:

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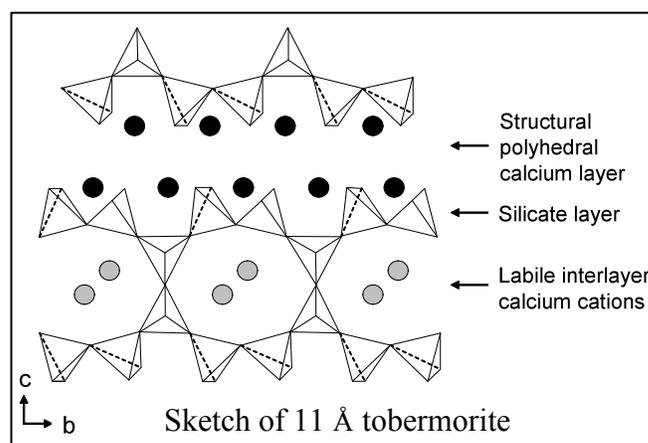
Interrelationships Between Synthesis Conditions, Structure and Ion-Exchange Behavior of Aluminous Tobermorites

Nichola J. Coleman

University of Greenwich, Faculty of Engineering & Science, Department of Pharmaceutical, Chemical & Environmental Science, Chatham Maritime, Kent, ME4 4TB, UK.

Background: Tobermorites are calcium silicate hydrate minerals comprising a double Ca–O sheet bound on both sides by silicate chains running parallel to the *b*-axis direction. Members of this family are characterised in terms of the length of their *c*-axis, which depends on the number of water molecules *per* unit formula. Tobermorites with basal spacings of 14.0, 11.3, 12.6, 10.0, and 9.3 Å have been reported.

11 Å tobermorite, $\text{Ca}_5\text{Si}_6\text{O}_{16}(\text{OH})_2 \cdot 4\text{H}_2\text{O}$, the most technologically significant polytype, is formed below 200 °C by the action of hydrous fluids on basic igneous rocks and is also found among the alteration products at the cement–rock interface of toxic and nuclear waste repositories. 11 Å tobermorite is readily synthesized in the laboratory and is the primary binder in contemporary autoclaved concrete blocks and in pozzolanic Roman maritime concrete. It is a candidate sorbent for nuclear and hazardous waste encapsulation owing to its ion-exchange behavior which arises from the facile replacement of labile interlayer cations.



The structure, thermal stability and ion-exchange capacity of 11 Å tobermorites vary widely as functions of silicate chain length distribution, extent of cross-linking between adjacent chains, stacking defects and isomorphic substitutions for both silicon and calcium. The interrelationships between synthesis conditions, structure, ion-exchange capacity, solubility and thermal stability, which are widely disputed, require clarification prior to the practical application of tobermorites in nuclear waste conditioning.

Objectives: Since natural deposits of tobermorite are very rare, an opportunity to explore the hydrothermal chemistry and phase-stability relationships of the mineral assemblages within the Surtsey system would provide invaluable information on the formation, structure and durability of tobermorites. Comprehensive characterization of the various 14.0, 11.3 and 12.6 Å tobermorites from Surtsey by X-ray diffraction, X-ray fluorescence, ^{29}Si and ^{27}Al nuclear magnetic resonance spectroscopy and Fourier transform infrared spectroscopy is proposed in order to understand how their structure and composition influence their ion-exchange behaviour, solubility and thermal stability. The findings of this investigation will be used to inform the bespoke synthesis of highly cation-selective tobermorites for nuclear and hazardous waste immobilization.

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Fossilized microorganisms in subseafloor basalts

Magnus Ivarsson¹

¹ Swedish Museum of Natural History, Department of Palaeobiology, Stockholm, Sweden, magnus.ivarsson@nrm.se

The oceanic crust makes up the largest potential habitat for life on Earth, yet next to nothing is known about the abundance, diversity and ecology of its biosphere. Because of difficulties with sampling, observing and culturing organisms, our understanding of the deep biosphere of subseafloor crust is, with a few exceptions, based on a fossil record. Paleontological material is, thus, central in the exploration of the subseafloor biosphere.

Various methods, depending on the nature of the samples, are used to study fossilized microorganisms. For 3D visualizations synchrotron-based X-ray tomographic microscopy (SRXTM) is being used, and detection of mineral phases and organic molecules are done by ESEM, Raman spectroscopy, Time-of-Flight secondary ion mass spectrometry (ToF-SIMS), or the combination of Focused Ion Beam-milling (FIB), Transmission Electron Microscopy (TEM) and synchrotron based X-ray Microscopy (STXM).

Fossilized microorganisms occur in veins and fractures in the basalt and are preserved both through embedding in hydrothermally precipitated minerals¹ and as various clay (montmorillonite) replacements within unfilled voids². Surprisingly, a majority of the fossilized microorganisms appear to represent fungi rather than prokaryotes. Even though this might be due to a bias in fossilization, the presence of fungi in these settings can not be neglected. Complex mycelial networks with anastomosing septate hyphae occur with clusters of cell-like objects, suggesting that both hyphal and yeast-like organisation is represented. Morphological diversity further suggests symbiotic relationships between eukaryotes and prokaryotes having close and specific spatial relationships³. The organisms are able to bore into mineral substrates (calcite and zeolites), forming characteristic galleries.

In a microbial context the Surtsey drilling program present a unique opportunity to study the rate and speed of microbial colonisation of fresh basalt. In a pilot study at the Swedish Museum of Natural History we extract ancient DNA from various fossil rich secondary minerals including carbonate veins in subseafloor basalt. The proposed Surtsey drill core would suit this study perfectly considering the young age and lack of diagenetic processes. Combining C¹⁴ dating with ancient DNA will make it possible to understand how microbial communities vary over time and during aging of the lithosphere as well as with depth.

References:

¹Ivarsson, M., Bengtson, S., Belivanova, V., Stampanoni, M., Marone, F., and Tehler, A. (2012) Fossilized fungi in subseafloor Eocene basalts. *Geology*, 40, 163-166.

²Ivarsson, M., Bengtson, S., Skogby, H., Belivanova, V., and Marone, F. (2013) Fungal colonies in open fractures of subseafloor basalt. *Geo-Marine Letters*, 33, 233-243.

³Bengtson, S., Ivarsson, M., Astolfo, A., Belivanova, V., Broman, C., Marone, F., Stampanoni, M. (2014) Deep-biosphere consortium of fungi and prokaryotes in Eocene sub-seafloor basalts. *Geobiology*. In press.

Authigenic Crystalline Cementitious Fabrics in Surtsey Tephra and Roman Seawater Concrete

Marie D. Jackson¹, James G. Moore², Sean R. Mulcahy³ and Martin Kunz⁴

¹. Department of Civil & Environmental Engineering, University of California, Berkeley, USA, mdjackson@berkeley.edu

². U. S. Geological Survey, Menlo Park, CA 94025, jmoore@usgs.gov

³. Department of Earth & Planetary Sciences, University of California, Berkeley, USA, mulcahy@berkeley.edu

⁴. Advanced Light Source, Lawrence Berkeley Laboratories, Berkeley, USA, mkunz@lbl.gov

Authigenic alteration processes in alkali olivine basalt tephra erupted by Surtsey volcano in 1963–1967 and in Roman harbor concretes constructed 2000 years ago with Campi Flegrei trachytic ash produce Al-tobermorite, a double-layered calcium-silicate-hydrate mineral; various zeolites, principally phillipsite; and sulphates and chlorides, mainly anhydrite and gypsum in the Surtsey deposits and hydrocalumite and ettringite in the Roman mortars (1, 2, 3). Al-tobermorite, phillipsite, and zeolitic tuffs show cation exchange capabilities for Cs^+ , Ba^{2+} , Sr^{2+} , Li^+ , Cd^{2+} , Pb^{2+} , Zn^{2+} , etc. and have relevance for encapsulations of toxic wastes (4, 5, 6, 7, 8), yet little is known about their material properties in changing temperature and chemical environments.

In the 1979 Surtsey drill core, authigenic crystalline fabrics in the vitric matrix and vesicles of glass particles mainly developed at 55–149 °C above and below sealevel; phillipsite appeared below sealevel at 37–72°C; and zeolite crystal size is greater in the submarine tuff (1). In massive Roman harbor concrete structures, an adiabatic thermal model based on exothermic hydration of calcium-aluminum-silicate-hydrate (C-A-S-H) binder suggests elevated temperatures $\leq 75\text{--}95$ °C for $\sim 2\text{--}3$ years. Al-tobermorite with $\text{CaO}/(\text{SiO}_2+\text{Al}_2\text{O}_3)=0.7\text{--}0.8$ crystallized in relict lime clasts. Al-tobermorite in pumice clasts, shown by X-ray microdiffraction analyses with synchrotron radiation, has a more siliceous composition, $\text{CaO}/(\text{SiO}_2+\text{Al}_2\text{O}_3)=0.6\text{--}0.7$, identical to crystals in Surtsey deposits (1). This may reflect post-pozzolanic processes after portlandite ($\text{Ca}(\text{OH})_2$) was consumed. Comparative analyses of Al-tobermorites from Roman mortars, Surtsey and laboratory syntheses (1, 2, 7, 8) will reveal how structure and composition influence ion-exchange behaviour, solubility and thermal stability.

In Surtsey tephra above sealevel, intermittent influxes of rain water and seawater storm surges may produce abrupt changes in a lower temperature, open chemical system, while in submarine deposits more gradual changes in fluid flow, chemical mass balance and temperature decrease may occur (9, 10, 11). In a Roman concrete pier exposed subaerially at Portus Cosa in Tuscany, for example, alteration of relict Campi Flegrei glass in the mortar produces a more complex authigenic zeolite assemblage than in the Baianus Sinus *pilae* in Pozzuoli Bay, which was submerged in 14–26°C seawater for two millenia. Alteration paths in 50-year-old Surtsey tephra sampled above and below sealevel by the new core may diverge, as well (10, 11).

Primary volcanic textures in Surtsey tephra may influence palagonitization, microbial interactions in fresh glass, and related development of authigenic crystalline fabrics. Al-tobermorite and zeolite in the fine ash rims of accretionary lapilli, for example, may reinforce interfacial zones; in vesicles of glass fragments they reduce pore space. Studies of variations in the volcanic and authigenic textures of the 50-year-old deposits will elucidate processes that influence long term changes in material characteristics, such as porosity, permeability, strength, fracture toughness, and elastic properties, along with fluid flow and ongoing reaction in the evolving pore space in tephra and tuff deposits of the volcanic edifice.

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Palagonitization and consolidation of the Surtsey tephra, Iceland

S. P. JAKOBSSON¹, J. G. MOORE² & I. H. THORSETH³

¹ Icelandic Institute of Natural History, Gardabaer (Iceland)

² US Geological Survey (USA)

³ University of Bergen (Norway)

During the explosive phase of the Surtsey eruption (1963-1967), basaltic tephra was deposited. Some 85 vol.% of the original tephra was basaltic glass. In early 1967 a hydrothermal system formed in the central part of the island. The first sign of alteration of the tephra was observed in 1969, and since then the process of alteration at surface has been followed closely. Furthermore, a 181 m hole was drilled in 1979 to study the alteration and structure of tephra at depth. The palagonitization of the basaltic glass and consolidation of the tephra is strongly temperature dependent. At 90°-100°C more than 90 vol. % of the glass is palagonitized in few years at surface. Below temperatures of $55^{\circ} \pm 4^{\circ} \text{C}$ the tephra in the drill core was not consolidated during 1967-1979. The consolidation of the tephra results from the palagonitization, as well as from the precipitation of secondary minerals. Chemical analyses of the basaltic glass and the palagonite reveal extensive mobilization of all major elements except Ti and Fe. Some of these elements, like Al and Mg, are partly restored in the palagonite following the crystallization of smectites. Signs of microbial activity have been found in most of the tuff samples. Evidence is still lacking for the involvement of bacteria during the main alteration phase of the Surtsey tephra. The area of Surtsey has shrunk from 2.65 km² in 1967 to 1.31 km² in 2013. By estimate, some 95 % of the volume of tephra above sea level has been transformed into palagonite tuff. The tuff is resistant to marine abrasion, indicating that the tuff core of the island will last for a long time, possibly thousands of years.

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Biotic Processes in Palagonite Formation

Steffen L. Jørgensen¹ and Ingunn H. Thorseth²

¹ Centre for Geobiology, Department of Biology, University of Bergen, Norway.

Steffen.jorgensen@bio.uib.no

² Centre for Geobiology, Department of Earth Sciences, University of Bergen, Norway.

ingunn.thorsethjorgensen@geo.uib.no

The presence and abundance of endolithic microbial cells within glassy basalt has, during the last two decades, been documented in both seafloor and sub-seafloor material, from a variety of different geographic locations (1- 5, 7). In the seafloor basalts numerous microbial cells of various morphologies associated with the altered glass (palagonite) rinds of most fractures and vesicles are often easily observed by electron microscopy. The microbial cells become heavily encrusted over time and accumulate as hollow, fossilised cells within the alteration rinds. The microbial growth and biomineralization partially control the porosity and texture in the altered glass and thus likely also the chemical exchange between basalt and seawater. Pit marks in the glass resembling the morphology of attached cells, as well as pitting in fractures without microorganisms, indicate microbial as well as abiotic mediated glass dissolution. In the glassy sub-seafloor basalts only fossilized cells are observed in fractures sealed by secondary mineral phases, demonstrating that the microbial activity continued as long as fluid circulation continued. The abundance is estimated to be in the range of 10^6 - 10^9 cells/gram glass for seafloor basalt and between 10^3 - 10^5 for buried basalt. These numbers are based on molecular analysis, such as qPCR, amino acids and direct cell counts (1,2,4) and are supported by estimates inferred through organic carbon content and thermodynamic calculations (6, 8). It appears that the communities are comprised mainly of *Bacteria* with only a minor fraction of *Archaea* present. Information concerning the taxonomic distribution in this habitat is scarce but it seems that *Proteobacteria*, *Actinobacteria*, *Bacteroidetes*, *Chloroflexi*, and *Firmicutes* are the dominating bacterial groups and members of *Marine Group I* and the *Deep Sea Archaeal Group* the main archaeal representatives. In general both the abundance and diversity is decreasing with age and burial. Based on taxonomic affiliation, culturing attempts and functional marker genes, a range of different metabolic pathways could potentially be utilized by the microorganisms present. This includes iron and manganese oxidation and reduction, sulphate reduction, and several steps in the nitrogen cycle. All of these pathways could have a significant impact on the alteration rate and palagonite formation.

However, to what extent these microbial communities are active and which pathways are dominating is unknown. Further, the factors controlling the potential *in situ* activity and hence the impact on weathering of basalt is unknown. These unknowns are of paramount importance to resolve or constrain in order to evaluate the microbial impact on palagonite formation and on basalt weathering in general. We would like to address these questions by applying high-resolution taxonomic community profiling of both DNA and RNA on both *in situ* samples and laboratory microcosm experiments.

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Characteristics of Oligocene, lithified and diagenetically altered “surtseyan” facies; Ohanapecosh Formation, Washington

Martin Jutzeler^{1,2} and Jocelyn McPhie²

¹. National Oceanography Centre, Southampton SO14 3ZH, United Kingdom, jutzeler@gmail.com

². Earth Sciences, University of Tasmania, Hobart, Australia, j.mcphie@utas.edu.au.

The >800-m-thick, Oligocene (~32 to 26 Ma) Ohanapecosh Formation records voluminous volcanoclastic sedimentation in a deep lake, or a protected sea embayment, adjacent to the northernmost Ancestral Cascades arc (Washington State, USA). The formation is well indurated and has a secondary mineral assemblage consistent with low-grade regional metamorphism (zeolite facies) and locally higher grade contact metamorphism close to younger intrusions.

A ~70-m thick part of the formation is basaltic and comprises well-bedded basaltic breccia and tuff, and basaltic dykes and sills. The beds are laterally continuous and even in thickness (3 cm-20 cm), and composed of well sorted, angular basaltic clasts. The basaltic clasts contain plagioclase laths with a trachytic texture and 20-30% irregular vesicles. Many beds are clast-supported and graded; coarse (>2 mm) clasts in the clast-supported beds have a mono-modal grain-size distribution and may be monomictic or polymictic (though dominated by texturally similar basaltic clasts). Accretionary lapilli and armoured lapilli occur at at least two levels in the succession.

The uniform components, their angular shapes and overall fine grain size, and the presence of accretionary lapilli suggest that the basaltic succession is the product of multiple, probably phreatomagmatic explosive eruptions. Underlying and overlying volcanoclastic facies have bed geometries consistent with deposition below wave base, so it is likely that this setting also applied during deposition of the basaltic succession. However, the water depth must have been relatively shallow because (1) explosive-magma water interaction occurred, (2) the explosions breached the water-air interface and produced accretionary lapilli, and (3) a small proportion of red, thermally oxidized clasts is present. This setting and style of eruptive activity existed on the flanks of Surtsey during its emergence, implying that the Ohanapecosh Formation basaltic succession could serve as a predictive analogue for the volcanoclastic facies to be drilled.

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Microbial Colonisation In Diverse Surface Soil Types In Surtsey And Diversity Analysis Of Its Subsurface Microbiota

Viggó Marteinnsson^{1,3}, Alexandra Klonowski¹, Eyjólfur Reynisson¹, Pauline Vannier¹ and Magnús Ólafsson²

[1] Mátis, Food safety, Environment & Genetics, Vínlandsleið 12, IS-113 Reykjavík, Iceland

[2] ÍSOR, Gensásvegi 9, 108 Reykjavík, Iceland

[3] Agricultural University of Iceland, Hvanneyri, IS-311 Borgarnes, Iceland

Correspondence to: V. Marteinnsson (viggo@matis.is)

Abstract

Colonisation of life on Surtsey has been observed systematically since the formation of the island 50 years ago. Although the first colonisers were prokaryotes, such as bacteria and blue-green algae, most studies have been focusing on settlement of plants and animals but less on microbial succession. To explore microbial colonization in diverse soils and the influence of associate vegetation and birds on numbers of environmental bacteria, we collected 45 samples from different soils types on the surface of the island. Total viable bacterial counts were performed with plate count at 22°, 30° and 37°C for all soils samples and the amount of organic matter and nitrogen (N) was measured. Selected samples were also tested for coliforms, faecal coliforms aerobic and anaerobic bacteria. The deep subsurface biosphere was investigated by collecting liquid subsurface samples from a 182 meters borehole with a special sampler. Correlation was observed between N deficits and the number of microorganisms in surface soils samples. The lowest number of bacteria (1×10^4 - 1×10^5 /g) was detected in almost pure pumice but the count was significant higher (1×10^6 - 1×10^9 /g) in vegetated soil or pumice with bird droppings. The number of faecal bacteria correlated also to the total number of bacteria and type of soil. Bacteria belonging to *Enterobacteriaceae* were only detected in vegetated and samples containing bird droppings.

We were able to collect hot subsurface samples deep in the centre of the volcanic island and record the temperature for 21 hours at 168 m depth. Both uncultivated bacteria and archaea were found in the subsurface samples collected below 145 m. The microbial community at 54°C and 172m depth was dominating with diverse bacteria and a homogeny archaeal community of *Methanobacteriales* while the archaeal community at 145 m depth and 80°C was dominated by *Archaeoglobus* like sequences. The subsurface microbial community in Surtsey may be regarded as indigenous subterrestrial microbiota as both bacteria and archaea showed low affiliation to any known microbiota and there is a high temperature barrier (130°C) atop. The indigenous subterrestrial microbiota has probably disseminated from the below faults and cracks of the seafloor in a similar manner as has been reported in other various subterrestrial environments, geothermal boreholes in Reykjavik (Marteinnsson et al., 2001a), fresh water hydrothermal vent cones in Eyjafjörður (Marteinnsson et al., 2001b) and in subglacial lakes on Vatnajökull (Marteinnsson et al., 2013). A new drill hole with core sampling in Surtsey will open a new window to the subterrestrial biome and give us insight into the role of microbes in corrosion and rock altering.

Surtsey 1979 Drilling

James G. Moore¹, Sveinn P. Jakobsson²

¹ U. S. Geological Survey, Menlo Park, CA 94025, jmoore@usgs.gov

² Icelandic Institute of Natural History, Hlemmur 3, IS-105, Reykjavik, Iceland,

The Surtsey eruption of Nov 1963-June 1967 occurred at the south end of the eastern volcanic zone 33 km off the south coast of Iceland. This zone is a part of the Mid-Atlantic Ridge spreading center. A new volcanic island of alkali olivine basalt was built on the insular shelf from a depth of ~123 m to a height of 174 m above sea level.

In 1979 a drilling program was organized to sample the volcanic products through this well-documented, new marine volcano. The drilling contract was jointly funded by \$11,350 from the Icelandic Museum of Natural History (now called the Icelandic Institute of Natural History) and by \$98,370 from the Geothermal Program of the United States Geological Survey. A major provision of the contract was removal of the drill rig and equipment and return of the island to its natural state after drilling. Transport of 38 tons of equipment, food, and water required 80 trips with an Icelandic Coast Guard helicopter and 6 trips with a large U.S. Air Force helicopter. Other transport was by fishing-boat-supported surf landings with a rubber dingy. Sea water pumped to the drill site was used for drilling fluid. The hole was drilled on the east side of the east vent June 4 to August 18, 1979. The 181-m-deep hole was started at 58 m above sea level and reached to the base of the volcano at 123 m below sea level. Core 4.7 cm in diameter was recovered from 95% of the hole depth. The drill hole encountered temperatures of 20°-142°C. After drilling, tidal flux in the drill hole was 2.08 m and was retarded 55 minutes from the tide at Heimaey. By 2004, 25 years after drilling, the maximum temperature had fallen to 129°C.

Most of the core is vesicular glassy basalt tuff and its alteration products. A 2-m-thick lava flow occurs near the top and a sub-vertical dike complex cuts basaltic tuff at 72-85 m depth. The dip of primary sedimentary layering in the core ranges from 10-60°, averaging about 30°. Slump planes are somewhat steeper, averaging about 50°. Accretionary lapilli occur throughout the core, and are more abundant above sea level. The volume percent of tuff vesicles is about 20% above sea level and about 10 % below sea level. Specific gravity averages about 1.7 above sea level and 1.9 below sea level. The hyaloclastite is generally palagonitized and hydrothermally altered. The principal secondary minerals are smectite, analcite, phillipsite, and tobermorite. Minor secondary minerals are gypsum, anhydrite, chabazite, calcite, xonotlite, and opal. Palagonitization has occurred at all levels, whereas lithification of tephra has only occurred above ~56°C.

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The 1973 Eruption of Eldfell Volcano, Heimaey, Iceland

James G. Moore¹

¹U. S. Geological Survey, Menlo Park, CA 94025, jmoore@usgs.gov

The Island of Heimaey lies off the south coast of Iceland on the eastern volcanic zone, a branch of the Mid-Atlantic Ridge spreading system. The island is underlain primarily by Pleistocene lavas and tuffs and is capped by a prominent volcano, Helgafell, which last erupted 5,000 years ago. The new volcano Eldfell grew during the period 23 January–early July, 1973 on the northeast side of Helgafell. The eruption began abruptly with lava fountaining along a 3-km-long north-northeast-trending fissure. Eruption soon consolidated into a single vent that built the 200-meter-high scoria cone of Eldfell. A massive aa lava flow more than 100 m thick in places moved north, northeast and east adding more than 2 km² to the island and cutting the pipeline and cable that supplied fresh water and electricity to Heimaey. The northern lava flow threatened to block the harbor entrance and thereby imperil 25% of Iceland's fishing catch. Within a few days 5000 inhabitants were evacuated because of heavy ash fall. A maintenance corps remained to clear the roofs of ash and make a concerted effort to impede movement of the lava flow. Tephra barriers were bulldozed in the lava's path and copious volumes of water were sprayed onto the flow, both from boats at sea and from pipes laid on the slowly moving flow. The flow thickened and finally stopped by the end of the eruption leaving the harbor entrance open. In fact, the flow improved the harbor by narrowing its east-facing opening.

Eventually about one third of the village was obliterated and 400 houses were destroyed by collapsing or when buried by tephra or lava. Others burned. When volcanic activity ceased in the summer of 1973 about half of the population returned; since then the village has grown back to its former size. Heat from the tephra-covered lava flow was "mined" by collection of steam formed by spraying water on the ash-covered lava flow. The steam was conducted to a heat exchanger where it heated fresh water that was eventually piped to most of the houses in the village. This system provided heat and hot water for 15 years until steam in sufficient quantities was no longer generated from the cooling lava.

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Best Practices for a Zero Impact Drilling Program Through the Surtsey Hydrothermal System

Dennis L. Nielson

DOSECC Exploration Services, LLC, Salt Lake City, Utah USA dnielson@dosecc-ex.com

In 1979, the USGS drilled a 181-meter deep core hole into Surtsey. This vertical hole was collared at an elevation of 59 m and drilled to a subsurface depth of 131 m. The core recovered has provided important insights into the processes that formed Surtsey, and into the alteration of hyaloclastite deposits in general. The hole also provides an important baseline for the thermal profile that impacts much of the drilling technology required for the project we are planning here. The coring process itself is not particularly difficult; however, the logistics associated with this project will dictate the methods that are employed and control project costs. The previous hole was drilled without Blow Out Protection equipment (BOPE), and we can assume that there is little probability that a blow out can occur in future drilling to comparable depths. This simplifies the drilling plan and reduces the amount of consumable supplies that must be transported to the island.

This workshop should develop scientific objectives for the drilling. These objectives can then be translated into the design of the hole(s) and subsequent measurements. Drilling up to 200 m depth can be done with relatively small, helicopter-transportable coring rigs. These rigs can drill either vertical or holes that are angled up to 45°. The coring will utilize sea water with a food-grade polymer used to increase viscosity. It is likely that we will experience lost circulation conditions through most of the drilling. However, excess fluid and cuttings can be returned to the ocean without environmental damage. It is advantageous for hole stability that drilling take place using two 12-hour shifts and operating seven days per week. We will use a three-person drilling crew and it is recommended that an equivalent science team be on site to process and secure the core.

We plan to use 4-1/2" casing to protect the surface of the hole from collapse. Coring will utilize an HQ or HQ3 (core in liner) system that drills a 96 mm hole with 63 mm core. This giving us the option of reducing to NQ (76 mm hole; 48 mm core) should hole conditions require. Following coring, the hole could be logged and a liner installed should continued temperature monitoring be required. Following the drilling, the site will be reclaimed to its pre-drilling condition.

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Geochemical Stratigraphy of the Hawaii Scientific Drilling Project

J. Michael Rhodes¹

¹Dept. of Geosciences, University of Massachusetts, Amherst, USA (jmrhodes@geo.umass.edu)

The Hawaii Scientific Drilling Project recovered ~ 3.5 km of basalt core from low on the flank of Mauna Kea volcano. This site was chosen to maximize the length of the recovered eruptive record (~ 200 - >600 ka) and to avoid intrusive units. Core logging identified 390 lithological units consisting of subaerial flows, hyaloclastite debris flows, pillow lavas, pillow breccia, and massive units (intrusive?). The abrupt transition from subaerial to submarine eruptions is at 1079 mbsl. XRF major and trace element analyses of 347 samples (sampling density ~ 10 m/sample) established the geochemical stratigraphy of the core. Drilling started in subaerial flows from Mauna Loa volcano. The transition from Mauna Loa to Mauna Kea flows is at 346 mbsl. The Mauna Loa shield-building tholeiites overlie a thin (107 m) sequence of alkalic to transitional tholeiite post-shield Mauna Kea lavas (eruption rate ~ 2 mm/yr). The underlying Mauna Kea shield-building lavas (eruption rate ~ 9 mm/yr) consist of four geochemically distinct magma types. Type-1 lavas (high SiO₂ and Zr/Nb) are ubiquitous below the post-shield lavas (1160 - 3506 mbsl) and are the dominant magma type throughout the core. Type-2 lavas (low SiO₂ but high Zr/Nb) are inter-layered with Type-1 lavas in the upper part of the core, especially in the subaerial section. Type-3 lavas (low SiO₂ and Zr/Nb) are present only between 1974 and 2468 mbsl. Below that they occur as intrusives, presumably feeders for the overlying extrusives. An enigmatic fourth magma type, present only as hyaloclastites, is restricted to 1765 - 1810 mbsl. It is characterized by high CaO, low SiO₂ and high incompatible element abundances and is underlain and overlain by Type-1 lavas. These lavas have affinities with the post-shield lavas and may reflect temporary waning in shield-stage magma production and supply.

Alteration of HSDP lavas is minimal throughout the core. Secondary minerals (gypsum, zeolites, clays) occur below 1000 mbsl, but are restricted to fractures or to lining vesicles. The geochemical effects of alteration are seen as losses in SiO₂, CaO, Na₂O, K₂O, Rb, Ba, U and Sr. The immobile elements include Al₂O₃, Fe₂O₃, MgO, TiO₂, P₂O₅, Ni, Cr, Th, Nb, Zr, Hf and the REE. These effects are attributed to freshwater leaching in permeable zones and the low downhole temperatures (40° C at 3 km).

What Next? The US Army, in search of water, have drilled and cored a 1.8 km hole between Mauna Kea and Mauna Loa volcanoes. A second ~ 2 km hole is to be drilled shortly. These cores will provide more realistic estimates of magma production and lava accumulation rates than the HSDP cores, which are minimum values. The geochemistry of these lavas, coupled with Ar dating, will provide even greater details of the transition from shield to post-shield volcanism as Mauna Kea moves off the Hawaiian hotspot.

Relevance to Surtsey Drilling Given the changes in the composition of Surtsey magmas during the eruption, detailed geochemistry of the core, along the lines of that undertaken during HSDP, should provide an unprecedented opportunity to study the development of a historic, well-studied, oceanic volcano from its inception on the sea floor, through the formation of a volcanic island, to the modification of the volcanic edifice by hydrothermal processes. The current and future studies of core from the Saddle region of Mauna Kea, may have further relevance to Surtsey drilling. There are numerous dikes of very young, evolved, post-shield lavas intruding older post-shield and shield stage lavas. Additionally, lavas below 1.4 km are hydrothermally altered and the downhole temperature is ~ 110° C.

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Mineral assemblages and material properties of ancient Roman harbor concretes

Rispoli C.⁽¹⁾, Cappelletti P.⁽¹⁾, Morra V.⁽¹⁾, Stanislao C.⁽²⁾

⁽¹⁾DiSTAR, Federico II University, 80134 Naples, Italy

⁽²⁾Geologist, Naples, Italy

This study reports results of mineralogical and petrographic analyses performed on pozzolanic mortars, coming from ancient marine concret cores, drilled by ROMACONS team in the 2006-2009 fieldwork. Concret cores here considered come from the Roman age harbours of Baia and Egnazia in Italy, Alexandria in Egypt, Chersonisos in Crete and finally Pompeiopolis in Turkey.

The following analyses were carried out: concrete cores sampling for thin sections realization; optical microscopy (OM); modal analyses on thin sections; X-ray powder diffraction; Scanning electron microscopy (SEM) and microanalyses (EDS).

Mineralogical and petrographic examinations performed on geomaterials from concrete cores of Roman harbours revealed coarse tuff aggregate, lime hydrated in seawater and pozzolanic volcanic fine sand.

Information from geological maps has allowed us to establish that the origin of the lime used for the dough and aggregate could be local.

The mineralogical-petrographic composition of Tuff aggregate and especially the typical mineralogic association (phillipsite > chabazite > analcime) allow us to say that those aggregates are from NYT (Neapolitan Yellow Tuff) formation, linked to the Campi Flegrei activity.

EDS microanalysis of phillipsite crystals showed that the content of major alkaline and alkaline-earth metals was very close to those of phillipsite from NYT, with K higher than Na and Ca as previously reported in literature (de' Gennaro et al., 2000). It clearly seems that minerals were not involved in cation exchange processes within the seawater.

Interesting is the composition of the cementitious binding matrix, with the contemporary presence of gel-like C-S-A-H, calcite, ettringite and Al-tobermorite.

Ettringite is to be ascribed to the interaction between calcium aluminates and ion sulphates from the seawater.

As far as the Al-tobermorite, there is not a reliable interpretation to explain its formation, at the current state of knowledge. Literature attests that tobermorite forms at higher temperatures, 150-200°C, than those of lime-based materials; moreover it is well known that the heat of hydration in pozzolanic cements is lower than normal cements (Massazza and Costa, 1979).

We can learn a great deal from the Surtsey natural laboratory because its hydrothermal minerals assemblage are similar with the cementitious system of 2000-years old Roman maritime concrete. Therefore it will be very important to perform rock analyses on Surtsey samples and correlate these with Roman samples and characterize long term diagenetic trends and their suitability for specific application in marine and waste encapsulation.

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Abiotic alteration of basaltic hyaloclastites: What we know (or think we know) about the process of palagonitization

Peter Schiffman¹, Bruce Pauly² and Robert Zierenberg³

^{1,2,3} Department of Earth and Planetary Sciences, University of California, Davis, USA
PSchiffman@UCDavis.edu, BDPauly@UCDavis.edu, RAZierenberg@UCDavis.edu

Palagonitization – a complex process entailing incongruent dissolution, hydrolysis, hydration, and metasomatism – occurs during the low temperature hydrothermal alteration and diagenesis of basaltic glass in the presence of both marine and meteoric fluids. Although microbial activity accompanies the low-T alteration of sideromelane, its role in mediating palagonitization is still unclear, and a new core hole at Surtsey would provide an opportunity to explore this relationship. Our current understanding of this process owes much to Sveinn Jakobsson's studies of active palagonitization on Surtsey. However, in the past few decades, advances in micro-analytical techniques have allowed for a better understanding of the rates, mechanisms and mineralogical transformations attending palagonitization of sideromelane in diverse geologic settings. High resolution transmitted electron micrographs have demonstrated that palagonitized glass is a quasi-crystalline material comprised of smectite microcrystallites and amorphous microparticles (Drief and Schiffman, 2004). As the microcrystallites coarsen – and amorphous components shed – with time or increased temperature, palagonitized glass becomes less isotropic as seen in cross-polarized light (so-called “gel” to “fibrous” palagonite). The smectite microcrystallites impart a significant cation exchange capacity (ca. 60 meq/100 g) to palagonitized glass (Schiffman and Southard, 1996). In hydrothermal environments, growth rates of palagonitized glass rinds appear to be highly temperature dependent, although this does not appear to be the case in diagenetic settings (Walton and Schiffman, 2003). Hydrolysis of sideromelane increases pore solution pH, thereby promoting co-precipitation of zeolites and other Ca-silicates in adjacent pore space. Palagonitized glass can contain as much as 30-40% H₂O as confirmed by Fourier transform infrared spectroscopy (Pauly et al., 2011) with subsequent decrease in specific gravity. Mass fluxes during palagonitization, as calculated by the isocon method, entail substantial losses in Si, Al, Mg, and Na, but also mobility of the “presumed” immobile elements Ti and Fe (Pauly et al., 2011). However, it isn't widely understood if this metasomatism extends beyond the hand specimen or outcrop scale. Consolidation of hyaloclastites during palagonitization is accompanied by an order of magnitude increase in unconfined compressive strength (Schiffman et al., 2006), stabilizing the flanks of submarine volcanic islands like Hawaii and the cores of tuff cones like Surtsey. Studies of palagonitization in a new Surtsey core hole – with Jakobsson's work as a reference frame – would allow for better constraints on rates and associated mineral transformations in a time/temperature context. Success in drilling into feeder dikes driving the Surtsey hydrothermal system would also allow study of the upper temperature limits of palagonitization.

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Disequilibrium aqueous speciation and chemical energy in hydrothermal systems

Andri Stefánsson¹, Hanna Kaasalainen¹, Nicole S. Keller¹, Ingvi Gunnasson² and Bergur Sigfússon³

¹. Institute of Earth Sciences, University of Iceland, Reykjavík, Iceland, as@hi.is

². Reykjavík Energy, Baejarhóls 1, Reykjavík, Iceland

³. Joint Research Centre - European Commission, Amsterdam, Holland

The ultimate source of chemical energy in natural systems rises from chemical reactions moving from disequilibrium conditions towards equilibrium. Many chemical reactions in hydrothermal fluids are fast and approaches thermodynamic equilibrium within a fraction of a second. Others are slow, including many reactions involving electron transfer, i.e. oxidation and reduction reactions, as well as many reactions between water and minerals.

In order to assess the reaction progress and chemical energies associated with hydrothermal fluids one needs to measure independently the concentration of all aqueous species involved in the reaction. In this attempt, sampling and analytical techniques have been developed in our laboratories that make in-situ or on-site analysis or alternatively sample stabilization and later laboratory analysis of aqueous species of importance. All elements interest are redox sensitive and include H (H₂, H₂O), O₂ (O₂, H₂O), S (SO₄, S₂O₃, S_nO₆, SO₃, H₂S), C (CO₂, CH₄), N (N₂, NH₄, NO₂, NO₃), Fe (Fe²⁺, Fe³⁺), As (As^{III} and As^V oxianions and thiocompounds), Cr (Cr^{III}, Cr^{VI}) and Mn (Mn^{II} and Mn^{III}). The chemical analytical techniques applied include chromatography (ion and gas) coupled with various detectors (e.g. HG-AFS, spectrophotometer, conductivity), spectrophotometry and in-situ voltammetry is also been tested at present. The analytical detection limits of these techniques are down to micro- and in some cases nanomolal scale (e.g. Stefansson et al., 2007, 2014; Kaasalainen and Stefansson, 2011; Keller et al., 2014)

The measured aqueous species concentrations in hydrothermal fluids have been combined with reaction equilibrium constants to assess the chemical affinities of over 200 reactions of microbiological and mineralogical interest possibly occurring under hydrothermal conditions at disequilibrium. The reactions have been categorized according to various electron acceptors and categorized with respect to their chemical affinities as a function of temperature (10-150°C) and pH (2-11).

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Microbial life at the glass-palagonite interface

Andreas Türke and Wolfgang Bach

University of Bremen, Department of Geosciences, Bremen, Germany, atuerke@uni-bremen.de

When basalt glass is exposed to oxygenated aqueous solutions, rims of palagonite form along fractures at the expense of glass. The flanks of mid-ocean ridges are the largest reservoir of basalt glass on Earth, and the flow of oxygenated seawater fluxes through these flanks is $>10^{16}$ kg/yr; [1]. Hence, a large amount of palagonite form in this setting, but palagonitization is kinetically sluggish at the prevailing temperatures of < 25 °C, allowing chemolithoautotrophic microbes (i.e., those that fix CO₂ by using inorganic energy sources of energy and electrons) to catalyze oxidation reactions of ferrous iron for catabolic energy gain. Tubular and granular alteration textures, present in basalt glass samples, both from modern and ancient rocks, are interpreted as trace fossils of endolithic microbes, chemically 'drilling' into fresh glass [2]. While the energy sources fuelling this putative microbial life in basalt are unknown, it has been suggested that steady-state Fe oxidation in ridge flanks can support a microbial biomass production on the order of 10^{11} g C per year [3].

However, these studies mostly focused on ridge flank systems. Ocean islands, such as Surtsey are hotspots in terms of fluid flow through volcanic rocks in oceanic settings.

We are interested in studying the interface of basalt and palagonite using different microscopic techniques (RAMAN, FTIR, FIB-TEM, EPMA) in order to assess the nature of microbial life and its potential energy sources in the Surtsey basalts.

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Rock Physics Characterization of Rock-Fluid Interactions Under HT-HP Conditions

Tiziana Vanorio¹, Anthony Clark¹ and Waruntorn Kanitpanyacharoen²

¹. Stanford Rock Physics Laboratory, Geophysics Department, Stanford, USA, tvanorio@stanford.edu

². Department of Geology, Faculty of Science, Chulalongkorn University, Bangkok, Thailand, waruntorn.k@chula.ac.th

One of the challenges faced today by the geophysical monitoring of processes that involve reactive fluids (e.g., dissolution and precipitation, healing and/or weakening processes across geothermal and seismogenic areas) is to understand how time-variant, thermo-chemo-mechanical processes change the spatial distribution of the properties of a rock skeleton (porosity, permeability, strength, and elastic properties) along with those of fluids in its pore space. This is a very challenging problem because of coupling processes: *pores deform chemo-mechanically while the fluid reacts and flows through an evolving pore space*. Understanding the geophysical signature of these coupled processes is far from being clear-cut as current rock physics interpretation tools are limited, mainly because of two reasons. On the one hand, information from current laboratory experiments is coarse and inadequate to answer the question. Experiments provide point-in-time snapshots of rock properties as well as a trackless path of changes to the property following natural processes. On the other hand, rock physics models are purely mechanical and best suited in relatively inert systems.

The first part of this presentation introduces seismic and rock physics characterization of the Campi Flegrei caldera (Vanorio et al., 2002 and Vanorio et al., 2005) along with recent experimental evidence of the occurrence of epigenetic graphite spherules within the thermo-metamorphic basement of the caldera (Kanitpanyacharoen and Vanorio, in preparation). Graphite spheres show an enriched carbon isotopic signature ($\delta^{13}\text{C}$) of up to -0.5 ± 0.1 and are texturally associated with the profuse occurrence of needle-shaped tremolite-actinolite, suggesting the existence of de-carbonation reactions within the magnesium-rich carbonates, which likely constitute the basement of the caldera.

The second half of this presentation describes the research efforts in progress to study thermo-chemo-mechanical processes (e.g., de-carbonation) and their elastic signatures. We recently completed the construction of a reaction vessel capable of inducing hydrothermal processes under conditions of confining and pressure pore fluid pressure (up to 30 MPa) and temperature (up to 500° C). We present the workflow developed so far to track the changes in elastic and transport properties along with changes in rock microstructure induced by dissolution-compaction processes.

The scientific idea behind this project is the rock physics characterization of hydrothermal processes through time-lapse laboratory experiments and advanced imaging techniques. One specific application is to study physical properties of Roman concrete and test new forms of cementitious composites using mixtures of volcanic ash undergoing hydrothermal processes.

Basaltic glass devitrification and formation of zeolites

Tobias B. Weisenberger¹, Rune S. Selbekk² and Hannes B. Mattsson³

¹. Oulu Mining School, University of Oulu, Finland, tobias.weisenberger@t-online.de

². Natural History Museum, University of Oslo, Norway, r.s.selbekk@nhm.uio.no

³. Institute of Geochemistry and Petrology, Swiss Federal Institute of Technology Zürich, Switzerland, hannes.mattsson@erdw.ethz.ch

Zeolites are among the most common products of chemical interaction between water-rich fluids and crustal rocks at low temperatures (<250°C), and low pressures. During alteration of basaltic rocks, in particular volcanic glass secondary mineral assemblages, including zeolites and other authigenic silicate minerals are formed during fluid rock interaction by percolating fluids. The type of secondary mineral depends on various components, including temperature, pressure and fluid/rock ratio, chemical and mineralogical composition of the rock and the chemical composition of the fluid including salinity and pH. In an open-system environment a vertical zonation of alteration minerals exists that reflects the chemical changes of the fluid moving through the system (*Sheppard and Hay, 2001*). Hydrothermal altered volcanic rocks in closed-system in characterized by depth-controlled mineral (zeolite) zones, which primarily reflects changes in temperature, but also depends on the change in fluid composition (*Neuhoff et al., 1999, 2000*). Detailed textural (i.e. cross-cutting relationships), mineralogical and geochemical investigations on small scale can give appropriate information about the thermal evolution and alteration of basaltic rock piles (*Neuhoff et al., 1999; Weisenberger and Selbekk, 2009*). Several alteration stages with increasing temperature occur: (1) celadonite at near surface alteration; (2) mafic phyllosilicates with increasing burial; (3) zeolite assemblage during burial, and (4) zeolite assemblages by later tectonic and hydrothermal events. The change from mafic phyllosilicates to zeolite precipitation is also a function of a change in fluid composition, whereas a decrease in Mg fluid activity triggers the change from mafic phyllosilicate to zeolite formation (*Neuhoff et al., 1999; Kousehlar et al., 2012*).

Research questions that will be addressed during this proposed study are:

- Spatial distribution of secondary minerals in particular zeolite species (detailed petrography and mineralogy)
- Secondary mineral formation in different structural position: above and below sea level, proximity to dike swarm (heat source)
- Temporal evolution of secondary mineral formation
- Seawater vs. meteoric water alteration system

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Some New Observations From Surtsey, and from the Partly Palagonitized Surtseyan Volcano Pahvant Butte (Utah, USA)

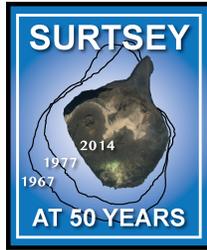
James D.L. White

Geology Department, University of Otago, Dunedin, New Zealand

New work in collaboration with Svein Jakobsson and others on Surtsey's eruption is extending our understanding of many aspects of its evolution before and after emergence. Improved understanding will be important for planning any new Surtsey drillhole, both to maximise what can be learned about the eruption, and to best support predictions of the deposit types to be encountered in a given hole. The 1979 Surtsey hole reached almost to the pre-eruption seafloor, and near its base are unlithified deposits of moderately vesicular (~50%) pyroclasts, many with large populations of small, spherical to sub-spherical vesicles. There are strong palagonite rims on pyroclasts at many intervals in the core, best developed on highly vesicular glassy pyroclasts. In the upper several meters are armoured lapilli, along with "vesiculated tuff", but no evidence for deep subsidence of surficial deposits at the site cored is apparent, and a working hypothesis is that an eruption stratigraphy can be established for the drillsite. On the subaerial cone are distinctive blocks of volcanoclastic turbidites. Though volumetrically sparse, these blocks were emplaced at many times in the eruption, raising questions about how they made their way from seafloor to surface through the vent. No fragments of pillow lava have been identified in Surtsey's ejecta, but there are many fragments of dikes. Juvenile bombs and lapilli display ubiquitous composite textures with glassy weakly fractured surfaces masking a contorted internal structure in which pyroclasts are entwined with stretched and bubbled coherent basalt. These textures are interpreted to have developed through strong 'recycling' processes that allowed capture of older pyroclasts within new ones through in-vent welding and agglutination, or in some cases by capture of particles within magma that was subsequently disrupted. The evidence for both ubiquitous hot-state particle recycling, and excavation and ejection of subvolcanic sedimentary strata at many times in the eruption must be integrated into a new interpretation of eruptive processes. Palagonitization of Surtsey tephra in both core and cone is well known, and observations at the partly palagonitized, partly fresh and glassy deposits of Pahvant Butte volcano, erupted in Lake Bonneville at ~15 ka, may indicate the 3-D geometry of palagonitization within Surtsey. As at Surtsey Pahvant's emergent cone is pervasively palagonitized, but much of the subaqueously formed part of the volcano preserves fresh, loose, unaltered sideromelane ash and lapilli ash. Terminations of palagonitized zones are commonly steep and irregular, cut across meters of stratigraphy, and are sharp to laterally gradational on scales of meters. The picture overall is of palagonitization of a broadly columnar central hydrothermal zone and overlying emergent cone, with unaltered deposits preserved laterally separated by a boundary of varying form and sharpness that is presumed to reflect vagaries in the flow and cooling of hydrothermal fluids through deposits with complex architecture and permeability structure.

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SURTSEY AT 50 YEARS - 2014 ICDP Workshop

Hótel Vestmannaeyjar and Conference Center

Vestmannabraut 28 900 Vestmannaeyjar ICELAND

September 30 to October 4, 2014

Program (16 September 2014)

Tuesday, September 30th 2014

Afternoon Arrival, check in, and room assignments.

6:30 PM Welcome "Icebreaker"

7.00 – 9.00 PM Light Dinner

Wednesday, October 1st 2014

7.30 – 8.30 AM **Breakfast, Hótel Vestmannaeyjar**

8.40 – 9.10 **Welcoming Address, Conference Center**

Hallgrímur Jónasson, Director of RANNÍS, The Icelandic Centre for Research, Chairman of the Surtsey Research Society, "Research and environmental priorities at the Surtsey Protected Area."

Orientation

Marie Jackson, UC Berkeley, "What we will learn about changes at Surtsey over the past 50 years?"

9.10 – 10.20 **I. Surtsey Overview**

1. James G. Moore & Sveinn Jakobsson (USGS, USA; Iceland Institute Natural History, Iceland) "1979 Surtsey Drilling Project." 30 minutes

2. Sveinn Jakobsson, James G. Moore & *Ingunn Thorseth** (Iceland Institute Natural History, Iceland; USGS, USA; *Univ Bergen, Norway*) "Palagonitization of the Surtsey tephra, Iceland." 20 minutes

3. James White (Univ Otago, New Zealand) "Some new observations from Surtsey, and from the partly palagonitized Surtseyan volcano Pahvant Butte (Utah, USA)." 20 minutes

Posters

4. Páll Einarsson (or student) (Univ Iceland, Iceland) "Deformation of the Surtsey edifice."

10.20 **Coffee Break**

10.30 – 11.45 **II. Eruptive, Constructive and Hydrothermal Processes**

5. *Martin Jutzeler & Jocelyn McPhie (Univ Southampton, UK; Univ Tasmania, Australia)* "Characteristics of Oligocene, lithified and diagenetically altered "surtseyan" facies; Ohanapecosh Formation, Washington." 20 minutes

6, 7. *Magnús Tumi Guðmundsson, Bernd Zimanowski & Ralf Büttner (Univ Iceland, Iceland; U Wuerzburg, Germany)* "The importance of water-rock interactions in Icelandic subglacial and submarine volcanism." (See also *Zimanowski & Büttner, "Experimental Studies on Formation and Thermal History of Surtsey Deposits."*) 20 minutes

8. J. Michael Rhodes (Univ Massachusetts Amherst, USA) "Geochemical stratigraphy of the Hawaii scientific drilling project." 15 minutes

9. *Andri Stefánsson¹, Hanna Kaasalainen¹, Nicole S. Keller¹, Ingvi Gunnasson² & Bergur Sigfússon³* (¹Univ Iceland, ²*Reykjavík Energy, Iceland*, ³*Joint Research Centre, Holland*) "Disequilibrium aqueous speciation and chemical energy in hydrothermal systems." 15 minutes

10. Robert Zierenberg (UC Davis, USA) "Sulfur sources and sinks in submarine hydrothermal systems." 15 minutes
- 11.45 – 12.15 **Open Discussion:** What are the major factors to be resolved in understanding the eruptive processes, constructive processes and hydrothermal system at Surtsey recorded in deposits above and below sealevel over the past 50 years? Moderators: Magnús Tumi Guðmundsson, Andri Stefánsson, & Robert Zierenberg
- 12.15 – 14.00 PM **Lunch and Posters**
- 14.00 – 14.50 **III. Biotic and Abiotic Processes in Basaltic Glass Alteration**
11. Peter Schiffman, *Bruce Pauly* & Robert Zierenberg (UC Davis, USA) "Abiotic alteration of basaltic hyaloclastites: What we know (or think we know) about the process of palagonitization." 20 minutes
12. Steffen Leth Jørgensen (Univ Bergen, Norway) "Biotic processes in palagonite formation." 15 minutes
13. Viggó Þór Marteinsson^{1,3}, *Alexandra Klonowski*¹, *Eyjólfur Reynisson*¹, *Pauline Vannier*¹, *Magnús Ólafsson*² (¹Matís Research Institute, Iceland; ²ÍSOR, Iceland; ³Agricultural Univ of Iceland) "Microbial colonisation in diverse surface soil types in Surtsey and diversity analysis of its subsurface microbiota." 15 minutes
- Posters**
14. Magnus Ivarsson (Swedish Museum Natural History, Sweden) "Fossilized microorganisms in subseafloor basalts."
15. Andreas Türke & *Wolfgang Bach* (Univ Bremen, Germany) "Microbial life at the glass-palagonite interface."
- 14.50– 16:00 **IV. The Ancient Roman Concrete Connection: Applied Mineralogy**
16. Marie Jackson¹, *Sean Mulcahy*¹, *Martin Kunz*² (¹UC Berkeley, USA, ²Lawrence Berkeley Lab, USA) "Authigenic crystalline cementitious fabrics in Surtsey tephra and Roman seawater concrete." 20 minutes
17. Piergiulio Cappelletti¹, *Diego Gatta*² & *David Bish*³ (¹Univ Naples, Italy; ²Univ Milan, Italy; ³Indiana Univ, USA) "Crystal chemistry and cation exchange in zeolite systems." 20 minutes
18. Nichola Coleman (Univ Greenwich, UK) "Interrelationships between synthesis conditions, structure and ion-exchange behaviour of aluminous tobermorite." 15 minutes
19. Tiziana Vanorio¹, *Anthony Clark*¹ & *Waruntorn Kanitpanyacharoen*² (¹Stanford Univ, USA; ²Univ Chulalongkorn, Thailand) "Rock physics characterization of rock-fluid interactions under HT-HP conditions." 15 minutes
- Posters**
20. Concetta Rispoli, Piergiulio Cappelletti, *Vincenzo Morra* & *Corrado Stanislao* (Univ Naples, Italy) "Mineral assemblages and material properties of ancient Roman harbor concretes."
21. Tobias Björn Weisenberger¹, *Rune S. Selbekk*² & *Hannes B. Mattsson*³ (¹Univ Oulu, Finland; ²Univ Oslo, Norway; ³Swiss Federal Institute Technology, Switzerland) "Basaltic glass devitrification and formation of zeolites."
- 16:00 – 16:30 **Open Discussion:** What are the major factors to be resolved in understanding the authigenic alteration processes in the Surtsey deposits ... and how these can be applied to innovative industrial and cementitious materials? Moderators: Piergiulio Cappelletti, Marie Jackson, Peter Schiffman, & Steffen Leth Jørgensen
- 16.30 **Coffee Break**
22. Dennis Nielson (DOSECC, USA) "ICDP: Funding and logistical support." 15 minutes
- 16:45 – 17.30 **Organized Discussion:** Descriptions of work sessions leading to writing the full drilling proposal; Leader and notetaker of focus groups determined; ICDP Funding and logistical support; Other potential funding agencies; Open Forum for discussion of proposed work by individual researchers. Moderators: Marie Jackson, Dennis Nielson

Wednesday, October 1st 2014 , continued

18.30 PM **Reception**

19.00 – 20.30 PM **Dinner**

Thursday, October 2nd 2014

7.30 – 8.30 AM **Breakfast, Hótel Vestmannaeyjar**

8.40 – 8.50 **Introduction to the day's activities, Conference Center**

8:50 – 10:20 **V. Zero Impact Drilling Program**

23. Þórdís V. Bragadóttir (Environment Agency, Iceland) "Vegetation and wildlife description, environmental status and protection measures within Surtsey." 30 minutes

24. Þórdís V. Bragadóttir, Aðalbjörg Birna Guttormsdóttir (Environment Agency, Iceland) "Environment Agency of Iceland, permitting process and information needed for an application to drill on Surtsey." 30 minutes

25. Dennis Nielson (DOSECC, USA) "Best practices for a zero impact drilling program through the Surtsey hydrothermal system." 15 minutes

Dennis Nielson (DOSECC, USA) "Downhole geophysical logging and imaging." 15 minutes

10.20 – 10:50 **Open Discussion:** What are the major factors involved in siting the Surtsey drill hole?

10.50 **Coffee Break**

11.00 – 17.00 **VI. Vestmannaeyjar Field Trip**

26. James G. Moore (USGS, USA) "The 1973 eruption of Eldfell volcano, Heimaey, Iceland." 20 minutes

Ingvar Atli Sigurðsson (Iceland Institute Natural History, Iceland) "Introduction to the afternoon field trip."

11:45 **Pick up bag lunches**

Group photo

12:00 **Board bus for afternoon field trip**

17:00 **Return to Hotel Vestmannaeyjar**

18.30 PM **Reception**

19.00 – 20.30 PM **Dinner**

Friday, October 3rd 2014

7.30 – 8.30 AM **Breakfast, Hótel Vestmannaeyjar**

8.40 – 8.50 **Introduction to the day's activities, Conference Center**

8.50 – 9.00 **Organization of focus group work sessions to write the full drilling proposal**

9.00 – 11.00 **Focus group work sessions to develop realistic, achievable scientific goals for the Surtsey drilling project** (Session leaders and notetakers to be determined on Thursday afternoon).

11.00 **Coffee Break**

11.15 – 12.30 **Focus group works sessions reconvene, with option to change groups**

12.30 – 1.30 PM **Lunch**

1.30 – 3.15 **Focus groups present their wish lists** (~10 minutes), followed by discussion about what is feasible and what is not from technical, budgetary and environmental perspectives.

3.15 – 4.15 **Focus groups write a detailed outline for proposed research projects**, a 2-3 page of points that can easily be worked into proposal text.

4.15 **Coffee Break**

4.30 – 5.30 **Open Discussion: The Road Ahead.** Completing the full drilling proposal and individual contributions to the Supporting Appendix**.

18.30 PM **Reception**

19.00 – 20.30 PM **Dinner**

Saturday – October 4th 2013

7.30 – 8.30 AM **Breakfast, Hótel Vestmannaeyjar**
8.50 – 9.00 **Wrap up, Conference Center**, and assignments with due dates for proposal components
9:00 – 10:30 **Writing session**, for group collaborations on components of the drilling proposal and individual contributions to the Supporting Appendix of the drilling proposal.
10.30 **Coffee Break**, and room check out

Hiking or a possible fishing boat trip around Surtsey (in good weather) in the afternoon.
Departures on the 11:30, 17:30 or 20:30 ferry to Landeyjahöfn (good weather) or the 15:30 ferry to Þorlákshöfn (bad weather)

Notes

* italics designate research collaborators not present at the workshop

**Individual contributions (1-3 pages) to the Supporting Appendix of the drilling proposal: If the drilling program at Surtsey were successfully implemented, and you had the opportunity to work on Surtsey material, then what specific research investigations would you undertake? What analytical, experimental, or theoretical methods would you employ? With whom would you collaborate? Where would you seek funding? Your contribution is due to Marie Jackson by October 20th, 2014, the same date that travel reimbursements must be received.

Sulfur Sources and Sinks in Submarine Hydrothermal Systems

Robert Zierenberg¹

¹ Dept. Earth & Planetary Sci., Univ. California - Davis, Davis, CA, USA, razierenberg@ucdavis.edu

Sulfur is a minor element in hydrothermal systems, but it has a major impact on the geochemistry and biology of these systems. In high temperature geothermal systems, sulfur concentration and redox state is a primary control on the transportation and deposition of metals, including iron, copper, zinc, silver and gold. Hydrogen sulfide gas in geothermal systems exploited for energy can be both a health and environmental hazard. In many low temperature geothermal systems, H₂S is the dominant reduced species utilized by chemosynthetic organisms, and it can support complex and diverse ecosystems in the absence of photosynthetic energy production. In anoxic settings, sulfate can act as an electron acceptor allowing microbial metabolism of organic compounds. The importance and diversity of effects of sulfur in geothermal and biological systems is related to the redox chemistry of sulfur, which in the case of sulfate reduction can involve a net change of eight electrons (S⁺⁶ to S⁻²). Despite the importance of sulfur in hydrothermal and microbiologic systems, there are significant gaps in our understanding of the cycling of sulfur through the oceanic crust and seafloor biosphere which could be addressed by drilling at Surtsey. Studies of deep sea hydrothermal systems, ophiolites, and ore deposits indicate there are two major sources of sulfur for marine hydrothermal systems; basaltic sulfur that is present as reduced (S⁻²) sulfur in the mineral pyrrhotite with a δ³⁴S value of ~0‰, and seawater sulfate with oxidized (S⁺⁶) sulfur with a δ³⁴S value of ~21‰. Seafloor hydrothermal vents typically expel reduced sulfur with δ³⁴S of 2-5‰, indicating that a small amount of seawater sulfate penetrates deeply into the hydrothermal system where high temperature reactions with basalt reduce the sulfate to sulfide. The least well understood part of this system is the recharge limb of the hydrothermal circulation cell. We know that most of the seawater sulfate is precipitated as anhydrite in the shallow part of the oceanic crust due to the fact that anhydrite solubility decreases with increasing temperature. However, as hydrothermal systems cool down, anhydrite is lost by redissolution in circulating seawater. Therefore, the only place where we can hope to quantify the depth of circulation, the temperature of precipitation and dissolution, and the extent of biological and inorganic sulfate reduction is to drill into active geothermal systems in the oceanic crust. Surtsey represents an important natural laboratory where we can quantify the concentration, redox state and isotopic composition of sulfur in the upper oceanic crust. Sulfur isotope ratios can help constrain the source of the sulfur, but must be interpreted in concert with biological cycling of sulfur, which imparts significant fractionation of sulfur isotopes during sulfate reduction. Microbial metabolism of H₂S to SO₄ is generally accompanied by little to no kinetic isotope fractionation, but sulfur in intermediate oxidation states can undergo further biological cycling. Fluid inclusions and oxygen isotope ratios in sulfate minerals recovered by drilling at Surtsey can constrain the temperature evolution of the system with depth. Sulfur isotope values of sulfide and sulfate can be used to infer the extent of biological sulfur cycling. Surtsey represents one of the best sites to explore the shallow, low-temperature cycling of sulfur in oceanic crust, and is possibly unique in our ability to access this system with on-land drilling technology that allows continuous core recovery and post drilling quantification of temperature and fluid flow dynamics.

Experimental Studies on Formation and Thermal History of Surtsey Deposits

Bernd Zimanowski¹ and Ralf Büttner²

¹ Physikalisch Vulkanologisches Labor, Institut für Geographie und Geologie, Universität Würzburg, Würzburg, Germany, zimano@mail.uni-wuerzburg.de

² Physikalisch Vulkanologisches Labor, Institut für Geographie und Geologie, Universität Würzburg, Würzburg, Germany, zimano@mail.uni-wuerzburg.de

With the aim to provide constraints for a better understanding of the eruption mechanisms, the energetics, and the production of volcanic particles by subaerial and submarine processes, standardized fragmentation experiments are proposed, to be conducted using remelted basaltic material, representative for the eruptions 50 years ago. The material should cover the variations of the magmatic source in terms of chemical (glass-) composition, crystallinity, and, most important porosity. The relevance of the experiments can be validated by comparison of the experimentally derived fragments with particles sampled from the respective natural deposits. The experiments will cover explosive magmatic and phreatomagmatic fragmentation and thermal granulation by non-explosive interaction of melt and watery coolants.

As the thermal granulation experiments will be performed in a calorimeter, also information on the thermal history of the products will emerge. Additional calorimetric experiments using original samples from Surtsey are proposed to investigate the influence of material properties of the deposits and geothermal fluids on the heat transport. This will have particular relevance to reference heat flow models.

Proposed experimental series (all experiments are standardized and in detail described in publications cited below

A Fragmentation experiments

- Stress induced magmatic¹
- MFCI²

B Calorimeter experiments (non-explosive interaction of magmatic melt with...)

- Pure coolant (sea water) at low temperature³
- Pure coolant (sea water) at high temperature⁴
- Particulate slurry coolant at low temperature⁵
- Particulate slurry coolant at high temperature⁵

References:

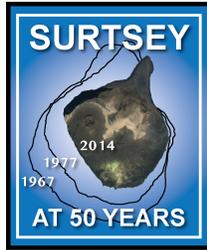
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SURTSEY AT 50 YEARS - 2014 ICDP Workshop

Hótel Vestmannaeyjar and Conference Center

Vestmannabraut 28 900 Vestmannaeyjar ICELAND

September 30 to October 4, 2014

PRINCIPAL INVESTIGATORS AND CO-PROPOSERS

Marie D. Jackson

Department of Civil and Environmental Engineering, University of California, Berkeley, USA

Wolfgang Bach

University of Bremen, Department of Geosciences, Bremen, Germany

Piergiulio Cappelletti

FEDERICO II University, Naples, Italy

Magnús Tumi Guðmundsson

Institute of Earth Sciences, University of Iceland, Reykjavik, Iceland

Peter Schiffman

Department of Earth and Planetary Sciences, University of California, Davis, USA

PRINCIPAL SCIENTIFIC ADVISOR

James G. Moore

U. S. Geological Survey, Menlo Park, California, USA

PRINCIPAL DRILLING ADVISOR

Dennis Nielson

DOSECC Exploration Services, LLC, Salt Lake City, Utah USA

PARTICIPANTS

Cappelletti, Piergiulio

Dipartimento di Scienze della Terra, dell'Ambiente e delle Risorse (DiSTAR)

FEDERICO II University, Naples, Italy

piergiulio.cappelletti@unina.it

Coleman, Nichola J.

Department of Pharmaceutical, Chemical & Environmental Science

University of Greenwich, Kent, UK

N.Coleman@greenwich.ac.uk

Einarsson, Páll

Institute of Earth Science, University of Iceland, Reykjavík, Iceland

palli@raunvis.hi.is

Guðmundsson, Magnús Tumi

Institute of Earth Sciences, University of Iceland, Reykjavik, Iceland

mtg@hi.is

Ivarsson, Magnus

Department of Palaeobiology, Swedish Museum of Natural History, Stockholm, Sweden

magnus.ivarsson@nrm.se

Jackson, Marie D.
Department of Civil and Environmental Engineering, University of California, Berkeley, USA
mdjackson@berkeley.edu

Jakobsson, Sveinn
Icelandic Institute of Natural History, Gardabaer, Iceland
sjak@ni.is

Jónasson, Hallgrímur
RANNÍS, The Icelandic Centre for Research, Reykjavík, Iceland
hallgrimur.jonasson@rannis.is

Jónasson, Kristjan
Icelandic Institute of Natural History, Gardabaer, Iceland
kristjan@ni.is

Jørgensen, Steffen Leth
Centre for Geobiology, Department of Biology, University of Bergen, Norway
Steffen.jorgensen@bio.uib.no

Marteinsson, Viggó Þór
Matís, Food Safety, Environment & Genetics, Reykjavík, Iceland
viggo@matís.is

McPhie, Jocelyn
Earth Sciences, University of Tasmania, Hobart, Australia
j.mcphie@utas.edu.au

Moore, James G.
U. S. Geological Survey, Menlo Park, California, USA
jmoore@usgs.gov

Nielson, Dennis
DOSECC Exploration Services, LLC, Salt Lake City, Utah, USA
danielson@dosecc-ex.com

Rhodes, J. Michael
Department of Geosciences, University of Massachusetts, Amherst, USA
jmrhodes@geo.umass.edu

Rispoli, Concetta
Dipartimento di Scienze della Terra, dell'Ambiente e delle Risorse (DiSTAR)
FEDERICO II University, Naples, Italy
concetta.rispoli@unina.it

Schiffman, Peter
Department of Earth and Planetary Sciences, University of California, Davis, USA
PSchiffman@ucdavis.edu

Sigurðsson, Ingvar Atli
South Iceland Nature Centre, Vestmannaeyjar, Iceland
ingvar@nattsud.is

Stefánsson, Andri
Institute of Earth Sciences, University of Iceland, Reykjavík, Iceland
as@hi.is

Türke, Andreas
University of Bremen, Department of Geosciences, Bremen, Germany
atuerke@uni-bremen.de

Vanorio, Tiziana
Stanford Rock Physics Laboratory, Geophysics Department, Stanford, USA
tvanorio@stanford.edu

Weisenberger, Tobias Björn
Oulu Mining School, University of Oulu, Finland
tobias.weisenberger@t-online.de

White, James
Geology Department, University of Otago, Dunedin, New Zealand
james.white@otago.ac.nz

Zierenberg, Robert
Department of Earth and Planetary Sciences, University of California, Davis, USA
razierenberg@ucdavis.edu

REPRESENTATIVES, ENVIRONMENT AGENCY OF ICELAND

Bragadóttir, Þórdís Vilhelmína
Environment Agency of Iceland, Reykjavík, Iceland
thordis.bragadottir@umhverfisstofnun.is

Guttormsdóttir, Aðalbjörg Birna
Environment Agency of Iceland, Reykjavík, Iceland
birnag@umhverfisstofnun.is

RESEARCH INVESTIGATORS ON SCIENTIFIC TEAM

David Bish
Department of Geological Sciences, Indiana University, Bloomington, USA
bish@indiana.edu

Diego Gatta
Dipartimento di Scienze della Terra "A. Desio", Milan University, Milan, Italy
diego.gatta@unimi.it

Gudmundur Oli Hreggviðsson
Matís, Food Safety, Environment & Genetics, Reykjavík, Iceland
Faculty of Life and Environmental Sciences, University of Iceland, Reykjavík, Iceland
gudmundo@matis.is

Bernd Zimanowski
Physikalisch Vulkanologisches Labor, Institut für Geographie und Geologie, Universität
Würzburg, Würzburg, Germany
zimano@mail.uni-wuerzburg.de