Proposal for Underwater Surveys at Surtsey

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Introduction

The volcanic eruptions that formed the island of Surtsey from 1963 to 1967 are one of the cornerstones in the development of volcanology, with respect to phreatomagmatic explosive eruptions. Furthermore, Surtsey is justly famous for the research that has been conducted here on the long-term colonization of new biota on a pristine terrain. However, most of the geologic and biological research conducted to date on Surtsey has been carried out in the subaerial environment, with the exception of biological surveys conducted during shallow scuba dives in the zero to 30 m depth range. As a result, information is largely lacking on biology and geology of the Surtsey region below 30 m. We propose a series of submersible and remotely operated vehicle dives on the submarine flanks of Surtsey and the related submarine volcanic cones of Surtla, Syrtlingur and Jólnir. This work will serve to characterize the nature of the submarine terrain, both in terms of biological and geological features. The proposed study is to be conducted in order to take advantage of the availability of two submersible vehicles in Iceland waters at this time, as a part of the equipment available on board the M/V Octopus.

Submarine Geology

During the Surtsey eruption from 1963 to 1967, four principal vents were erupting, located on an NE-SW trend. They are, from the NE to the SW, Surtla, Syrtlingur, Surtsey (two main craters), and Jólnir furthest to the SW (Fig. 1). Only Surtsey proper has remained above sea level and been investigated in detail. The Surtla submarine volcanic cone was built up between December 1963 and January 1964. It has a length of 0.9 km and its width about 0.6 km, and it rises about 60 m above the sea floor. Further submarine activity formed the island of Syrtlingur in 1965 just to the NE of Surtsey. This island was temporary, however, and today only a submarine platform remains, measuring 1.2 km in diameter and rising 70–80 m above the sea floor. Another island formed by volcanic activity in 1965–1966 called Jólnir, about 1 km southwest of Surtsey. Today this is a seamount, with diameter of 1.7 km and an elevation of 60–70 m above the sea floor. A very comprehensive review of the development of Surtsey is presented in Baldursson et al. (2006).

The dominant volcanic activity observed during the Surtsey eruption and the formation of the three other vents was characterized primarily by explosive eruptions and the production of basaltic tephra. It is clear that the explosions were the result of interaction of sea water and the erupting magma, with phreatomagmatic or steam explosions leading to extensive magma fragmentation and formation of tephra. These explosions ceased when the crater was built above sea level. The very initial stage of the submarine eruption of Surtsey and during formation of the three other submarine volcanic cones of Jólnir, Surtla and Syrtlingur is, on the other hand, unknown.

The general theory of submarine eruption of basaltic magma in the deep ocean has the view that formation of pillow lava is the dominant process, and that phreatomagmatic explosive (surtseyan) volcanism occurs only when the submarine volcanic vent reaches shallow depths. The transition from pillow lava eruption in deep water to phreatomagmatic or surtseyan explosive eruption in shallow water is attributed to the increasing volume fraction of steam with decreasing water depth and therefore decreasing ambient pressure. At greater depths, the high water pressure inhibits or limits the volume expansion of the steam phase and fragmentation of the magma is therefore absent or minor. At shallow depths the explosive steam expansion during flashing of sea water to steam in contact with the

approximately 1200ºC hot magma in the low-pressure environment is sufficient to lead to magma fragmentation and the production of tephra, as observed at Surtsey. The critical depth level towards shallower waters where the transition from pillow lava to explosive eruption and tephra production in shallower waters is unknown.

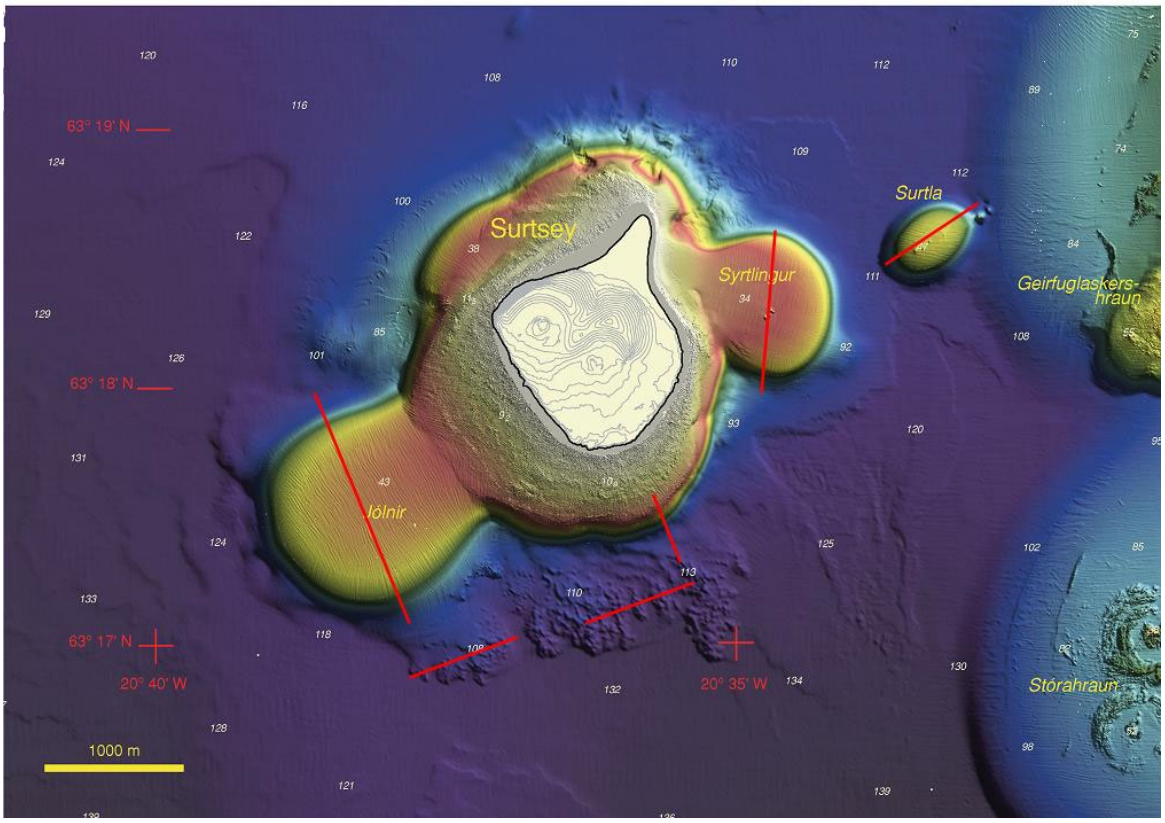

Fig. 1. Multibeam bathymetric chart of the Surtsey region, showing the approximate location of the survey transects (red lines) during ROV and submersible dives proposed in this document. After Jakobsson et al. 2009.

In the absence of earlier dives and direct observations of the deeper (beyond 30 m) parts of the four submarine volcanic cones of Surtsey, it is not known whether pillow lavas were extruded in the initial stage of the volcanic activity here. Jakobsson and Moore (1986) suggest however that the depth of the sea floor in the Surtsey region is insufficient to produce pillow lava, and no pillow lava was encountered by them in a drill hole that penetrated to a depth of about 120 m below sea level on Surtsey. Nevertheless, irregular topography on the sea floor surrounding the base of the submarine volcanic cones, such as in the region south of Surtsey and Jólnir, is not characteristic of a tephra deposit and may on the other hand indicate submarine lava flows. Jakobsson et al. (2009) have discussed these features and propose that they are lava flow that originate from the subaerial lava activity of Surtsey, and are not pillow lavas derived from deep eruption. The question remains open. The proposed ROV and submersible dives will address this problem directly and contribute greatly to our knowledge base of the structure of the Surtsey submarine volcanic cones.

Benthic habitats and communities

Investigation of benthic fauna around Surtsey began in 1963. In these surveys, samples were collected using grabs and dredges, but those gears were often inappropriate due to the ruggedness of the substrate (Sigurðsson 1965, Nicolaisen 1970). Soon after the eruption stopped i.e. in 1967, data

collection by diving in the sublittoral zones was initiated and terminated in 1997 (Sigurðsson 1968, 1970, 1972, 1974, 1982, 2000, Hauksson 1992, 2000). Divers obtained samples and took underwater photographs at stations at 5, 10, 15, 20, 25 and 30 m depth all around Surtsey. This data provides good information on successional patterns of benthic organisms in the 0-30 m depth range. The number of benthic marine species that were recorded around Surtsey rose rapidly from 1964 until 1970 but levelled off after that. There were clear differences in the vertical distribution of benthic organisms, with increasing cover of sessile animals with depth (Hauksson 1992, Sigurðsson 2000, Gunnarsson and Hauksson 2009).

Overall, there is very limited information on benthic assemblages below 30 m depth. In this proposal we seek to fill this gap by surveying these areas using ROV and submersible vehicles in deeper waters. During surveying, video footage and underwater photographs will be obtained that will be subsequently analyzed by the staff at the Marine Research Institute of Iceland with respect to the biological data under supervision of Stefán Áki Ragnarsson and by Haraldur Sigurðsson at Eldfjallasafn, the Volcano Museum, with respect to the geological data. No samples will be collected, and as such this underwater exploration does not impose any harm to the potentially vulnerable fauna and habitats found in the deeper parts around Surtsey. This survey will address many of the intriguing questions regarding the sucessional processes of benthic assemblages found in deeper waters around Surtsey.

ROV and Submersible Vehicles

We will use two underwater vehicles for this research, to be deployed from the 130 m long ship M/V Octopus, which is registered in the Bahamas islands. One of these is the Octo ROV unmanned vehicle, with a depth rating of 3 km, equipped with a 1080 HD video camera, with direct live video feed to the surface vessel. It is further equipped with two manipulator arms and a sampling tube, CTD sensor and depth sensor, as well as hydrophone and compass and multiple lights. The other dive vessel is the 10-person manned submersible Pagoo, with depth rating of 365 meters. It has a life support system of 96 hours. The Pagoo submersible has an HMI lighting manipulator, High Definition Camera, 6 thrusters, Doppler Velocity Log Strobe (Double Burst Flash), 2 Altimeters, Seakeeper's Probe, and a RF Beacon. The choice of a dive vessel during each experiment will be determined by the sea state and general conditions during the dives.

Cruise Plan

The M/V Octopus will spend approximately two days in the Surtsey region. The vehicles will be deployed to make transects (Fig. 1) of the submarine flanks of the volcanic cones of Surtla, Syrtlingur, Jólnir and of Surtsey island, from the pre-eruption sea bed, at ≈130 m depth, to the shelf break at ≈30 m depth (see below). During the survey, data will be collected on biological and geological features. This involves collection of video footage and still photos (high-resolution camera system), navigational data, temperature and salinity recordings. Copies of all data, images and video material collected during the expedition will be made available to the Icelandic authorities at the Icelandic Institute of Natural History and the Marine Research Institute, to facilitate further research by other Icelandic scientists on this material.

Description of underwater surveys and study sites

1) *Surtla, Syrtlingur and Jólnir submarine cones*

These underwater submarine volcanic cones probably consist mostly of coarse tephra with scattering of lava fragments. It is possible that the substrates at the base of the cones may differ but this is not known. During the eruption, Jólnir and Syrtlingur rose above the surface of the sea. The high wave height (up to 16 m; Jakobsson et al., 2009 and refereinces therein) during storms at Surtsey can

probably cause erosion of substrates down to 30-40 m, and so resulting in sediments to be washed over the sides of the cones. These erosional processes are especially apparent for Jólnir, and to Syrtlingur that now consist as erosional platforms located at 43 and 34 m respectively, surrounded by a slope down to 100 m depth. Surtla that was located at 23 m depth after cessation of the eruption was exposed to much less erosion and is now found at 51 m depth. It would be of high interest to investigate the succession of the fauna in these unstable sedimentary environments. On top of Syrtlingur and Surtla are knolls that are from 20-50 m in length and rise 4-15 m above the surroundings (Jakobson et al 2009). These knolls provide a habitat for various sessile organisms that are most likely not found in surrounding sediments. ROV transects will be carried out that transverse each volcano starting and ending in the deep on either side (Fig. 1). In these transects, the knolls on Syrtlingur and Surtla are also explored. The length of these transects vary from 1 km for the Surtla cone to 3 km for Jólnir. The resulting video footage and still photographs will be used to characterize and compare the geology and the fauna in and around the different volcanic cones.

2) Slope and the potential submarine pillow lava field

The seafloor south of Surtsey is very interesting. The island is surrounded by a shallow erosional platform with a lava scree (Jakobsson et al. 2009). The dominant substrate type in the 0-30 m depth range consists of rocks and boulders with sand in between (Gunnarsson and Hauksson 2009). The substrate characteristics and the benthic assemblages below 30 m depth are more or less unknown. The slope south of the erosional platform is ≈30°, ranging from ≈40 m depth at the edge of the erosional platform to ≈100 m at the base of the slope. The slope may consist mainly of tephra intermingled with rock and boulders. The sediment stability should increase with depth down the slope, and this should have large influence on what benthic organisms have colonized these areas. We will carry out a single transect down the slope and this should address whether there are differences in the abundance benthic assemblages and substrate types down slope.

The landscape at the base of the slope is very rugged. Similarly, at the southwest of Surtsey various interesting topographic highs are found that may be formed through submarine extrusions of lava in spring 1964 (Jakobson et al 2009). Various sources of data (Jakobson et al 2009 and references therein) suggest that these areas consist of pillow lava covering an area of ≈5km^2. However, it has not yet been verified whether this is indeed pillow lava and we hope to do that in this cruise. These pillow lava fields are below the depth wave-induced disturbances would generally influence benthic communities (e.g. McArthy 2003). The ruggedness of the lava is likely to promote colonization of sessile habitat forming organisms such as bryozoans, sponges, gorgonian and stony corals, but there are records of stony corals in the canyons south of Surtsey (Steingrimsson and Einarsson, 2004). Growth rates of some of these habitat forming organisms, such as the cold-water corals can be very slow, or from 0.5-2 cm/year^{-1} (e.g. Mortensen and Mortensen 2005). The fact that the age of the lava around Surtsey can be dated with high accuracy allows investigation on the succession process by slow growing habitat forming organisms to entirely **new** lava in deep waters. We aim to take at least 2 transects trough the lava field that are located south of Surtsey and Jólnir, each of which is about 1 km (Fig. 1).

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