SUBGLACIAL AND SUBMARINE VOLCANISM IN ICELAND. S. P. Jakobsson, Icelandic Inst. of Natural History, P. O. Box 5320, 125 Reykjavik, Iceland

Introduction: Iceland is the largest landmass exposed along the Mid-Ocean Ridge System. It has been constructed over the past 16 Ma by basaltic to silicic volcanic activity occurring at the Mid-Atlantic Ridge, and is topographically elevated because of the abundant igneous material produced in association with the Iceland hot spot, the center of which is thought to be located beneath Vatnajokull glacier [1]. The axial rift zones which run through Iceland from southwest to northeast are in direct continuation of the crestal zones of the Mid Atlantic Ridge and are among the most active volcanic zones on Earth.

Subglacial Volcanism: Volcanic accumulations of hyaloclastites which are deposits formed by the intrusion of lava beneath water or ice and the consequent shattering into small angular vitric particles, combined with pillow lavas, irregular intrusions and occasionally subaerial lavas, are widely exposed in the volcanic zones of Iceland. These rocks mainly formed subglacially during the Upper Pleistocene but also during Recent times. The origin of the hyaloclastite volcanoes was for a long time a matter of controversy [2] and these volcanoes are still imperfectly known.

The distribution of Upper Pleistocene and Recent eruption units whose essential constituent is hyaloclastite, is shown in Fig. 1. Most of of these units belong to the Moberg Formation [3] formed during the Upper Pleistocene (0,01 - 0,78 Ma). They are predominantly of subglacial origin. Tuffs and tuff breccias predominate along with pillow lavas. Moraines and fluvioglacial deposits are often intercalated with the hyaloclastites. Intra- and interglacial lavas are also an important constituent. Subglacial eruptions within the ice caps of Vatnajökull and Myrdalsjökull have continued up to the present [4].

The hyaloclastite units shown in Fig. 1 cover an area of about 10.600 km2. Hyaloclastites hidden by present ice caps may bring the total area to some 15.000 km2. Basalts are estimated to be • 90 % of the volume, probably < 5 % are intermediate rocks and • 5 % silicic rocks. These eruption units can be divided into three morphological classes, hyaloclastite mounds and ridges, tuyas (flat topped and steep sided volcanoes that erupted into a glacial lake thawed by the volcano), and extensive flows of hyaloclastites combined with columnar basalt.

Distinction is made between three main phases in the generation of a subglacial volcano, e. g. pillow lava, hyaloclastite and subaerial lava.

A pile of undegassed pillow lava forms if the hydrostatic pressure exceeds the gas pressure of the magma. Pillow lavas are often found at the base of hyaloclastite mounds, ridges and tuyas [5]. The thickness of basal basaltic pillow lava piles often exceeds 60-80 meters and a 300 m thick section has been reported. Pillow lavas may also form lenses or pods at a higher level in the volcanoes.

It has been suggested that at a water depth less than approximately 100-150 m, basaltic phreatic explosions produce hydroclastites. It appears feasible to subdivide the hyaloclastites of the Icelandic ridges and tuyas, genetically into two main types. A substantial part of the base of the submarine Surtsey tuya is poorly bedded, unsorted, hydroclastite, which probably was quenched and rapidly accumulated below the seawater level without penetrating the surface [6]. Only 1-2 % of the volume of extruded material in the 1996 Gjalp eruption fell as air-fall tephra, the bulk piled up below the ice [4]. The coarse-grained, often massive core of many of the larger tuyas and ridges may have formed in this way.

At shallow water depths (approximately 20-30 m in the submarine Surtsey eruption, the phreatic eruptions start to penetrate the water level and bedded hyaloclastite (tephra) is deposited by air-fall or base-surge on ice or land, as e. g. in the Surtsey and Gjalp eruptions. In many cases part of the tephra is deposited in ponded water or by running water at or close to the volcano during the eruption. These hyaloclastites are generally more fine-grained than the lower, more massive part described above. Pillows never occur. Examples of this type of hyaloclastites are ubiquitous in Iceland.

Subaerial lavas cap the hyaloclastites section of the tuyas and possibly about 10-15 % of the Icelandic hyaloclastite ridges. These lavas are comparable to other subaerial lavas, sheet lavas are most common but massive, simple flows also occur. The lavas grade into foreset breccias, and sometimes into gently dipping, degassed pillow lava.

Subglacial hyaloclastite ridges, mounds and tuyas are distributed throughout the volcanic zones of Iceland. The number of exposed units may easily exceed 1000-1200 [2]. A recent study (unpublished) in the northern part of the Western Volcanic Zone has identified 83 generally large subglacial volcanoes, of which 59 are hyaloclastite ridges or mounds and 24 are tuyas. The most common lithofacies is poorly bedded tuff breccia, often with pods and lenses of pillow lava and finely bedded tuff.

The area between Vatnajökull and Myrdalsjökull in the Eastern Volcanic Zone is dominated by hyaloclastite ridges, no tuyas are found in the area [7]. The ridges are generally much longer than in the Western Volcanic Zone and may reach a length of 45 km. They commonly have a present relief of 300-400 m.

Submarine volcanism: A minor part of the hyaloclastite volcanoes in Iceland have formed in marine environments. The best examples are found in the archipelago of Vestmannaeyjar, southwest of the tip of the Reykjanes Peninsula and offshore the Northern Volcanic Zone. A few the hyaloclastite volcanoes in the coastal regions of Iceland may also have formed in a submarine environment. According to the present terminology, most of the abovementioned islands are hyaloclastite ridges, a few are tuyas. As far as can be seen these islands are built up in the same way as the subglacail volcanoes, however, they are generally much more eroded due to marine abrasion.

The best known Icelandic example of a submarine hyaloclastite volcano is the island of Surtsey, which was constructed from the sea floor (depth 130 m) by phreatic submarine and effusive subaerial volcanic activity during 1963-1967, on the Vestmannaeyjar shelf 30 km off the south coast of Iceland [8]. When the eruption ceased the volume of Surtsey was ~ 0.80 km3, of which 0.12 km3 was above sea-level. The island had then reached a maximum height of 174 m and area of 2.7 km2. The island tuya consists of bedded alkali basalt hyaloclastite deposited by phreatic eruptions during 1963 -1964; lava flows of 1964 -1967, that produce foreset breccias where they enter the sea; coastal sediments formed by marine abrasion; aeolian sand formed by wind erosion of tephra, mainly deposited on the flanks of the tephra cones [6].

Marine abrasion has caused rapid cliff recession, and longshore currents have deposited a sand-gravel spit on the north shore. Lava units, particularly thin pahoehoe sheets, have been heavily abraded. Subaerial lava is currently dissappearing at • 0.1 km2 per year. However, the palagonite tuff, formed by hydrothermal activity, is most resistant to marine erosion. The area of Surtsey has shrunk from its original 2.7 km2 to 1.48 km2. Experiments with models of the decrease indicate, however, that Surtsey will last for a long time. Perhaps the final remnant of Surtsey before complete destruction will be a palagonite tuff crag similar to several of the other islands in the Vestmannaeyjar archipelago.

Consolidation and alteration. The bulk of the hyaloclastites in Iceland are consolidated and altered. Volcanic glass is thermodynamically unstable and basaltic glass alters easily to palagonite, which is a complex substance and variable in composition. Alteration primarily occurs under two different types of conditions, in short-lived, mild, hydrothermal systems and at weathering conditions. In Surtsey, hydrothermal activity, consolidation of the tephra, have been monitored closely since 1967 [6,9]. A hydrothermal system was developed due to intrusive activity within the tephra cones in late 1966. Surface temperature measurements in the hydrothemal area showed nearly constant heatflow until 1973 when temperatures started to decline. Temperatures in a drill hole in the eastern margin of the hydrothermal area indicate that the system has been cooling at a rate of • 1° C per year since 1980. Hydrothermal activity caused rapid alteration of tephra producing the first visible palagonite tuff in 1969. By estimate 65 % of the tephra pile was converted to palagonite tuff in 1976. Since then the visible area of palagonite tuff has gradually increased due to erosion of loose tephra on the surface.

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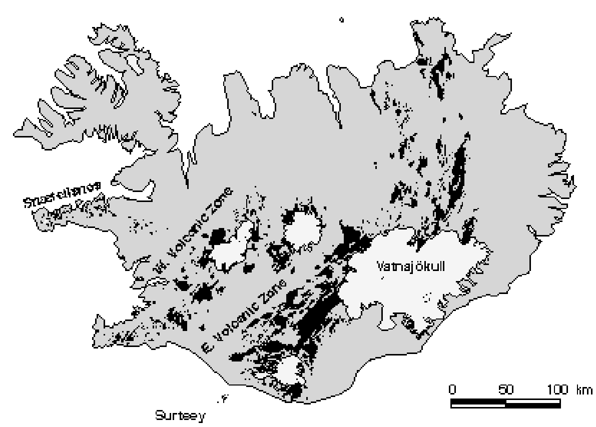

Fig. 1. Distribution of Upper Pleistocene (<0,78 Ma) and Recent hyaloclastites and associated lithofacies in Iceland. Modified after [10].