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The emplacement of an obsidian dyke through thin ice: Hrafntinnuhryggur, Krafla Iceland

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ABSTRACT

An eruption along a 2.5 km-long rhyolitic dyke at Krafla volcano, northern Iceland during the last glacial period formed a ridge of obsidian (Hrafntinnuhryggur). The ridge rises up to 80 m above the surrounding land and is composed of a number of small-volume lava bodies with minor fragmental material. The total volume is <0.05 km^3. The lava bodies are flow- or dome-like in morphology and many display columnar-jointed sides typical of magma–ice interaction, quench-fragmented lower margins indicative of interaction with meltwater and pumiceous upper surfaces typical of subaerial obsidian flows. The fragmental material compromises poorly-sorted perlitic quench hyaloclastites and poorly-exposed pumiceous tuffs. Lava bodies on the western ridge flanks are columnar jointed and extensively hydrothermally altered. At the southern end of the ridge the feeder dyke is exposed at an elevation ~95 m beneath the ridge crest and flares upwards into a lava body.

Using the distribution of lithofacies, we interpret that the eruption melted through ice only 35–55 m thick, which is likely to have been dominated by firn. Hrafntinnuhryggur is therefore the first documented example of a rhyolitic fissure eruption beneath thin ice/firn. The eruption breached the ice, leading to subaerial but ice/firn-contact lava effusion, and only minor explosive activity occurred. The ridge appears to have been well-drained during the eruption, aided by the high permeability of the thin ice/firn, which appears not to have greatly affected the eruption mechanisms. We estimate that the eruption lasted between 2 and 20 months and would not have generated a significant jökulhlaup (<70 m^3 s^{-1}).

1. Introduction: subglacial rhyolite eruptions

In recent years a number of field studies in Iceland have yielded new insights into the range of behaviour exhibited by rhyolitic eruptions beneath ice. The spectrum of documented eruption types, summarised in McGarvie (2009-this issue) includes small-volume effusive eruptions dominated by quench hyaloclastite (Furnes et al., 1980; Tuffen et al., 2001), larger-volume explosive eruptions, some of which pierce the ice surface and create tuyas (Tuffen et al., 2002a; Stevenson, 2005; Stevenson et al., 2006), mixed eruptions with both explosive and effusive behaviour (Tuffen et al., 2008a) and larger volume effusive eruptions (McGarvie et al., 2007).

The salient findings of these studies include: (1) subglacial cavities are generally well-drained although some meltwater is available to interact with rising magma; (2) in effusive eruptions the ice roof is close to the growing edifice; (3) explosive eruptions involve significant magma vesiculation, (4) tuya-building eruptions terminate with effusion of degassed, subaerial lava flows and (5) interactions between magma and water include phreatomagmatic fragmentation, quench fragmentation and perlite formation. The range of styles of eruption has been attributed to a range of magma discharge rates—with explosive eruptions favoured by rapid magma discharge and melting (Tuffen et al., 2007) although different magma volatile contents may also be important.

Another factor that has not been considered is the contrasting effect that different ice thicknesses may have on the mechanisms of rhyolitic eruptions, as most deposits studied to date are inferred to have been emplaced beneath relatively thick ice (>150 to >600 m). Detailed studies of subglacially erupted basaltic sequences have shown that there are important differences between the products of eruptions under thick and thin ice (Smellie and Skilling, 1994; Smellie, 2000). Basaltic eruptions under thin ice (<150 m) involve considerably less magma–meltwater interaction due to the permeable nature of the ice, as the rate of ice deformation around subglacial meltwater drainage channels is sluggish, allowing efficient drainage of meltwater through a hydrological system that is most likely at atmospheric pressure. By contrast basaltic eruptions beneath thicker ice are characterised by the formation of a quasi-stable englacial or ice-contact lake and extensive interaction between rising magma and meltwater (e.g. Skilling, 1994).

Meltwater accumulation is thought to be much less important during rhyolitic eruptions under ice, possibly due to the positive pressure changes expected during melting of ice by lower-temperature rhyolitic magma (Hoskuldsson and Sparks, 1997; Tuffen et al., 2002b).

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Nonetheless it is not known whether the degree of interaction with meltwater differs during rhyolitic eruptions beneath thick and thin ice, or whether the mechanism of rhyolitic eruptions beneath thin ice differ greatly from those beneath ice hundreds of metres thick. The aim of this paper is thus to document for the first time the products of a rhyolitic eruption beneath thin ice—at Krafla in northern Iceland—and to reconstruct the type of interaction between magma and ice and meltwater that occurred, before considering which factors may have controlled the mechanisms of the eruption.

2. Geological setting of Krafla central volcano

Krafla central volcano is located on the northern rift zone of Iceland (Fig. 1) and comprises a ~15-km diameter central volcano and a 100-km-long basaltic fissure swarm. Rhyolitic volcanism at Krafla occurred in two main phases, each of which produced about 1 km^3 of magma (Jónasson, 1994), followed by a smaller third phase. The first phase occurred at about 100 ka, near the beginning of the last glacial period, and may have triggered collapse of a ~8×6 km caldera. The eruption generated a rhyolitic dome at Hágöng and a 2.5-km^3 welded airfall tuff that comprises 1 km^3 of rhyolitic magma that was incompletely mixed with basaltic magma. The second phase also occurred during the last glacial period and formed three subglacial rhyolite ridges just outside the caldera rim. These are Jörundur, Hliðarfjall and Gaesafjallarani (Fig. 1), which are about 300 m high and have a total volume of 0.7 km^3. They consist of rhyolitic lava lobes and quench hyaloclastite.

The third phase involved a small-volume (<0.05 km^3) rhyolitic eruption that formed Hrafntinnuhryggur (Obsidian Ridge) at about 24 ka (Ar/Ar date from Sæmundsson et al., 2000), a minor eruption near Krokkuvotn that generated mixed dacitic–andesitic lavas and hyaloclastites, and two postglacial eruptions of rhyolitic pumice, the Hveragil tephra at about 9000 BP and the 1724 Viti pumice (Jónasson, 1994). Krafla volcano is best known for the spectacular 1975–1984 basaltic fissure eruption and associated rifting (e.g. Einarsson and Brandsdottír, 1980).

3. Structure of Hrafntinnuhryggur

Hrafntinnuhryggur is a SSW–NNE trending ridge 2.5 km in length within the eastern part of the Krafla caldera (Figs. 1–3). It rises up

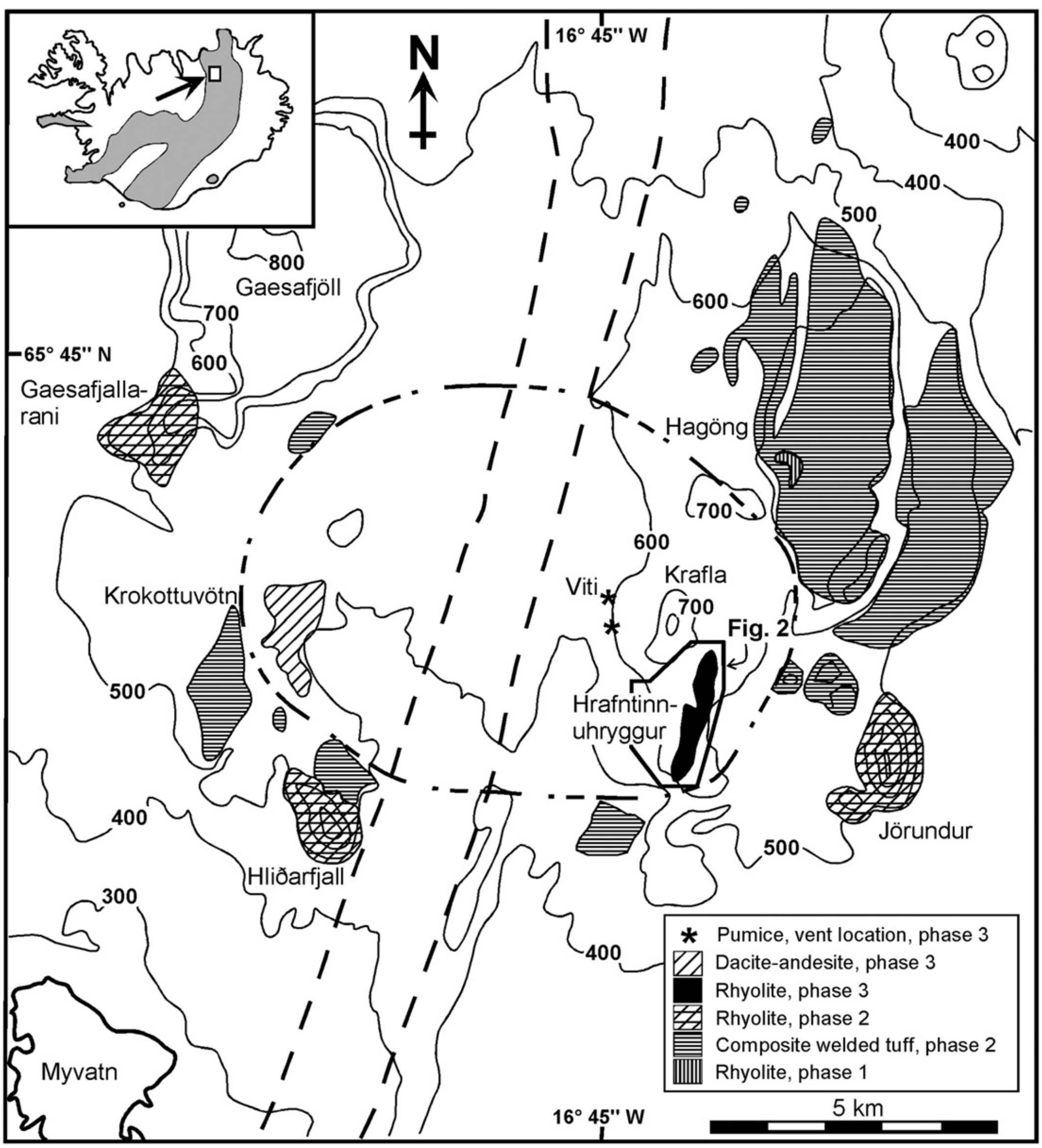

Fig. 1. Simplified geological map of the Krafla central volcano, showing its location in northern Iceland (inset map, with neo-volcanic zones shaded). The main outcrops of silicic rocks are indicated, together with the approximate location of the inferred caldera (bold dot-dash line), the presently active fissure swarm (bold dotted line) and the geological map in Fig. 2 (bold solid line). Note that Hrafntinnuhryggur is orientated parallel to the presently active fissures. Map redrawn from Jónasson (1994).