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Intrusion of basalt into frozen sediments and generation of Coherent-Margined Volcaniclastic Dikes (CMVDs)

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ABSTRACT

Coherent-Margined Volcaniclastic Dikes (CMVDs) are described for the first time from Askja (Dyngjufjöll), Iceland. These dikes display continuous, coherent glassy margins 5 cm thick and have a variety of clastic interiors comprising vitric tephra, pillow and pillow-fragment bearing lapilli tuffs. CMVDs are interpreted to form when basaltic dikes interact with subglacial ice-cemented volcaniclastic sediments. Formation requires chilling of dike margins, drainage of the dike interior and flooding of the cavity by meltwater, followed by non-explosive mingling of magma, clastics and water. Evidence for ice-cementation includes minimal interaction with the host (<3 mm peperite), local pillowed dike margins and the preservation of continuous glassy coherent margins along the edge of a drained dike cavity. CMVDs should be present at other volcanic centers with ice-cemented sediments, including the Martian cryosphere.

1. Introduction

Askja is one of the largest and best-exposed, formerly ice-confined, volcanoes on Earth. Most research has been on its Holocene (ice-free) evolution. The complex of basaltic glaciovolcanic massifs is dominated by volcaniclastic deposits that are cut by several calderas, and surrounded by Holocene subaerial lava flows (Fig. 1).

Monogenetic basaltic eruptions under thick ice initially form a subglacial cavity filled with a temporally variable meltwater volume, subaqueous lavas and a variety of clastic deposits (White, 1996; Höskuldsson et al., 2006; Edwards et al., 2009; Skilling, 2009). Eruptions may become explosive and emerge through the ice to generate an edifice of ice-confined phreatomagmatic tephra (Gudmundsson et al., 1997; Smellie and Hole, 1997). However, models of the evolution of basaltic glaciovolcanic centers have largely neglected intrusive processes. There are detailed discussions of the interactions of intrusions with the Martian cryosphere (Head and Wilson, 2002; Wilson and Head, 2002); however, there is a current lack of the three-dimensional exposure required to explore these interactions further (Head and Wilson, 2002).

Basaltic glaciovolcanic centers on Earth demonstrate the common presence of intrusions emplaced into wet and unconsolidated, or partially cemented, volcaniclastic deposits (Schopka et al., 2006; Edwards et al., 2009; Mercurio, 2011). Dike formation can be simplified into three steps: 1) fracture of the host, 2) propagation of magmatic gasses at the dike tip (Carrigan et al., 1992) and 3) emplacement of magma and chill margin formation (Baer, 1995; Platten, 1995). This process is often repeated, as evidence of multiple magmatic pulses is preserved in vesicle bands and multiple chill margins (Huppert and Sparks, 1989; Baer, 1995; Platten, 1995; Liss et al., 2002; Taisne and Jaupart, 2010). Dike emplacement may be punctuated by volumetric contraction, or drainage of the dike (Agnon and Lyakhovsky, 1995).

Clastic dikes are common in sedimentary settings such as deep marine, lacustrine and glacial environments (Jolly and Lonergan, 2002). Volcaniclastic dikes have been described in various volcanic terrains (Heiken et al., 1988; Ross and White, 2005) . Examples of clastic dikes formed in unconsolidated sediment clearly demonstrate that the host sediment need not be lithified to fracture in a brittle manner (Rijsdijk et al., 1999; Jolly and Lonergan, 2002; Ross and White, 2005). The dominant mechanism responsible for the formation of clastic dikes is the fluidization of saturated sediments under excess pore fluid pressures (Rijsdijk et al., 1999; Jolly and Lonergan, 2002; Ross and White, 2005). These fluidized sediments fill fractures in the host that formed when the tensile strength of the host was exceeded by the fluid pressure. This process, referred to as hydrofracturing, is common in environments with high sedimentation rates (e.g. deep marine shelf) and under rapid loading (e.g. glacial) (Boulton and Caban, 1995; Jolly and Lonergan, 2002). The interior fills of such dikes are sourced from deposits stratigraphically below the host sediment, with the exception of some glacial clastic dikes (Rijsdijk et al., 1999; Jolly and Lonergan, 2002). CMVDs differ from clastic dikes as the dikes are lined with coherent glassy chill margins, and we also interpret the dike interiors as volcaniclastic material derived in situ in the dike fracture.

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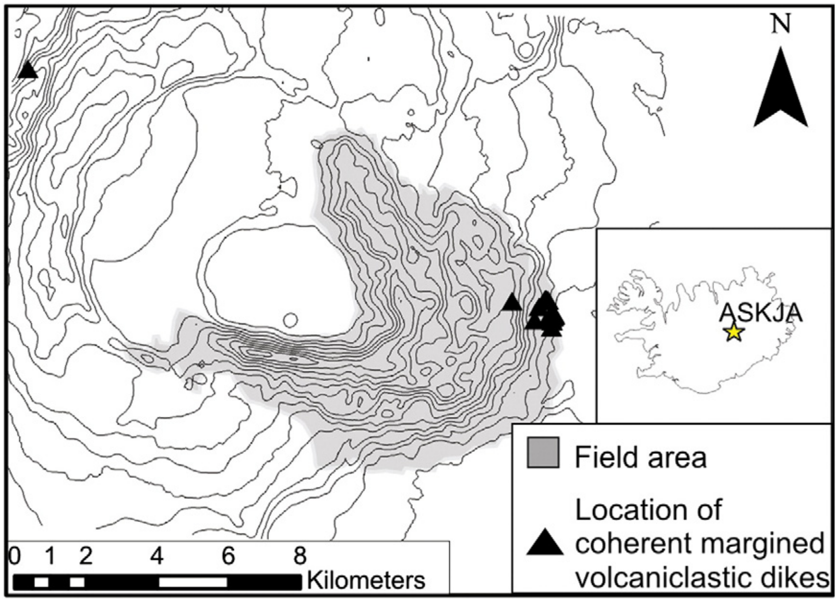

Fig. 1. Study area with regional location of Askja in inset. The triangles mark the locations of CMVDs.

2. Observations

Ninety-four intrusions were described within the tholeiitic ca. 800 m Austurfjöll massif (Fig. 1). They are subdivided into three types: 1) coherent dikes with no clear interaction with their host, 2) coherent dikes with irregular morphologies and pillowed margins in 2–4 m wide domains of fluidal and blocky peperite and 3) dikes we term CMVDs, that display multiple continuous basaltic glassy coherent chill margins, very thin (<3 mm) marginal peperite and a variety of vitriclastic interiors. The first two types of dike have been observed and described at other glaciovolcanic (Edwards et al., 2009; Mercurio, 2011) and submarine settings (Kano, 1989; Befus et al., 2009).

Sixteen CMVDs were documented, dominantly within a 1 km^2 area 10–300 m above the massif base (Fig. 1). At least two additional examples have been investigated, at a reconnaissance level, in the western massif, 17 km away from the main cluster, and within 300 m of the local base elevation (Fig. 2). The CMVDs were emplaced into a variety of bedded and massive ash and lapilli tuffs. The dikes are 0.5–2 m in diameter and are exposed in three dimensions over 10–100s of meters in length. They dip steeply (~60°) with fairly constant strikes, but have minor variations in orientation over 10s of meters and can display minor offshoots. In the western massif the CMVDs have less tabular morphologies but retain similarities to the main dike cluster in margin, fill type, scale and interaction with the surrounding host.

2.1. Dike margins

CMVDs display continuous margins of coherent unvesiculated basaltic glass up to 2 cm thick, with an additional 1–3 cm of coherent vesiculated (up to 40 vol.%, 0.1–1 mm vesicles) glass on the margin interior (Fig. 3). The margins retain consistent thicknesses on both sides of a dike. Some have slickenline-like textures between the vesiculated and unvesiculated zones (Baer, 1991). Localized margin variations include mini-pillows (<7 cm long) (Fig. 3) and rare segments of absent glassy margin. The clasts of absent margin (up to 6 cm long) can be found within 5 m of their origin, in the interior of the dike. The bulk of the margin (2–3 cm) contains occasional (ca. 5 vol.%) faint, rounded,

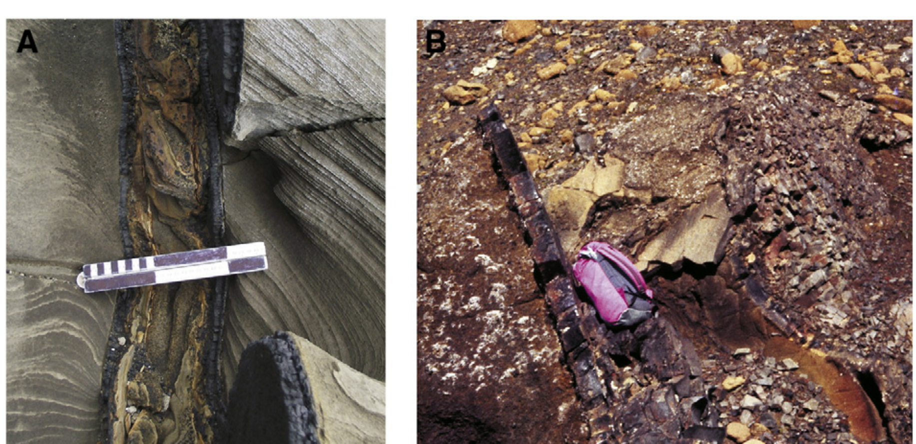

Fig. 2. Images of examples of CMVDs. Common features are the consistent glassy margins and complex volcaniclastic interiors. A) Example from main area of CMVD distribution, the segments on the scale are 10 cm. Note the lack of mechanical or thermal alteration of the host sediment by the dike. B) Example of CMVD from western massif of Askja (17 km from main cluster), backpack for scale.