II. ÖRÆFAJÖKULL VOLCANO: GEOLOGY AND HISTORICAL FLOODS

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1. Introduction and scope

Glacial outburst floods (jökulhlaups[1]) are a potent hazard in the proximal and distal regions of an erupting subglacial volcano (Tilling, 1989; Roberts, 2005; Gudmundsson *et al.*, 2008). Besides meltwater, volcanogenic jökulhlaups comprise fragmented ice and primary and secondary volcaniclastic material (Major and Newhall, 1989; Tómasson, 1996). Such fluid-sediment mixtures can produce a variety of flow properties, ranging from turbulent, Newtonian discharge to cohesionless, hyper-concentrated torrents (Maizels, 1989). Moreover, volcanogenic jökulhlaups descending from steep, erodible slopes often produce sediment-laden flows by entraining debris dynamically (e.g. Naranjo *et al.*, 1986; Waythomas, 2015).

In 1362 CE, and again in 1727 CE, an explosive eruption at Öræfajökull — an ice-capped stratovolcano located on the southern coast of Iceland — resulted in a massive, short-lived jökulhlaup that caused fatalities and extensive damage to farmland (Thorarinsson, 1958). The Plinian eruption of 1362 is considered paroxysmal, equivalent to six on the volcano explosivity index (VEI) (Gudmundsson *et al.*, 2008), and the largest explosive eruption in Europe since Mount Vesuvius erupted in 79 CE. The following eruption of Öræfajökull, 365 years later in 1727, is thought to have been VEI ~4 in magnitude. Eyewitness accounts of the 1727 jökulhlaup depicts a scene where floodwater rushed from high on the side of Öræfajökull to the adjacent floodplain (sandur) within tens of minutes (Thorarinsson, 1958 and references therein). During both historical floods, water burst from two sets of combined glaciers: Falljökull and Virkisjökull (herein referred to as Falljökull) and Kotárjökull, and Rótarfjallsjökull (herein referred to as Kotárjökull), as shown in Figure II-1. There is also credible evidence of jökulhlaup activity on the southern flanks of the ice-cap (Höskuldsson, personal communication, October 2015), including a possible pre-historical route via Kvíárjökull (Thorarinsson, 1958; Iturrizaga, 2008). Remarkably, both historical floods deposited blocks of glacial ice on the sandur that took decades to melt. In several cases, these stranded masses were renamed as glaciers as they melted amongst jökulhlaup deposits (Sigurðsson and Williams, 2008).

Despite the documented severity and lasting geomorphic imprint of the 1362 and 1727 jökulhlaups, there is scant information about the routing and extent of these floods. Using published descriptions, field observations, aerial photographs, and modern-day analogues, we reconstruct the 1362 and 1727 jökulhlaups. The goal is to constrain the duration, extent, composition, and maximum discharge of the two floods. The results

[1] Note that the terms jökulhlaup and flood are used interchangeably in this chapter when describing lahar-type flows from Öræfajökull.

provide new insight into the routing and maximum discharge of volcanogenic floods from Öræfajökull, thereby contributing toward hazard assessment in the region (Helgadóttir *et al.*, 2015, Chapter IV) and (Pagneux and Roberts, 2015, Chapter V).

A geological overview of Öræfajökull is presented next, summarising the stratigraphy, ice cover, and Holocene eruptive activity of the volcano. This is followed by descriptions of the 1362 and 1727 jökulhlaups. The chapter concludes by considering hazard-related issues, including (i) floodwater routing, timing, and extent; (ii) flow properties; (iii) maximum discharge; and (iv) modern-day comparisons.

2. Geological overview

The Öræfajökull volcano is located about 50 km southeast of the active rift zone in Iceland forming, together with Esjufjöll and Snæfell, a 120 km long, discontinuous volcanic flank zone (Sæmundsson, 1979; Björnsson and Einarsson, 1990; Sigmundsson, 2006). Öræfajökull is the highest volcano in Iceland, rising from sea level to over 2,100 m to form Iceland's highest peak, Hvannadalshnjúkur (~2110 m AMSL) (Figures II-1 and II-2). The mountain massif of Öræfajökull is elongated slightly, with a north-south base diameter of 25 km, while the east-west basal diameter is about 20 km.

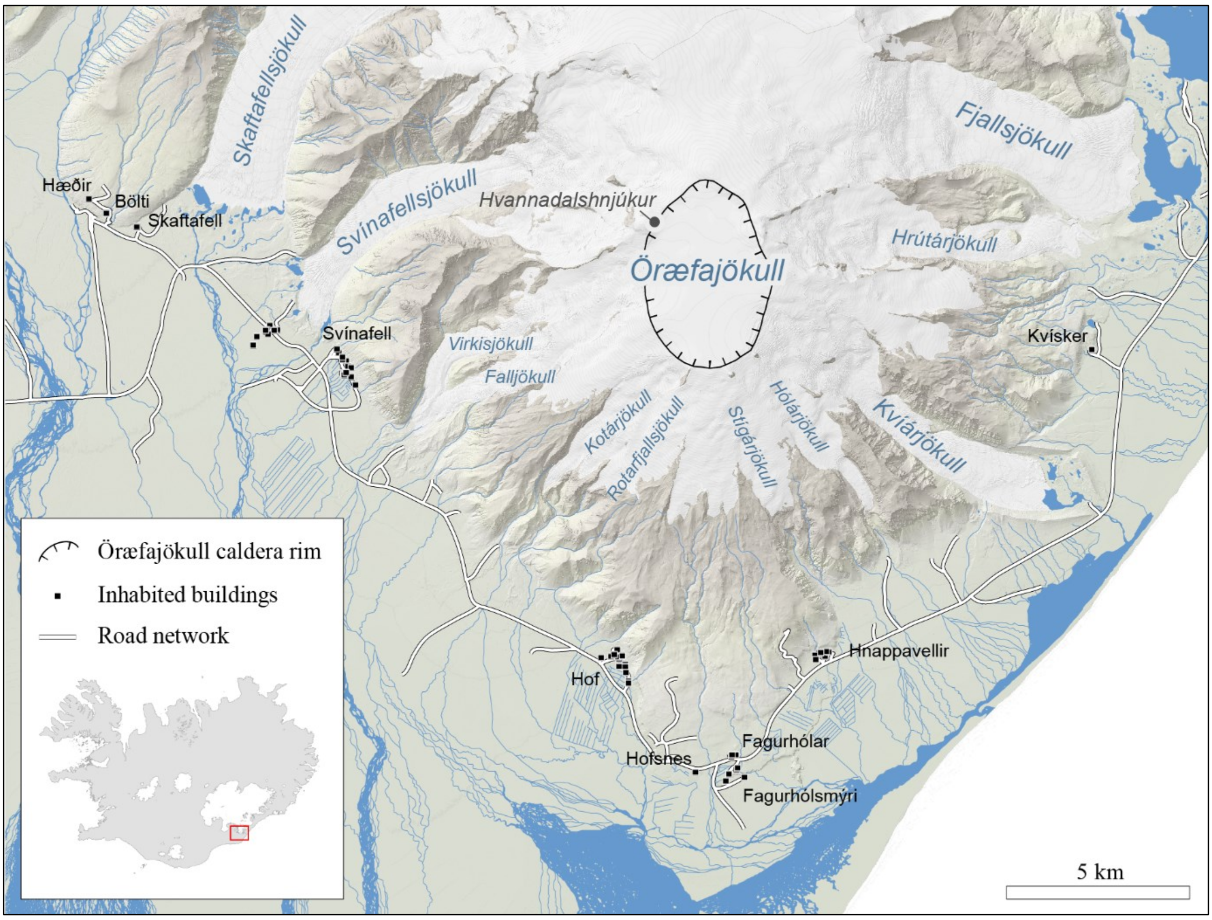

Figure II-1: Location of Öræfajökull, an ice-capped stratovolcano in south-east Iceland. The summit of the ice cap, Hvannadalshnjúkur, is ~2110 m AMSL and the highest point in Iceland. Radio-echo sounding measurements from the surface of the ice cap show that ice within the caldera is up to 540 m thick (Magnússon et al., 2012b). The magnitude of the 1362 eruption may have caused deepening and widening of the volcano's caldera. Both historical eruptions occurred either within the caldera or on its rim; however, in 1362 most flooding came from Falljökull, implying that the eruption site was within the caldera.

A 14 km^2 summit caldera exists in the southern part of the massif (Figures II-1 and II-2). The ice-covered upper part of Öræfajökull is the southernmost region of Vatnajökull, connected to the main ice-cap at Hermannaskarð. Valley glaciers from the extensively eroded northern part of Öræfajökull have progressively carved overdeepened valleys, resulting in up to 550-m-thick valley glaciers such as Svínafellsjökull (Figures II-1 and II-2; Magnússon *et al.*, 2012b).

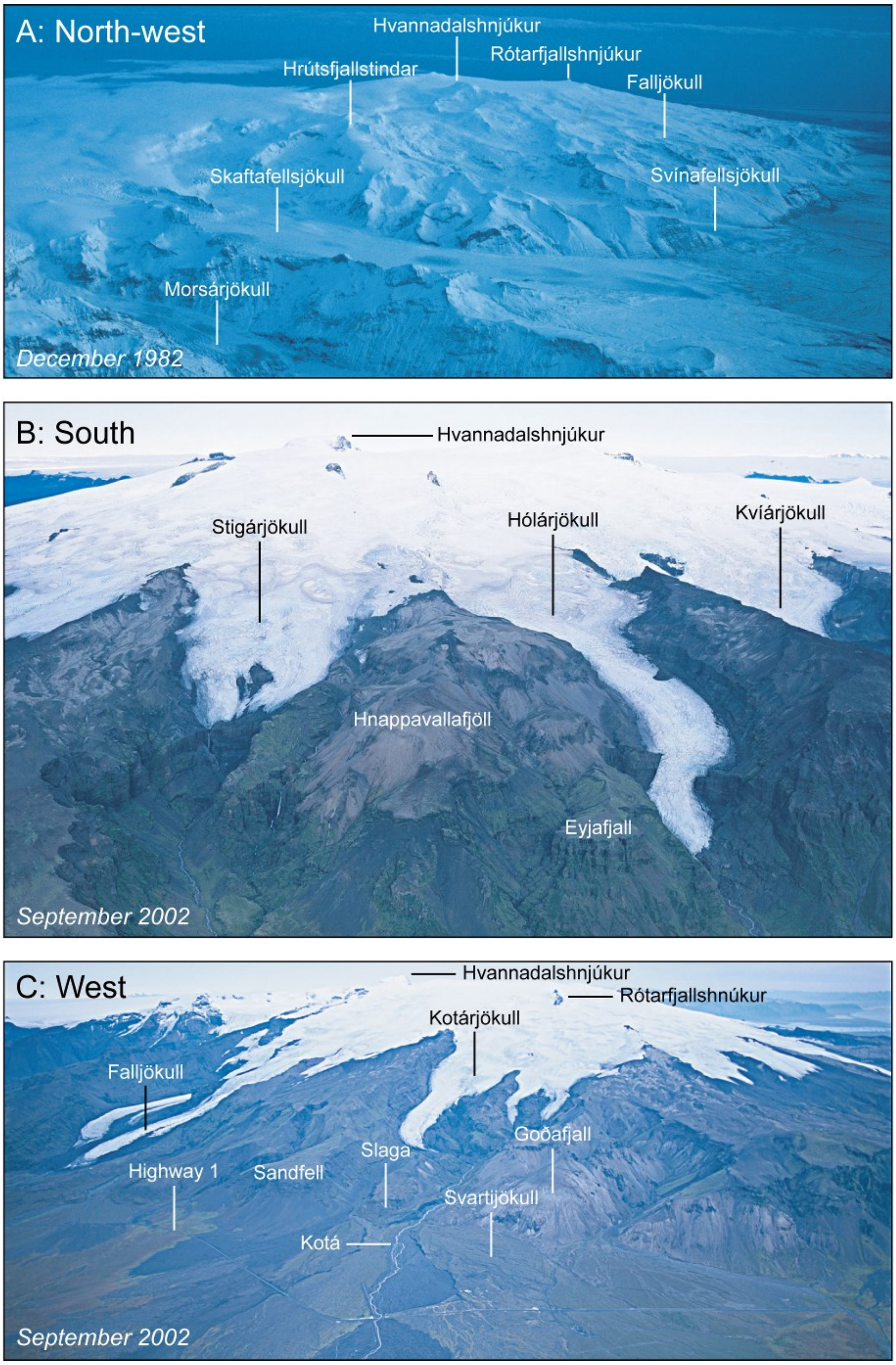

Figure II-2: Oblique aerial photographs of Öræfajökull. (A) View from the north-west; (B) southern flank; and (C) western flank. Photographer: O. Sigurðsson.

2.1. Stratigraphy

The oldest rocks are found in the northern part of the Öræfajökull massif, with the volcanic strata becoming progressively younger on the volcano's southern side. A boundary occurs roughly along a line between Svínafellsjökull, Tjaldskarð and Fjallsjökull. To the north of this line the rocks are predominantly from the Matuyama magnetic chron (2.58–0.78 Ma) or older, as deduced from pronounced magnetic lows in aeromagnetic surveys (Jónsson *et al.*, 1991) and confirmed by stratigraphic mapping and radiometric dating (Helgason, 2007; Helgason and Duncan, 2001). South of the divide is the presently active Öræfajökull stratovolcano, comprising normally magnetized rocks from the Brunhes chron (<0.78 Ma). The oldest dated rocks found near the base of Svínafell have an Ar-Ar age of 0.76 Ma (Helgason and Duncan, 2001; Helgason, 2007).

Thorarinsson (1958) published chemical analyses of the 1362 tephra from Öræfajökull; he also described the overall morphology and geology of the volcano. Torfason (1985) compiled a geological map of southeast Iceland, including Öræfajökull. Later stratigraphy work was undertaken by Helgason and Duncan (2001, 2013) on the northern parts of the massif. The petrology of Öræfajökull was considered by Prestvik (1982), whereas Stevenson *et al.* (2006) analysed the physical volcanology of a large Pleistocene rhyolitic lava flow on the southeast side of the volcano. Jakobsson *et al.* (2008) classified the Öræfajökull central volcano as belonging to the transitional alkalic series, together with other volcanoes in the Öræfajökull-Snæfell flank zone. Other notable studies include that of Gudmundsson (1998) who used tephrochronology to study the Holocene volcanic history of Öræfi. Björnsson (1988) published the first results of radio-echo soundings from a north-south traverse and measured the depth of the 14 km^2 summit caldera. Magnússon *et al.* (2012b) performed an extensive radio-echo survey on Öræfajökull, deriving ice thickness for the caldera and the upper and lower areas of the valley glaciers; the study's results are summarised in § 2.2.

Some of the nunataks on the caldera rim are made of rhyolites. Rhyolite formations are also found on the lower southwest slopes and on the eastern side where the Vatnafjöll ridge to the north of Kvíárjökull is made partly of a massive rhyolitic lava flow (Stevenson *et al.*, 2006). For the most part, the lower slopes consist of hyaloclastites and lava flows of basaltic to intermediate composition. In summary, eruptions contributing to the growth of the edifice are thought to have occurred mainly during glacial periods. This is also apparent in the form of the lower slopes of Öræfajökull, which are steeper than the upper slopes, suggesting partial confinement by glacial ice during extended periods over the volcano's existence.

2.2. Ice cover

The upper parts of Öræfajökull, south of Hermannaskarð, have a mean slope angle of 15 degrees, with glacial ice covering most of the volcano above about 1000 m AMSL. The summit plateau between Hvannadalshnjúkur, Snæbreið and Hnappar has an elevation of 1800–1850 m AMSL. The plateau is the surface expression of the 14 km^2 summit caldera, containing 3.9 km^3 of ice at depths of up to 540 m in the caldera centre (Magnússon *et al.*, 2012b). Ice flows out of the caldera in all directions, although mostly westwards to Falljökull and southeast to Kvíárjökull.

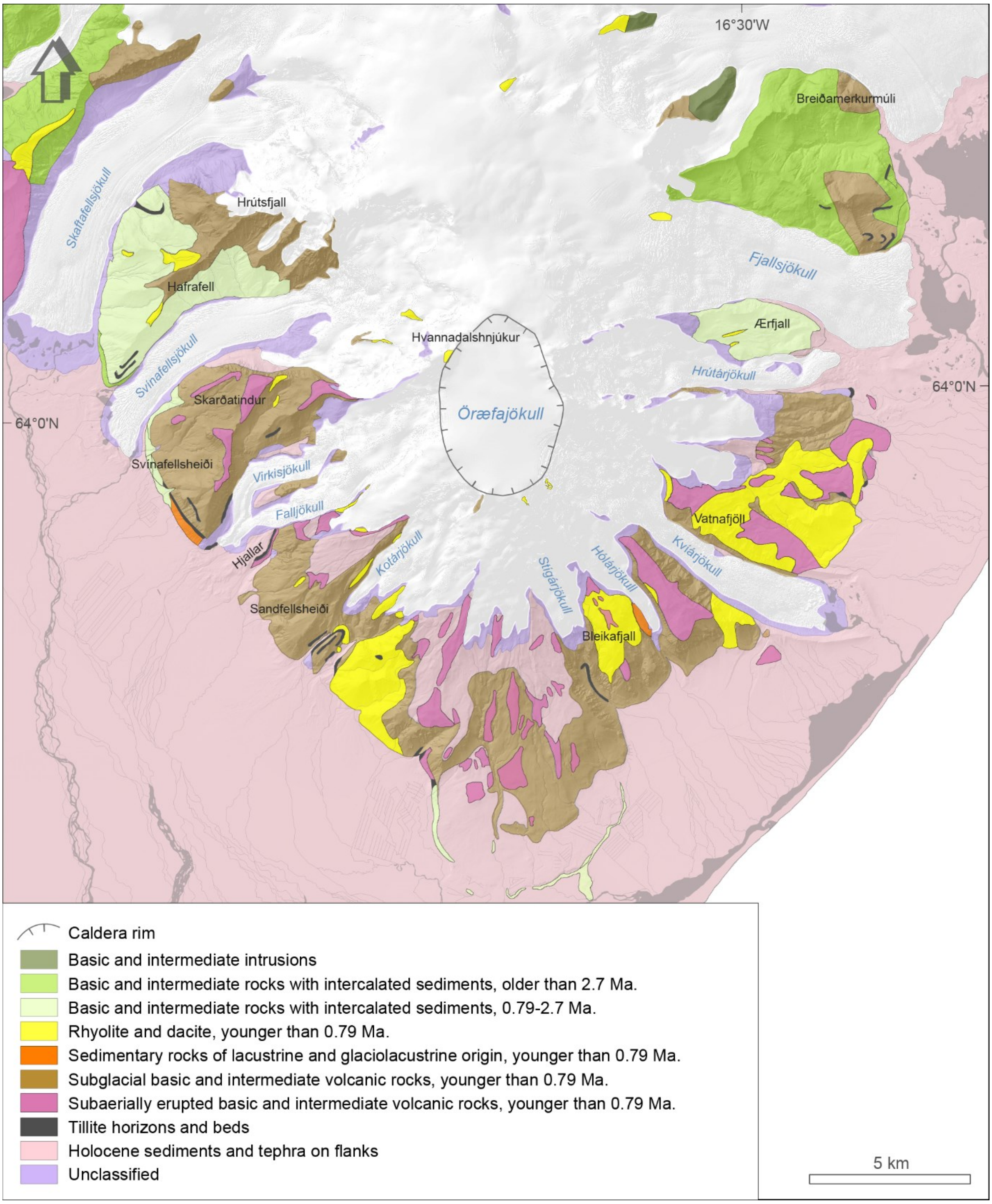

Figure II-3: Geological map of Öræfajökull (modified from Torfason, 1985).

A small area near the southwest margin of the caldera drains to Kotárjökull. Radio-echo soundings reveal that the lowest bedrock points are where Falljökull and Kvíárjökull drain out of the caldera. These low points are 270–290 m higher than the base of the caldera.

The steep-sloping ice falls of Falljökull and Kvíárjökull result in ice thicknesses of 50–100 m. Thicker ice exists near to the termini of the valley glaciers, some of which have eroded deep bedrock troughs (Magnússon *et al.*, 2012b).

2.3. Volcanic production rate and Holocene activity

The total volume of rocks above sea level south of Hermannaskarð is about 370 km^3. The volume of ice in the same area is 25–30 km^3. Of the 370 km^3 massif, it appears that roughly half the volume belongs to the present volcano, younger than 0.79 Ma. A rough, lower bound for the production rate of the volcano may be obtained by assuming that the present edifice has been built incrementally during this period. Consequently, the rate of volume growth is about quarter of a cubic kilometre every thousand years. However, the long-term mean eruption rate must have been considerably higher given the erosive effects of repeated glaciations and jökulhlaups.

The two historic eruptions of 1362 and 1727 are discussed in more detail later, but the first one is considered to be the largest explosive eruption in Iceland in the last 1100 years. Selbekk and Trønnes (2007) described rhyolitic tephra from 1362 as fine-grained vesicular glass, indicative of fast magma ascent to form a Plinian eruption plume. Rhyolitic tephra fell over large parts of Iceland during the 1362 eruption, although the main area of deposition was oriented out to sea, with a dispersal axis towards the east-southeast (Thorarinsson, 1958). Thorarinsson (1958) estimated the bulk volume of freshly fallen tephra at 10 km^3. Deposits of pyroclastic density currents have been found on the slopes and lowlands to the south and southwest of the volcano (Höskuldsson and Thordarson, 2006, 2007).

Holocene volcanic activity before the 1362 eruption was modest, with two minor lava flows on the east side of the volcano. One is on the lowlands west of Kvíárjökull while the other is higher up on the slopes in Vatnafjöll on the north side of Kvíárjökull. Tephrochronology of soils around Öræfajökull has been studied, suggesting that a few, relatively small rhyolitic eruptions occurred during the period (Guðmundsson, 1998). Thus, apart from the 1362 eruption, activity in Öræfajökull has been modest in Holocene times. It has been proposed that a trachyandesite lava-flow by the northern side of Kotárjökull, on the eastern side of Mount Slaga, is an ice-confined lava, emplaced during the 1727 eruption (Forbes *et al.*, 2014). This location is also the same area where floodwater burst from Kotárjökull in 1727 (§ 5.3).

3. Jökulhlaups due to eruptions of Öræfajökull

Since Norsemen first settled Iceland in the late 9th Century CE, there are two written accounts of volcanic activity at Öræfajökull. Before the 1362 eruption the ice-cap was known as Knappafellsjökull, but in the aftermath of the eruption the name was changed to Öræfajökull in recognition of the devastation wreaked by the eruption (Thorarinsson, 1958). Before 1362, the lowlands flanking Öræfajökull hosted fertile grazing land, which supported at least 40 farms in a regional settlement known formerly as Litlahérað (Ives, 1991 and references therein).

Deposits from pyroclastic density currents have been identified in the lowlands as belonging to the 1362 eruption. Tephra fall was prevalent during both historical eruptions, particularly in 1362. Excavations of relic dwellings to the immediate south and west of the volcano show that, during the onset of 1362 eruption, several pyroclastic surges occurred (Höskuldsson and Thordarson, 2007), followed by extensive fall-out of rhyolitic ash (Thorarinsson, 1958). A wider examination of the region (Höskuldsson, 2012), reveals that pyroclastic density currents from the 1362 eruption reached a distance of over 10 km from the centre of the caldera (Gudmundsson *et al.*, 2008). In this chapter, only deposits due to jökulhlaups are considered; however it should be borne in mind that tephra-related hazards were probably responsible for the apparent total destruction of Litlahérað.

4. Methods

Several methods were used to reconstruct the timing, routing, and geomorphic impact of the 1362 and 1727 jökulhlaups. The sequence of events for both jökulhlaups was pieced together mainly from published sources, as explained in § 4.1. Similarly, palaeo-estimates of subaerial floodwater routing and floodwater extent at maximum discharge were derived from published sources, as well as an examination of aerial photographs (§ 4.2). The same mosaic of images was used to map coarse-scale flood deposits and features (§ 4.3). The following sub-sections outline the methodological details of each approach.

4.1. Historical accounts

The pioneering monograph by Thorarinsson (1958) is the foremost resource about the 1362 jökulhlaup; this source is used extensively here. Detailed first-hand accounts of the 1727 jökulhlaup exist (Thorarinsson, 1958 and references therein), and they are used here to infer how the 1362 jökulhlaup developed. Likewise, qualitative comparisons are made with volcanogenic jökulhlaup in Iceland from 1918 onwards (§ 10).

4.2. Geomorphic mapping

A digital surface model (DSM) and high-resolution aerial photographs were used to identify and map flood deposits to the west and south of Öræfajökull. The DSM was derived from an airborne LIDAR survey of the region, performed during the summers of 2011 and 2012. The horizontal and vertical accuracy of the initial scan was <0.5 m. These measurements were used to create a DSM that depicted surface features exceeding 1 m^2 in area. The DSM was also used to measure the depth of kettle-holes and to extract cross-sectional profiles. In this context, the estimated vertical accuracy of the model is <0.5 m. For details of the LIDAR survey and data handling, see Jóhannesson *et al.* (2013).

Flood deposits and erosional features were studied during fieldwork that was carried out in 2003, 2005, and 2006 (Figure II-4). Features including kettle-holes, boulder clusters, and terraces were mapped using a *Trimble Pathfinder* backpack-mounted GPS.

A differential correction was applied to the data using continuous measurements from a fixed GPS site in Reykjavík (baseline distance: ~247 km). The calculated accuracy of the results is ~0.7 m horizontally and ~1.3 m vertically. Geomorphic features were identified from aerial photographs (§ 4.3) using established criteria for the recognition of jökulhlaup deposits (Maizels, 1993, 1997; Russell and Marren, 1999; Marren, 2005; Russell *et al.*, 2005) (Table II-1).

Figure II-4: Field assessment of jökulhlaup deposits. (A) Collection of bulk samples of sediment from the Kotá fan on 18 March 2003 (§ 5.3). (B) Boulder survey to the west of Falljökull on 27 August 2006. Note the person for scale.

Table II-1: Criteria for the recognition of jökulhlaup deposits (after Marren 2005, p. 233).

Criteria indicative of high-magnitude flooding	Sedimentary characteristics
Hyperconcentrated flow:	*Poor sorting; massive; reverse grading; poor imbrication; floating clasts; traction carpets.*
Debris flow:	*Very poor sorting; massive; may show correlation between maximum particle size and bed thickness.*
Strongly uniform palaeo-flow:	*Indicative of a lack of reworking by falling-stage flows.*
Thick, inversely graded (upward coarsening) units:	*Inversely graded units in coarse sediment thicker than ~2 m. Formed under rising-stage conditions.*
Large-scale gravel foresets:	*Thick (>2 m) cross-bedded coarse gravel. Formed in expansion or pendant bars and in mega-dunes.*
Ice-block features:	*Steep-walled and inverse conical kettle-holes; circular 'rimmed' kettles; obstacle marks and tails; hummocky terrain.*
Rip-up clasts:	*Blocks of subglacial diamict, bedrock, or river-bank sediment uprooted and deposited out-of-place.*
Large-scale geomorphic features:	*Hummocky terrain; mega-scale bars and terraces; boulder fields; palaeo wash-limits.*

4.3. Analysis of aerial photographs

Using Thorarinsson's (1958) delineation of flood routes, aerial photographs from *Loftmyndir ehf.* were used to classify surface features indicative of flooding in 1362 and 1727. The imagery was made available in geo-referenced format at a pixel resolution of <1 m. Combining the images with the DSM enabled a detailed geomorphological view of the region, allowing erosional and depositional features to be classified using *ArcGIS 10*. Aerial photographs from the National Land Survey of Iceland were also used to aid field investigations in 2005 and 2006.

5. Course of events

As well as considering the geomorphic legacy of prehistoric jökulhlaups, this section describes the development of the 1362 and 1727 jökulhlaups. As described in § 3, pyroclastic density currents would have been prevalent during eruptions of Öræfajökull. Partial collapse of the eruption plume could have triggered pyroclastic density currents, which would have scoured large zones of the ice-cap, causing significant and pervasive ice-melt (e.g., Naranjo *et al.*, 1986). In fact, anecdotal accounts of the 1362 eruption describe every gully awash with floodwater (Thorarinsson, 1958). Thermal and mechanical erosion of the ice-cap by the passage of pyroclastic density currents could account for the deposition of some jökulhlaup deposits; however this is not addressed here. For further details about tephra deposition, see Thorarinsson (1958) and Höskuldsson (2012).

5.1. Prehistoric jökulhlaups

According to Thorarinsson (1958) a prehistoric jökulhlaup burst from Kvíárjökull at a lateral breach known as Kambskarð in the terminal moraines (see also Iturrizaga, 2008) (Figure II-5). Sketchy accounts exist of the 1362 jökulhlaup draining partly from Kvíárjökull, but Thorarinsson disputed this. He argued that tephra fall from the eruption caused significant and widespread melting of the ice-cap, thereby causing a jökulhlaup that cascaded across the surface of Kvíárjökull. The Stórugrjót outwash fan to the immediate west of Kvíárjökull extends into the sea. Thorarinsson believed that Stórugrjót is prehistoric as it underlies the terminal moraine of Kviárjökull, which is thought widely to have formed ~500 BCE (Thorarinsson, 1956). West of Kvíárjökull, boulders from the Stórugrjót surface overtop the fringe of a basaltic, postglacial lava flow (Figure II-5). Thorarinsson (1956) claimed that the terminal moraine of Kvíárjökull post-dates the aforementioned lava flow. According to Thorarinsson, the lava flow originated to the east of Kvíárjökull; therefore, an eruption occurred at a time when Kvíárjökull was much farther up-valley than the position demarcated by the terminal moraine.

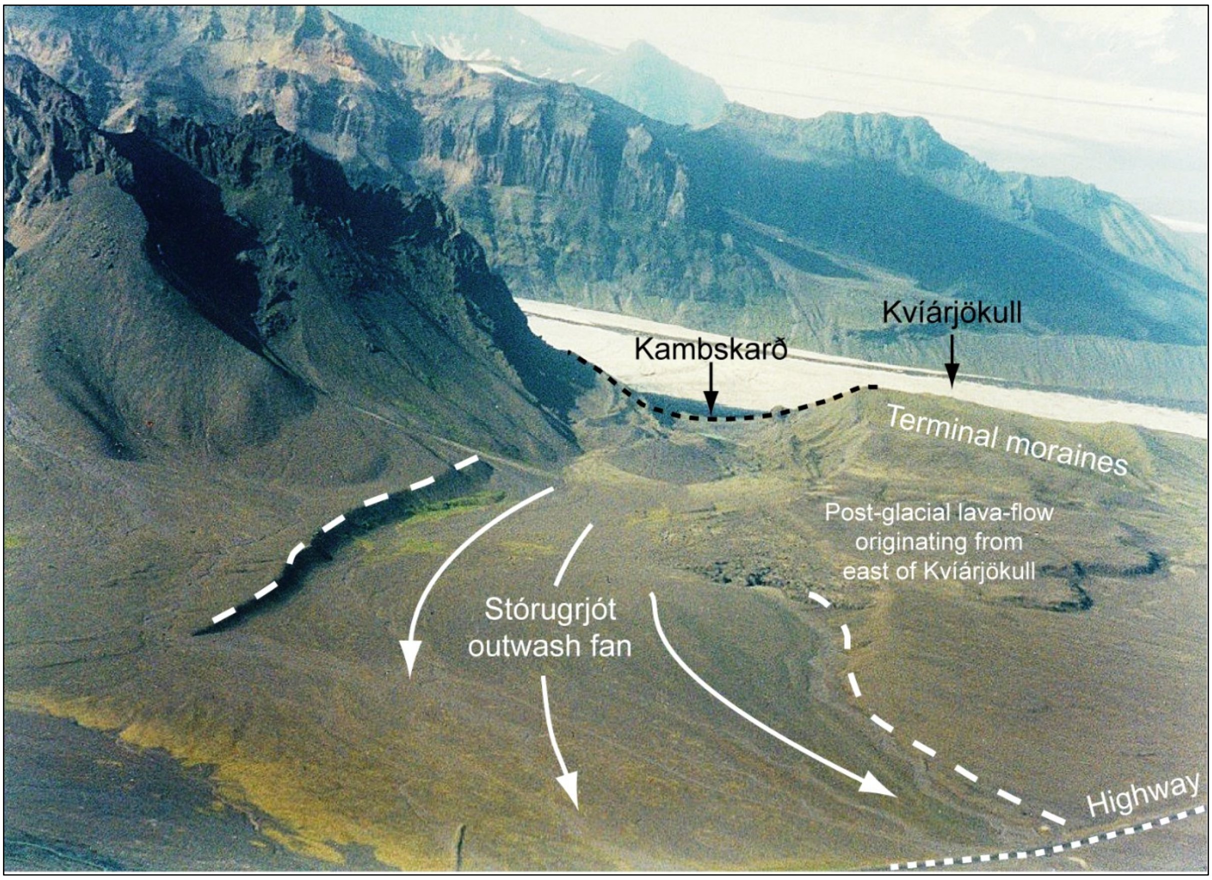

Figure II-5: Oblique, aerial view of Kvíárjökull showing the lateral breach in the terminal moraine and the relic outwash-fan extending from it. Photographer: M. J. Roberts, July 2000.

5.2. 1362 jökulhlaup

As Thorarinsson (1958) acknowledged, contemporary accounts of the 1362 eruption are vague, claiming that the entire settlement was obliterated during the eruption. Likewise other descriptions made decades after the eruption allude to complete destruction of Litlahérað. The only direct reference to the 1362 jökulhlaup is found in the fragmented church annals of Skálholt, written at a monastery in Möðruvellir, Northern Iceland. Thorarinsson's (1958, p. 26) translation of this text is as follows: "*At the same time [as the eruption] there was a glacier burst from Knappafellsjökull [Öræfajökull] into the sea carrying such quantities of rocks, gravel and mud as to form a sandur plain where there had previously been thirty fathoms [~55 m] of water.*"

Thorarinsson (1958) considered that the 1362 eruption began in mid-June and it persisted until the autumn. Flooding, though, was confined mostly to the onset of the eruption and possibly the first 24 hours (*c.f.* Magnússon *et al.*, 2012b). The eruption created direct hazards of unprecedented magnitude. Melting of ice through rapid heat transfer from magma to ice, most likely within the volcano's ice-filled caldera, would have generated masses of meltwater at a bedrock elevation of ~1600 m AMSL (Gudmundsson *et al.*, 2015, Chapter III). The ensuing jökulhlaup propagated through Falljökull and Kotárjökull before inundating farmland on the western side of Öræfajökull at an initial elevation of ~80 m AMSL and a distance of 10–30 km from the eruption site (Figure II-6). Church annals written in the decades following the eruption depict a colossal flood that swept pieces of the ice-cap across Skeiðarársandur, cutting off all access to the region (Thorarinsson, 1958).

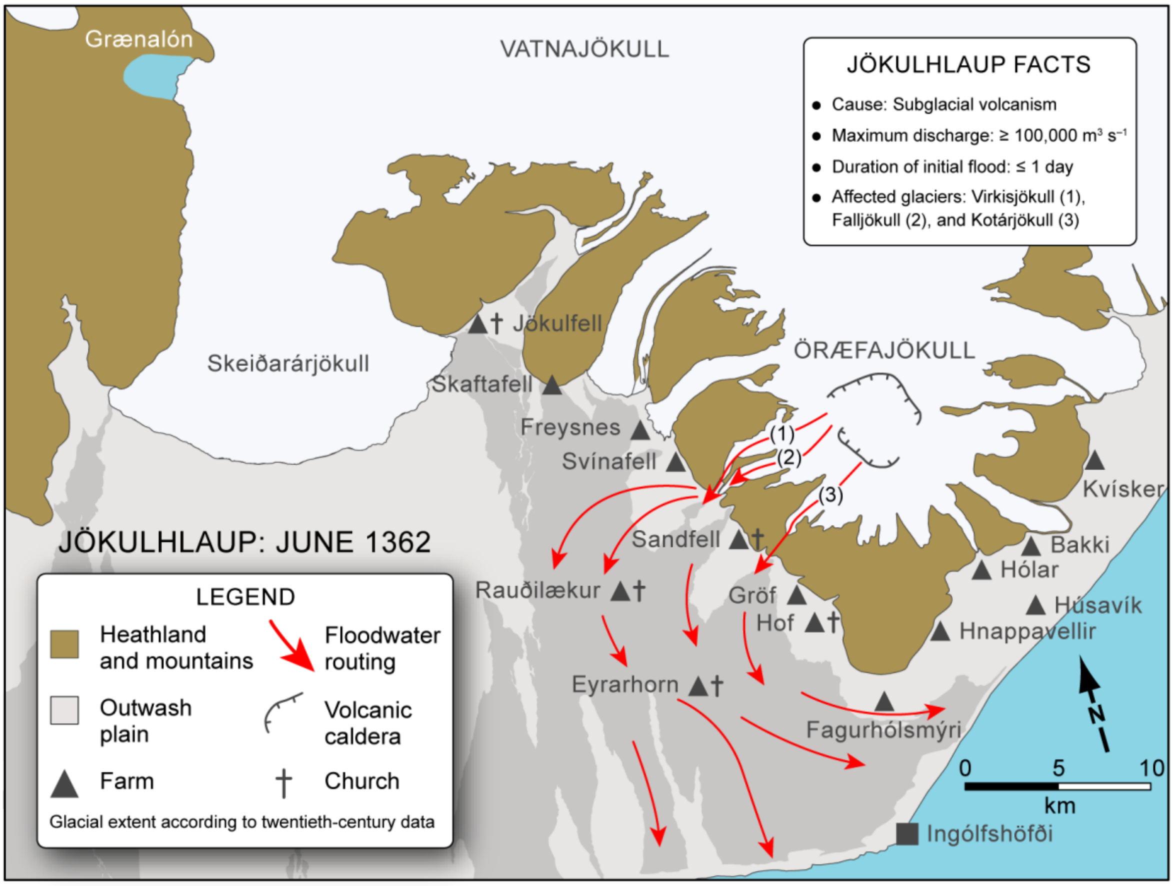

Figure II-6: Postulated routing of floodwater from Öræfajökull during the 1362 eruption (after Thorarinsson, 1958). Note the location of churches and farms along the flood path.

From historical descriptions and geomorphological evidence, Thorarinsson (1958) concluded that the 1362 jökulhlaup burst primarily from Falljökull. Flood deposits, recognisable by the presence of light-coloured rhyolitic tephra, extend over a much larger area than dark-coloured, basaltic deposits from the 1727 eruption (Figure II-7). Moreover, rhyolitic tephra from 1362 comprises coarse silt-sized grains (e.g. Selbekk and Trønnes, 2007), whereas 1727 material is mostly coarse sands and pebbles. To the west and northwest of Falljökull, a boulder-strewn lag of vegetated, water-lain deposits extends to the present-day course of Skaftafellsá (Figure II-7). Outcrops of the same surface continue west beyond Skaftafellsá to the former eastern edge of Skeiðará. Large jökulhlaups from Skeiðarárjökull (e.g. 1861, 1938, and 1996) would have reworked or buried the Öræfajökull deposits, blurring the western extent of the sedimentary record on Skeiðarársandur (Thorarinsson, 1959; Björnsson, 2003).

Clearly, flows to the west and northwest of Falljökull carried large quantities of glacial ice and metre-scale boulders. This is supported by two lines of reasoning: Firstly, the area was renamed at some point after the 1362 eruption as Langafellsjökull, signifying that copious blocks of ice were left on the sandur (Thorarinsson, 1958; Guttormsson, 1993; Sigurðsson and Williams, 2008). Secondly, clusters of angular-shaped rocks lie ~4 km west from Falljökull (e.g. Figure II-4B); projecting 4–5 m above the sandur, these boulders are estimated to weigh more than 500 tonnes and they are inter-bedded with jökulhlaup deposits (Thorarinsson, 1958). Another notable boulder deposit is the smjörsteinn (butter stone) southeast of Svínafell; it is believed that this boulder was transported to its present location by the 1362 jökulhlaup (Thorarinsson, 1958) (Figure II-7). In addition to the breccia of ice blocks, boulders, and juvenile deposits known as Langafellsjökull, three other named deposits have been associated with the 1362 jökulhlaup; these are: Forarjökull, Grasjökull, and Miðjökull, which all contained masses of ice and remained stranded at the foot of Öræfajökull for decades (Thorarinsson, 1958; Sigurðsson and Williams, 2008) (Figure II-7).

In the foreground of Kotárjökull, evidence of the 1362 jökulhlaup is less obvious than at Falljökull. From aerial assessments of palaeo-flood extent and ground-based surveys of sedimentary deposits, it is apparent that most of the 1362 deposits were either buried or washed away by the 1727 jökulhlaup. There are, however, occasional outcrops of lighter sediments within the distal path of the 1727 jökulhlaup; Thorarinsson (1958) described an area east of Kotá as an example (Figure II-7).

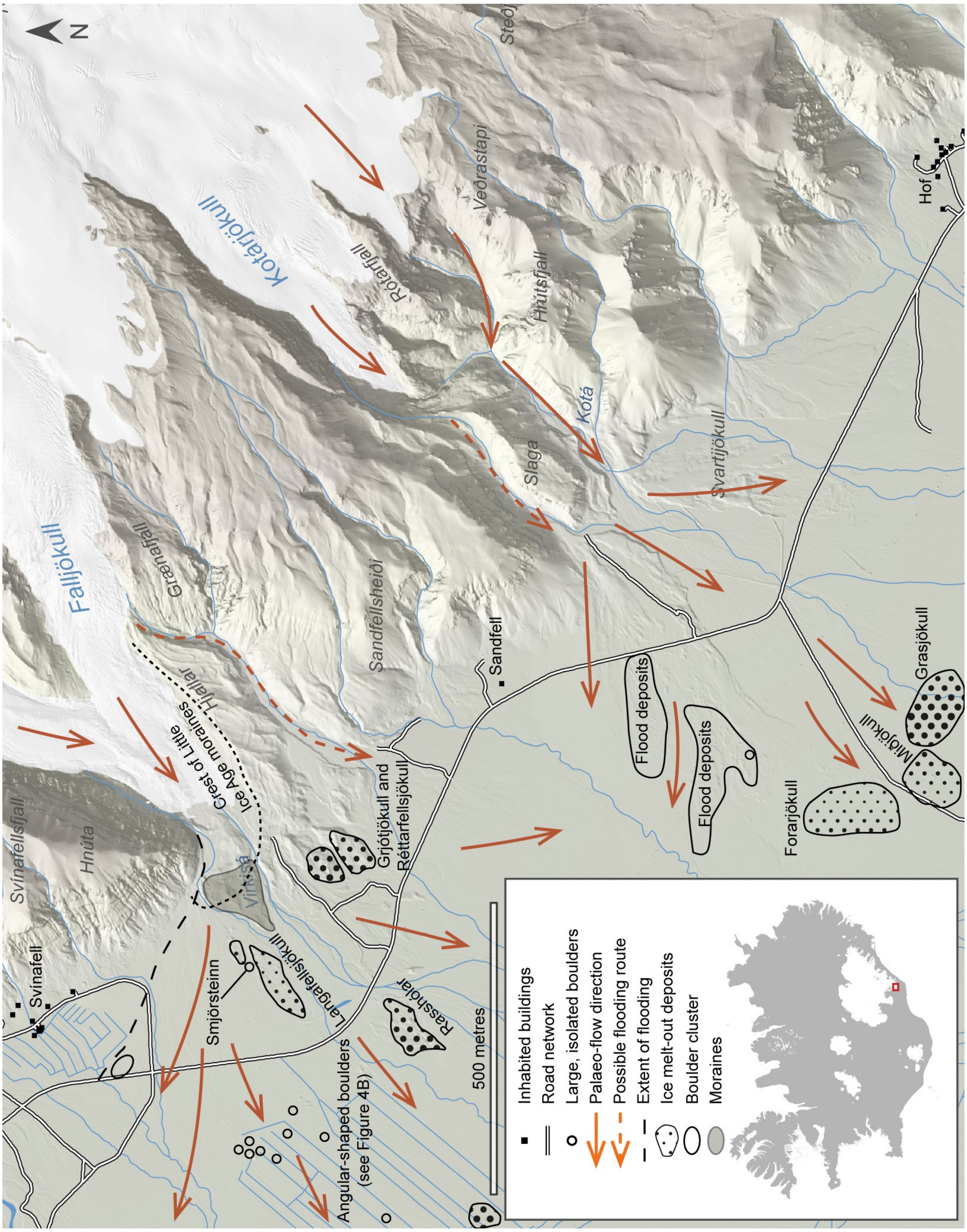

Figure II-7: Extent of jökulhlaup deposits associated with the 1362 eruption of Öræfajökull 1727 jökulhlaup.

5.3. 1727 jökulhlaup

The prelude to the 1727 eruption and the consequent jökulhlaup was described by the rector of Sandfell, Reverend Jón Þorláksson, who documented the course of events over 50 years after the eruption (Olavius, 1780). This description was translated into English by Henderson (1818), with corrections made by Thorarinsson (1958). Whilst holding a sermon at Sandfell on 3 August 1727, the congregation felt earthquakes that became progressively stronger. Damaging earthquakes continued to occur on 4 August and it was noted that booming noises, akin to thunder, radiated from the ice-cap (Háldanarson, 1918). Soon after 09:00 on 4 August, three particularly loud thunderclaps were heard, after which the jökulhlaup began. The jökulhlaup affected Kotárjökull mainly (Háldanarson, 1918), but it is likely that some floodwater drained via Falljökull. Traces of 1362 flood deposits between Sandfell and Hof imply that the 1727 flood inundated roughly the same region, mostly likely covering pre-existing deposits. It can therefore be assumed that the 1727 jökulhlaup from Kotárjökull was comparable in magnitude to the 1362 flood from the same glacier (Thorarinsson, 1958).

The 1727 jökulhlaup caused three fatalities, in addition to the loss of sheep, cows, and horses that were grazing in the path of the initial flood. From Thorarinsson's (1958) translation of accounts, the jökulhlaup occurred as a series of floods, the last of which was by far the greatest. Although the jökulhlaup is thought to have peaked within three to five hours, waning-stage discharge on 11 August from the remains of Kotárjökull was almost too warm for horseback riders to cross. From experience gained at Eyjafjallajökull in 2010 (Magnússon *et al.*, 2012a), such high temperatures are a result of meltwater interacting with advancing lava. As the 1727 jökulhlaup subsided it was clear that Falljökull and Kotárjökull had "*...slid forwards over the plain ground, just like melted metal poured out of a crucible...*" (Thorarinsson, 1958, p. 31). The jökulhlaup was sufficiently large and extensive to allow blocks of glacial ice to reach the sea, in addition to depositing masses of sediment at the foot of the ice-cap.

Decades elapsed before the stranded ice around Sandfell disappeared. When explorers Eggert Ólafsson and Bjarni Pálsson travelled through Öræfi in 1756, they described the terrain between Sandfell and Hof as a jumble of debris-covered ice, ~3 km wide and ~13 km long (Ólafsson, 1974) (Figure II-8). Many pits and ravines were present in the melting ice, making travel through the area difficult. Ólafsson (1974) likened the landscape to the appearance of Skeiðarárjökull, only much lower. The region to the immediate east of Kotá, near to Goðafjall, was named Svartijökull (black glacier) in acknowledgement of the lingering ice (Thorarinsson, 1958; Guttormsson, 1993; Sigurðsson and Williams, 2008); this name remains today. The uppermost surface of Svartijökull is characterised by closely spaced kettle-holes, resulting in hummocky topography (Figure II-8). Angular blocks of palagonite tuff also project through the fan surface, implying simultaneous incorporation and deposition of glacial ice and bedrock from a high-energy, sediment-laden flow (e.g. Maizels, 1989; Russell and Knudsen, 2002). Figure II-9 shows seven surface profiles taken from the DSM of Svartijökull. These profiles depict a highly pitted surface, with some kettle-holes forming inverse conical depressions, whereas others are shallower and edged by a low-amplitude mound of sediment. The former morphology is indicative of in-situ melt-out of buried ice, whereas the later signifies melting of a partially buried block with resultant subaerial deposition of glacial debris (Russell *et al.*, 2005 and references therein). Viewed from above, the field of kettle-holes shows a distinct radial pattern, reflecting flow expansion from the valley between Mount Slaga and Goðafjall (Figure II-8). Additionally, kettle-hole diameters diminish noticeably with increasing distance from the apex of the fan.

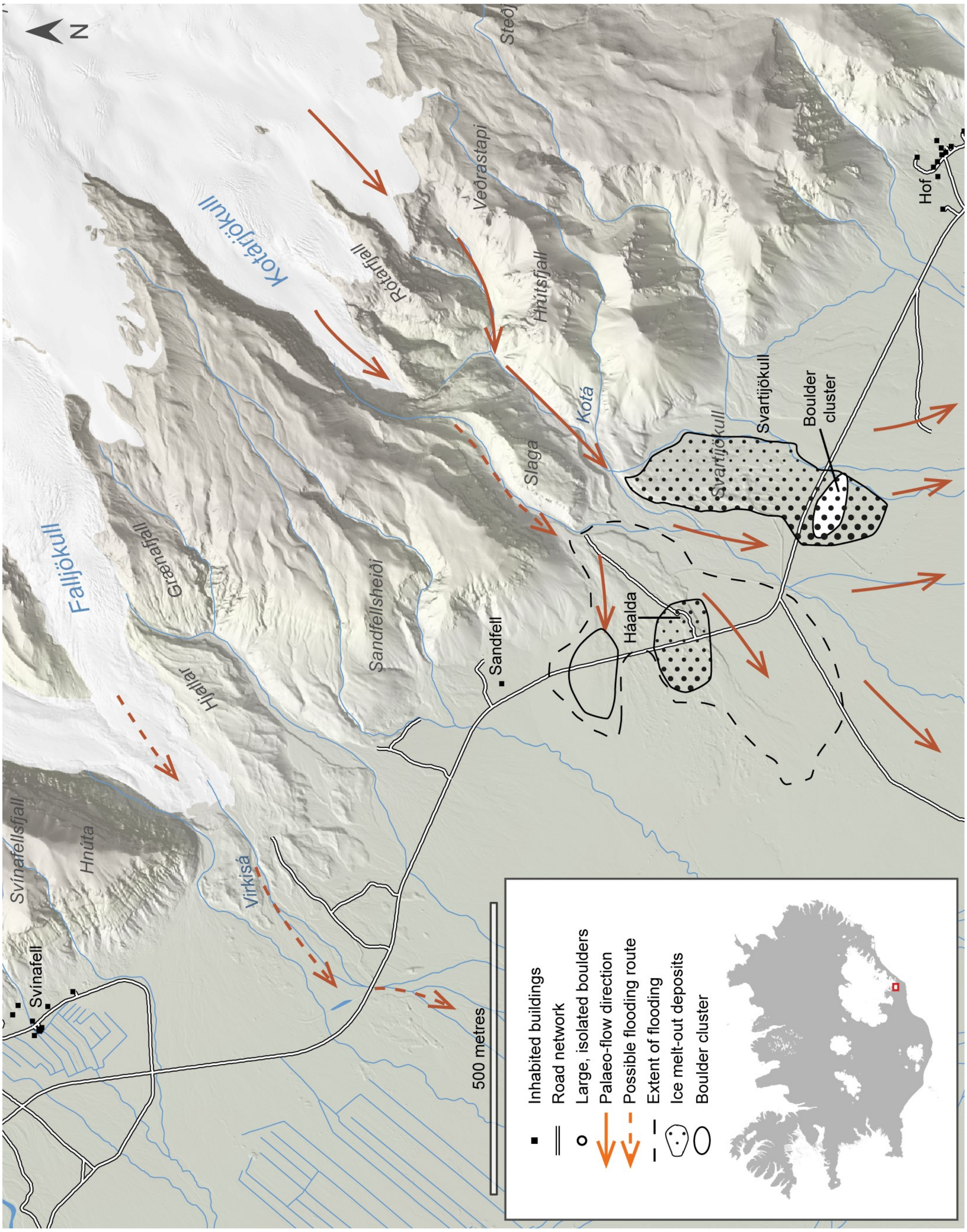

Figure II-8: Extent of jökulhlaup deposits associated with the 1727 eruption of Öræfajökull.

Fluvial terraces incised into the head of Svartijökull show a ~25 m section of sediment in the form of a conformable sequence of interbedded, laterally continuous, water-lain deposits (e.g. Figure II-4A). In places, up to eight nested terraces remain intact. The deposits are dominated by angular, basaltic tephra typically ≤1 cm in diameter, which Thorarinsson (1958) attributed to the 1727 eruption. Thompson and Jones (1986) claimed that the fan contained mostly air-fall pyroclastic deposits. This reasoning was based on the presence of dark, angular fragments of basalt lacking matrix support. However, such massive, homogenous, granular sediment could equally have been deposited under jökulhlaup conditions (Maizels, 1991, 1997; Russell and Knudsen, 1999, 2002). Thompson and Jones (1986) also argued that the distinctive terraces at the head of Svartijökull developed after 1727 as a result of gradual fluvial recovery from the aggradational effects of the jökulhlaup. In contrast, Thorarinsson (1956, 1958) concluded that the terraces formed during the waning-stage of the 1727 jökulhlaup. This is entirely plausible as flooding occurred intermittently over four days (Thorarinsson, 1958). Furthermore the terrace tops show hardly any signs of fluvial reworking, which would be expected if braided streams had flowed over the area for sustained periods. Smaller jökulhlaup could have incised unconsolidated sediments from the main outburst on 4 August 1727, as noted by Dunning *et al.* (2013) for the 2010 eruption of Eyjafjallajökull.

In the foreground of Falljökull, the geomorphic impact of the 1727 jökulhlaup is less prominent. Periods of glacier advance and retreat have extensively reworked flood deposits from 1362 and 1727; moreover the area is vegetated by dwarf birch, which obscures the surface topography. Beyond the periphery of the Little Ice Age (1750–1900 CE) terminal moraines at Falljökull, pitted and boulder-strewn surfaces remain intact (Figure II-7). The moraines themselves and the intervening zone to the ice margin result presumably from glacially reworked flood deposits, particularly those of 1727. For details about modern-day ice retreat at Falljökull, see Bradwell *et al.* (2013) and Hannesdóttir *et al.* (2015).

6. Floodwater routing

Historical accounts and geomorphic evidence substantiate that the 1362 and 1727 eruptions occurred in different locations of Öræfajökull. This is based mainly on the contrasting extent of dark-coloured, basaltic deposits in the river catchments of Falljökull and Kotárjökull (§ 5.3). In the vicinity of Kotá, thick deposits of coarse-grained basaltic tephra are present, whereas this sediment type is less prominent near to Virkisá. The 1362 eruption is thought to have occurred within the caldera; this is supported on two accounts. Firstly, the subglacial catchment of Falljökull extends toward the centreline of the caldera, where ice thickness exceeds 500 m (Magnússon *et al.*, 2012b). Such a quantity of ice, coupled with an eruption of very high mass-discharge rate (Gudmundsson *et al.*, 2015, Chapter III), could account for the volume of water required to deposit large boulders in high-energy, sediment-laden flows kilometres downstream from Falljökull. Secondly, large-scale mechanical break-up of Falljökull, as implied by former dead-ice masses such as Langafellsjökull, necessitates floodwater bursting from the ice surface to effectively sever the lower part of the glacier from the icefall (e.g. Sturm *et al.*, 1986).

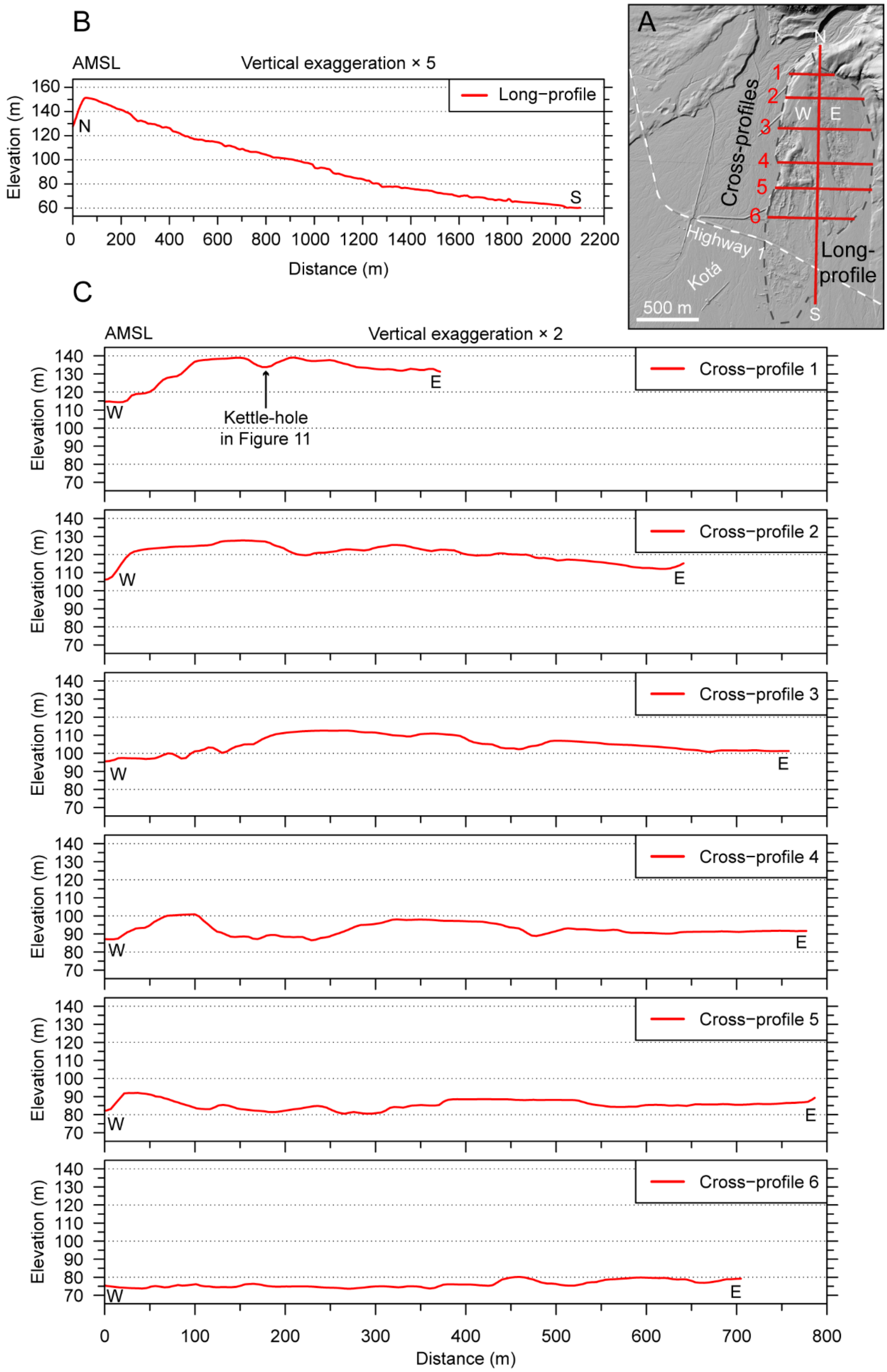

Figure II-9: Longitudinal and transverse profiles of Svartijökull – a mass of hummocky terrain arising from the 1727 jökulhlaup. (A) Map showing profile locations; (B) long-profile; (C) cross-sections depicted in (A). Note the location of Figure II-11 in cross-section 1. Survey data derived from a digital surface model (see § 4.2).

As outlined in § 5.3, the 1727 jökulhlaup was preluded by thunder-like sounds. At Eyjafjallajökull during the summit eruption of 2010, booming sounds emanated from the ice-cap on 15 April, followed immediately by a volcanogenic jökulhlaup (§ 10.5). The sound was attributed to floodwater cascading down the lateral flanks of Gígjökull due to outlets forming high on the glacier (Roberts *et al.*, 2011; Magnússon *et al.*, 2012a). The similarity of the sounds and their timing gives confidence to the idea of subglacial flood-water bursting from the upper slopes of Öræfajökull in 1727. With the benefit of modern-day observations (Roberts, 2005; § 10), subglacial floodwater would have burst preferentially from the thinnest section of Falljökull, which would have been the icefall region (Figure II-10). This, again, implies a floodwater source from within the caldera. It should be noted, however, that Björnsson (2005) disputed a caldera origin for the 1362 eruption, believing instead that the eruption occurred outside the caldera rim in an area of comparatively thinner ice, thus ruling out a high-elevation origin for floodwater. Björnsson (2005) reasoned that an eruption within the caldera would undoubtedly have affected Kvíárjökull. Mapping of bedrock topography in the volcano's caldera by Magnússon *et al.* (2012b) demonstrates that a water source within the subglacial catchment of Falljökull would not necessarily cause flooding down Kvíárjökull. This is an important point to consider in relation to Björnsson's assertions.

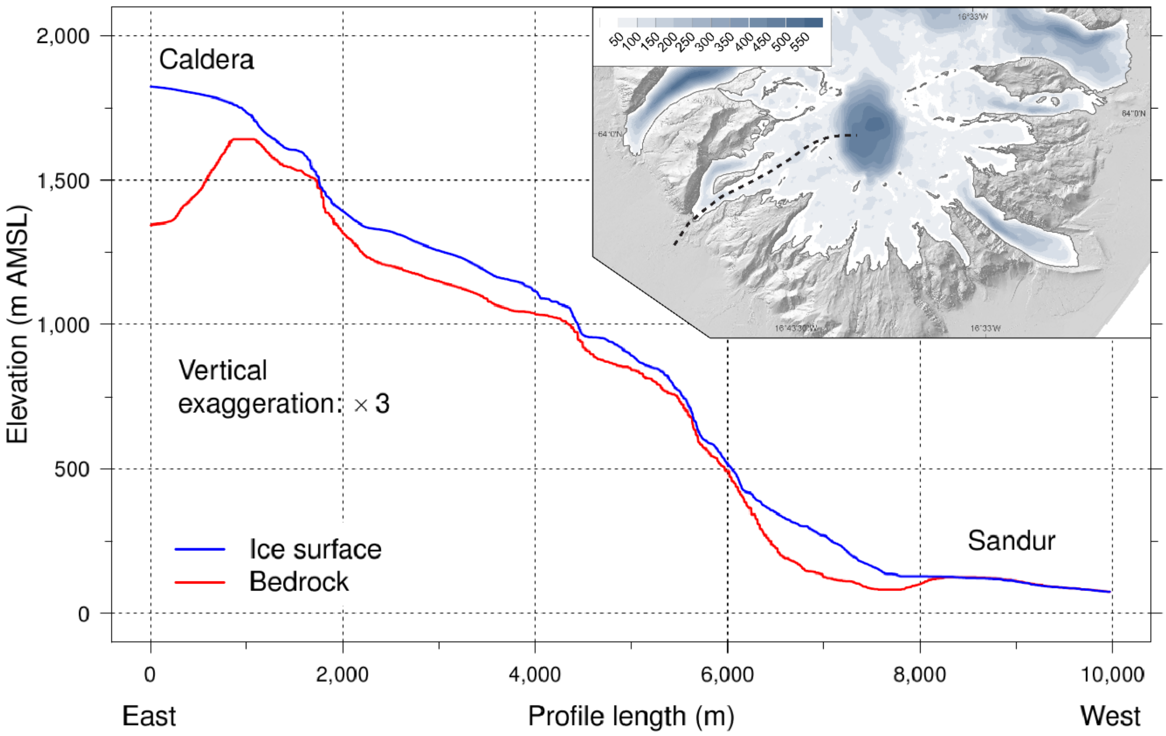

Figure II-10: Northward cross-sectional profile of Falljökull, showing bedrock and ice-surface topography. The inset map shows the extent of the profile on the western flank of Öræfajökull, with shading denoting ice thickness in metres. Bedrock profile data derived from Magnússon et al. (2012b).

Additional insight into the subaerial routing of the 1727 jökulhlaup can be gained from the terrain surrounding Mount Slaga (Figure II-8). The southern part of the region is dominated by the hummocky, steep-sloping surface known as Svartijökull. A boulder-strewn surface to the northwest of Svartijökull also radiates in a down-sandur direction from around the base of Mount Slaga (Figure II-8). This surface, comparable to a debris-flow deposit (Pierson, 2005), appears to represent the initial flood-wave from Öræfajökull, before floodwater focussed on the present-day route of Kotá. It is possible that the boulder-strewn surface also underlies deposits at Svartijökull. The routing of the debris-flow deposit to the north-west of Svartijökull is uncertain. Some of the flow could have been routed between Mount Slaga and Goðafjall, although the adjacent valley between Mount Slaga and Sandfell could have conveyed some of the flow. For this to occur, the Kotá valley must have filled with floodwater, allowing discharge from the western branch of the glacier to descend into the neighbouring valley. This hypothesis is especially plausible if floodwater descended over the surface of Kotárjökull (*c.f.* Roberts *et al.*, 2011).

7. Flood timing and extent

The exact timing of both historical jökulhlaups is difficult to ascertain. Of the two eruptions, only accounts of 1727 contain any detail (§ 5.3). As noted by Thorarinsson (1958), the 1727 eruption began soon after 09:00 on 4 August, and it is thought to have peaked within three to five hours. Nevertheless, the actual duration of the main rise to maximum discharge could have been two to four hours. An hour could have elapsed between the beginning of the subglacial eruption and the onset of flooding from the ice-cap (Gudmundsson *et al.*, 2015, Chapter III). Jökulhlaup deposits from 1727 shed light on the form of the palaeo-hydrograph. Sediments ranging from coarse sands to large, angular boulders were deposited simultaneously within individual, upward-coarsening units such as the Kotá fan; overall such sequences represent large-scale bedding deposited parallel to the slope of the flooded surface. Such deposits would have originated from a pulsating, high-energy flow, limited mainly by sediment supply rather than flood power (Maizels, 1997). The architecture and vertical sedimentary structure of jökulhlaup deposits on the western side of Öræfajökull represent continuous aggradation of sediment during a rapid, linear rise to maximum discharge, akin to a dam burst (*c.f.* Russell *et al.*, 2010).

Scant geomorphic features preserve the downstream extent of the 1362 and 1727 jökulhlaups. As flows expanded from the western flank of Öræfajökull, floodwater would have drained across the eastern side of Skeiðarársandur. In distal regions, mostly sand to cobble-sized sediment would have been deposited from turbulent flows. Despite being laterally extensive, such deposits would either be eroded by Skeiðará or buried by subsequent jökulhlaups on Skeiðarár-sandur. During the fourteenth century, climate-induced thickening and advance of Skeiðarárjökull forced the drainage of meltwater to the western and eastern edges of the glacier (Björnsson, 2003). Over subsequent centuries Skeiðará would have flowed over distal flood deposits from Öræfajökull. This process would have been particularly effective during large, eruption-related jökulhlaups from Skeiðarárjökull, especially in 1861, 1938, and 1996 (Þórarinsson, 1974; Snorrason *et al.*, 1997).

8. Flow properties

Both the 1362 and 1727 jökulhlaups would have transported masses of freshly erupted material, especially while the eruptions were confined beneath ice (Gudmundsson *et al.*, 2015, Chapter III). As ice blocks became entrained in the developing floods, this would have increased the volume of the jökulhlaups significantly. In this section we review both the rheology and ice-content of the two historic floods.

8.1. Rheology

From existing sedimentological studies at Öræfajökull (Thorarinsson, 1958; Maizels, 1991) and inferences from other volcanogenic floods in Iceland (Tómasson, 1996; Russell *et al.*, 2005; Duller *et al.*, 2008), it is possible to speculate on floodwater composition during the 1362 and 1727 jökulhlaups. Explosive fragmentation during both subglacial eruptions would have created a copious supply of fine-grained volcaniclastic material (Gudmundsson *et al.*, 2015, Chapter III). Combined with fast-flowing water due to steep terrain, sediment would also have been eroded from the entire flood tract, including subglacial pathways. At the onset of flooding, when the amount of floodwater was minor compared to the volume at maximum discharge, sediment concentrations could easily have ranged from hyperconcentrated (40–80% solids by mass) to debris flow conditions (>80% solids by mass). The initial front of both floods would have reached the lowland as a fast-moving, debris-laden wall of muddy material (*c.f.* Russell *et al.*, 2010; Waythomas *et al.*, 2013). Maizels (1991) ascribed debris-flow conditions to matrix-supported clastic deposits at the base of the Kotá fan; the implication being that clasts were supported by a fabric of fine-grained pyroclasts as the 1727 flow emanated from Kotárjökull.

As both the 1362 and 1727 floods continued to rise, water-flood conditions would have prevailed (Maizels, 1991). However, owing to high discharge, steep water-surface slopes, and topographic constrictions, flows would have remained deep and fast enough to produce high shear stresses and strong turbulence (Pierson, 2005). Such conditions would allow for prodigious quantities of sediment transport, ranging from granular- to boulder-sized clasts (*c.f.* Duller *et al.*, 2008).

8.2. Role of ice

The extent of glacial ice on Öræfajökull would have been significantly greater in 1727 than during the 21st Century. In the 1750s, Kvíárjökull is thought to have reached the crest of the terminal moraines (Hannesdóttir *et al.*, 2015), so it is probable that Kotárjökull was advancing also (Guðmundsson *et al.*, 2012). When the 1727 eruption occurred, Kotárjökull was at least 30% more extensive than it was in 2011 (Guðmundsson *et al.*, 2012); this explains why ice-release was so ubiquitous during the 1727 jökulhlaup.

The 1362 and 1727 eruptions were noted for widespread deposition of glacial ice by floodwater (see § 5.2 and 5.3). Densely-clustered kettle holes in the foreground of Falljökull and Kotárjökull are indicative of downstream flow expansion and a corresponding reduction in flood power, leading to ice-block grounding (Baker, 1987; Fay, 2002; Russell and Knudsen, 2002) (Figure II-11). Ice blocks that were buried by rising-stage sediment aggradation led to the formation of circular kettle holes (e.g. Háalda in between Sandfell and Hof), whereas partially buried fragments gave rise to scour-like formations (e.g. lower parts of Svartijökull) (Figure II-8). From eyewitness descriptions of the 1727 jökulhlaup (§ 5.3), large sections of Falljökull and Kotárjökull were broken from Öræfajökull; smaller pieces even reached the coastline, over 18 km away. Grounding of ice blocks during waning-stage flows could have caused floodwater to pond behind an ice dam in regions of flow expansion. Ice blockades, either close to the eruption site, or in the proximal region of Kotá, could account for the series of 1727 floods noted by Thorarinsson (1958) (see § 5.3).

The densely pitted sandur around Kotá affirms to a colossal release of ice from the upper flanks of Öræfajökull. For the 1727 jökulhlaup, mechanical break-up of Kotárjökull by floodwater travelling beneath, along, and on top of the glacier would have readily produced fragmented ice. If the initial flood-wave was a slurry mixture, then the density of the flow itself may have been sufficient to raft tabular sections of Kotárjökull downstream within minutes of the jökulhlaup beginning; this image is consistent with accounts from 1727 (see § 5.3).

Figure II-11: Kettle-hole on the surface of Svartijökull – note the person for scale (photographer: P. Alho, September 2005). The depression formed due to melting of stranded blocks of ice, which were deposited in the region during the 1727 jökulhlaup (Ólafsson, 1974; Thorarinsson, 1958). For the location and dimensions of the kettle-hole, see Figure II-9.

9. Maximum discharge

Historic descriptions of the 1727 jökulhlaup, together with the geomorphic consequences of the 1362 and 1727 eruptions, are clear evidence for a rapid, ephemeral rise to maximum discharge. For instance, Reverend Jón Þorláksson (§ 5.3) recalled that the 1727 jökulhlaup on 4 August peaked within 3–5 hours. Thorarinsson (1958) favoured flooding analogous to volcanogenic jökulhlaups from Katla (Tómasson, 1996), thereby implying a rapid rise to a maximum discharge that would be very high compared to the volume of the jökulhlaup. With this in mind, Thorarinsson (1958) postulated that the 1362 jökulhlaup peaked at > 1×10^5 m^3/s.

The 1727 jökulhlaup burst primarily from Kotárjökull, and the extent of flooding was similar to that of 1362 (§ 5.3), however the 1362 jökulhlaup drained foremost from Falljökull (§ 5.2), signifying that the 1727 jökulhlaup was lower in magnitude. From slope-area calculations based on the width of the Kotá valley between Mount Slaga and Goðafjall (Figure II-12) and a corresponding surface velocity of 12.1 m/s, the maximum discharge of the 1727 jökulhlaup is estimated at ~4×10^4 m^3/s (Figure II-12). Palaeo-discharge estimates are, of course, hindered by the masses of sediment, rock, and glacial ice that are known to have been transported onto the sandur. The maximum discharge from the eruption site (Gudmundsson *et al.*, 2015, Chapter III) is naturally lower than the downstream equivalent, as bulking factors such as sediment and ice need to be considered. For volcanogenic floods from Öræfajökull, a bulking factor as high as ~25% seems reasonable, especially when considering initially hyperconcentrated conditions (§ 6) and exceptional amounts of ice-release (§ 8.2).

Further credence for a rapid rise to maximum discharge comes from a sedimentological interpretation of palaeo-hydrograph form. Large-scale, upward-coarsening units of sand- to cobble-sized deposits (§ 7) demonstrate high-energy flow conditions equivalent to the passage of a lahar (Waythomas *et al.*, 2013). Such sequences could from only under sustained high discharge, resulting in a rising-stage hydro-graph akin to a dam-burst.

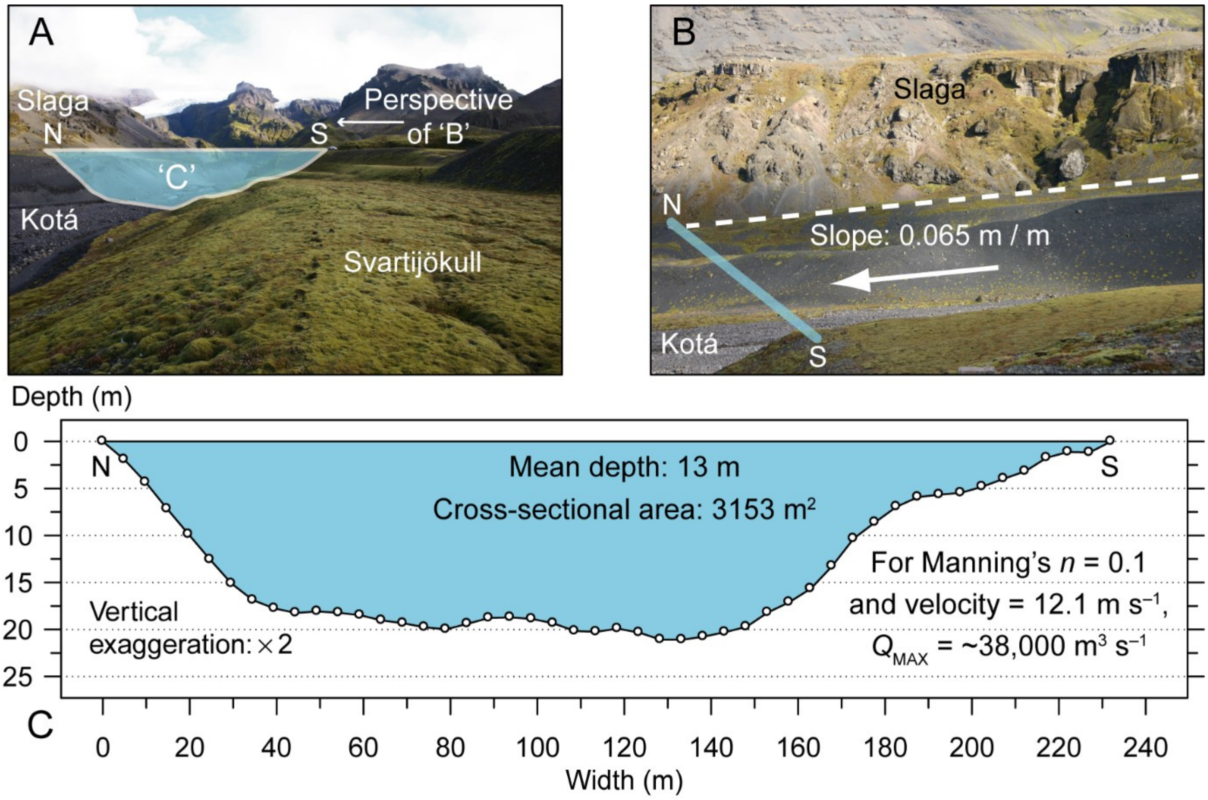

Figure II-12: Reconstructed maximum discharge during the 1727 jökulhlaup from Kotárjökull. (A) Cross-section of the Kotá valley from Mount Slaga to the uppermost surface of Svartijökull (see Figure II-9); (B) calculated slope of the palaeo water-surface; (C) channel cross-section and hydraulic data. Survey data derived from a digital surface model (see § 4.2).

10. Modern-day comparisons

This section highlights occasions when supraglacial flooding has occurred in connection with volcanic activity. The purpose is to use modern-day analogues to better understand how the 1362 and 1727 jökulhlaups developed. Examples are taken from Iceland and Alaska, U.S.A. The Icelandic examples from Eyjafjallajökull and Sólheimajökull are especially relevant, as the affected glaciers are similar in surface profile and ice thickness to the Öræfajökull flood paths.

10.1. Redoubt: 1989–1990 and 2009

The surface of Drift glacier has been disrupted on several occasions by subglacial volcanism at Mount Redoubt in 1989–1990 and 2009 (Trabant *et al.*, 1994; Waythomas *et al.*, 2013). Instead of draining entirely beneath Drift glacier, debris-laden outpourings of floodwater have broken repeatedly through the glacier's surface at high elevation (Trabant *et al.*, 1994). In some locations, glacial ice has been stripped away to bedrock by repeated floods. Distinctive 'ice diamict' deposits have been mapped on the glacier surface and also several kilometres downstream, revealing the extent of supraglacial flooding (Waitt *et al.*, 1994). During the 2009 eruption of Redoubt, floods and pyroclastic flows removed 0.1–0.2 km^3 of ice from Drift Glacier (10–20% of total ice volume) (Waythomas *et al.*, 2013).

10.2. Skeiðarárjökull: 1996

Skeiðarárjökull is a surge-type piedmont glacier draining from the Vatnajökull ice cap. The northern edge of the glacier's water-divide neighbours the Grímsvötn subglacial lake. From 30 September 1996 to early October 1996, a subglacial eruption took place north of Grímsvötn (Gudmundsson *et al.*, 1997). Late on 04 November 1996, 35 days after the start of the eruption, floodwater began to drain from Grímsvötn at a lake-level of 1510 m AMSL. Floodwater exited Grímsvötn through a rapidly expanding subglacial conduit. The initial flood-wave took ~10.5 hours to travel the 50 km distance from Grímsvötn to the edge of Skeiðarárjökull; at peak flow the transit time decreased to about 3 hours (Björnsson, 1998). The jökulhlaup ceased after 40 hours, having released ~3.6 km^3 of floodwater onto Skeiðarársandur (Gudmundsson *et al.*, 1997). During the initial rising stage of the jökulhlaup, floodwater blasted through the surface of Skeiðarárjökull, producing multiple supraglacial outbursts across the terminus (Roberts *et al.*, 2000). In some locations, floodwater burst through ~350 m of ice before reaching the glacier surface. Where floodwater burst through the ice surface close to the margin, large volumes of ice were released (Roberts *et al.*, 2002).

10.3. Sólheimajökull: 1999

Sólheimajökull drains from the Mýrdalsjökull ice cap, which is underlain by the Katla volcano. Sólheimajökull is a 9 km long, non-surging valley glacier, with a surface area of ~78 km^2 and a terminus ~1 km wide. On 10 July 1999, the river issuing from Sólheimajökull (Jökulsá á Sólheimasandi) was abnormally high. People travelling across Sólheimasandur between 14 and 17 July informed local authorities that the river was unusually dark, high, and extremely odorous (Sigurðsson *et al.*, 2000). At 17:00 UTC on 17 July, prolonged seismic tremors were detected from beneath Mýrdalsjökull; this seismicity intensified through the evening, culminating at ~02:00 hours on 18 July. This peak in seismic activity was concomitant with the release of a jökulhlaup from Sólheimajökull (Roberts *et al.*, 2000).

During the jökulhlaup, numerous high-capacity outlets developed across the terminus, western lateral flank and surface of Sólheimajökull (Roberts *et al.*, 2000). Peak discharge at the terminus and 6 km downstream was estimated at ~5,000 m^3/s and 1,940 m^3/s, respectively (Sigurðsson *et al.*, 2000; Russell *et al.*, 2010); these values indicate marked downstream flow attenuation, analogous to flash-floods in ephemeral regions. Eyewitness accounts from the bridge over Jökulsá á Sólheimasandi suggest that the jökulhlaup persisted for ~6 hours, having peaked within an hour (Sigurðsson *et al.*, 2000).

10.4. Eyjafjallajökull: 2010

Sourced from within the volcano's ice-filled caldera, the April 2010 eruption of Eyjafjallajökull stratovolcano caused repeated jökulhlaups in response to initial subglacial volcanism, followed by phreatomagmatic activity and lava-flow confined by ice (Roberts *et al.*, 2011; Magnússon *et al.*, 2012a). The ice-surface in the summit caldera lies at 1500–1600 m AMSL, with the ice being up to 200 m thick. This ice mass forms Gígjökull – a northward flowing valley glacier. The summit eruption began at 01:15–01.30 UTC on 14 April. By 06:45, stage measurements 1 km from Gígjökull confirmed the onset of flooding. Gauged 18 km downstream from Gígjökull, the initial jökulhlaup reached a discharge of 2,700 m^3/s within 88 minutes of arrival. A smaller, concurrent jökulhlaup also burst from the southern flank of Eyjafjallajökull, carving a 3-km-long trench into the ice surface. On both 14 and 15 April 2010, floodwater descended across the surface and flanks of Gígjökull as it broke through the glacier at an elevation as high as 1400 m AMSL. Such breakout pits formed in several places on the upper reaches of Gígjökull and allowed ice-laden slurries to debouch across the ice-surface (Roberts *et al.*, 2011; Magnússon *et al.*, 2012a).

11. Summary

The stark geomorphic imprints of the 1362 and 1727 jökulhlaups are a testament to the impact of historical volcanism at Öræfajökull. Despite only two confirmed volcanic eruptions during the past thousand years, the landscape in the vicinity of Virkisá and Kotá is almost entirely a consequence of high-magnitude flooding (*c.f.* Duller *et al.*, 2014). In 1362 floodwater was routed primarily via Falljökull, whereas in 1727 floodwater affected Kotárjökull more so, implying different eruption sites within the caldera for the two eruptions. Both historical jökulhlaup were fleeting in nature, rising to maximum discharge in a matter of hours. Although difficult to constrain, the maximum discharge of the 1362 jökulhlaup was on the order of 1×10^5 m^3/s; the peak of the 1727 jökulhlaup, although smaller, was in the region of 4×10^4 m^3/s — a flood discharge equivalent to the height of the November 1996 jökulhlaup from Grímsvötn.

A first-hand account of the 1727 jökulhlaup described floodwater rushing from Falljökull and Kotárjökull, followed by the complete break-up and removal of Kotárjökull. Flooding peaked during the 1727 eruption in a matter of hours; this timeframe necessitates rapid run-off from the eruption site, combined with swift drainage of floodwater to the lowlands. Although onlookers' descriptions of the 1727 jökulhlaup do not refer explicitly to supraglacial outbursts, it is asserted here that such flooding dominated the onset of both the 1362 and 1727 jökulhlaups. From modern-day measurements of subglacial bedrock topography and ice-surface elevation at Öræfajökull, it is evident that floodwater draining from the caldera region would have broken through the ice surface at ~1,500 m AMSL. The implication of this is twofold: Firstly, glaciers such as Falljökull and Kotárjökull would have been severed by fractures conveying floodwater to the ice surface; and secondly, such a process would lead to rapid fragmentation and eventual ice removal, as attested by written accounts. By bypassing subglacial drainage routes, supraglacial outbursts of floodwater would have caused a rapid rise to maximum discharge — a situation akin to a dam-burst. Rapid mechanical disruption of the lower reaches of Falljökull and Kotárjökull would have led to ice-blocks being incorporated constantly into rising-stage flows.

The findings of this chapter provide constraints for estimating the melting potential of Öræfajökull eruptions, as studied in Chapter III by Gudmundsson *et al.* (2015); they are also pertinent to the simulation of volcanogenic floods from Öræfajökull, as explored in Chapter IV by Helgadóttir *et al.* (2015). Furthermore, insights into flood extent, floodwater composition, and the prevalence of ice blocks provides an empirical basis for the rating of flood hazards in the Öræfi region (Pagneux and Roberts, 2015, Chapter V).

12. Acknowledgements

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