2 Southern Iceland: Volcanoes, Tourism and Volcanic Risk Reduction

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2.1 Introduction

Iceland is well known for its active volcanoes with small eruptions (<0.1 km^3 Dense Rock Equivalent—DRE) occurring approximately every 4–5 years, and large flood-basalt eruptions (>10 km^3 DRE) occurring every 500–1,000 years (Guðmundsson et al. 2008). The exceptionally high rate of volcanism is due to the interaction of the Mid-Atlantic Ridge (MAR) with a mantle plume centred beneath Iceland (Sigmundsson, 2006). Offshore, ridges to the north and southwest of Iceland represent the MAR. Onshore, the MAR is comprised of a series of seismic and volcanic zones (Einarsson and Saemundsson 1987). Holocene volcanism is contained within these discrete 15–50 km wide zones that jointly cover approximately one-third of the country (Fig. 2.1).

Iceland boasts nearly all known volcano types and eruption styles on Earth with volcanoes located in subaerial, subglacial and submarine environments (Thordarson and Larsen 2007). Volcanic hazards are therefore diverse and often catastrophic. The Icelandic Meteorological Office (Veðurstofa Íslands—www.vedur.is) monitors volcanic activity through the South Iceland Lowland (SIL) national seismic network, various volumetric strain meters and continuous geodetic GPS stations. The three most significant volcanic hazards produced during eruptive events are jökulhlaups (a sudden burst of meltwater from a glacier, often caused by a subglacial eruption), tephra fallout and lightning. Other hazards include earthquakes, lava flows, poisonous gases, pyroclastic density currents and tsunami (Guðmundsson et al. 2008).

Located in a major tourist region, the infamous Hekla, Katla and Grímsvötn volcanoes, and their associated fissure systems, have the highest eruption frequency and greatest volcanic productivity in Iceland (Thordarson and Larsen 2007). In 2010, however, Eyjafjallajökull became Iceland's most famous volcano when tephra circulated through international airspace causing widespread chaos to the aviation industry. While Eyjafjallajökull remained quiet in 2011, its neighbours Hekla, Katla and Grímsvötn did not. In the next sections we describe the volcanic systems of Hekla, Eyjafjallajökull, Katla and Grímsvötn and their recent activity.

2.2 Hekla

The ridge-shaped stratovolcano, Hekla is Iceland's second most active volcano with 23 confirmed eruptions (Table 2.1) since its first historic eruption in 1104 AD. Although the 1104 AD eruption was a purely explosive Plinian eruption, Hekla is typically characterised by mixed eruptions. Usually beginning with a vigorous, but short-lived (0.5–2 h long) Plinian or sub-Plinian phase, the eruption transitions into a several-hour long phase, with simultaneous sustained emissions of moderately widespread tephra fall and fountain-fed lava flows (Thordarson and Larsen 2007). During these initial stages, the eruption plume can reach heights of 36 km above sea level (Höskuldsson et al. 2007). As the lava/tephra ratio increases dramatically, the eruption intensity equally decreases. The final phase of a Hekla eruption typically consists of discrete Strombolian explosions with very low magma discharge (Thordarson and Larsen 2007, and references within).

Prior to the 20th century, Hekla erupted one to three times per century. Since the 1947 eruption, however, the volcano has experienced regular eruptions in 1970, 1980–1981, 1991

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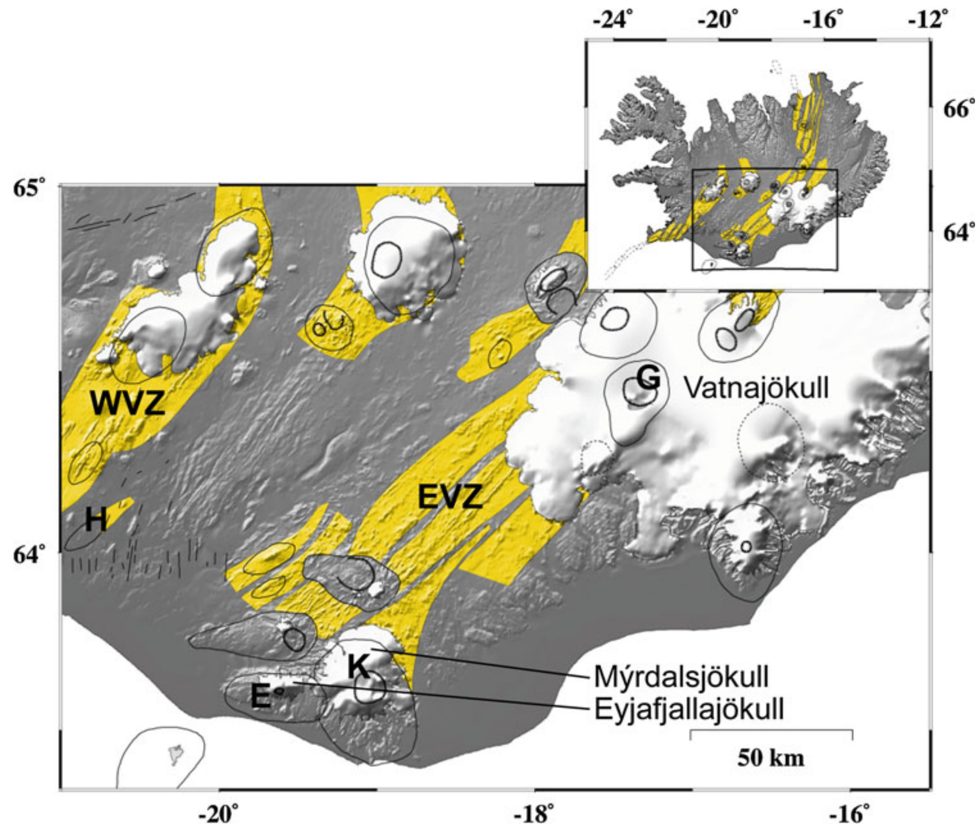

Fig. 2.1 The Western Volcanic Zone (*WVZ*) and Eastern Volcanic Zone (*EVZ*), and the volcanoes Hekla (*H*), Eyjafjallajökull (*E*), Katla (*K*) and Grímsvötn (*G*). The inserted map shows all the volcanic zones across Iceland. *Source* Einarsson and Saemundsson (1987)

Table 2.1 The Hekla, Eyjafjallajökull, Katla and Grímsvötn volcanic systems (from Thordarson and Larsen 2007, unless otherwise stated)

Volcano	Maximum elevation above sea level (m)	Length (km)	Width (km)	Area (km^2)	Confirmed eruptions since ~870 AD[a]	Last confirmed eruption[b]	Largest explosive eruption[c]	Largest effusive eruption[d]
Hekla	1491	60	19	720	23	2000	1104 VEI 5	1766–1768 1.3 km^3
Eyjafjallajökull	1666	30	14	300	4	2010	2010 VEI 4[e]	~920 0.05 km^3
Katla	1480	110	30	1300	21	1918	934 VEI 5	934 18 km^3
Grímsvötn	1722	100	23	1350	~71	2011	1783 VEI 4	1783 14 km^3

[a] From M. T. Guðmundsson et al. (2008) and Veðurstofa Íslands (2011a)
[b] From Veðurstofa Íslands (2011a)
[c] From M. T. Guðmundsson et al. (2008)
[d] From M. T. Guðmundsson et al. (2008)
[e] From Sammonds et al. (2010)

and 2000 (Gronvold et al. 1983; Veðurstofa Íslands 2011a), with each consecutive eruption decreasing in magnitude. Nevertheless, Hekla has produced significant quantities of tephra and lava during historic times, which equates to an estimated total volume of 13–14 km^3 of erupted magma (Thordarson and Larsen 2007).

Due to the high quantity of fluorine in Hekla's magma, nearly all eruptions have led to fluoride poisoning (fluorosis) in grazing livestock. In addition, extensive tephra fallout during the 1693 eruption caused mass trout deaths in lakes up to 110 km from the source (Guðmundsson et al. 2008). Hekla eruptions are also known to produce small pyroclastic flows (Höskuldsson et al. 2007), but seismicity has only been recorded in association with its eruptions (Einarsson 1991) making eruption predictions difficult. However, the distinct pattern of crustal deformation (measured by continuous borehole strain meters), and a small swarm of earthquakes recorded half an hour before the 1991 eruption, led to a short-term prediction of the 2000 eruption (Soosalu et al. 2005).

The Earth Science Institute at the University of Iceland and the Icelandic Meteorological Office recorded small but significant seismicity at Hekla volcano at 16:55 and 17:07 on 26 February 2000, respectively (Stefánsson 2000). A subsequent warning, stating that an eruption was imminent within an hour, was issued at 17:20. Based on strain meter data, the eruption began at 18:17 and an eruption column was observed at 18:20, which extended to 11 km above sea level by 18:25 (Stefánsson 2000). This eruption resulted in a 6.6 km fissure running SW to NE along the length of the Hekla volcano, slightly south of the summit (Höskuldsson et al. 2007). Considered the smallest and shortest of all Hekla eruptions, the 2000 eruption also followed the shortest repose period (Lacasse et al. 2004). Deformation around Hekla continued throughout 2011. However, media reports that an eruption was imminent were unfounded. Nevertheless, the Icelandic Department of Civil Protection and Emergency Management advised that hikers should take adequate precaution when climbing Hekla.

2.3 Eyjafjallajökull

Considered one of the oldest active volcanoes in Iceland, Eyjafjallajökull typically generates relatively small amounts of material (Sturkell et al. 2009). The shield-like central volcano consists of an elliptical 2.5 km wide caldera that is covered by a 200 m thick ice-cap of the same name. Due to the icecap, Eyjafjallajökull typically yields subglacial phreatomagmatic eruptions with very fine-grained ash deposits (Larsen et al. 1999) and small to medium jökulhlaup (Table 2.2) (Guðmundsson et al. 2005). Eyjafjallajökull is far less active than Hekla, Katla and Grímsvötn with only four eruptions since ~870 AD: in ~920, 1612, from 1821–1823, and the recent 2010 events. The first event of the 2010 eruptions occurred on the flank of the volcano along a fissure at Fimmvörðuháls in between the Mýrdalsjökull and Eyjafjallajökull icecaps (Sigmundsson et al. 2010) and, despite the sophisticated volcanic monitoring system, it was local residents who initially spotted the first signs of the eruption (Bird et al. 2011). After this uncertain start, the Icelandic emergency management organisations worked together with the local population to effectively mitigate risk.

The initial phase of the eruption produced spectacular fire-fountain activity and lava flows, which attracted many domestic and international onlookers. As the "Fimmvörðuháls" flank eruption was reduced to a 'hazard phase' on 13 April 2010, the Icelandic Meteorological Office recorded increased seismicity in Eyjafjallajökull. This activity was a precursor to the subglacial eruption of Eyjafjallajökull that commenced on 14 April 2010. The explosive eruption resulted in medium-sized jökulhlaups to the north, small jökulhlaups to the south and considerable ash fall to the east and east-southeast of the volcano (Almannavarnadeild Ríkislögreglustjórinn, 2010). The tephra that was ejected during the first few days of the 2010 subglacial eruption had a high proportion of very fine-grained ash that reached high altitudes in the atmosphere and, due to the prevailing north-westerly to westerly winds, air traffic was grounded in many countries throughout Europe. In comparison to the three largest producers of tephra—Hekla, Katla and Grímsvötn –Eyjafjallajökull volcano is considered to be a small tephra producer and the 2010 eruption was nothing out of the ordinary (Davies et al. 2010). The main factor that facilitated chaos within the aviation industry was the prevailing wind.

Table 2.2 Categorisation of Icelandic jökulhlaup (from Guðmundsson et al. 2005)

Category		Peak discharge (m^3s^{-1})
1	Very small	<3,000
2	Small	3,000–10,000
3	Medium	10,000–30,000
4	Big	30,000–100,000
5	Catastrophic	>100,000

The continuing eruption also produced lightning, gas emissions and lava flows within close proximity of the crater and heavy sound blasts were heard especially to the south and east of the volcano (Veðurstofa Íslands 2010). While the Fimmvörðuháls eruption had a positive economic impact in Iceland, the subglacial Eyjafjallajökull eruption did not and many communities are still dealing with ash impacts. Despite the risk that Eyjafjallajökull poses to farms and tourist accommodation at the base of the volcano, prior to 2010, much more interest in emergency management was given to its very active and more hazardous neighbour, Katla.

2.4 Katla

The Katla central volcano consists of a 5 km wide magma chamber sitting at a shallow depth of 1.5 km below sea level (Sturkell et al. 2003). The caldera is 14 km long, 600–750 m deep and is overlain by the Mýrdalsjökull icecap (Fig. 2.2), which has a maximum thickness of ~740 m (Björnsson et al. 2000). Historically, Katla is characterised by subglacial phreatomagmatic eruptions and has erupted on average, one to three times per century with the last confirmed eruption in 1918 (Thordarson and Larsen 2007). Small, sudden jökulhlaup in 1955 and 1999 are believed to have been the result of minor eruptions that did not break the glacier surface (Gudmundsson 2005). However, eruptions under the icecap typically melt large volumes of ice

Fig. 2.2 Katla volcano is blanketed by the Mýrdalsjökull icecap in the central southern region of Iceland. *Photo* Guðrún Gísladóttir

within a few hours with some resulting in catastrophic jökulhlaup that attain a peak discharge of 100,000–300,000 m^3s^{-1} (Björnsson et al. 2000).

The Katla jökulhlaup, produced during the eruption that began on 12 October 1918, reached a peak discharge of over 300,000 m^3s^{-1} and transported vast amounts of sediment and ice. The jökulhlaup carved its way through the glacier creating a gorge 1,460–1,830 m in length, 366–550 m in width and more than 145 m in height. This caused the detachment of a segment of glacier, which was transported in blocks estimated to be 40–60 m high onto the floodplain (Tómasson 1996). This flood was considered to be the world's largest known historic flood caused by volcanism (O'Connor and Costa 2004). Although, resident's descriptions recorded in annals suggest that the jökulhlaup produced during the 1755 Katla eruption was most likely larger (Guðmundsson and Högnadóttir 2006).

However, not all Katla eruptions have been subglacial. The 934–938 AD Eldgjá flood lava eruption occurred along a ~75 km discontinuous fissure that began under the Mýrdalsjökull icecap in the southwest and continued for 60 km through subaerial mountainous terrain to the northeast of the icecap (Larsen 2000). This eruption produced jökulhlaups, a hyaloclastite flow and two major lava fields. Pahoehoe lavas dominate Eldgjá lava fields although these are interspersed with rootless cones (pseudo-craters), which indicate that the lava was emplaced over shallow lakes or moist ground. Not only is this eruption the largest volcanic event in Iceland's history but it is also the largest of its kind on Earth in the last 2000 years (Thordarson and Larsen 2007). It is therefore not surprising that Eldgjá caused the most extensive environmental changes created by volcanism during the last 11 centuries in Iceland (Larsen 2000).

In addition to jökulhlaups and lava, Katla eruptions have produced heavy tephra fall approximately 20 cm thick to distances of 30 km from source and lightning in areas within 30–40 km of the eruption site (Guðmundsson et al. 2008; Larsen 2000). Coupling these hazards with its proximity to inhabited regions on the south coast, Katla has earned the reputation of being one of Iceland's most hazardous volcanoes (Guðmundsson et al. 2007). High levels of seismicity and crustal deformation, particularly in 2011, suggest that Katla is in a heightened state of activity. Earthquake activity within and around the Katla caldera intensified prior to a small jökulhlaup flood from the southeast corner of Mýrdalsjökull on 8 July 2011. Local residents and tourists were evacuated from the area and the main highway was cut as the flood destroyed one bridge. While several emergency centres were established as a precaution, an eruption column did not penetrate the glacier and the event was declared over within two days.

2.5 Grímsvötn

Due to its position underneath Europe's largest glacier, Vatnajökull, the Grímsvötn central volcano, also typically generates subglacial phreatomagmatic eruptions. Since settlement, Grímsvötn has been the most active volcanic system in Iceland (Guðmundsson et al. 2004) with recent eruptions in 1902, 1922, 1933, 1934, 1938, 1983, 1998, 2004 and 2011 (Veðurstofa Íslands 2011a). Within the Grímsvötn caldera lies a subglacial lake that drained in periodic jökulhlaups every 4–6 years prior to the 1996 fissure eruption in Gjálp. Occurring to the north of Grímsvötn, the 1996 Gjálp eruption caused glacial meltwater to accumulate in the

Fig. 2.3 Twisted metal debris from a bridge destroyed by the jökulhlaup produced from the 1996 Gjálp eruption near Grímsvötn. *Photo* Deanne Bird

Grímsvötn subglacial lake for a month before it flooded to the south of Vatnajökull between 4 and 7 November 1996. This jökulhlaup reached a peak discharge rate of approximately 55,000 m^3s^{-1} (Stefánsdóttir and Gíslason 2005), draining 3.2 km^3 of meltwater from the Grímsvötn lake in about 40 h (Bjornsson 1998).

Emerging across the alluvial floodplain, the jökulhlaup impacted 750 km^2 of land, extended the coastline by 800 m and created approximately 7 km^2 of new land (Smellie 2000). Carrying massive icebergs weighing up to 1000 tons, the floodwaters damaged and destroyed several bridges and roads, including the main highway. A section of a destroyed bridge is displayed on the main highway and serves as a permanent reminder to passing motorists of the shear catastrophic force of Iceland's volcanoes (Fig. 2.3). However, not all jökulhlaups are triggered by eruptions. For example, the reverse occurred in 2004 when an eruption was triggered by the pressure release of draining meltwater (jökulhlaup) that had accumulated in the Grímsvötn caldera due to geothermal activity (Sturkell et al. 2006).

Similar to Katla, the largest eruption from the Grímsvötn system was a subaerial fissure event along a mixed cone row that extended continuously for 27 km (Thordarson and Larsen 2007). This flood lava eruption, known as the Laki eruption, occurred over eight months from 1783 to 1784 AD and is the second largest event of its kind in Iceland (Sigurdsson 1982). Emitting 122 megatons of SO_2 into the atmosphere and generating a sulphuric aerosol veil that was suspended over the Northern Hemisphere for more than five months, the Laki eruption resulted in a reduction of the annual mean surface temperature in Europe and North America by 1.3° for two to three years. Locally, the volcanic haze or dry fog caused plants to wither and killed more than 60 % of Iceland's livestock, mostly through fluoride poisoning (fluorosis). This led to widespread famine which lasted from 1783–1786 and caused severe malnutrition, scurvy and the death of ~20 % of the Icelandic human population (Thordarson and Self 2003). Further afield, the volcanic haze spread westward across Europe to the Altai Mountains in China (Sigurdsson 1982), causing considerable damage to vegetation and crops throughout Europe and stunted tree-growth in Scandinavia and Alaska (Thordarson and Hoskuldsson 2002).

The most recent volcanic activity in Grímsvötn, however, was nowhere near severe. On 21 May 2011 a subglacial eruption created an ash plume that reached a maximum altitude of 20 km (Veðurstofa Íslands 2011b). Ash fallout was experienced locally to the south and east of the volcano and 60–70 lightning strikes were recorded per hour on 22 May 2011 (Jakobsdóttir et al. 2011). Since this eruption occurred at the same location as the 2004 eruption, ice-melt was not significant enough to produce a jökulhlaup (Guðmundsson et al. 2011). This eruption ended on 28 May 2011 (Veðurstofa Íslands 2011b), only 7 days after it began.

Despite, or because of, these infamous volcanoes, many visitors flock to Iceland every year to experience its natural beauty and witness firsthand, the geological processes taking place. Importantly, visitors can feel at ease with the

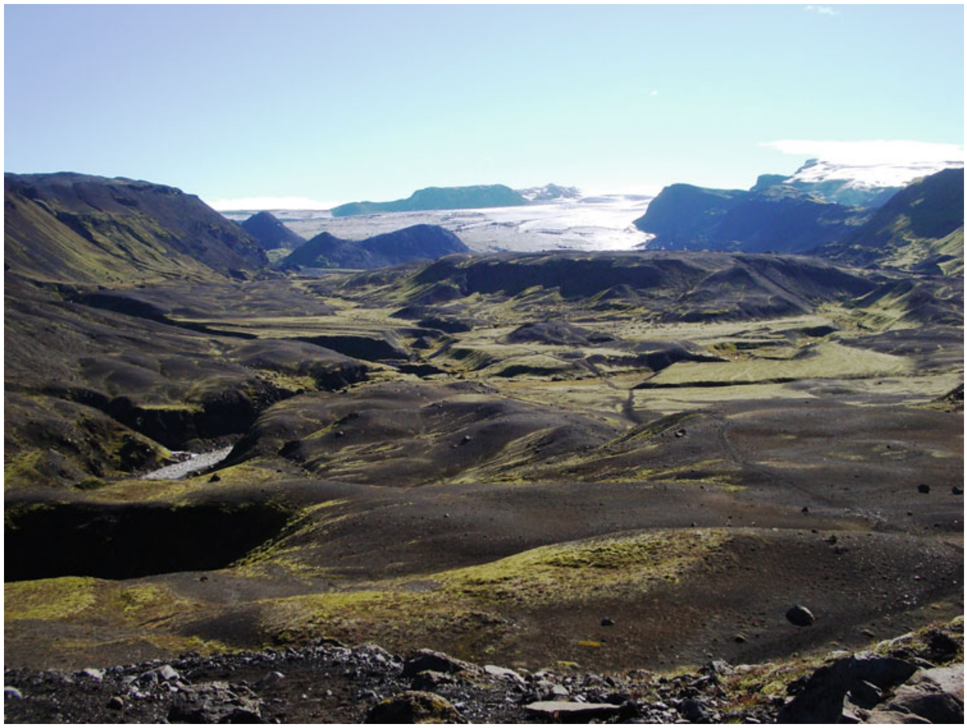

Fig. 2.4 Hiking trails scattered around the landscape surrounding the Mýrdalsjökull icecap and Katla volcano. *Photo* Deanne Bird

knowledge that, in Iceland, only two people perished in volcanic eruptions during the 20th century and none have died during the 21st century. However, due to the rising number of tourists on and around Iceland's volcanoes, the possibility for fatalities in moderate-sized explosive eruptions is increasing (Guðmundsson et al. 2008). In the next section we describe tourism in southern Iceland and what government agencies are doing to reduce risk in these volcanic environments.

2.6 Tourism in Southern Iceland

Iceland is an accessible and popular destination with many local and international tourists exploring the dramatic volcanic landscape of the south (Benediktsson et al. 2011; Bird et al. 2010b). Located within a short drive from the capital Reykjavík and the international airport at Keflavík, the southern region offers a myriad of activities including canyoning, ice and mountain hiking (Fig. 2.4), horse riding, kayaking, mountain climbing, quad biking, snowmobiling, 4WD super jeep trips and white water rafting. There are plenty of organised single or multiday trips from Reykjavík or, alternatively, visitors can hire a car and discover the south coast themselves.

Obviously, Iceland's volcanic landscape and geothermal activity are significant features of many organised tours. In particular, super jeep and hiking tours explore the lava fields and summit of Hekla. Organised ice-hiking, snowmobiling and super jeep tours also traverse the glaciers covering Katla and Grímsvötn while special tours can be arranged to drive or hike over Eyjafjallajökull. However, the most popular hiking path in Iceland is the Laugavegur route, which traverses 55 km of glacial and volcanic landscapes from Landmannalaugar to Þórsmörk. For the more adventurous traveller, this hike continues along the Fimmvörðuháls hiking track that negotiates the rough mountain pass between Eyjafjallajökull and Mýrdalsjökull (Fig. 2.5) and encompasses the region affected by the recent 2010 flank eruption.

Figure 2.6 highlights a steady increase in international tourist numbers staying overnight in hotels and guest houses in southern Iceland since 2002, with a somewhat small decrease in 2010. The total number of overnight stays by Icelandic and international tourists in wilderness lodges and camping grounds has been less predictable during the same period. Nevertheless, there was a definite decrease in 2010 from 2009 in both international (29.1 %) and Icelandic tourists (38.0 %) (Hagstofa Íslands, 2011), which might be attributed to the subglacial Eyjafjallajökull eruption, but this was followed by an overall increase in 2011 of 12.9 % and 40.5 %, respectively (Hagstofa Íslands 2012). Although wilderness lodge accommodation in 2012 remained constant, hotel and guesthouse accommodation increased by 15.6 % in 2012 from 2011 (Hagstofa Íslands 2013). Due to the increasing risk of another eruption in southern Iceland, government agencies and tourism operators are implementing risk management strategies.

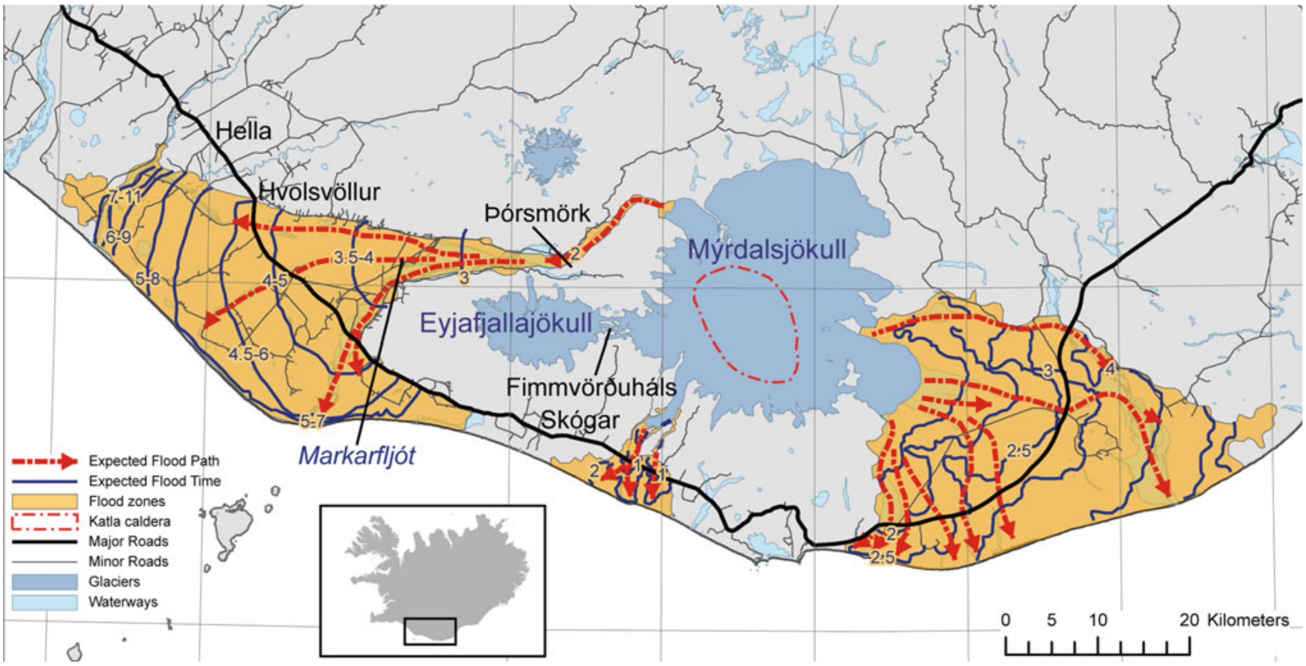

Fig. 2.5 The popular tourist destination of Þórsmörk, situated to the west of Mýrdalsjökull, and the eastern, southern and western jökulhlaup hazards zones around Katla. *Source* (from Ríkislögreglustjóri almannavarnadeild 2008a, b). *Map* produced by James O'Brien, Risk Frontiers

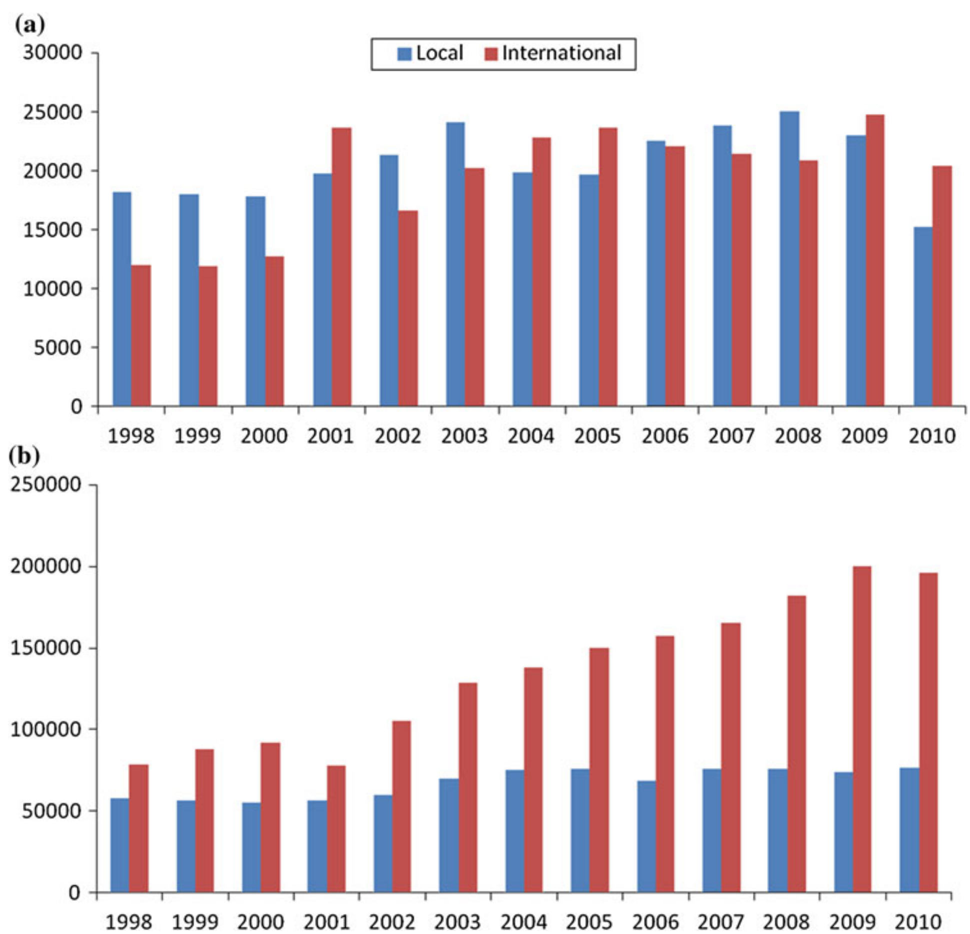

Fig. 2.6 **a** The total number of overnight stays by Icelandic and international tourists in wilderness camping grounds and lodges in southern Iceland from 1998 to 2012; **b** The total number of overnight stays by Icelandic and international tourists in hotels and guesthouses in southern Iceland from 1998 to 2012. *Source* (Hagstofa Íslands 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013)

Fig. 2.7 A jeep crossing the river Krossá, which flows into the Markarfljót near Þórsmörk. *Photo* Deanne Bird

Fig. 2.8 Wilderness lodges and camping grounds at a mountain hut area on the floodplain in Þórsmörk. Mýrdalsjökull is seen in the background. *Photo* Deanne Bird

2.7 Volcanic Risk Management in Southern Iceland

Post-eruption famine is highly unlikely to occur in contemporary Iceland (Guðmundsson et al. 2008). However, loss of livestock and damage to property and infrastructure will cause severe economic consequences for a nation of only 320,000 people, as experienced following the 2010 Eyjafjallajökull eruption. Moreover, there is an increasing likelihood of fatalities during an eruption due to the increasing number of tourists frequenting active regions (Guðmundsson et al. 2008). This potential would be further exacerbated if a Katla eruption was to produce a catastrophic jökulhlaup.

Government agencies have therefore developed regional volcanic risk management strategies. In particular, emergency management officials have been preparing for a Katla eruption (Sigthorsson et al. 2006) and emergency response procedures have recently been developed or revised for communities located in the eastern, southern and western jökulhlaup hazard zones (see Fig. 2.5) (Almannavarnir 2006; Bird 2010; Bird et al. 2009, 2011). If an eruption is imminent, officials will enforce road closures preventing people from crossing glacial rivers that are vulnerable to jökulhlaup. In

Fig. 2.9 Travellers reading the hazard and emergency response information sign entitled 'Katla-Mýrdalsjökull' on a hiking track in Þórsmörk. *Photo* Damian Gore

the popular tourist destination of Þórsmörk (see Fig. 2.5), this is considered a necessary precaution since the Þórsmörk access road traverses the Markarfljót floodplain, crossing dangerous rivers and tributaries (Fig. 2.7). It is estimated that a catastrophic jökulhlaup with a discharge rate greater than 100,000 m^3s^{-1} would produce a flood height across the plain in excess of 20 m and that it would reach Þórsmörk around 2 h after an eruption commences (Guðmundsson and Gylfason 2005). It is therefore essential to close roads susceptible to flooding until the threat has passed.

Each of the mountain hut communities in Þórsmörk: Húsadalur, Langidalur and Básar, are either on, or adjacent to, floodplains (Fig. 2.8). During a Katla eruption, people located in the Þórsmörk region will be instructed to go to higher ground and avoid low-lying areas, especially near glacial rivers.

During the 2008 summer, the Icelandic Department of Civil Protection and Emergency Management together with local police and rescue teams, scheduled hazard education and emergency response training campaigns with the Þórsmörk tourism sector. These consisted of information meetings with tourism companies, onsite training at each mountain hut community, distribution of brochures entitled 'Eruption Emergency Guidelines' available in six languages, and the erection of hazard and emergency response information signs entitled 'Katla-Mýrdalsjökull' in mountain huts and in prominent positions along hiking trails (Fig. 2.9).

Similar precautions have been developed surrounding Hekla, Eyjafjallajökull and Grímsvötn with local information centres (Table 2.3) providing essential hazard and emergency response information for travellers.

2.8 How Prepared are Tourists for a Volcanic Eruption in Southern Iceland?

To assess the vulnerability of the tourism sector in southern Iceland, surveys were carried out from July to September in 2007 and 2009. In total, 139 face-to-face questionnaire interviews were conducted in 2007 and 124 in 2009. For information about the methodology used see Bird et al. (2010a, b). The results of the survey show that education and training campaigns implemented in 2008 were well accepted by tourists and tourism employees. However, they were not entirely successful at increasing knowledge or preparedness (Table 2.4). Respondents believed the map was inappropriately scaled for the Þórsmörk region and found it confusing. For example, information within the brochure refers to 'Mt. Katla' but 'Mt Katla' is not marked on the map. Additionally, the first instruction in the brochure states:

> Examine the map to see where glacial floods have flowed in the past. If an eruption warning signal is given, keep to the upper slopes. The main escape routes are shown by red arrows on the map. No entry signs indicate road closures.

However, many respondents commented that it is very difficult to determine their location on the map, the extent of previous floods or designated escape routes. The only instruction for tephra is: '*It is advisable not to drive where tephra is falling, as it can damage the engine*.' Although the section on tephra states that it can be harmful to the eyes and respiratory system, it provides no advice on how to protect oneself. In comparison, the sections entitled 'Risk of lightning' and 'Toxic gases' provide useful, detailed information about these hazards and how to reduce personal vulnerability.

2.9 Conclusion

The results of these surveys suggest that emergency management agencies are making progress to reduce the risk within the tourism sector but improvements can be made by:

- Improving the "Eruption Emergency Guidelines" brochure including the hazard and risk map to ensure that they are comprehendible and in a user-friendly format. This can be achieved through public consultation and workshops;
- Exploring alternate methods for educating tourists e.g. travel guides (Lonely Planet, Rough Guide, etc.), social media (Facebook, Twitter, etc.), tourist websites, and educational films on local and tourist buses; and,

Table 2.3 Information centres located in southern Iceland that provide tourists with details of local volcanic areas and emergency response procedures

Centre	Address	Telephone	Email
Hveragerði regional information centre	Sunnumörk 2–4 810 Hveragerði	+354 483-4601	tourinfo@hveragerdi.is
Hekla centre	Leirubakki 851, Hella	+354 487-8700	bookings@leirubakki.is
Hvolsvöllur district information centre	Austurvegur 8 860 Hvolsvöllur	+354 487-8043	tourinfo@hvolsvollur.is
Eyjafjallajökull visitor centre	Þorvaldseyri 861 Hvolsvöllur	+354 487 5757	info@icelanderupts.is
Vík district information centre—including the Katla centre	Víkurbraut 28 870 Vík	+354 487-1395	info@vik.is
Skaftafell visitors centre	Vatnajökull National Park Skaftafell 785 Öraefi	+354 470-8300	skaftafell@vjp.is

Table 2.4 Levels of knowledge and preparedness in 2007 and 2009 among tourists in Þórsmörk. Some sections do not equal 100 % due to rounding

	2007	2009
% of participants who were travelling with a guide	9	11
% of participants who carried a mobile phone	71	91
% of participants who had informed someone of their location in this region	78	53
% of participants who stated they knew there was an early warning system	22	57
% of participants who stated they knew the emergency procedures	4	28
If a jökulhlaup warning is issued, % of participants who would:		
go to the highest point	40	39
escape Þórsmörk	18	21
report to wardens	15	23
follow procedures	12	7
other	14	10
If there was a volcanic eruption, % of participants who would:		
report to wardens or guide	54	32
call an emergency number (e.g. 112) or friend	19	7
listen to radio	9	2
evacuate Þórsmörk	5	20
go to higher ground	–	28
other	13	10
% of participants who had:		
Seen an 'Eruption Emergency Guidelines' brochure	–	26
Read an 'Eruption Emergency Guidelines' brochure	–	17
Seen a 'Katla-Mýrdalsjökull' sign	–	44
Read a 'Katla-Mýrdalsjökull' sign	–	42

- Adopting an all-hazards approach to education, i.e. include information on other volcanic systems (e.g. Eyjafjallajökull, Hekla and Grímsvötn) and provide additional detail in relation to glacial melt associated with geothermal activity and, information on seasonal melt in addition to earthquakes, extreme weather conditions, etc.

For more information on Iceland's volcanic hazards and related preparedness measures see:

- http://www.safetravel.is/
- http://en.vedur.is/
- http://www.earthice.hi.is/page/ies_volcanoes
- http://www.vegagerdin.is/english/road-conditions-and-weather/

For more information on the National and Geo-Parks that encompass southern Iceland's volcanoes see:

- http://katlageopark.is/
- http://en.south.is/
- http://www.vatnajokulsthjodgardur.is/english

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