Millennium
European Climate

SG4

Explosive and partly explosive eruptions during the last millennium: Dispersal of airfall tephra and ocean-rafted pumice towards the North Icelandic shelf

Millennium SG4: Marine Proxies for the Millennium

Gudrún Larsen and Jón Eiríksson

Reykjavík 2010
March 2010 / RH-07-2010

INSTITUTE OF EARTH SCIENCES
UNIVERSITY OF ICELAND

Explosive and partly explosive eruptions during the last millennium: Dispersal of airfall tephra and ocean-rafted pumice towards the North Icelandic Shelf

Millennium SG 4: Marine Proxies for the Millennium

Gudrún Larsen and Jón Eiríksson

Institute of Earth Sciences, University of Iceland
Askja, Sturlugata 7, IS-101 Reykjavík

Reykjavík, March 2010
RH-07-2010

Contents

1. Introduction

This report is part of Workpackage WP15 (Deliverable D18) of Subgroup 4 of the Millennium project. Workpackage WP15 concerns the last 1000 years cf. p. 136 in Annex I - Description of Work. The report provides background data for tephrochronological dating of the marine sediments on the north Icelandic shelf (SG4) where multicores, box cores and gravity cores were collected (Figure 1), as well as for lake sediments in West Iceland (SG3).

The report focusses on dispersal of airborne tephra that may have reached the shelf off north Iceland. However, other methods of transport into that area are also considered. These include rafting of pumice from offshore eruptions elsewhere around Iceland, from offshore tephra fall or river-rafted pumice from inland areas of heavy tephra fall, and potential contributions from volcanogenic jökulhlaups.

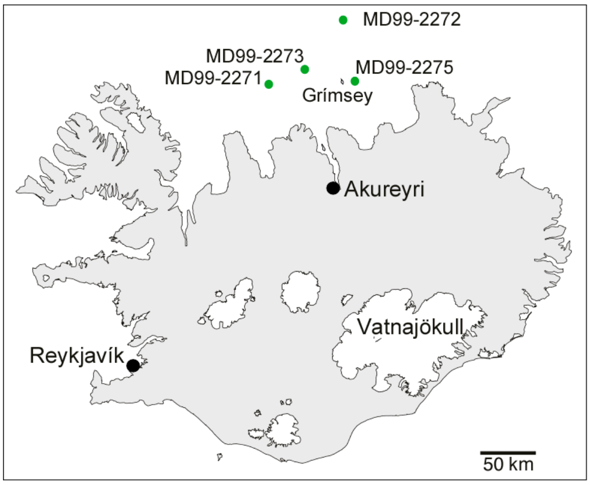

Figure 1. Locations of cores MD99-2271, MD99-2272, MD99-2273 and MD99-2275 on the North Icelandic Shelf.

2. Sources of tephra: the volcanic systems

Volcanism in Iceland and on the Icelandic shelf is confined to numerous volcanic systems (Figure 2). About 30 such volcanic systems have been defined on land while those on the shelf are less well known (Sæmundsson 1978, 1979; Jakobsson 1979, Jakobsson et al. 2008; Jóhannesson and Sæmundsson 1998). During the last millennium at least 12 volcanic systems have contributed basaltic and silicic tephra, most of them land-based. The number of submarine volcanic systems active during this time slice remains, however, uncertain.

The major producers of basaltic tephra during the last millennium are the Grímsvötn, Veidivötn-Bárdarbunga and Katla volcanic systems, all partly ice-covered, as well as the partly submarine Reykjanes and Vestmannaeyjar systems. Several submarine volcanic systems on the Reykjanes ridge have erupted during this time slice and possibly two volcanic systems on the fracture zone off North Iceland. The major producers of silicic tephra are the Hekla, Öræfajökull and Askja volcanic systems (Larsen and Eiríksson 2008 and references therein).

The type of volcanic activity that has the potential to disperse basaltic tephra tens or hundreds of km from the source is hydromagmatic explosive activity, also referred to as phreatomagmatic and surtseyan activity. This includes eruptions in subglacial, submarine and subaquous settings and in areas of high ground water. Some of these eruptions may be classified as mixed eruptions if the eruption style changes to effusive during some stage or persists on parts of the volcanic fissure.

Tephra of silicic and intermediate composition (rhyolitic, dacitic, andesitic) is generated by explosive eruptions or explosive phases of the Plinian or subplinian type in the dry environment. At volcanoes that are capped by ice or perennial snow, the opening phase may be phreatoplinian, generating much finer grained tephra than the Plinian and subplinian eruptions/phases. Many of these eruptions produce substantial lava flows as well as tephra and belong to the category of mixed eruptions.

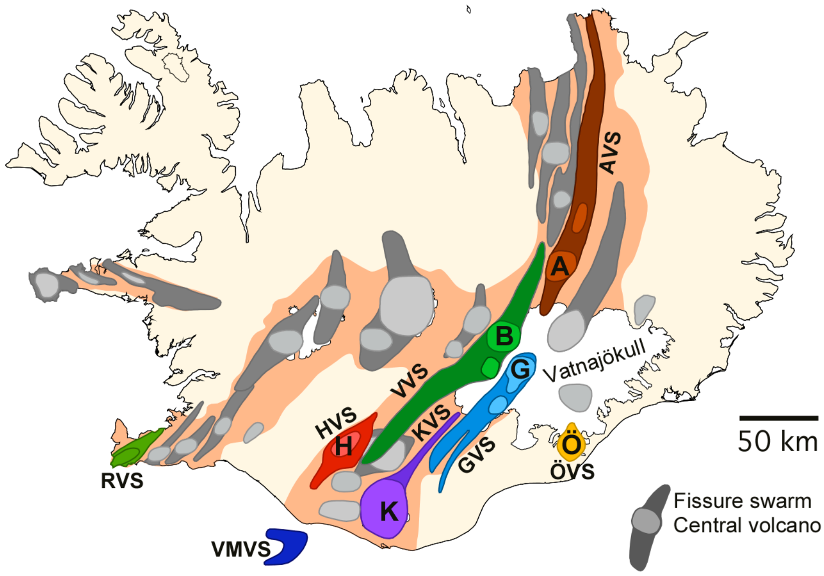

Figure 2. The volcanic systems of Iceland. The major producers of tephra during last millennium are shown in colour, that also reflect the different chemical characteristics of these systems. Adapted from Jóhannesson and Sæmundsson (1998).

3. Sources of information on volcanic eruptions of the last millennium

Sources of information about explosive and partly explosive eruptions in Iceland fall mainly into two categories.

1) Written descriptions of volcanic eruptions or phenomena that could be caused by volcanic eruptions. These (e.g. annals, reports from officials, letters) may include date of the eruption (year, month, day, hour) location of the volcano, description of the type of activity and course of events, duration of the activity, type of products, direction or area of tephra fall, areas of damage. This is the case for many eruptions of the Hekla and Katla volcanoes which lie close to farming areas in S-Iceland and eruptions within the Vatnajökull ice cap (e.g. Thorarinsson 1958, 1967, 1974, 1975 and references therein).

For eruptions in more remote areas such as the central highlands or Vatnajökull ice cap the information may consist only of the eruption year and a few words about eruption cloud or fire, glow in the sky, tephra fall, darkness, flood, or other phenomena that people thought were signs of volcanic activity. Location of the eruption site may be vague or attributed to the wrong volcano. Also, names that differ from the present ones may have been used for mountains, ice caps and districts at the time of writing.

In genereal, however, the date of an eruption is likely to be more accurate than the location of the volcano because the calendar was a common knowledge although the geographical knowledge was often poor. Volcanic eruptions were as much news then as they are today and were definitely worth mentioning in the annals.

Volcanic eruptions or phenomena that could be caused by volcanic activity are mentioned or described in various documents from the 12th century onwards. Some sightings of phenomena that were interpreted as signs of volcanic eruptions may - or may not - have been caused by volcanic activity. Some accounts of tephra fall may also be false - as late as in the 2004 Grímsvötn eruption reports of tephra fall were spurred by dust storms.

2) The volcanic products, which in this case are tephra layers, that have been identified, mapped and/or chemically fingerprinted. Tephra layers have many macroscopic and microscopic characteristics that can be used to identify, correlate, map and trace tephra layers to source - and to build a local or regional tephra stratigraphy. Many volcanic systems in Iceland have chemical characteristics that allow correlation of their product to the source - and can support or verify correlations of tephra layers in the field.

Many descriptions of eruptions and tephra fall are detailed enough to allow correlation of certain tephra layers to definite dated eruptions, thereby providing securely dated tephra horizons within the local or regional tephra stratigraphy. Such marker horizons facilitate further correlation of tephra layers to dated eruptions. Dated pairs or series of tephra layers can also serve as marker horizons. The first such series in the Icelandic tephrochronology consisted of the H-1766, K-1721 and H-1693 tephra layers (Thorarinsson 1944).

Aeolian dust layers are, normally, easily recognizable for the trained eye. In Iceland this dust is mostly volcanic glass but differs from fresh tephra in being inhomogenous both in grain morpology and composition, and the layers are not laterally extensive. No such layers are considered in the following chapters.

4. Transport of volcanic material: Air-fall, ocean-rafting, jökulhlaups

The most common transport of primary tephra is by an eruption cloud carried downwind from the volcano, covering distances of tens to thousands of km. *Air-fall* deposition has delivered by far the most tephra to the sediments off North Iceland in Holocene time. In large plinian eruptions, such as the prehistoric Hekla-3 and Hekla-4 eruptions, offshore deposition coveredan area of several hundred thousand km^2. In small plinian, subplinian or phreatomagmatic eruptions the fallout area may be confined to narrow sectors of limited area. The number of eruptions that have dispersed tephra off the north coast during the last millennium is not precisely known but will almost certainly exceed the 30+ eruptions listed in this report (chapter 6).

Pumice rafts have been known to float for hundreds of km on the ocean before becoming waterlogged and sinking (e.g. Newton 1999). In the Hekla eruptions of 1970, 1947 and 1766 pumice rafts were formed off the south coast of Iceland as a result of offshore tephra fall (1947) or seaward transport by rivers (1970, 1766) and transported clockwise by currents along the west and north coast of Iceland during the next three months (see chapter 6). Although no reports of ocean-transported pumice off North Iceland exist for other eruptions the presence of such pumice cannot be excluded. In the Öræfajökull eruption in 1362 pumice rafts were reported off West Iceland and rounded pumice on salt-marshes in West Iceland has been correlated to eruption off Reykjanes in 1226/27 (see chapter 6).

Jökulhlaups are the third transport mechanism that may have delivered volcanic glass to the sediments off North Iceland. Askja pumice was carried 130 km by a glacial river, Jökulsá á Fjöllum, to the north shore and then at least 70 km at sea to the Grímsey island, close to the North Iceland Millennium sites (see chapter 6). The river still transports Askja pumice into Öxarfjördur, more than 130 years after the deposition in 1875. Its spring floods carry a load of volcanogenic material into Axarfjördur, and silt-coloured water is known to extend as far out as Grímsey. The volcanic glass particles are, however, unlikely to be of homogenous composition. Larger floods in Jökulsá á Fjöllum and in Skjálfandafljót, caused by subglacial eruptions, are likely to have extended at least as far and are therefore potential contributors of volcanogenic material at the Millennium sites. Although unlikely to consist of homogenous glass a resemblance to a primary tephra layer cannot be excluded.

5. Explosive and partly explosive eruptions 2005-870 - an overview

Some 185 tephra producing eruptions are known to have occurred since late 9th century, of which about 170 happened during the last 1000 years. Figure 3a&b summarizes the current knowledge on frequency of explosive and partly explosive eruptions in Iceland for this period.

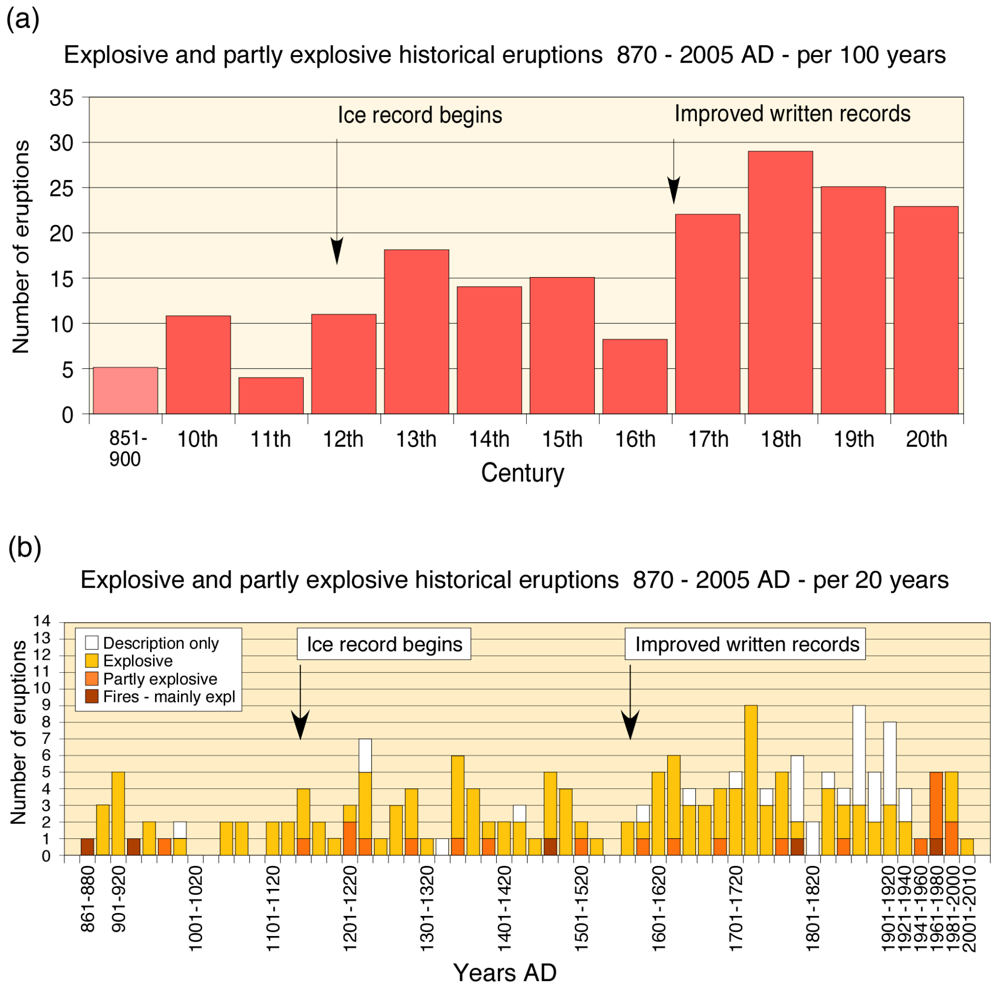

Figure 3. Frequency of explosive and partly explosive eruptions between AD 870 and AD 2005, binned a) per 100 years and b) per 20 years. Adapted from Thordarson and Larsen (2007) and Larsen and Eiríksson (2008). Roughly 170 tephra-producing eruptions are known during last millennium, of them about 30 are "reported only" eruptions within Vatnajökull ice cap. The frequency per 20 years varies from 0 to 9 eruptions, with peaks spaced 120-160 years apart. An apparent general increase in eruption frequency with time is probably an artifact, reflecting improved knowledge. Tephra layers in Vatnajökull ice go back to the 12th century, greatly adding to the knowledge of volcanic eruptions within the Vatnajökull ice cap (first arrow). Written descriptions, including those of volcanic eruptions, improve in the 17th century (second arrow). Information based on Jónsson (1945), Thorarinsson (1950, 1958, 1963, 1965, 1966, 1967, 1970, 1974), Jóhannesson (1977, 1983, 1984, 1987), Jóhannesson and Einarsson (1988), Sæmundsson (1991), Steinthorsson (1978), Larsen (1982, 1984, 2000), Larsen et al. (1992, 1998), Sigurgeirsson (1992), Thordarson and Self (1993), Thordarson et al. (2003), Grönvold et al. (1995), Zielinski et al. (1995), Eiriksson et al. (2004), Lacasse et al. (2004), Sigmundsson and Gudmundsson (2004), Óladóttir (2009) and Larsen and Gudmundsson unpubl. data.

The frequency per 100 years is shown on Figure 3a. Eruption frequency was exceptionally low at the beginning of the AD 2005-1000 time slice, the period under consideration in the Millennium project, with only 4 explosive or partly explosive eruptions known in the 11th century. The 18th and 19th century experienced the highest frequency of explosive and partly explosive eruptions on record, but most of these eruptions were small.

The majority, or about 120 of the explosive and partly explosive eruptions can be assigned a date based on written sources. Not all tephra layers can be correlated to a documentary date - there are more tephra layers than dates. Those tephra layers that cannot be correlated to an eruption year are assigned a date calculated using soil or sediment accumulation rate (SAR), or based on ice thickness between securely dated tephra horizons. These are often accurate to ±5 years or ±10 years, which is why binning to 20 years is used in Figure 3b. Furthermore, not all eruptions mentioned in documents can be fitted to a tephra layer, and about 30 eruptions are labelled "description only" on Figure 3b. Even in the last century there are several eruptions that are classified as reported only because no corresponding volcanic products have been found.

An apparent general increase in eruption frequency with time in Figure 3 is an artifact, reflecting improved documentary records. Tephra layers in Vatnajökull ice go back to the 12th century (first arrow). Written descriptions improve in the 17th century (second arrow). The highs (15-30 eruptions/100 years) and lows (2-8 eruptions/100 years) revealed by the 100 bins represent actual changes in eruption frequency. The 16th century low and the 17th century rise in eruption frequency is, for instance, seen in all three archives used to compile the graphs, written documents, soil sections and glacier ice. Frequency per 20 years varies from 0 to 9 eruptions, with peaks spaced 120-160 years apart (Larsen et al. 1998).

6. Relevant tephra producing eruptions 2005-1001 - short descriptions

In this chapter semi-standardized information on explosive and partly explosive erupions is compiled, including the location, time and length of eruptions if known, type of explosive activity, dispersal and volume of the tephra together with selected references. The dispersal maps are based on comtemporary descriptions and on ground data (thickness measurements or mass per unit area). Areas of documented tephra fall are shown and potential dispersal off N-Iceland is indicated. River and/or ocean transport of pumice and volcanogenic sediments is indicated by arrows. Potential rafting of pumice from submarine eruptions is also indicated by an arrow and a question mark.

Note that the dispersal maps provided in this report do not necessarily include all known areas of deposition for the tephra layers on land because the emphasis is on the North Iceland shelf and W-Iceland. In the following sections, a small tephra layer refers to 0.01-0.05 km^3, moderate 0.05-0.1, average 0.1-0.5, fairly large 0.5-1 km^3 as freshly fallen.

6.1 Tephra producing eruptions 2005-1901

Verified and reported explosive or partly explosive eruptions in the period 2005-1901 are at least 24, counting the Surtsey fires as a single eruption. Of them 17 eruptions have been verified. Airborne tephra from at least 11 eruptions was carried northwards across Iceland and onto the shelf off North Iceland (Figure 4). Below are short descriptions of these erupions together with relevant references. Also included are those that delivered large quantities of pumice into the sea through tephra fall or by eruption at sea. Volcanogenic jökulhlaups into Skjálfandaflói and Axarfjördur are included as flood water can extend tens of km into the sea.

Grímsvötn 2004
Eruption site: Grímsvötn caldera, Grímvötn volcanic system. Eruption began around 22 o'clock on Nov. 1, 2004 and lasted for a week.

Subglacial opening stage was followed by subaerial explosive activity and the only product was basaltic tephra. Maximum height of eruption cloud was 12-13 km according to the weather radar of the Icelandic Meterorological Office (IMO). Tephra dispersal was towards NNE, N, NNW and minor tephra fall reached the coast of NE Iceland. The tephra layer was a small one, with the mass of tephra close to 25 million tons.

(Sigmundsson and Gudmundsson 2004; Oddson et al. 2007).

Hekla 2000
Eruption site: Hekla central volcano, Hekla volcanic system. Eruption began at 18:19 on Feb. 26, 2000 and lasted 12 days.

Subplinian opening stage emitted basaltic-andesitic tephra, followed by mixed explosive and effusive activity. Maximum height of the eruption cloud was 11-12 km according to the weather radar of the IMO. The main tephra producing phase lasted a few hours, tephra was carried NNE onto the shelf off North Iceland along a narrow sector crossing Grímsey Island, where 10-15 g/m^2 was deposited. The tephra layer was a small one, calculated volume is 10 million m^3.

(Haraldsson 2001, Haraldsson et al 2002; Árnason 2002; Lacasse et al. 2004; Soosalu and Einarsson 2005).

Grímsvötn 1998

Eruption site: Grímsvötn caldera, Grímvötn volcanic system. Eruption began around 09:30 o'clock on Dec. 18, 1998 and lasted until the Dec. 28.

Subaerial explosive explosive activity, apparently without a preceding subglacial stage, only product basaltic tephra. Maximum observed height of eruption cloud was about 10 km asl. Main tephra dispersal was towards ESE but minor tephra fall reached the coast of North Iceland. The volume of the north trending tephra sector is not known.

(Gudmundsson et al. 1999, 2000; Óskarson et al. 1999; Sigmarsson et al. 2000).

Gjálp 1996

Eruption site: Gjálp in Vatnajökull, Grímvötn volcanic system. Eruption began around 22 o'clock on Sept. 30, 1996 and lasted until the Oct 13/14.

Subglacial opening stage was followed by subaerial explosive activity, only product was basaltic-andesitic tephra. Maximum observed height of eruption cloud was about 9 km asl. Main tephra dispersal was towards NW and minor tephra fall reached the coast of North and Northwest Iceland. The volume of the tephra layer was estimated at about 10 million m^3.

(Gudmundsson et al. 1997, 2004; Sigmarsson et al. 2000; Steinthorsson et al. 2001)

Hekla 1991

Eruption site: Hekla central volcano, Hekla volcanic system. Eruption began at 17 o'clock on Jan. 17, 1991 and lasted until March 11.

Plinian opening stage emitted basaltic-andesitic tephra and was followed by mixed explosive and effusive activity. Maximum observed height of the eruption cloud was 12 km asl. The main tephra producing phase lasted a few hours, tephra was carried NNE onto the shelf off North Iceland along a sector east of Grímsey Island, where about 1 g/m^2 was deposited. The tephra layer was a small one, calculated volume is 20 million m^3.

(Gudmundsson et al. 1992; Larsen et al. 1992).

Hekla 1980

Eruption site: Hekla central volcano, Hekla volcanic system. Eruption began at ca 13:27 on August 17 and ended on August 20.

Plinian opening phase emitted basaltic-andesitic tephra and was followed by mixed explosive and effusive activity. Maximum observed height of the eruption cloud was 15 km asl. The main tephra producing phase lasted 4-5 hours. The tephra was carried due N to the coast where 1-2 g/m^2 were deposited and onto the shelf off North Iceland along a sector mainly west of Grímsey Island. The tephra layer was a moderate one, calculated volume is about 60 million m^3. Activity was resumed in April 1981 and lasted 7 days. Weak explosive activity in several shortlived phases dispersed tephra up to 40 km from source. Maximum cloud height was only 6.6 km asl as observed by radar.

(Sverrisdóttir 1982; Grönvold et al. 1983).

Hekla 1970

Eruption site: flanks of Hekla central volcano, Hekla volcanic system. Eruption began between 21:20 and 21:25 on May 5 and lasted 2 months.

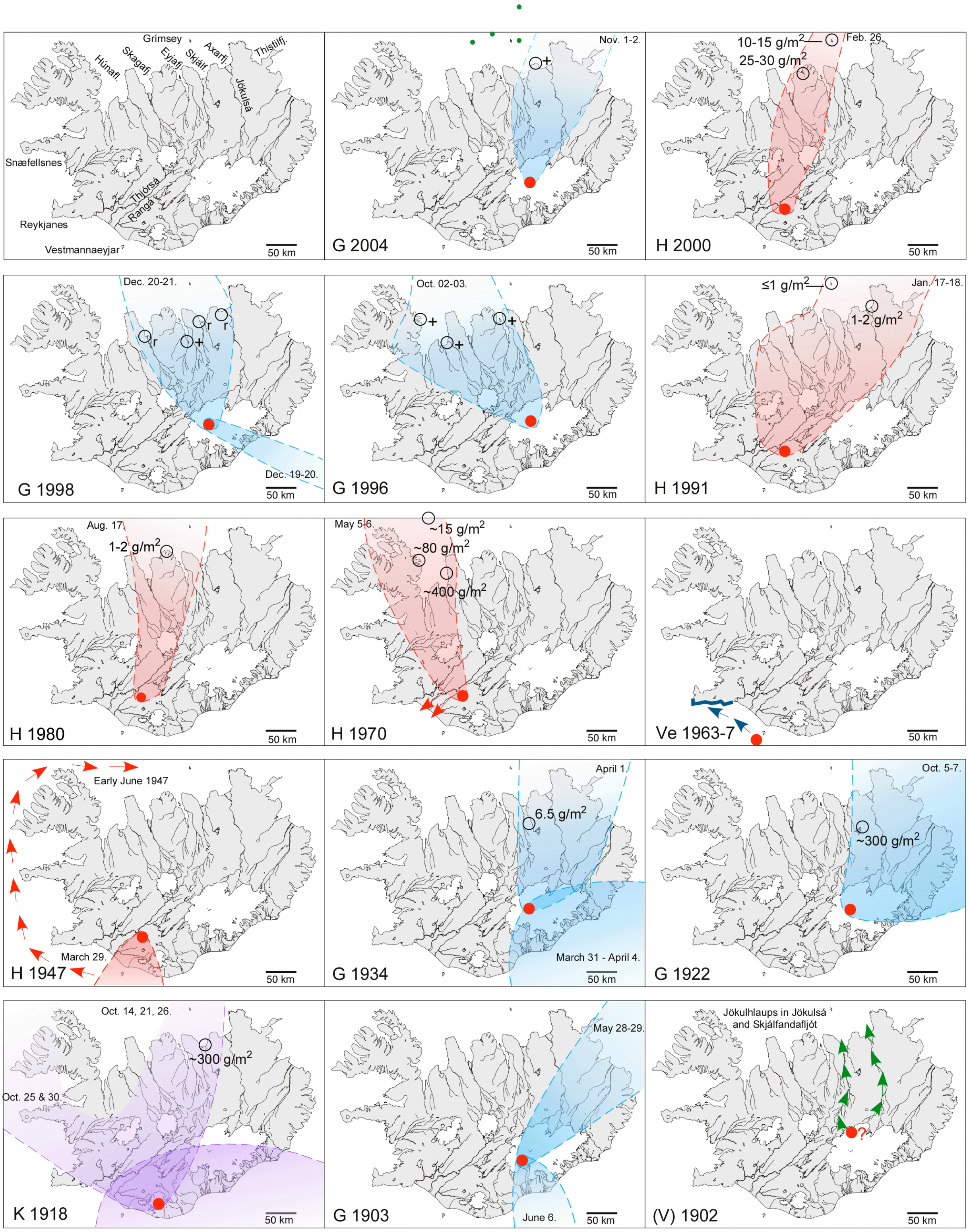

Figure 4: Relevant eruptions in the period 2005-1901. Red: Hekla. Blue: Grímsvötn. Green: Veidivötn-Bárdarbunga (and erupitions off Reykjanes). Violet: Katla. Arrows indicate routes of ocean rafted pumice, river rafted pumice and jökulhlaup routes. Small green dots indicate core locations. Small circles with numbers indicate locations where mass of deposited tephra is known near or off the north coast, "+" and "r" indicate confirmed and reported traces of tephra, respectively. Estimated mass of ~300 g/m^2 is assigned to localities where footprints were traceable after light tephra fall, in accordance with Thorarinsson (1955).

Plinian/subplinian opening phase emitted basaltic-andesitic tephra from two separate fissures and was followed by mixed explosive and effusive activity. Maximum observed height of the eruption cloud was about 16 km asl. The main tephra producing phase lasted 4-5 hours. The tephra was carried NNW to the coast where up to 160 g/m^2 were deposited and onto the shelf off North and Northwest Iceland where up to 15 g/m^2 were deposited at about 66°50' north. The tephra layer was a moderate one, calculated volume is about 70 million m^3.

Rafts of pumice were observed along the Northwest coast (Raudisandur) in May 1970 and off and along the North coast in late June and July 1970 (Strandir to Skjálfandaflói). This was assumed to be Hekla tephra that was transported down to the sea by rivers in South Iceland during and after the Hekla eruption.

(Thorarinsson 1970, Thorarinsson and Sigvaldason 1972).

Surtsey fires 1963-1967

Eruption site: Vestmannaeyjar archipelago, Vestmanneyjar volcanic system. The eruption was first observed on November 14, 1963 and lasted intermittently until June 4, 1967.

The eruption episode beginning on November 14, 1963, consisted of several events. The eruption sites were permanent or temporary islands were built above sea level were at Surtsey in 1963-1967, Syrtlingur in 1965, and Jólnir in 1966. In all instances the activity was submarine for some time before explosive activity broke the surface of the sea. At Surtsey the explosive activity continued for 4.5 months and built a double tephra cone before the activity turned effusive. At Syrtlingur and Jólnir the explosive activity died down after 5 and 7 months and both islands disappeared shortly after.

The tephra produced at these eruption sites is estimated to have exceeded 600 million m^3. Airborne tephra was not widely spread but reached Heimaey, 20 km to the NE. Rafts of pumice were frequently observed around the eruption sites and such pumice repeatedly reached the shores of Reykjanesskagi, 80-120 km to the WNW. Sea-transported pumice was reported on beaches in southwest Iceland (Álftanes) and northeast Iceland (Melrakkaslétta) in 1965 and in north Iceland (Höfdaströnd) in late summer 1966. This was assumed to be the product of the Surtsey fires.

(Thorarinsson 1965a, 1966, 1968; Gudmundsson and Ingólfsson 1968; Morgunbladid 1965, July 6, p. 2, and 1966, September 10, p. 32).

Hekla 1947

Eruption site: Hekla central volcano, Hekla volcanic system. Eruption began around 06:40 on March 29 and lasted 13 months.

Plinian opening phase emitted andesitic to basaltic-andesitic and was followed by mixed explosive and effusive activity. Maximum observed height of the eruption cloud during the opening phase was about 30 km asl. The main tephra producing phase lasted about an hour but strong explosive activity continued into the afternoon and was significant during the next two days. The tephra produced during these first days was carried due S and to the European mainland. Currents carried some of the tephra that was deposited into the sea westwards along the coast. The tephra layer was an average one, calculated volume is about 180 million m^3.

Weaker explosive activity continued intermittently during the next 2-3 months and tephra was carried towards west and north on several occasions but so far no information exists on tephra fall in West or North Iceland or off the north coast. However, rafts of pumice and ash that resembled shoals of herring as seen from a distance were observed off North Iceland in June 1947. This was assumed to be part of the tephra that fell offshore on March 29.

(Thorarinsson 1954, 1967; Morgunbladid 1947, June 14, p. 12).

Grímsvötn 1934

Eruption site: Grímsvötn caldera, Grímvötn volcanic system. The eruption was first observed on March 30 and lasted until middle of April.

Presumably the eruption had a subglacial opening stage that was followed by subaerial explosive activity. The only known product was basaltic tephra. Maximum observed height of eruption cloud was about 12.8 km asl. Tephra dispersal was towards SE, E and N. In North

Iceland 6 g/m^3 to perhaps 300 g/m3 of tephra were deposited 30 to 60 km inland. Tephra fall in the coastal areas and offshore must have been considerably less. Estimated volume of tephra is 10-20 million m^3.

(Áskelsson 1936; Thorarinsson 1974)

Grímsvötn 1922

Eruption site: Grímsvötn caldera, Grímvötn volcanic system. The eruption began on October 2 and lasted at least until October 23.

Presumably the eruption had a subglacial opening stage that was followed by subaerial explosive activity. The only known product was basaltic tephra. Tephra dispersal was was mainly towards N, NE and E between October 5-7, across North and Northeast Iceland and off the coast. Minor tephra fall (dust) was reported in Northwest Iceland. The tephra volume erupted in October was at least 15-20 million m^3.

A predominantly effusive eruption that began in November on the Askja volcanic system may have contributed slightly to the tephra deposits in Northeast Iceland later on.

(Thorkelsson 1923; Thorarinsson 1974).

Katla 1918

Eruption site: Katla caldera in Mýrdalsjökull, Katla volcanic system. The eruption began on October 12 and lasted for three weeks.

Presumably the eruption had a short subglacial opening stage that was soon followed by strong hydromagmatic explosive activity producing basaltic tephra. Explosive activity was most intense during the first days and continued intermittently throughout the eruption. The tephra was dispersed widely and tephra fall reached North Iceland on October 14 and also later during the eruption. On October 26 tephra deposition in Akureyri and Húsavík village on the north coast of Iceland may have exeeded 300 g/m3 (footprints traceable). The tephra layer was fairly large, estimated volume was about 700 million m^3.

(Morgunbladid 1918, October 15, p. 1, October 27, p. 1; Sveinsson 1919; Eggertsson 1919; Thorarinsson 1955, 1975; Larsen 2000).

Grímsvötn 1903

Eruption site: Thordarhyrna, Grímvötn volcanic system. The eruption was first observed on May 28 and continued intermittently for over 7 months.

Presumably the eruption had a subglacial opening stage that was followed by subaerial explosive activity. The only known product was basaltic tephra. Maximum height of eruption cloud is not known. Tephra production was most intense during the first two days and the tephra was carried towards NE over Northeast and East Iceland and off the coast. Tephra fall was reported by a ship 30 miles east of the coast, off Langanes. Tephra was also dispersed towards SSE. The tephra layer was an average one, estimated volume on land was about 100 million m^3.

(Thoroddsen 1924; Mouritzen and Noe-Nygaard 1950; Thorarinsson 1974).

Summary 2005-1901

Tephra from 11 eruptions was carried northwards across Iceland and onto the shelf off North Iceland in the period 1900-2005 (Figure 4).

All the northbound Hekla tephra layers are small, between 10 and 70 million m^3. Where data exists on tephra deposition offshore in the Hekla eruptions the mass is 1-15 g/m^2, and north of 66°N the range is 1-80 g/m^2.

Tephra from Grímsvötn eruptions forms thinner "tephra veils" in north Iceland than the tephra from Hekla eruptions, partly because of different type of explosive activity and in some cases because the main tephra dispersal was towards other directions.

In the 1918 Katla eruption tephra fall in North Iceland may have exceeded 300 g/m^2 in Húsavík (footprints traceable) at 66°N. This eruption was the largest eruption of the 20th century.

In nine eruptions airfall may have reached the area of cores MD99-2271, MD99-2272, MD99-2273 and MD99-2275. These were the Katla 1918, Grímvötn 1934, Hekla 1970, 1980, 1991, Gjálp 1996, Grímsvötn 1998, Hekla 2000 and Grímsvötn 2004 eruptions. Known tephra deposition off the north coast was minor, ranging from less than 1 g/m^2 to ~15 g/m^2.

The best candidates for 20th century isochrones in the area where the cores MD99-2271, MD99-2272, MD99-2273 and MD99-2275 were collected are probably the Hekla 2000 and Katla 1918 tephras.

6.2 Tephra producing eruptions 1900-1501

The documentation of volcanic events in the period AD 1900-1501 improves after AD 1600 and is reasonably good for the last two centuries (Figure 3). Eruption frequency was exceptionally low at between AD 1600 and 1500, with only 8 or 9 explosive or partly explosive eruptions on record. This is, however, not caused by poor documentation because only a few tephra layers are found in soil sections and in Vatnajökull ice during this period.

Verified and reported explosive and partly-explosive eruptions in the period 1900-1501 are at least 84, counting the 1783-85 Skaftá fires as a single eruption. Over twenty eruptions are "reported only" which means that corresponding tephra layers have not been found. The tephra layers of the remaining 63 eruptions range from small to large (0.01-1 km^3). Of them 16 have a fairly wide dispersal: Askja 1875; Hekla 1845, 1766, 1697, 1636, 1597, 1510; Katla 1755, 1721, 1660, 1625; Grímsvötn 1873, 1783 (Skaftá fires), 1619; Veidivötn-Bárdarbunga 1717.

Airborne tephra from at least 11 eruptions was carried northwards across Iceland and potentially onto the shelf off North Iceland during this period (Figures 5 and 6). Below are short descriptions together with relevant references. Also included are eruptions that delivered large quantities of pumice into the sea through tephra fall or by river transport and eruptions at sea. Volcanogenic jökulhlaups in Jökulsá á Fjöllum are included because flood water is known to extend tens of km into the sea at Axarfjördur, even in spring floods.

Reykjanes ridge 1879

Eruption site: Geirfuglasker volcanic system? Eruption began on May 30 and lasted intermittently until mid-June.

Submarine eruption SW of Reykjanes, possibly 30 km offshore. Eruption plume was seen from Hafnir village but the area of the reported minor tephra fall was not specified. The eruption was apparently a small one, the eruption site was never visited and pumice rafting is not mentioned. Rafting of pumice by ocean currents (branch of Irminger current or coastal currents flowing clockwise along the W and N coast) towards N is possible but not likely in this case.

(Thorarinsson 1965b; Jakobsson 1974, Jakobsson et al. 2008)

Askja 1875

Eruption site: Askja volcanic system, central volcano and fissure swarm. Activity at Askja central volcano in Dyngjufjöll began in January 1875.

Minor (basaltic) tephra fall from Dyngjufjöll was reported in Kelduhverfi, Axarfjördur, sometime before mid-February. The phreatoplinian and plinian eruption on March 29 emitted between 1 and 2 km^3 of silicic tephra which was carried towards E, the tephra fall reaching Scandinavia within 24 hours. The eruption left thick deposits of silicic pumice in the uppermost part of the drainage basins of Jökulsá á Fjöllum and its tributary river Kreppa, which transported substantial quantities of pumice into Axarfjördur. The pumice washed up onto the shore from Tjörnes in the W to Þistilfjördur in the E. In the spring of 1875 pumice-rafts were reported N of Grímsey island. Jökulsá still transports pumice from the 1875 eruption into Axarfjördur. Minor tephra fall was reported in Mývatnssveit on April 5, either from Askja or from the effusive eruption on the fissure swarm.

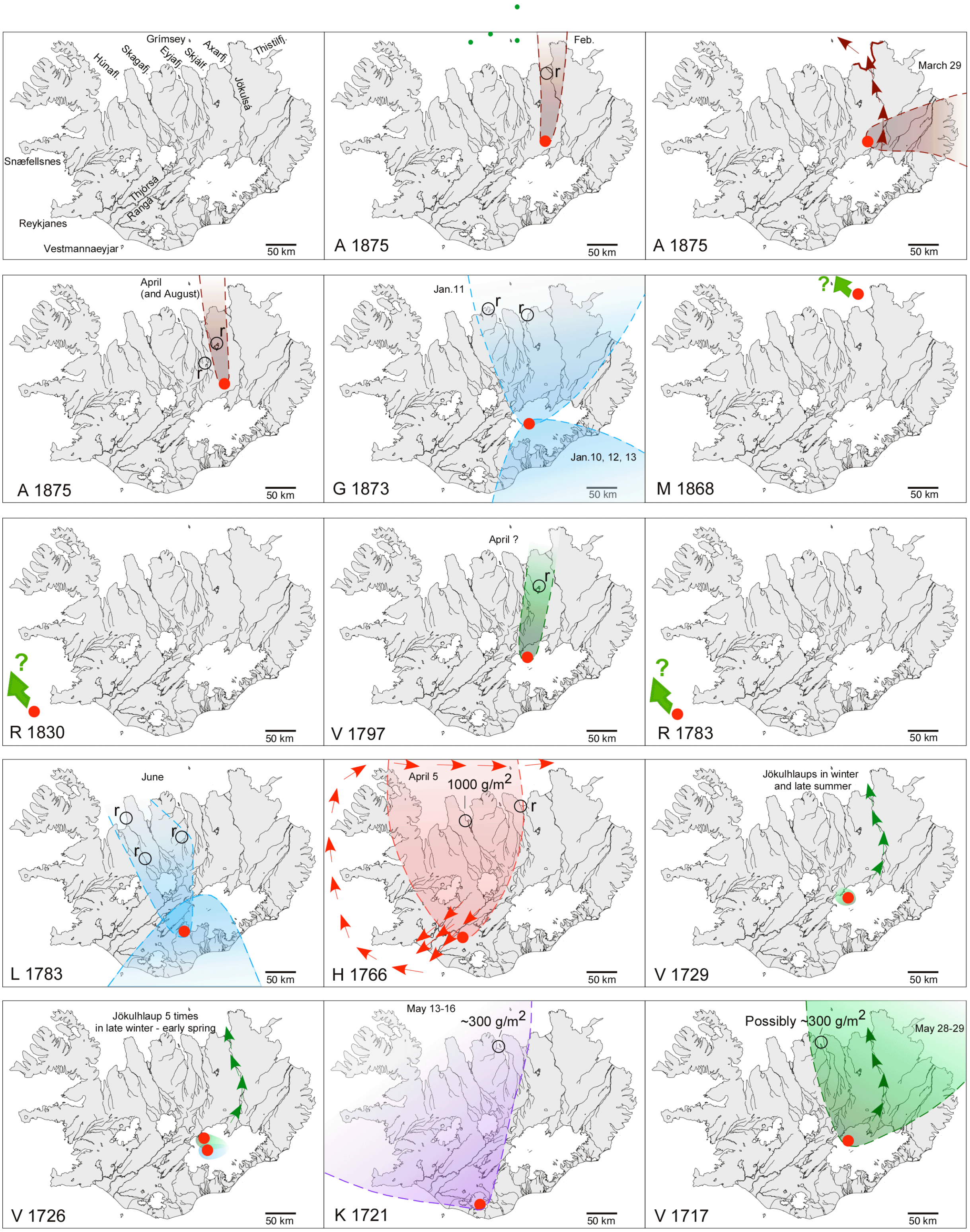

Figure 5. Relevant eruptions in the period 1900-1701. Red: Hekla. Blue: Grímsvötn. Green: Veidivötn-Bárdarbunga (and erupitions off Reykjanes). Violet: Katla. Brown: Askja. Arrows indicate routes of ocean rafted pumice, river rafted pumice and jökulhlaup routes. Small green dots indicate core locations. Small circles with numbers indicate locations where mass of deposited tephra is known near or off the north coast, "+" and "r" indicate confirmed and reported traces of tephra, respectively. Estimated mass of ~300 g/m^2 is assigned to localities where footprints were traceable after light tephra fall, in accordance with Thorarinsson (1955).

(Nordanfari 14, 1875; Ísafold II, 9, 1875; Jónsson 1945; Thorarinsson, 1963; Sparks et al. 1981; and references in these papers).

Grímsvötn 1873
Eruption site: Grímsvötn central volcano, most probably the Grímsvötn caldera. Eruption began on January 8 or 9, 1873.

Presumably the eruption had a subglacial opening stage that was followed by subaerial explosive activity. The only known product was basaltic tephra. Tephra production was most intense between January 9 and 13, in particular on January 10, but the eruption lasted intermittently until August. Tephra dispersal was towards N and NE on January 9, 10 and 11, with tephra fall in North and Northeast Iceland (e.g. Siglufjördur, Húsavík) and, presumably, off the coast. Tephra was also carried to the SE and E. The tephra volume erupted in January is estimated at several hundred million m^3, and the 1873 eruption is the largest Grímsvötn eruption on record.

(Thorarinsson 1974 and references therein)

Mánáreyjar area 1868
Likely eruption site: Theistareykir volcanic system north of Mánáreyjar islands (possibly a separate system, Tjörnesgrunn). Activity was reported in January 1868.

Descriptions of the activity N of Mánáreyjar are scarce, only mentioning "fire " rising from the sea. Neither tephra nor pumice rafts are mentioned. This is, however, included here because the eruption site may have been 40 km or less from the coring sites around Grímsey island.

(Nordanfari 7, 1868; Thorarinsson 1965b; Jakobsson et al. 2008)

Reykjanes ridge 1830
Eruption site: Eldeyjarbodi volcanic system? Eruption began on March 13 and lasted intermittently for a year.

Submarine eruption SW of Reykjanes, possibly 55-60 km offshore. Large eruption plume was evident from Reykjavík in late March. Great quantities of scoria and pumice were formed at the eruption site. Rafting of pumice by ocean currents (branch of Irminger current or coastal currents flowing clockwise along the W and N coast) towards N is possible but no reports are known.

(Thorarinsson 1965b; Jakobsson et al. 2008)

Veidivötn-Bárdarbunga 1797
Eruption site(s): Veidivötn-Bárdarbunga volcanic system, subglacial part below NW Vatnajökull. Some activity was reported in winter (possibly April) 1797 and observed in July-August 1797.

Presumably the eruption had a subglacial opening phase but without an ensuing jökulhlaup. The observed activity in July-August was in the NW corner of Vatnajökull, apparently a rather small hydromagmatic eruption featuring three separate plumes. Minor tephra fall in NE Iceland apparently occurred earlier in 1797.

(Thorarinsson 1974 and references therein)

Reykjanes ridge 1783
Eruption site: Gullhóll volcanic system, Reykjanes Ridge. Activity first reported on May 1, 1783.

Submarine eruption SW of Reykjanes, about 150 km offshore. Sursteyjan activity gradually built a small island, given the name Nýey, which disappeared within a year. Huge amounts of floating pumice were reported W of Reykjanes in May 1783, extending over an area 20 to 25 miles wide. Most authors assume that these are Danish nautical miles, 7.4 km, in which case the pumice covered a 150-200 km wide area. In case these were 1.85 km long nautical miles the area is 37-47 km wide. The rafts were so thick that ships were slowed down. Rafting of pumice by ocean currents farther towards N is possible but no reports are known.

(Thoroddsen 1925; Thorarinsson 1965b; Jakobsson 1974, Jakobsson et al. 2008, and references in these papers)

Lakagígar 1783-85

Eruption site: Grímsvötn volcanic system, Lakagígar fissure and Grímsvötn central volcano. Eruption began on June 8 1783 and continued until May 1785.

The atmospheric pollution and haze resulting from the large Skaftáreldar fissure eruption 1783-84 was heavily felt in N and NE Iceland, but tephra fall is only reported in two locations in Central and North Iceland. Tephra fell on Kjalvegur, Central Iceland, on July 24, 1783. In Skagaströnd minor tephra fall (greyish sand) is reported in 1783 but no date is given. Official reports from Húnavatnssýsla and Strandasýsla mention that fine sand has fallen "here and there" without further specifications, presumably in the summer 1783. Official reports from Eyjafjardarsýsla mention that fine black sand accompanied the haze the southern part of the district in the summer 1783.

(Gunnlaugsson et al. 1984; Thordarson 1991, Thordarson and Self 1993 and references in these papers)

Hekla 1766

Eruption site: Hekla volcanic system, Hekla central volcano. Eruption began on April 5, 1766 and lasted intermittently until April 1768.

Plinian opening stage, lasting 5-6 hours, emitted andesitic to basaltic-andesitic tephra and was followed by mixed explosive and effusive activity. Tephra was carried towards N and tephra fall was reported in NW and N Iceland from Strandasýsla to the western part of N-Thingeyjasýsla. Tephra was probably deposited on the shelf off North Iceland along a sector from Hornstrandir in the W to Skjálfandaflói in the east. Axis of thickness crossed the Skagafjördur district and its continuation on the shelf probably lay some 50 km west of Grímsey island. It is likely that some air-fall tephra was deposited to the east of Grímsey island as well. Assuming that contemporary reports on tephra thickness in Skagafjördur are reliable, the minimum mass deposited there per m^2 was 1000 g. The darkness caused by the tephra fall was so intense that two fishingboats collided at sea. The tephra layer has a calculated volume of 400 million m^3.

The tephra sector crosses the rivers Y-Rangá and Thjórsá just N of Hekla. So much pumice was deposited into Y-Rangá that it was temporarily dammed and both rivers carried huge quantities of pumice to the sea off the south coast. The pumice rafts were too thick for rowing boats to pass through. Coastal currents transported the pumice rafts westwards and then clockwise along the coast to the shelf off N-Iceland. Using the 1947 Hekla eruption as an analog this is likely to have occurred within 3-4 months from the beginning of the eruption. It is possible that sea-transported grains of pumice and ash have been deposited in marine sediments outside (and within) the areas affected by the tephra fall.

(Thorarinsson 1967 and references therein)

Veidivötn-Bárdarbunga 1729 and 1726

Likely eruption site(s): Veidivötn-Bárdarbunga volcanic system, subglacial part below NW Vatnajökull, in 1729 and 1726. Simultaneous activity may have occurred somewhere on the Grímsvötn volcanic system in 1726.

Jökulhlaups, almost certainly of volcanogenic origin, were reported in Jökulsá á Fjöllum in winter and late summer 1729 and five times in late winter – early spring 1726. Reports on the volcanic activity within Vatnajökull are poor but and tephra fall appears to have been confined to the ice cap. However, the reports on the jökulhlaups are considered reliable. Jökulsá discharges into Axarfjördur and at least one of those jökulhlaups carried pumice down to the sea.

During springfloods in Jökulsá á Fjöllum the silty water extends tens of kilometers out into the Axarfjördur bay, reportedly even as far as Grímsey island. Meltwater in volcanogenic jökulhlaups is likely to behave similarily and these floods are therefore included here. However, the pumice and sandsize material are not necessarily primary material from the eruptions that cause the jökulhlaups and may consist partly or mostly of remobilized material from older deposits along their course.

Thorarinsson 1950; Steinthorsson 1978; Ísaksson 1985; Larsen et al. 1998; and references in these papers)

Katla 1721
Eruption site: Katla caldera in Mýrdalsjökull, Katla volcanic system. Eruption began on May 11 and lasted until autumn.

A short subglacial phase was followed by hydromagmatic explosive eruption producing basaltic tephra and a large jökulhlaup. Explosive activity was most intense during the first days and the tephra was dispersed towards W, NW and N. Tephra fall reached North Iceland on May 13-16 and may have exceeded 300 g/m^3 in the northern part of Eyjafjördur (footprints traceable). The eastern limit of the tephra fall was most likely east of Grímsey island. A large jökulhlaup discharged into the sea at the south coast but pumice rafting similar to that observed in Hekla eruptions is not reported. The estimated volume of the airborne tephra is about 300 million m^3.

(Thorarinsson 1955, 1975; Larsen 2000; and references in these papers).

Veidivötn-Bárdarbunga 1717
Eruption site: Veidivötn-Bárdarbunga volcanic system, subglacial part below NW Vatnajökull. The eruption occurred in summer 1717.

Presumably the eruption had a subglacial opening phase, followed by hydromagmatic explosive activity producing basaltic tephra and generating a substantial jökulhlaup. Tephra was dispersed to N, NE and ENE and tephra fall was reported from Eyjafjörður in the W to the Fljótsdalshérad in the E. The tephra has been identified in soil and analysed. In the northern part of Eyjafjördur it may have exceeded 300 g/m^3 (footprints traceable). The offshore extension is not known but the tephra fall in Eyjafjördur indicates that the western limit of the tephra fall area may lie some 50 km west of Grímsey island.

The ensuing jökulhlaup followed the course of Jökulsá á Fjöllum and discharged into Axarfjördur.

(Jónsson 1945; Thorarinsson 1950; Larsen 1982)

Hekla 1693
Eruption site: Hekla volcanic system, Hekla central volcano. Eruption began on February 13, 1693 and lasted at least 7 months.

The Plinian opening stage, emitting andesitic to basaltic-andesitic tephra, was most intense during the first half an hour and tephra fall was mostly over in about 12 hours. Tephra was carried towards NW and tephra fall was reported in NW and N Iceland, having eastern limit at Skagaströnd, Húnavatnssýsla. Axis of thickness crossed the Hrútafjördur area. Tephra was probably deposited on the shelf off NW and N Iceland along a sector from Dýrafjördur in W to Húnaflói in the east. The eastern limit of tephra fall on the shelf probably lay more than 100 km west of Grímsey island. The tephra layer has a calculated volume of 300 million m^3.

The tephra sector crossed the rivers Y-Rangá and Thjórsá just NW of Hekla and both rivers carried huge quantities of pumice to the sea off the south coast. The sea around the Westman Island was, reportedly, completely covered by ash. It is likely, although no reporst are known, that coastal currents transported the ash and pumice rafts westwards and then clockwise along the coast towards the shelf off N-Iceland. It is therefore possible that sea-transported grains of ash and pumice were deposited in marine sediments outside (and within) the areas affected by the tephra fall.

(Thorarinsson 1967 and references therein)

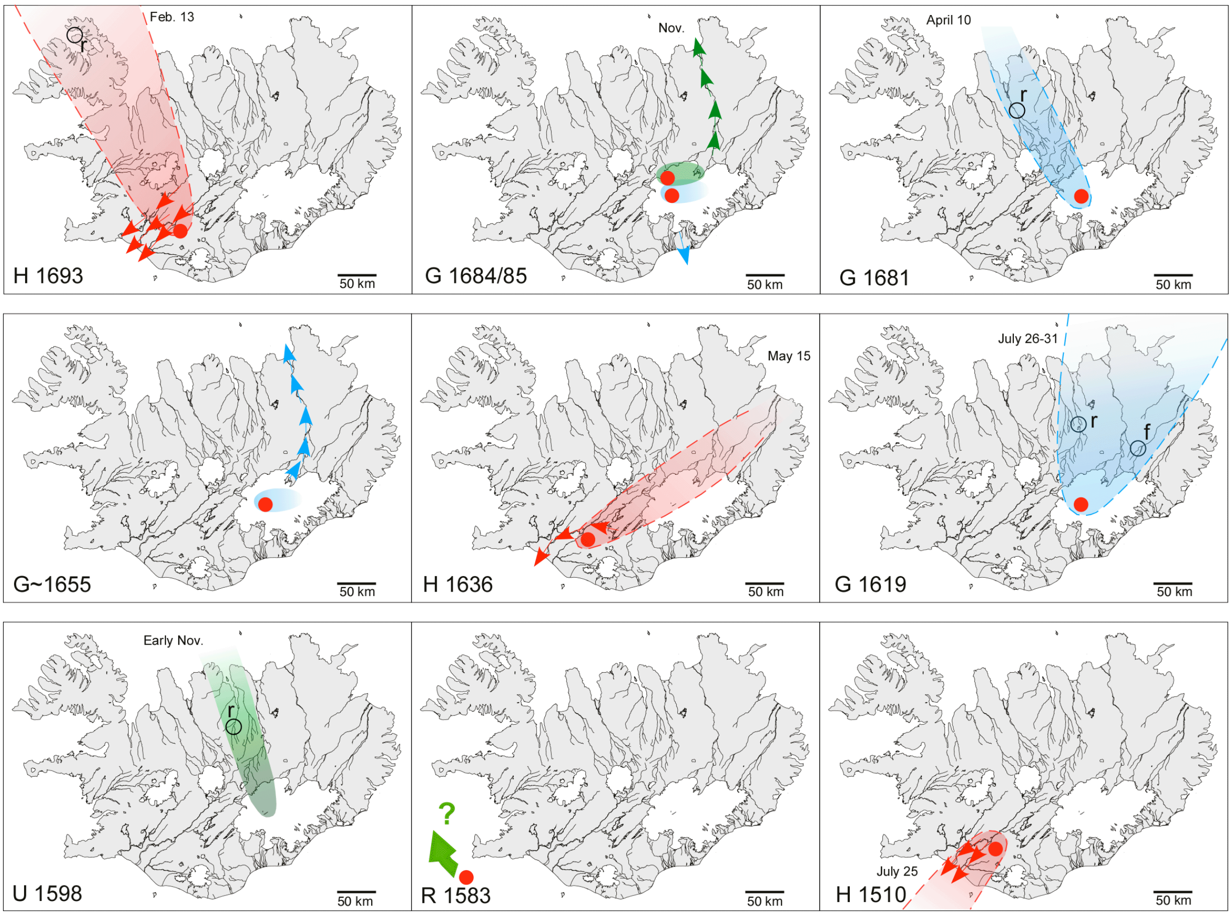

Figure 6. Relvant eruptions in the period 1700-1501. Red: Hekla. Blue: Grímsvötn. Green: Veidivötn-Bárdarbunga (and erupitions off Reykjanes). Arrows indicate routes of ocean rafted pumice, river rafted pumice and jökulhlaup routes. Small green dots indicate core locations. Small circles with numbers indicate locations where mass of deposited tephra is known near or off the north coast, "f" and "r" indicate confirmed and reported traces of tephra, respectively. Estimated mass of ~300 g/m^2 is assigned to localities where footprints were traceable after light tephra fall, in accordance with Thorarinsson (1955).

Grímsvötn 1684/85; 1681, 1655

Likely eruption site(s): Grímsvötn volcanic system, subglacial part. Simultaneous activity may have occurred somewhere on the Bárdarbunga-Veidivötn volcanic system.

Reports on the activity within Vatnajökull in this period are scant. Minor tephra fall was reported in Skagafjördur on April 10, 1681. It may have reached the coast but deposition farther north is unlikely. Grímsvötn are mentioned as the source but the source could be elsewhere within Vatnajökull. Jökulhlaups in Jökulsá á Fjöllum in 1684/85 were also attributed to an eruption in Grímsvötn.

(Jónsson 1945; Thorarinsson 1974 and references therein)

Hekla 1636

Eruption site: Hekla volcanic system, Hekla central volcano. Eruption began on May 8 or 15, 1636 and lasted at least á year.

The opening phase may have been subplinian rather than Plinian and emitted basaltic-andesitic tephra towards NE. Minor airfall may have reached the shelf off E Iceland. The tephra layer has a calculated volume of 180 million m^3.

The axis of thickness crossed the Tungnaá river about 30 km NE of Hekla, one of the main tributaries of the Thjórsá river. Substantial quantities of pumice must therefore have been rafted into the Thjórsá river and into the sea off the south shore. An annal claims that drowning of men on a ferry on the Thjórsá river was caused by the pumice. Although no reports describe pumice rafts off the coasts the deposition of sea-transported grains of ash and pumice in marine sediments W and N of Iceland cannot be ecluded.

(Thorarinsson 1967 and references therein; Larsen et al. 1999)

Grímsvötn 1619

Eruption site: Grímsvötn volcanic system, most probably the Grimsvötn caldera. Eruption began in July 1619.

The eruption presumably had a subglacial opening stage that was followed by subaerial explosive activity. The only known product was basaltic tephra. Tephra production was most intense in late July. Tephra dispersal was towards N and NE with tephra fall in North and Northeast Iceland, as reported in Bárdardalur, and in Jökuldalur the tephra has been identified in soil and analysed. The tephra fall may have extended offshore east of Grímsey island. Tephra fall also reached Faroe islands and Norway and the 1619 eruption is thought to be among the largest Grímsvötn eruptions, but no volume estimates exist.

(Thorarinsson 1974, 1981; Larsen 1982, Larsen et al. 1998; and references in these papers).

Unknown 1598

Likely eruption site: Within Vatnajökul but location is unknown. Beginning and duration of this eruption is unknown.

Minor tephra fall was reported in Eyjafjördur in November 1598. It may have reached the coast and possibly a limited area offshore, to the west of Grímsey island.

(Jónsson 1945; Thorarinsson 1974)

Reykjanes ridge 1583

Eruption site: Reykjanes Ridge. Location is not known but may have been in the vicinity of Eldey.

Reports of this eruption are uncertain, fire was seen at sea from a merchant ship. It is not known whether an island was formed. Rafting of pumice from a submarine eruption is possible but in this case not very likely.

(Thoroddsen 1925; Thorarinsson 1965b and references therein)

Hekla 1510

Eruption site: Hekla central volcano, Hekla volcanic system. Eruption began around July 25, 1510 but its duration is not known.

Reports on this eruption are very scant but tephrochronological studies indicate that its Plinian opening phase was similar to but more intense than that of the Hekla 1947 eruption. The andesitic to basaltic-andesitic tephra was carried towards SSW and great quantities must have been deposited at sea off the south coast. The rivers affected by the tephra fall may have added substantial quantities. The tephra layer has calculated volume of about 320 million m^3.

It is likely that currents carried some of the tephra that was deposited offshore in clockwise fashion along the Icelandic coast, as happened in 1947. Given the magnitude of the eruption some rafts of pumice and ash may have reached the shelf off North Iceland and deposition of grains in the marine sediments there cannot be excluded.

(Thorarinsson 1954, 1967 and references therein)

Summary 1900-1501

Tephra from 11 eruptions was carried northwards across Iceland and onto the shelf off North Iceland in the period 1900-1501 but in five cases the tephra dispersal was limited (Figure 5).

The north-bound tephra layers have volumes up to 400 million m^3. The two most distinct tephra layers in North Iceland from this period are the H 1766 and V 1717 tephra layers. At the north coast the mass per m^2 is thought to be close to 300 g (footprints traceable).

Tephra from hydromagmatic Katla and Grímsvötn eruptions forms thinner "tephra veils" in north Iceland than the tephra from plinian Hekla eruptions, partly because of different type of explosive activity and partly because the main tephra dispersal was towards other directions. In the 1721 Katla eruption tephra fall in Eyjafjördur, North Iceland, may have exceeded 300 g/m^2 (footprints traceable).

In five eruptions airfall tephra may have reached the area of cores MD99-2271, MD99-2272, MD99-2273 and MD99-2275. These were the G 1873, H 1766, K 1721, V 1717 and G 1619 eruptions. Three minor tephra falls may also have reached some parts of this area in 1875, 1797 and 1598.

Ocean-rafted pumice from the eruptions in Askja 1875 and Hekla 1766 is known to have reached the coring area. To what extent this resulted in deposition of volcanic material is not known. Although other occurrences have not been reported such possibility should not be entirely disregarded.

6.3 Tephra producing eruptions 1500-1001

Contemporary reports mentioning volcanic eruptions in this period are more scarce and less detailed than in the following centuries. In many cases the only knowledge about an eruption is a tephra layer revealed by tephrochronological research. Eruption years indicated by "~" are not based on written documents but on age calcultions using soil accumulation rate (SAR) between tephra layers having documented eruption year.

Amongst the 61 explosive or partly explosive eruptions known between 1001 and 1500 are 7 Hekla eruptions with tephra volumes ranging from 0.04 to 2 km^3, the 1362 Öræfajökull eruption and the Veidivötn eruption with about 10 km^3 of tephra each, and 9 Katla eruptions with volumes ranging up to 0.5 km^3. Some 30 eruptions occurred on the ice-covered parts of the Grímsvötn and Veidivötn volcanic systems. No volume estimates exist for these, but most of them are thought to be of small to moderate (0.01-0.1 km^3) volume.

Airborne tephra from at least 7 eruptions was carried northwards across Iceland and potentially onto the shelf off North Iceland during this period (Figure 7). Below are short descriptions together with relevant references. Also included are eruptions that delivered large quantities of pumice into the sea through tephra fall or by river transport and eruptions at sea.

Grímsvötn~1500
Eruption site: Grímsvötn volcanic system. No reports mention this eruption. The tephra has been identified in soil and geochemically fingerprinted. Its age was calculated using SAR between tephra layers of known age.

The activity during this eruption is presumed to be typical for Grímsvötn eruption with a subglacial opening stage followed by subaerial explosive activity. The only known product was basaltic tephra. Tephra dispersal was towards N and NE with tephra fall in North and Northeast Iceland, between Bárdardalur in the W and Jökuldalur in the E. The tephra fall may have extended offshore east of the Grímsey island. The volume of tephra has not been estimated.

(Larsen 1982, Larsen et al. 1998).

Veidivötn~1477
Eruption site: Bárdarbunga-Veidivötn volcanic system, Veidivötn fissure on southwestern part of the system. Simultaneous activity may have occurred on the subglacial part below NW Vatnajökull and also on the Grímsvötn volcanic system.

The Veidivötn eruption was a predominantly phreatomagmatic eruption producing over 10 km^3 of basaltic tephra. The tephra, which has been geochemically fingerprinted and mapped in detail, was carried to the N, NE and E. The 1 cm isopach extends offshore indicating extensive deposition on the shelf off N, NE and E Iceland. The tephra sector has a sharp western limit on land indicating that its boundary of the shelf lies some tens of km W of Grímsey island.

Some subglacial activity below NW Vatnajökull, generating jökulhlaup in the river Jökulsá á Fjöllum, may have occurred simultaneously with the eruption on the southwestern part. Presence of subordinate tephra component having Grímsvötn composition in part of the Veidivötn tephra layer indicates simultaneous or near-simultaneous eruption on that volcanic system.

(Larsen 1982, Larsen et al. 2002; Benjamínsson 1982)

Katla~1440

Eruption site: Katla volcanic system. No reports mention this eruption. The tephra has been identified in soil and geochemically fingerprinted. Its age was calculated using SAR between tephra layers of known age.

The activity during this eruption is presumed to be typical for Katla eruption with a subglacial opening stage followed by explosive hydromagmatic activity. The only known product is basaltic tephra. The known tephra dispersal was towards N with minor tephra fall in Eyjafjördur district, North Iceland. The tephra fall may have extended offshore towards the Grímsey island. The volume of this tephra layer is estimated as small to moderate.

(Larsen 2000).

Reykjanes ridge 1422

Eruption site: Reykjanes Ridge. Location off Reykjanes but not known.

This eruption is briefly mentioned in an old annal as fire at sea forming an island. Pumice rafting is not mentioned but possible.

(Thoroddsen 1925; Thorarinsson 1965b and references therein)

Veidivötn~1410

Eruption site: Bárdarbunga-Veidivötn volcanic system. No reports mention this eruption. The tephra has been identified in soil and geochemically fingerprinted. Its age was calculated using SAR between tephra layers of known age.

The activity is presumed to be typical for an eruption on the ice-covered part of this system, beginning with a subglacial opening stage followed by explosive hydromagmatic activity. The only known product was basaltic tephra. The known tephra dispersal was towards N and NE with tephra fall in North and Northeast Iceland, between Bárdardalur in the W and Jökuldalur in the E. The tephra fall may have extended offshore east of the Grímsey island.

(Larsen 1982, Larsen et al. 1998).

Unknown 1372

Eruption site: Kolbeinsey Ridge? Location is not known.

Reports of this eruption are uncertain. A new island was reportedly seen NW of Grímsey from several localities in North Iceland. The distance from the coring sites around Grímsey island is not known. Rafting of pumice off North Iceland - if there was an eruption - is likely.

(Thoroddsen 1925; Thorarinsson 1965b and references therein)

Öræfajökull 1362

Eruption site: Öræfajökull volcanic system, caldera of the central volcano. The eruption is described in the old annals and began at spring time, but the eruption year differs slightly between annals. The tephra has been identified in soil, mapped and geochemically fingerprinted.

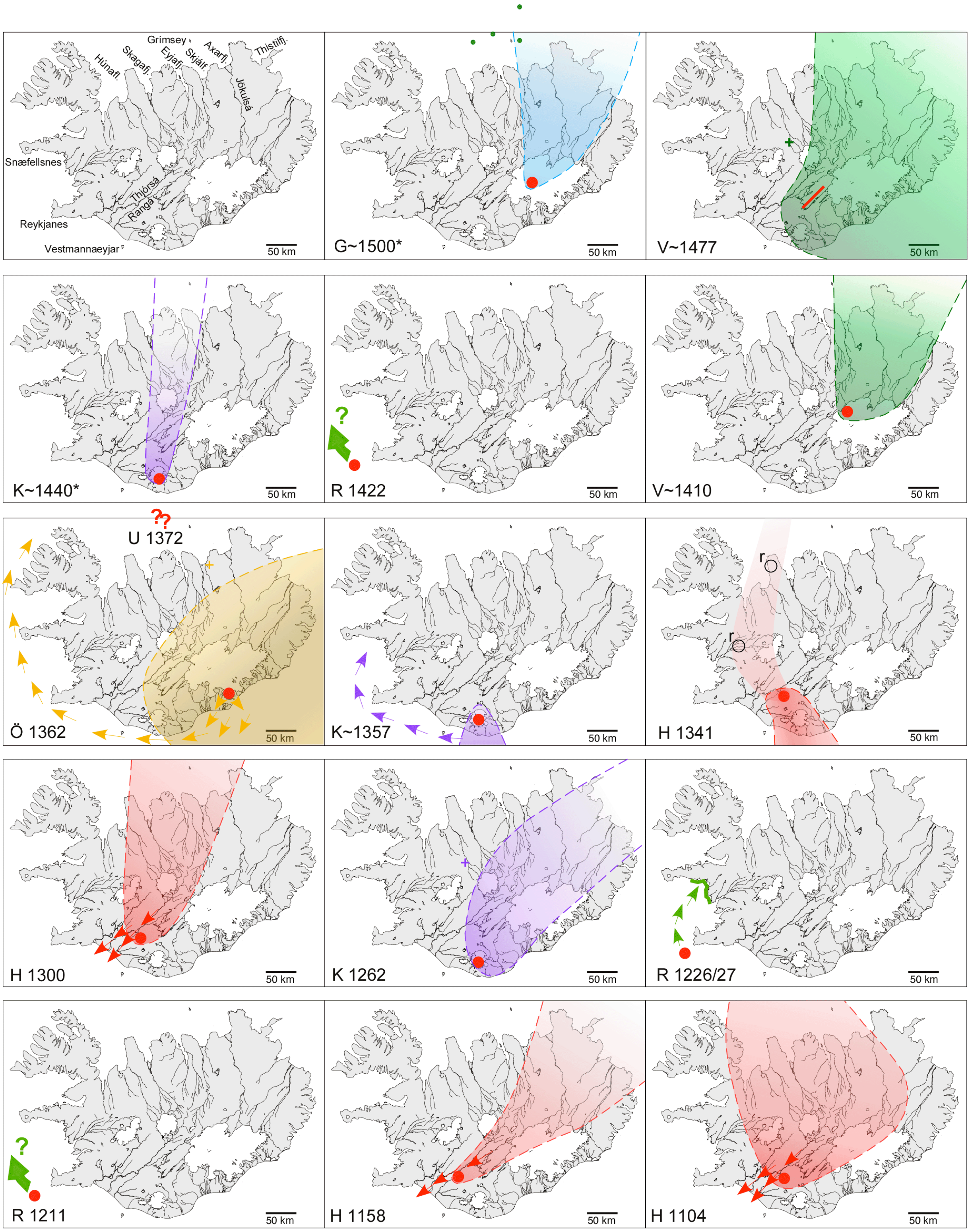

Figure 7. Relevant eruptions in the period 1500-1001. Red: Hekla. Blue: Grímsvötn. Green: Veidivötn-Bárdarbunga (and erupitions off Reykjanes). Violet: Katla. Yellow: Öræfajökull. Arrows indicate routes of ocean rafted pumice, river rafted pumice and jökulhlaup routes. Small green dots indicate core locations. Small circles with numbers indicate locations where mass of deposited tephra is known near or off the north coast, "+" and "r" indicate confirmed and reported traces of tephra, respectively.

The Öræfajökull eruption was Plinian with phreatoplinian opening phase, producing one of the largest tephra layer of the last millennium. The thickness axis of the tephra trends towards SW but tephra fall reached Northeast Iceland and possibly the north coast. Jökulhlaups carrying pumice, and possibly pyroclastic surges or flows, discharged into the sea at the south shore. Pumice rafts thick enough to slow down ships were reported off the Western fjords. Such rafts are likely to have continued into the seas off North Iceland but no reports exist. Estimates of tephra volume differ but are up to 10 km^3.

(Thorarinsson 1958; Jónsson et al. 2007; Karma et al. 2008)

Katla~1357

Eruption site: Katla volcanic system, Katla caldera. The eruption is briefly mentioned in Annals, the eruption site is misplaced but tephra fall area is correctly placed. The tephra has been identified in soil, mapped and geochemically fingerprinted.

The activity during this eruption is presumed to be typical for Katla eruption with a subglacial opening stage followed by explosive hydromagmatic activity. The only known product was basaltic tephra. The known tephra dispersal was towards S across Mýrdalur and off the south coast, which lies about 30 km south of the Katla caldera. Therefore, the tephra deposited offshore was relatively coarse and formed pumice rafts that were transported westwards and were reported as far as west as the Snæfellsnes penisula. Pumice rafts may have travelled farther north but no reports exist. The tephra volume is estimated at ca 300 million m^3.

(Thorarinsson 1975; Einarsson et al. 1980; Larsen 2000).

Hekla 1341

Eruption site: Hekla volcanic system, Hekla central volcano. Eruption began on May 19, 1341 and lasted at least 2 months.

The Plinian opening stage was intense and emitted andesitic tephra that was mostly carried towards SE. This part of the tephra layer has been identified and mapped. Some tephra fall was reported in West and Northwest Iceland between Borgarfjördur and Skagi but this tephra has not yet been identified in soil sections. No pumice rafting is mentioned in connection with this eruptions and is considered unlikely. Tephra volume is estimeated as 180 million m^3.

(Thorarinsson 1967; Larsen et al. 1999)

Hekla 1300

Eruption site: Hekla volcanic system, Hekla central volcano. Eruption began on July 12, 1300 and lasted nearly 12 months.

The Plinian opening stage was violent and emitted andesitic tephra that was carried towards N. Tephra fall was reported from Skagafjördur to Axarfjördur and particularly stated that people in the area did not dare to go out on boats for two days. Tephra was deposited on the shelf off North Iceland along a sector from Skagi in the W to Slétta in the E. Axis of thickness crossed the Skagafjördur district and its continuation on the shelf probably lay some tens of km west of Grímsey island. The tephra layer was fairly large and has a calculated volume of 500 million m^3.

The tephra sector crosses the rivers Y-Rangá and Thjórsá just N of Hekla. So much pumice was deposited into Y-Rangá that it was temporarily dammed and both rivers carried huge quantities of pumice to the sea off the south coast. The pumice rafts were still on the ocean between Iceland and the Faroes in the summer of 1301. It is possible that coastal currents transported the pumice rafts westwards and then clockwise along the coast to the shelf off N-Iceland. Using the 1947 Hekla eruption as an analog this is likely to have occurred within 3-4 months from the beginning of the eruption. It is possible that sea-transported grains of pumice and ash have been deposited in marine sediments outside (and within) the areas affected by the tephra fall.

(Thorarinsson 1967 and references therein)

Katla 1262

Eruption site: Katla volcanic system, Katla caldera. The eruption and tephra fall is briefly mentioned in Annals. The tephra has been identified in soil, mapped and geochemically fingerprinted.

The activity during this eruption is presumed to be typical for Katla eruption with a subglacial opening stage followed by explosive hydromagmatic activity. The only known product was basaltic tephra. The known tephra dispersal was towards (N and) NE across NE Iceland. It is still uncertain whether the tephra fall reached the north coast but in that case deposition east of the Grímsey island is possible. The tephra volume is estimated at about 500 million m^3.

(Thorarinsson 1975; Larsen 2000).

Reykjanes 1226/27; 1211;

Eruption sites: Reykjanes volcanic system. Locations on and off Reykjanes.

Between 1240 and 1211 annals mention several eruptions on the Reykjanes volcanic system (1240, 1238, 1231, 1227, 1226, 1223, 1211, 1210), in most cases off Reykjanes but one annal mentions an eruption at Reykjanes, i.e. onshore. "Sandfall-winter" is reported 1231 and a minor tephra layers erupted off Reykjanes is attributed to this eruption. Another "sandfall-winter" is reported 1226 and 1227 (probably winter 1226/27), the tephra is now known as the "Midaldalag 1226", and is thought to have erupted several km off Reykjanes. Remnants of two tephra rings at the westernmost tip of Reykjanes are thought to have formed in an eruption in 1211.

Pumice rafting is likely in all these eruptions, but those of 1226/27 and 1211 are known to have produced large quantities of pumice that could have resulted in extensive pumice rafts. Sea-transported pumice, found on salt-marches in West Iceland, has been correlated to the younger of these two eruptions.

(Thoroddsen 1925; Thorarinsson 1965b; Sigurgeirsson 1992, 1995 and references therein; Gehrels et al. 2006)

Hekla 1158

Eruption site: Hekla volcanic system, Hekla central volcano. Eruption most likely began on January 19, 1158, although some Annals place it 1157. The duration is unknown. The tephra has been identified in soil, mapped and geochemically fingerprinted.

A strong Plinian opening stage emitted dacitic tephra that was carried towards NE and was deposited from Axarfjördur in the N to Nordfjördur in the E. Tephra was probably deposited on the shelf off NE Iceland, but the western limit was at least 50 km E of Grímsey island. The tephra layer has a calculated volume of 300 million m^3.

The axis of thickness crossed the Tungnaá river 30 km NE of Hekla and also followed a 40 km stretch of the Kaldakvísl river, the two main tributaries of the Thjórsá river. Substantial quantities of pumice must therefore have been rafted into the Thjórsá river and into the sea off the south shore. Although no reports mention pumice rafts off the coasts the deposition of sea-transported grains of ash and pumice in marine sediments W and N of Iceland cannot be excluded.

(Thorarinsson 1967; Larsen et al. 1999; Sigurgeirsson 2000; and references in these papers)

Hekla 1104

Eruption site: Hekla volcanic system, Hekla central volcano. The eruption most likely took place in AD 1104, the year in which the metropolitan see in Denmark was established, but one Annal places the tephra fall in 1105 as “sand-fall winter”.

A violent Plinian opening stage emitted rhyolitic tephra that was carried towards N and NE and was deposited from Steingrímsfjördur in the N to Axarfjördur in the E. Tephra was deposited on the shelf off North Iceland in a nearly 250 km wide sector. The tephra layer was large and has a calculated volume of about 2 km^3.

The axis of thickness crossed the Y-Rangá and Thjórsá rivers 10-20 km N of Hekla. Substantial quantities of pumice must therefore have been rafted into the sea off the south shore. Although no reports mention pumice rafts off the coasts the deposition of sea-transported grains of ash and pumice in marine sediments W and N of Iceland cannot be excluded.

(Thorarinsson 1967; Larsen et al. 1999; and references in these papers)

Eruptions in the 11th century

Only four explosive or partly explosive eruptions are known during this century - an all time low of the last 11 centuries - and no tephra fall is known to have occurred in North Iceland. One possible reason for this lull in volcanic activity could be that two major eruptions on 75 and 65 km-long fissures, the Eldgjá ~934 and Vatnaöldur ~870, took place in the preceding 130 years. This may have relaxed the "system" temporarily. As a result the beginning of the millennium is poorly defined by tephrochronology.

Summary 1500-1001

Tephra from at least 7 eruptions - possibly 8 eruptions - was carried northwards across Iceland and onto the shelf off North Iceland in the period 1500-1001 (Figure 6).

In at least 5 of the eruptions airfall may have reached the area where one or more of the cores MD99-2271, MD99-2272, MD99-2273 and MD99-2275 were retrieved. These were the G~1500, V~1477, V~1410, H 1300 and H 1104 eruptions eruptions. In addition minor tephra fall may have extended into the coring area around AD 1440.

No instances of pumice rafting into the area are known. Jökulhlaup into Axarfjördur in 1477 is suspected but has not been verified.

The largest basaltic tephra layer is that of the ~1477 Veidivötn eruption, with an estimated volume of ~10 km^3. The dispersal is limited to the E part of the coring area. The largest silicic tephra layer is that of the 1104 Hekla eruption, with an estimated volume of 2 km^3. It forms the most widespread marker horizon of the last millennium on the North Icelandic shelf and it is also the oldest known north-bound tephra layer of the last 1000 years.

7. Summary and conclusions

Known *explosive and partly explosive* eruptions in Iceland during the last millennium are close to 170, including those that are "reported only". The average number of tephra-producing eruptions per century is thus 17 eruptions and the average interval between eruptions is 5-6 years.

In reality, the eruption frequency has varied between 3 and 29 eruptions per century during this time-slice and the intervals between eruptions from a couple of weeks to at least 30 years. The volumes of tephra generated in these eruptions has also varied greatly, from less than 0.01 km^3 to over 10 km^3.

Airborne tephra in 25-30 eruptions had the potential to reach the MILLENNIUM sites off North Iceland. Among them are the G 2004, H 2000, G 1998, G 1996, H 1991, G 1934, G 1922, K 1918, A 1875 (April), G 1873, V 1797, L 1783, H 1766, K 1721, V 1717, G 1681, G 1619, U 1598, G~1500, V~1477, K~1440, V~1410, H 1300, H 1158, H 1104 eruptions. Many of these are small and their tephra has limited dispersal on the shelf. The two largest are the V~1477 and H 1104 eruptions with 10 and 2 km^3 of tephra (as freshly fallen), respectively.

Over 20 events that could have resulted in sea-transport of pumice into the shelf area off North Iceland are known but reliable reports of pumice rafts off North Iceland are few, in the Hekla eruptions 1947 and 1766, and in the Askja eruption 1875 (March 29). The Askja pumice was carried to the sea at the north coast by the Jökulsá river.

No instances of pumice transport by volcanogenic jökulhlaups into the coring area around Grímsey have been verified.

References

Árnason, SG. 2002. Heklugosid 2000. Kornastærd, berggerd og kornalögun gjóskunnar. BSc thesis, University of Iceland, Reykjavík, 81 pp.

Áskelsson, J. 1936. On the last eruptions in Vatnajökull. Soc. Sci. Isl. XVIII, Reykjavík, 65 pp.

Benjamínsson, J. 1982. Gjóskulag "a" á Norð-Austurlandi. In *Eldur er í Norðri*, Thórarinsdóttir H, Óskarsson ÓH, Steinthórsson S, Einarsson Th (eds). Sögufélag: Reykjavík; 181-185.

Eggertsson, S. 1919. Ýmislegt smávegis vidvíkjandi Kötlugosinu 1918. *Eimreidin* 1919: 212-222.

Einarsson, E.H., Larsen, G. and Thórarinsson, S. 1980: The Sólheimar tephra layer and the Katla eruption of 1357. *Acta Nat. Isl. 28:* 1-24

Eiríksson, J., Larsen, G., Knudsen, K.L. Heinemeijer, J. and Símonarson, L.A. 2004: Marine reservoir age variability and water mass distribution in the Iceland Sea. *Quaternary Science Reviews* 23: 2247-2268.

Gehrels, W.R., Marshall, W.A., Gehrels, M.J., Larsen, G., Kirby, J.R., Eiriksson, J., Heinemeier, J., and Shimmield, T. 2006. Rapid sea-level rise in the North Atlantic Ocean since the first half of the nineteenth century *The Holocene* 16: 949-965

Grönvold, K., Larsen, G., Einarsson, P., Thorarinsson, S. and Sæmundsson, K. 1983. The Hekla eruption 1980-1981. *Bulletin of Volcanology 46:* 349-363.

Grönvold K., Óskarsson N., Johnsen SJ., Clausen HB., Hammer CU., Bond G. and Bard E. 1995. Ash layers from Iceland in the Greenland GRIP ice core correlated with oceanic and land based sediments. *Earth and Planetary Science Letters* 135: 149-155.

Gudmundsson, A., Oskarsson, N., Gronvold, K., Saemundsson, K., Sigurdsson, O., Stefansson, R., Gislason, S., Einarsson, P., Brandsdottir, B., Larsen, G., Johannesson, H., Thordarson, Th. 1992: The 1991 eruption of Hekla, Iceland. *Bull. Volcanol. 54:* 238-246.

Gudmundsson, F. and Ingólfsson, A. 1968. Helsingjanef á Surtseyjarvikri (Goose Barnacles (Lepas spp.) on Surtsey Pumice). *Náttúrufrædingurinn* **37**: 222-235.

Gudmundsson, M.T., Sigmundsson, F. and Björnsson, H. 1997. Ice-Volcano interaction of the 1996 Gjálp subglacial eruption, Vatnajökull, Iceland. *Nature 389*: 954-957.

Gudmundsson, M.T., Sigmundsson, F. Larsen, G., Högnadóttir, Th., Björnsson, H. and Pálsson, F. 1999. Grímsvatnagosið 1998. Geoscience Society of Iceland, Spring Meeting 1999: 47.

Gudmundsson, MT., Högnadóttir, Th., Pálsson, F. and Björnsson, H. 2000. Grímsvötn: Eldgosið 1998 og breytingar á botni, rúmmáli og jarðhita 1996-1999. RH-03-2000.

Gudmundsson, MT, Sigmundsson, F, Björnsson, H, and Högnadóttir Th. 2004. The 1996 eruption at Gjálp, Vatnajökull ice cap, Iceland: Course of events, efficiency of heat transfer, ice deformation and subglacial water pressure. *Bulletin of Volcanology* 66: 46-65.

Gunnlaugsson, G., Gudbergsson, GM., Thorarinsson, S., Rafnsson, S. and Einarsson, Th. 1984. Skaftáreldar 1783-1784. Ritgerdir og heimildir. Mál og menning, Reykjavík. 442 pp.

Haraldsson, KÖ. 2001. Heklugosid 2000. Dreifing gjósku frá fyrsta gosdegi á landi. BSc thesis, University of Iceland, Reykjavík, 34 pp.

Haraldsson, KÖ., Árnason, SG., Larsen, G. and Eiríksson, J. 2002. The Hekla eruption of 2000 - The tephra fall. The 25th Nordic Geolocical Winter Meeting Abstract Volume: 71. Januar 6-9 2002, Reykjavík.

Ísafold II, 1875, no. 9, May 25, p. 67-68.

Ísaksson, SP. 1985. Stórhlaup í Jökulsá á Fjöllum á fyrri hluta 18. aldar. Náttúrufrædingurinn 54: 165-191.

Jakobsson, SP. 1974: Eldgos við Eldeyjarboða. (Volcanic eruptions at Eldeyjarbodi, the Reykjanes Ridge). *Náttúrufrædingurinn* 44, 22-40.

Jakobsson, SP. 1979. Petrology of recent basalts of the Eastern Volcanic Zone, Iceland. *Acta Naturalia Islandia* **26**: 1-103.

Jakobsson, SJ., Jónasson, K. and Sigurdsson, IA. 2008. The three igneous rock series of Iceland. *Jökull* 58: 117-138

Jóhannesson H, 1977. Þar var ei bærinn sem nú er borgin. *Náttúrufrædingurinn* **47**: 129-141.

Jóhannesson, H. 1984. Grímsvatnagos 1933 og fleira frá thví ári (Grímsvöth eruption 1933). *Jökull* 34: 151-158.

Jóhannesson, H. 1987. Heimildir um Grímsvatnagosin 1902-1910. Fjölrit Náttúrufrædistofnunar 4, 49 pp.

Jóhannesson, H., Einarsson S. 1988. Krísuvíkureldar I. Aldur Ögmundarhrauns og Midaldalagsins. *Jökull* 38: 71-87.

Jóhannesson, H., Sæmundsson K. 1998. *Geological map of Iceland. Tectonics*. 1:500.000. Icelandic Institute of Natural History, Reykjavík.

Jónsson, Ó. 1945. *Ódádahraun II.* Bókaútgáfan Nordri, Akureyri; 447 p.

Jónsson, PVK., Höskuldsson, Á., Thordarson Th. and Einarsson BF. 2007. Eldgosid í Öræfajökuli 1362, framgangur og afleiðingar. Geoscience Society of Iceland, Spring Meeting 2007: 16.

Karma, K., Self, S., Blake, S., Thordarson, Th. and Larsen, G. 2008: The AD 1362 Öræfajökull eruption, S.E. Iceland: Physical volcanology and volatile release. Journal of Volcanology and Geothermal Research 178, 719-739.

Lacasse, C., Karlsdóttir, S. Larsen, G. Soosalu, H. Rose, W.L. and Ernst, G.G.J. 2004. Weather radar observations of the Hekla 2000 erutpion cloud, Iceland. *Bulletin of Volcanology* 66: 457-473.

Larsen, G. 1982. Gjóskutímatal Jökuldals og nágrennis. In *Eldur er í Norðri*, Thórarinsdóttir H, Óskarsson ÓH, Steinthórsson S, Einarsson Th (eds). Sögufélag: Reykjavík; 51-65.

Larsen, G. 1984. Recent volcanic history of the Veidivötn fissure swarm, southern Iceland - an approach to volcanic risk assessment. *Journal of Volcanology and Geothermal Research* 22: 33-58.

Larsen, G., 2000. Holocene eruptions within the Katla volcanic system, south Iceland: Characteristics and environmental impact. *Jökull 49*: 1-28.

Larsen, G. and Eiríksson, J. 2008. Late Quaternary terrestrial tephrochronology of Iceland - frequency of explosive eruptions, type and volume of tephra deposits. *Journal of Quaternary Science* 23: 109-120.

Larsen, G., Vilmundardóttir, E.G. and Thorkelsson, B., 1992. Heklugosid 1991: Gjóskufallid og gjóskulagid frá fyrsta degi gossins (The Hekla eruption of 1991 - The tephra fall). Náttúrufrædingurinn 61: 159-176.

Larsen, G., Gudmundsson, MT., Björnsson, H. 1998. Eight centuries of periodic volcanism at the center of the Iceland hotspot revealed by glacier tephrostratigraphy. *Geology* **26**: 943-946.

Larsen, G, Dugmore AJ, Newton AJ. 1999. Geochemistry of historical-age silicic tephras in Iceland. *The Holocene* 9: 463-471.

Larsen, G., Eiríksson, J., Knudsen, K.L. and Heinemeier, J. 2002: Correlation of late Holocene terrestrial and marine tephra markers in North Iceland. Implications for reservoir age changes and linking land-sea chronologies in the northern North Atlantic. *Polar Research* 21(2): 283-290.

Morgunbladid 1918, October 15, p. 1, October 27, p. 1;.

Morgunbladid 1947, June 14, p. 12.

Morgunbladid 1965, July 6, p. 2.

Morgunbladid 1966, September 10, p. 32.

Mouritzen, M. and Noe-Nygaard, A. 1950. Volcanic ash from the Grímsvötn eruption in 1903. Medd. Dansk. Geol. Foren. 71: 583-584.

Newton, AJ. 1999. *Ocean-transported pumice in the North Atlantic.* Ph.D. thesis, University of Edinburgh, Edinburgh, 394 pp.

Nordanfari 7, 1868, no. 3-4, February 15. p. 8.

Nordanfari 14, 1875, no 21-22, April 22, p. 48.

Oddson, B., Gudmundsson, MT., Larsen, G. and Karlsdóttir, S. 2007. The Grímsvötn 2004 erutpion: Volcanic plume transport and tephra dispersal in a basaltic phreatomagmatic eruption. IUGG XXIV, July 2-13, Perugia, Italy.

Óladóttir, BA. 2009. Holocene eruption history and magmatic evolution of the subglacial Vatnajökull volcanoes, Grímsvötn, Bárdarbunga and Kverkfjöll, Iceland. PhD thesis, University Blaise-Pascal and University of Iceland, 142 pp + Append.

Óskarson, N., Sverrisdóttir, G. and Grönvold, K. 1999. Grímsvatnagos 1998: Gosefni, samsetning og bergfræði. Geoscience Society of Iceland, Spring Meeting 1999: 61-62.

Sigmarsson, O., Karlsson, H. and Larsen, G. 2000. The 1996 and 1998 subglacial eruptions beneath Vatnajökull ice sheet: contrasting geochemical and geophysical inferences on magma migration. *Bulletin of Volcanology* 61: 468-476.

Sigmundsson, F. and Gudmundsson, MT. 2004. Gos í Grímsvötnum 1.-6. nóvember 2004 (Grímsvötn eruption, November 1-6, 2004). Jökull 54: 139-142.

Sigvaldason GE. 1974. The petrology of Hekla and origin of silicic rocks in Iceland. In *The eruption of Hekla 1947-48,* V-1, Einarsson T, Kjartansson G, Thorarinsson S (eds). Societas Scientarum Islandica: Reykjavík; 1-44.

Sparks, R.S.J., Wilson, L. and Sigurdsson, H. 1981. The pyroclastic deposits of the 1875 eruption of Askja, Iceland. Phil. Trans. Roy. Soc. Lond., Series A 299, 241-273.

Sigurgeirsson, MÁ. 1992. Gjóskumyndanir á Reykjanesi (Tephra deposits on the Reykjanes volcanic system). MSc thesis, University of Iceland, 114 pp.

Sigurgeirsson, MÁ. 1995. Yngra-Stampagosid a Reykjanesi. (The Younger-Stampar eruption at Reykjanes, SW-Iceland). *Náttúrufrædingurinn* **64**: 211-230.

Sigurgeirsson, MÁ. 2000. Gjóskulög á Austurlandi - Samantekt. Greinargerd 00/04, 8 pp. Vedurstofa Íslands, Reykjavík.
Soosalu, H. and Einarsson, P. 2005. Seismic characteristics of the Hekla volcano and its surroundings, Iceland. Jökull, 55, 87-106.
Steinthorsson, S. 1978. Tephra layers in a drill core from the Vatnajökull Ice Cap. *Jökull* 27: 2-27.
Steinthorsson, S. B.S. Hardarson, R.M. Ellam and G. Larsen, 2000: Petrochemistry of the Gjálp-1996 subglacial eruption, Vatnajökull, SE Iceland. *Journal of Volcanology and Geothermal Research* 98: 79-90.
Sveinsson, G. 1919. *Kötlugosid 1918 og afleidingar thess* (The Katla eruption of 1918 and its consequences). Prentsmidjan Gutenberg: Reykjavík, 61 p.
Sverrisdóttir, G. 1982. Efnasamsetning og eiginleikar gosefna frá Heklu 1980. BSc honours thesis, University of Iceland, Reykjavík, 67 pp.
Sæmundsson, K. 1978. Fissure swarms and central volcanoes of the neovolcanic zones of Iceland. *Geological Journal Special Issue,* **10,** 415-432.
Sæmundsson, K. 1979. Outline of the geology of Iceland. *Jökull* 29: 7-28.
Sæmundsson, K. 1991. Jardfrædi Kröflukerfisins. In *Náttúra Mývatns*, Gardarson A, Einarsson Á (eds). Hid íslenska náttúrufrædifélag: Reykjavík; 25-95.
Thorarinsson, S. 1944. Tefrokronologiska studier pa Island. *Geografiska Annaler* 26, 1-217.
Thorarinsson, S. 1950. Jökulhlaup og eldgos á jökulvatnasvædi Jökulsár á Fjöllum. *Náttúrufrædingurinn* **20**: 113-133.
Thorarinsson, S. 1954. The tephra-fall from Hekla on March 29th 1947. In *The eruption of Hekla 1947-48,* II-3, Einarsson T, Kjartansson G, Thorarinsson S (eds). Societas Scientarum Islandica: Reykjavík; 1-68.
Thorarinsson, S. 1955. Öskufall svo sporrækt vard og Kötlugosið 1721. Náttúrufrædingurinn 25, 87-98.
Thorarinsson, S. 1958. The Öræfajökull eruption of 1362. *Acta Naturalia Islandica* II, 2: 1-100.
Thorarinsson, S. 1963. *Askja on fire.* Almenna bókafélagið, Reykjavík. 55 pp.
Thorarinsson, S. 1965a. Sitt af hverju um Surtseyjargosid (Some facts about the Surtsey eruption). *Náttúrufrædingurinn* **35**: 153-181.
Thorarinsson, S. 1965b. Nedansjávargos vid Ísland (Submarine eruptions off the coasts of Iceland). *Náttúrufrædingurinn* **35**: 49-74.
Thorarinsson, S. 1966. *Surtsey - the new island in the North Atlantic.* Almenna bókafélagid, Reykjavók, 105 pp.
Thorarinsson, S. 1967. The eruptions of Hekla in historical times. In *The eruption of Hekla 1947-48,* I, Einarsson T, Kjartansson G, Thorarinsson S (eds). Societas Scientarum Islandica: Reykjavík; 1-177.
Thorarinsson, S. 1968. Sídustu thættir Eyjaelda (The last phases of the Surtsey eruption). *Náttúrufrædingurinn* **38**: 113-135.
Thorarinsson, S. 1970b. Hekla. Almenna Bókafélagid, Reykjavík, 59 pp.
Thorarinsson, S. 1974. *Vötnin stríd. Saga Grímsvatnagosa og Skeidarárhlaupa.* Bókaútgáfa Menningarsjóds, Reykjavík, 258 pp.
Thorarinsson, S. 1975. Katla og annáll Kötlugosa (Katla and its historical eruptions). *Árbók Ferdafélags Íslands* 1975: 125-149.
Thorarinsson, S. 1981. Greetings from Iceland. *Geografiska Annaler* **63**A: 109-118.
Thorarinsson, S. and Sigvaldason, GE. 1972. The Hekla eruption of 1970. *Bulletin Volcanologique* XXXVI-2: 269-288.
Thordarson, Th. 1991. *Skaftáreldar 1783-1785. Gjóskan og framvinda gossins.* Háskólaútgáfan, Reykjavík, 187 pp.
Thordarson, Th., Self, S. 1993. The Laki (Skaftár Fires) and Grímsvötn eruptions in 1783-1785. *Bulletin of Volcanology* **55**: 233-263.
Thordarson, Th, Larsen, G. 2007. Volcanism in Iceland in historical time: Volcano types, eruption styles and eruptive history. *Journal of Geodynamics* **43**: 118-152.
Thordarson, Th., Larsen, G., Steinthorsson, S., Self, S. 2003. The 1783-1785 A.D. Laki-Grímsvötn eruptions II: Appraisal based on contemorary accounts. *Jökull* **53:** 11-48.
Thorkelsson, Th. 1923. Eldgosin 1922 (Volcanic eruptions in Iceland 1922). Tímarit V.F.Í. 1923: 29-43.
Thoroddsen, Th. 1924. Fjórar ritgjörðir. Safn Frædafélagsins um Ísland og Íslendinga. Copenhagen.
Thoroddsen Th. 1925. Die Geschichte der isländischen Vulkane. Det Kongelige danske Videnskabernes Selskabs Skrifter, 8. række. Naturvidenskabelig og mathematisk Afdeling B IX. Høst og Søn: København, 458 pp.
Zielinski GA, Germani MS, Larsen G, Baille MGL, Whitlow S, Twickler MS, Taylor K. 1995. Evidence of the Eldgjá (Iceland) eruption in the GISP2 Greenland ice core: relationship to eruption processes and climatic conditions in the tenth century. *The Holocene* **5**: 129-140.