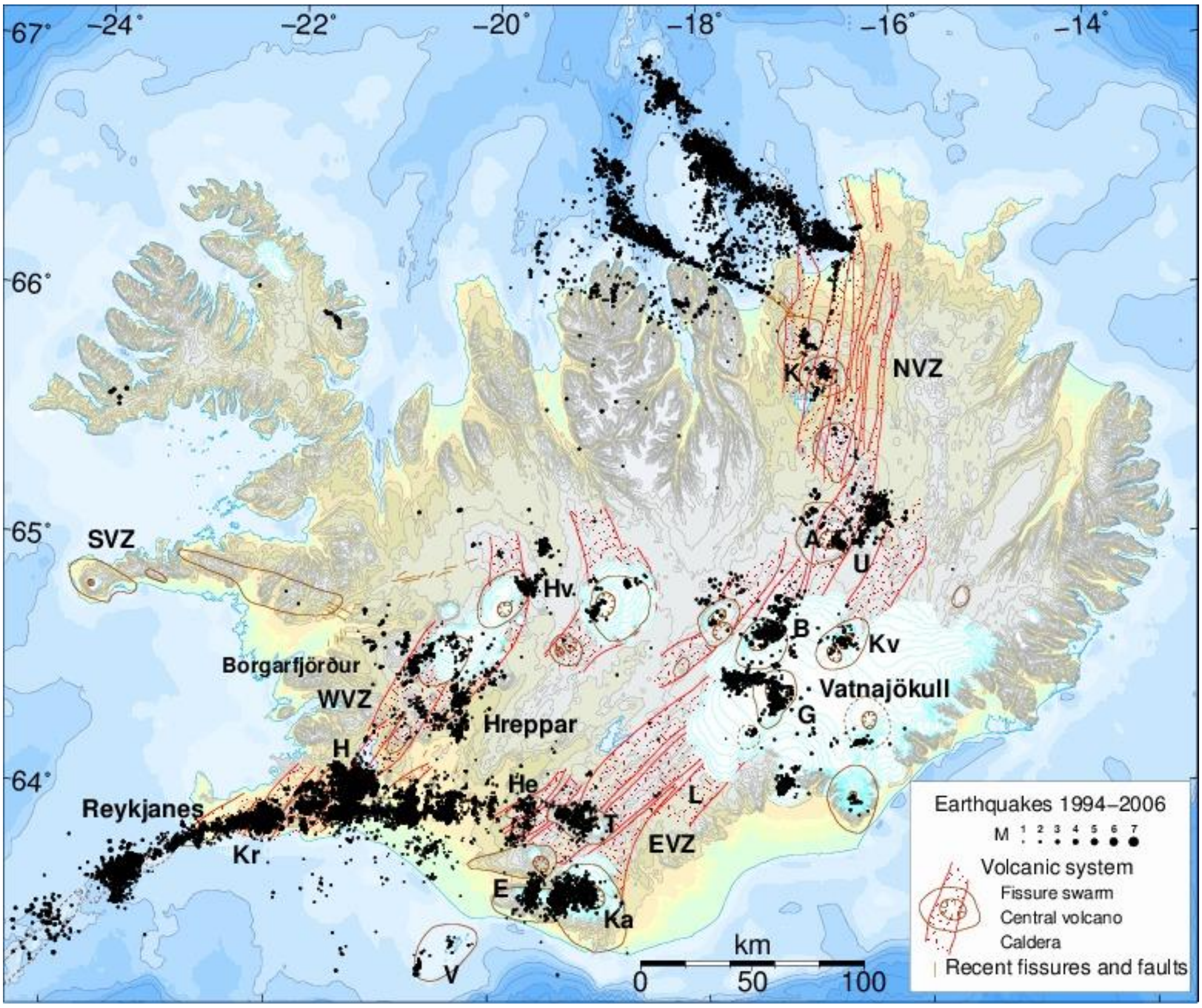
CHAPMAN CONFERENCE, SELFOSS 2019 / ICELAND

Post-conference field trip: The South Iceland Seismic Zone and the Volcanoes of South Iceland

Date: October 19, 2019



Field Guide and Road Log

compiled by

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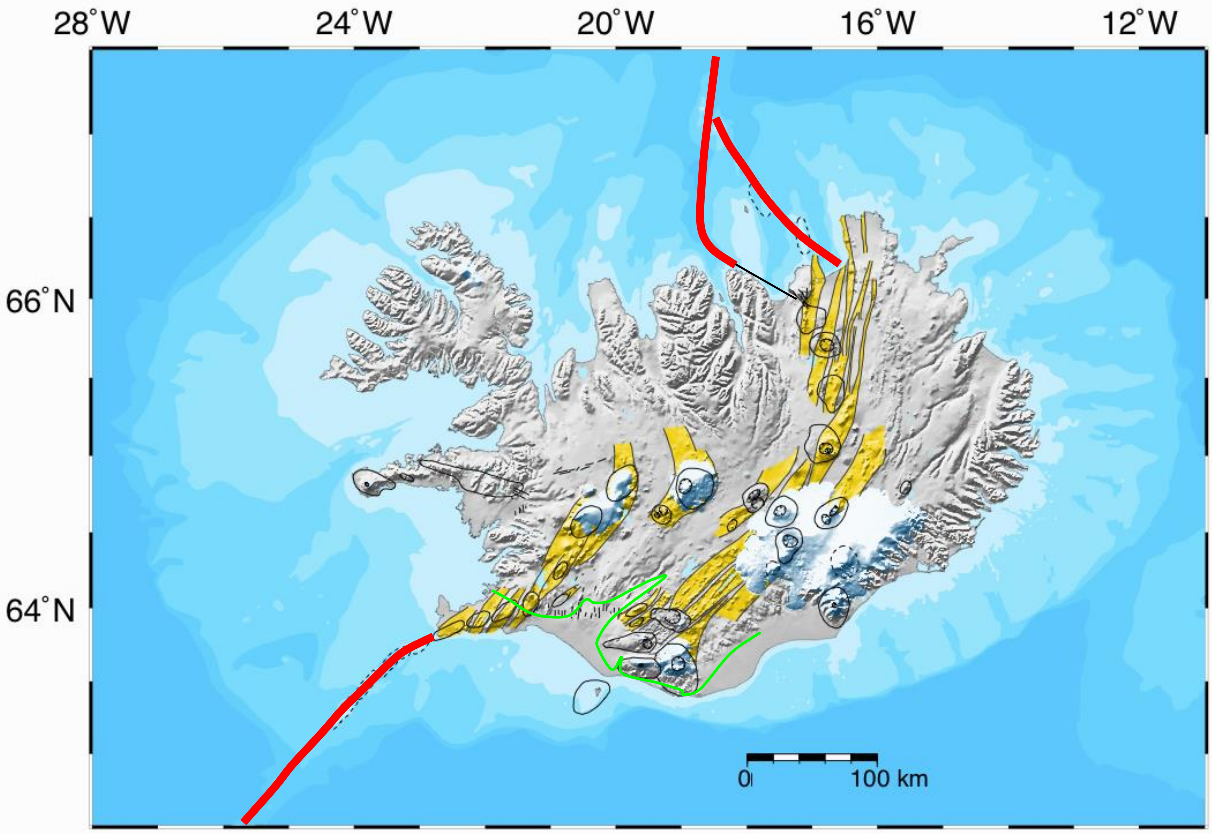
Reykjavík, October 2019

General Introduction

The main targets of this trip will be the South Iceland Seismic Zone and the volcanoes of South Iceland. The trip takes you from Selfoss, along the South Iceland Transform Zone to Hekla, one of the most active volcanoes of Iceland. Hekla is presently inflating way beyond previous levels, so watch out! We stop at tephra deposits from Hekla and strike-slip faults active in the 1912 earthquake (M 7). Then jökulhlaup deposits of the 2010 disruptive eruption of Eyjafjallajökull will be visited. We cross historic and prehistoric jökulhlaup deposits of Katla. Stop at Vík village, jökulhlaup threat and possible defences discussed. Then we observe the Síða-hyaloclastites, presumed to be flood basalt deposited in the presence of water. The massive 1783 lava flows from Laki will be crossed and observed. After supper at Kirkjubæjarklaustur we return on Route 1 to Selfoss.

There will be short hikes (1-2 hours) but considerable driving. Bring your hiking boots, rucksack, and rain gear. Temperatures are typically 0-8°C.



THE ICELANDIC RIFT ZONES AND TRANSFORMS

Most of the tectonic and volcanic activity of Iceland is in some way related to the mid-Atlantic plate boundary that crosses the country. The relatively simple tectonic picture of a mid-oceanic plate boundary with spreading centers and transform faults, however, does not readily apply to Icelandic tectonics. Here the plate boundary is superimposed on a large hot spot with a presumed deep root in the mantle. The excessive hot spot volcanism has built up the Icelandic lava pile and is responsible for Iceland´s existence above the sea surface. The plate boundary slowly drifts westwards with respect to the hot spot, resulting in successive eastwards jumps of the spreading zones. It is postulated that a new rift zone starts propagating from the center of the hot spot when the plate boundary has migrated some critical distance off it. At times two or more parallel zones have been active simultaneously. At least one ridge jump has occurred in North Iceland, and in South Iceland the second ridge jump seems to be in progress at present.

In response to this unstable situation, complex fracture zones have developed in the north (the Tjörnes Fracture Zone), and south (the South Iceland Seismic Zone), that connect the eastward displaced rift zones in Iceland to the spreading centers of the Mid-Atlantic Ridge to the north and south of the island. Differential movements are taken up by these fracture zones. Because they are relatively young and the stress field that induces them unstable, complex series of faults are formed that are not oriented parallel to the spreading direction. In comparison with most large submarine fracture zones, they exhibit subdued surface morphology, which may indicate transience of the individual fractures.

The structure of the volcanic zones is characterized by structural units called **volcanic systems**. The volcanic systems are arranged subparallel or en echelon within the volcanic zones. Each volcanic system consists of a central volcano and a fissure swarm that transects it. Volcanic production is highest in the central volcano of each system, but fissure eruptions may occur out to considerable distance in the fissure swarm area. Frequently a geothermal field, silicic volcanism and a caldera structure are associated with the central volcano.

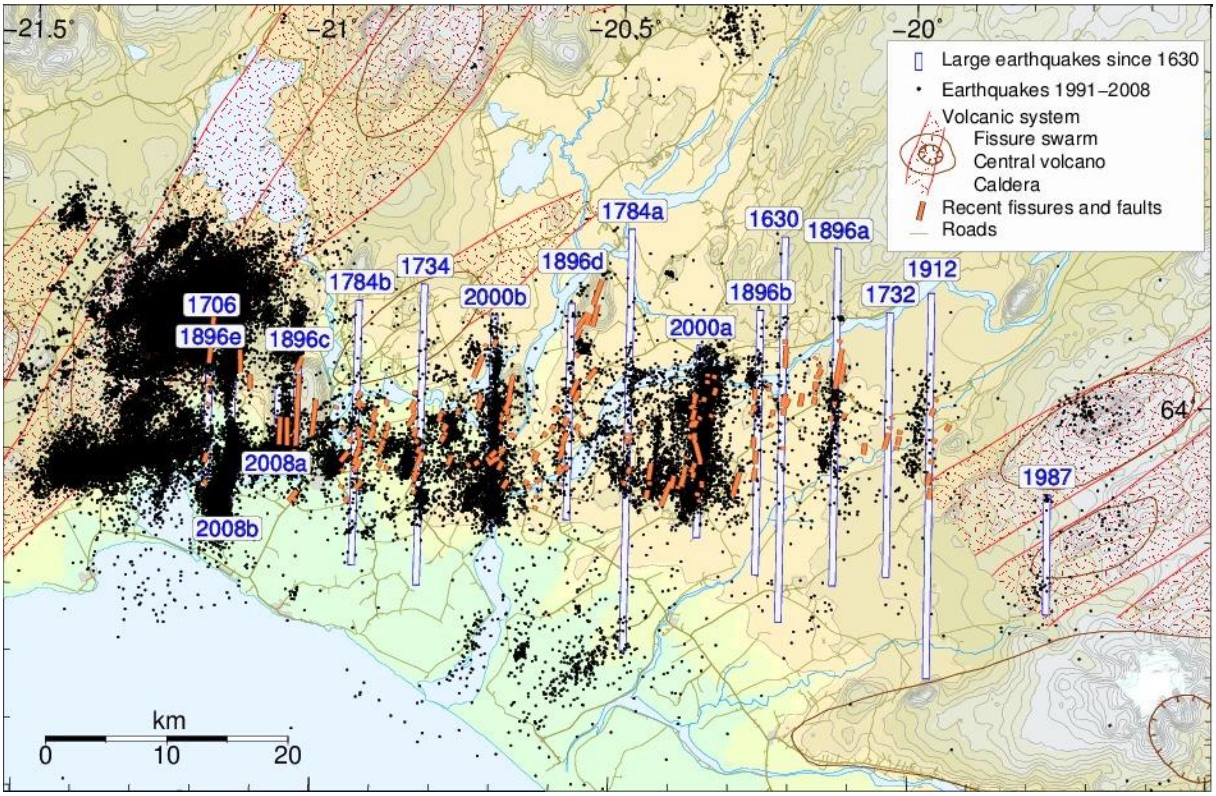
A little lesson in Icelandic pronounciation is in order here:

Þ (thorn) makes the same sound as *th* in thanks.
ð (eth) makes the same sound as *th* in this.
æ makes the same sound as *i* in hi.
ú makes the same sound as *oo* in root.
á sounds like *ou* in couch.
j always makes a sound like the english *y*.

I. The South Iceland Seismic Zone – the transform

On the way:
South Iceland Seismic Zone, parallel strike-slip faults
Selfoss, a town of high seismic risk
Þjórsá lava, about 8000 y BP, 15-20 km^3 volume, from the EVZ.

Most destructive earthquakes in Icelandic history originate within a zone that bridges the gap between the two subparallel rift zones, the Western and Eastern Volcanic Zones. It marks the southern margin of the Hreppar Microplate and takes up the transform motion between the Reykjanes Peninsula oblique rift and the Eastern Volcanic Zone. It is a zone of high seismicity and large earthquakes (M~7), and has been defined by destruction areas of historical earthquakes, surface ruptures and instrumentally determined epicenters. It is oriented E-W and is 10-15 km wide. Destruction areas of individual earthquakes and surface faulting show, however, that each event is associated with faulting on N-S striking planes, perpendicular to the main zone. Destruction areas are elongate in the N-S direction, and detailed mapping of surface fractures reveals N-S trending arrays of en echelon tension fractures indicating right-lateral faulting. The over-all left-lateral transform motion along the zone thus appears to be accommodated by right-lateral faulting on many parallel, transverse faults and counterclockwise rotation of the blocks between them, "bookshelf faulting". We cross several of these bookshelf faults on our way from Hveragerði to Þjórsá. The first one, active in 1896, passes through the town of Hveragerði. Another one, active in 2000, crosses the road at the Skeið road junction.



Source faults of historical damaging earthquakes in the South Iceland Seismic Zone. From Einarsson (2015).

Þjórsárhraun lava flow. Large part of the SISZ is covered by prehistoric lavas from the western part of the Eastern Volcanic Zone that have flowed down the valley west of Hekla. The longest one, the Þjórsá Lava, flowed all the way past Selfoss, covered most of the district Flói and went into the ocean at Eyrarbakki and Stokkseyri. This, probably the largest single lava flow known in Iceland, was erupted from an unknown fissure in the Bárðarbunga volcanic system about 8000 years ago.

Earthquake sequences. Earthquakes in South Iceland tend to occur in major sequences in which most of the zone is affected. These sequences last from a few days to about 3 years. Each sequence typically begins with a magnitude 7 event in the eastern part of the zone, followed by smaller events farther west. Sequences of this type occurred in 1896, 1784, 1732-34, 1630-33, 1389-91, 1339 and 1294. The sequences thus occur at intervals that range between 45 and 112 years, and it has been argued that a complete strain release of the whole zone is accomplished in about 140 years. The 1896 earthquakes were followed by a long quiet interval, which in 1985 led to a long-term forecast of a major earthquake sequence within the next decades.

The earthquakes of June 2000. The forecast of 1985 was fulfilled in June 2000 when two magnitude 6.5 events occurred in the central part of the zone. The sequence started on June 17 with a magnitude 6.5 event in the eastern part of the zone which was immediately followed by triggered activity along at least a 80 km long stretch of the plate boundary to the west. The second mainshock of about the same magnitude occurred about 20 km west of the first one on June 21. It was clearly preceded by clustering of microearthquakes in the coming hypocenter. The mainshocks of the sequence occurred on N-S striking faults, transverse to the zone itself. The sense of faulting was right-lateral strike-slip. The events confirmed the model of “bookshelf faulting” for the SISZ. The two mainshocks occurred on pre-existing faults and were accompanied by surface ruptures expressed by en echelon tension gashes and push-up structures typical for strike-slip faults. The main zones of rupture were about 15 km long, had a N-S trend and coincided with the epicentral distributions. Fault displcements were of the order of 0.1-1 m. Faulting along conjugate faults was also observed, but was less pronounced than the main rupture zones.

The observed faulting structures were clearly smaller than those observed in associated with earlier historical earthquakes such as those of 1630, 1784, 1896 and 1912. These earlier earthquakes were therefore larger than the earthquakes of June 2000.

High acceleration was recorded by a network of strong-motion accelerographs. The highest recorded acceleration was 0.83 g, recorded by an instrument in a bridge abutment within 3 km of the source fault of the June 21 event. Indications of acceleration in excess of 1 g, such as overturned stones, were abundant in the source areas. In light of the high accelerations the damage to man-made structures was surprisingly low. Only 20 houses were deemed unusable, none of them collapsed, however. Damage was strongly correlated with age of the buildings. There were no casualties and very little injury to humans or animals.

The May 29, 2008, earthquakes. The earthquake sequence of June 2000 was relatively small and only relieved about ¼ of the potential seismic moment accumulated by plate movements since the 1896-1912 sequence. Continuation of the 2000 earthquakes was therefore anticipated. The Ölfus district was considered the most likely source region. The earthquake took place on last May 29 in the afternoon. Foreshocks occurred beneath the SW corner of the Ingólfsfjall mountain, followed about an hour later by a mainshock that was widely felt in Iceland. The mainshock was a double event. The first part occurred on a N-S fault at the location of the foreshocks and was followed within seconds by an even larger slip on another N-S fault a few kilometers to the west of the first one. The combined event amounts to a magnitude 6.3 (M_w) earthquake. Surface effects of the earthquake were substantial. Rock falls were abundant, sand boils were seen near the Ölfusá river, shattered rock, overturned and moved rocks were observed. Surface ruptures were considerably smaller than in the 2000 earthquakes, consistent with the smaller magnitude. Damage was, however, much larger this time, mainly because of the proximity of the event to two towns, Selfoss and Hveragerði. Beside a few barns no houses collapsed. There were no casualties and only few people suffered injuries in spite of rather heavy material damage.

The major earthquake sequence, 1896-1912. The earthquake sequence of 1896-1912 is sometimes taken as the type example of South Iceland sequences. After a relatively quiet interval of 112 years the sequence began with a M 6.9 earthquake in the district Land in the eastern part of the seismic zone on August 26. There were apparently no foreshocks or other warning signs, and people were totally unprepared for the disaster. Fortunately the event occurred during favorable time and weather, and there were no deaths in spite of nearly total destruction of houses in a large area surrounding the epicenter. The fault was apparently in the mountain Skarðsfjall. A second earthquake struck in the early morning of August 27. This event apparently was of similar magnitude and originated on a fault west of the first one. The fault break of the earthquake can today be traced for 9 km, and is clearly exposed near the farm Lækjarbotnar. It caused some additional damage in the area, but most houses had been so severely damaged by the first event that additional damage was not possible. One person in Vestmannaeyjar was killed by falling rocks from cliffs.

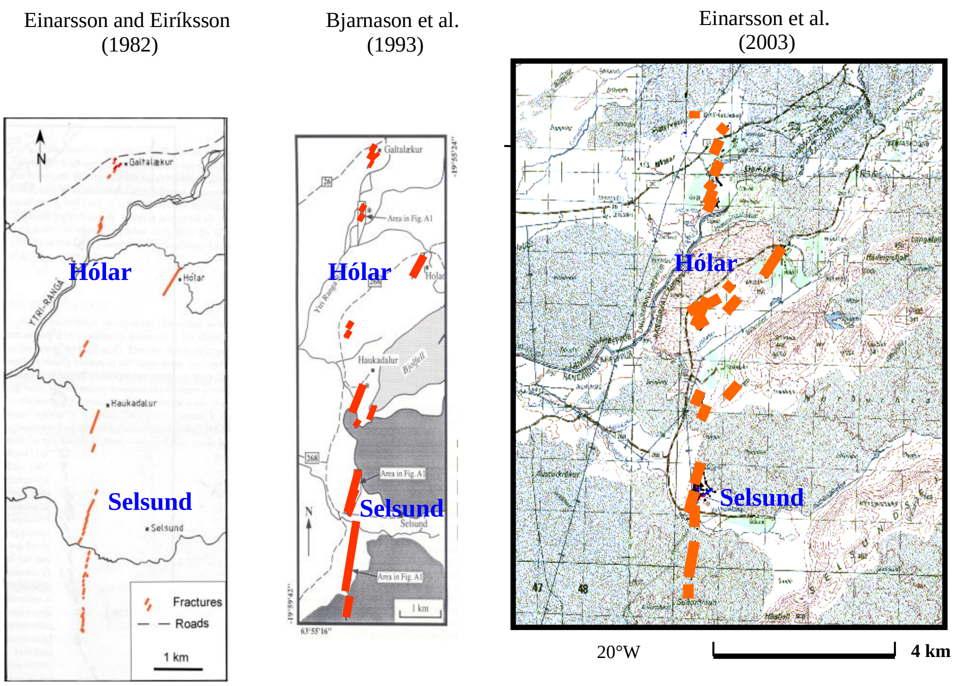
The initial burst of activity was followed by a period of relative quiescence. On September 5 two earthquakes occurred within a short interval, one of M 6 near Selfoss and the other of M 6.5 in the Skeið district near the center of the seismic zone. The areas hardest hit were Flói and Skeið, and together these earthquakes caused as much damage as the first earthquakes. Two people we killed in Selfoss. The fault of the Skeið earthquake is exposed in several places, notably near the farms Arakot and Borgarkot.

The activity migrated farther west. A M 6 earthquake hit the Ölfus district west of Selfoss the following morning. It caused heavy destruction but no deaths since all people stayed outside after the earthquake the previous day. A small tsunami was generated in the Ölfusá river. The last destructive event occurred on September 10. It mainly affected the area east of Selfoss and was smaller than the previous events.

An earthquake of M 7 occurred in 1912 east of the source areas of the 1896 earthquakes. The destruction area was larger than for any of the 1896 events, but the area was not as densely populated. One child was killed beneath a collapsing roof. The fault active in this earthquake can still be traced for at least 11 km in the Rangárvellir district, most clearly near the farm Selsund. The magnitude of the 1912 event was determined instrumentally, and the magnitude of the 1896 earthquakes has been estimated from the relative sizes of their destruction areas.

Stop: Selsund fault, source of the 1912 earthquake, M_S 7

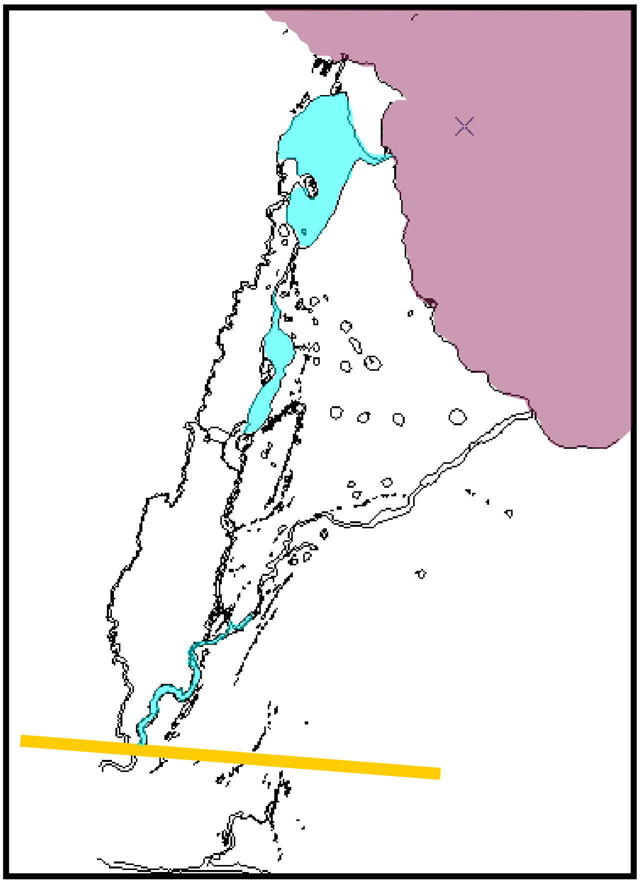
The 1912 earthquake occurred near the eastern end of the South Iceland Seismic Zone and was the largest earthquake in Iceland in the twentieth century. In spite of its occurring in the early years of instrumental observation its magnitude of $M_S = 7$ is well determined. This event provides an important link between the destruction areas and the magnitude, which has been used to estimate the magnitude of earthquakes in the area from 1700 to the beginning of the 20th century when seismographs became available. Surface fractures from the earthquake have been mapped by several authors and at different scales and degrees of completeness. The mapped fractures form a N-S elongated pattern located in the central part of the destruction zone of the earthquake. The pattern is segmented. Individual fractures within each segment have a northeasterly trend and show a strong en-echelon arrangement. The faults have been mapped by several authors:



The arrangement of the fractures is mostly left-stepping indicating right-lateral motion. Right-stepping arrangement indicative of left-lateral motion on conjugate segments is also found in several places. Push-up structures, small hillocks, and sinkholes are prominent structures that connect most of the fracture segments. Most segments are located on a straight line extending from Galtalækur in the north to Selsund in the south, of a total length of 11 km. There is indication that the fractures were originally traceable for longer distance. This line is the surface expression of the main source fault of the earthquake. There are splay fractures branching off from the main fault at Bjólfell, Haukadalur and Hólar. The most spectacular fault structures are observed on the N Selsund segment, west of Selsund, where we will stop. Here the main fault trace is marked by large push-ups and tension gashes. Several conjugate segments and splays can also be identified.

Evidence for an earlier slip-event on the N Selsund segment can be seen in a streambed immediately west of the segment. It is conspicuously straight, most likely fault controlled. Furthermore, one of the push-ups forms an island in a pond. A contemporary account states that “.. an island in the pond was uplifted ..”. This indicates that the push-up in the pond was there before the 1912 event.

By comparing the 1912 surface structures, such as push-ups, with the structures found in the source areas of the June 2000 earthquakes we conclude that the displacements in 1912 were at least a factor of two larger than in 2000.



Map by P. Einarsson, and M. Khodayar. Yellow line is the road, blue is water.

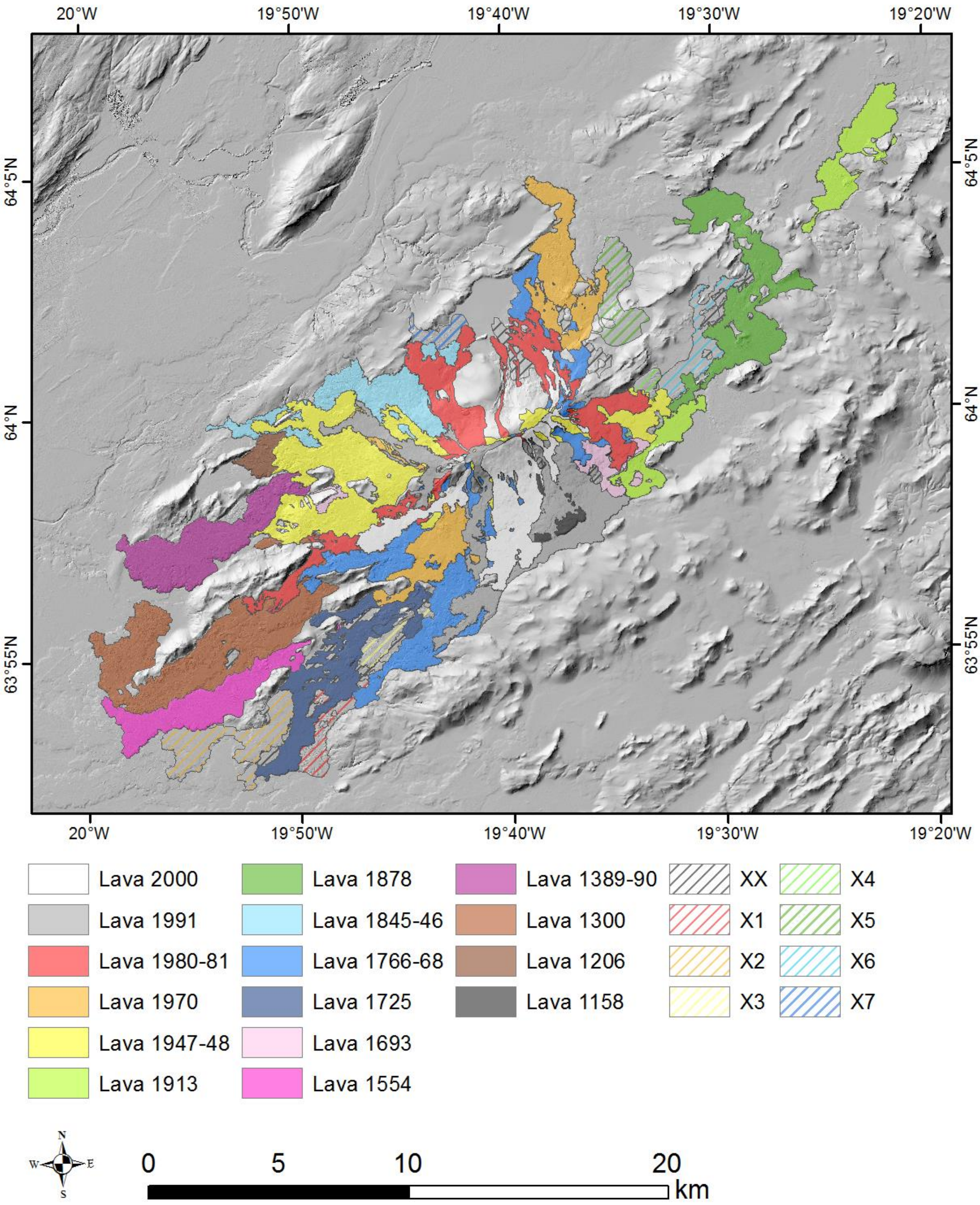
II. Hekla volcano – one of the four great

The volcano Hekla is located at the intersection of the transform zone of South Iceland with the Eastern Rift Zone. Both in terms of eruption frequency and production rate it is among Iceland´s most active volcanoes. Most of the flanks of the cone are covered with lavas erupted in the last century, in the eruptions of 1947, 1970, 1980-81, 1991 and 2000. Intervals between eruptions in historic times have typically been 50 to 80 years. The latest 4 eruptions therefore represent a change in the eruption pattern.

The magma chemistry of Hekla is unique for Iceland, resembling that of calc-alkaline volcanoes in subduction zones. The lavas range between highly silicic and andesitic types. Intermediate lavas may result from mixing of two end members. The composition of lavas at the beginning of an eruption is a function of the length of the preceding repose period. The longer the repose, the more silicic is the initial product, the more violent is the outbreak, and the more voluminous is the eruption likely to be.

Three types of activity have been identified:
1. Basaltic fissure eruptions within the Hekla volcanic system, but outside the main edifice (1440, 1554, 1725, 1878, and 1913AD).
2. Eruptions of basaltic andesite from the central part of the system, many large, i.e. of the order of 0.1-1 km^3 (1158, 1206, 1222, 1300, 1341, 1389, 1510, 1597, 1636, 1693, 1766, 1845, 1947, 1970, 1980, 1991, and 2000).

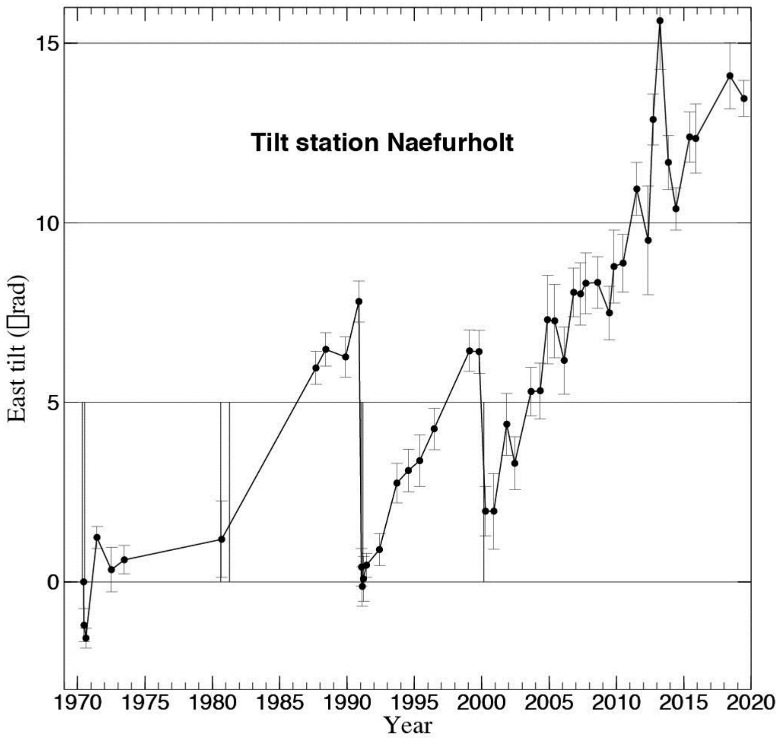
3. Large Plinian eruptions with high silica content (70-74% in the initial phase) from the center of the system. Volumes of the order of a few km^3 (about 7000, 4500, 3500 and 2900 years ago, and in 1104 AD).



A map of recent lava flows of Hekla. From Pedersen et al. (2018).

Hekla is notably aseismic. Very few earthquakes have been located in the immediate surroundings of the volcanic cone. The latest eruptions have been preceded by a very short seismic prelude of half to one-and-a-half hour, consisting of small earthquakes and continuous tremor. The eruptions themselves are then accompanied by tremor and some earthquake activity.

Recent results of InSAR, tilt, strain and GPS-measurements of Hekla in association with its 2000 eruption indicate that magma accumulates continuously between eruptions at more than 14 km depth beneath the volcano. The magma is then brought to the surface through a pipe-like structure. The eruptive fissures appear to be a shallow structures, possibly limited in depth to the volcano edifice.



The tilt record displayed here (Erik Sturkell et al.) shows how the pressure in the magma storage zone dropped measureably in the eruptions of 1991 and 2000 but reached the pre-eruption level in 2005. Inflation continues at the present time and Hekla therefore appears to be ready for the next eruption.

Stop: Hekla pumice quarry. Some of the large eruptions of Hekla have produced tephra fallout over large parts of the country, in particular in N-Iceland. The tephra deposits can be quite thick in the near-field of the volcano. We stop in a pumice quarry where the pumice is mined and exported. The most prominent tephra layer here is the H3, erupted about 2900 years ago. Total tephra volume was about 12 km^3, considered to be the biggest of all Hekla eruptons. Sometimes the H4 tephra is exposed at the bottom of H3. It was erupted about 4500 years ago. The layer at the top of the section is called Hc, erupted about 2600 years ago. Other major tephra layers of Hekla are found on the slopes and in the gullies of surrounding hills. The one that is most visible from the distance is the light-colored H1, erupted in the year 1104 AD. Eruptions in the last few centuries have produced dark-coloured tephra.

III. The South Iceland Volcanic Zone.

On our drive to Kirkjubæjarklaustur we pass the volcanoes of the South Iceland Volcanic zone, sometimes described as the tip of a propagating rift. It is a group of volcanoes of quite variable appearance and products. Rifting structures are insignificant in this zone.

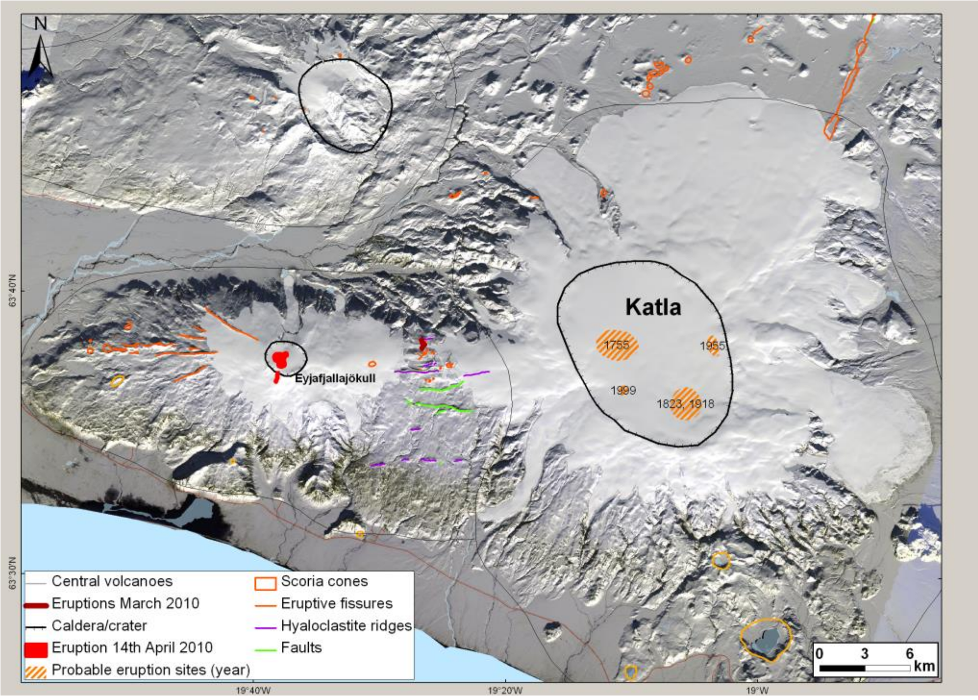
Central volcanoes seen from the road as we drive are, in addition to Hekla, of course:
1. Vatnafjöll, eruptions in early Holocene.
2. Tindfjallajökull, eruption in late Pleistocene and early Holocene.
3. Katla, many large and small eruptions in Holocene, last large eruption in 1918. Unrest period 1999-2005, inflation and earthquakes.
4. Eyjafjallajökull, latest eruptions 2010 and 1821-23, intrusions 1994 and 1999.
5. Vestmannaeyjar, eruptions of Heimaey 1973 and Surtsey island formed 1963-67.

Katla and Eyjafjallajökull

Four volcanoes stand out as the most productive and most frequently erupting volcanoes in Iceland, Hekla Katla, Bárðarbunga, and Grímsvötn. Katla is located in the South Iceland volcanic flank zone, at some distance from the plate boundary. It has a structural connection to the Eastern Volcanic Zone, however. Eldgjá and its associated fissure swarm belong to the Katla volcanic system. The central volcano of the system encompasses all the mountains in Mýrdalur, east of Fimmvörðuháls, south of Mælifellssandur and west of Mýrdalssandur. Part of Katla is covered by the Mýrdalsjökul glacier. It covers the 8x10 km wide caldera of the volcano, and there the ice thickness reaches 700-800 m. This accounts for one of the largest hazard associated with Katla eruptions, the jökulhlaups. Massive melting of glacier ice in the beginning of caldera eruptions leads to large floods. The floods are channeled out of the caldera through three openings in the caldera rims. Most frequently the floods issue from the SE glacier outlet, Kötlujökull, and cover the Mýrdalssandur plain. Prehistoric floods have also issued from Entujökull and covered the flood plain west of the volcano, Markarfljótsaurar and Landeyjar district. The third passage of floods is down Sólheimajökull and onto Skógasandur and Sólheimasandur flood plains.

Three different types of eruptions are known to have occurred in the Katla volcanic system:
1. Basaltic eruptions in the caldera, the „conventional" Katla eruption. Eruptions of this type have occurred once to twice per century throughout historic times, even more frequently in earlier times. These seem to produce up to 1 km^3 of material and can be quite explosive due to the interaction of the magma with ice and water. They are accompanied by large jökulhlaups. The last eruption of this type occurred in 1918.
2. Silicic eruption in the caldera region. These eruptions appear to be relatively small but explosive. May be associated with formation of lava domes around the caldera. On the average they occur every 2000 years.
3. Large basaltic eruption associated with rifting on the adjacent fissure swarm and fissure eruptions. The type example is the Eldgjá eruption that began in 934 AD. The time between such eruption is probably on the 1000 years time scale.

The last confirmed eruption of Katla occurred in 1918. Since then small volcanic events took place in 1955, 1999, and 2011, with jökulhlaups in the rivers destroying bridges, associated earthquake activity, and formation of new ice cauldrons in the glacier, but no eruption column through the glacier. The Katla volcano has been seismically active almost continuously since seismic monitoring began. A remarkable process was discovered a few weeks ago. A mountain on the west flank of the volcano has been collapsing for the last 60 years or more. A huge landslide has lowered a good part of the mountain by 180 meters. A recently installed GPS-instrument shows a movement of 5 mm/day at the present time.



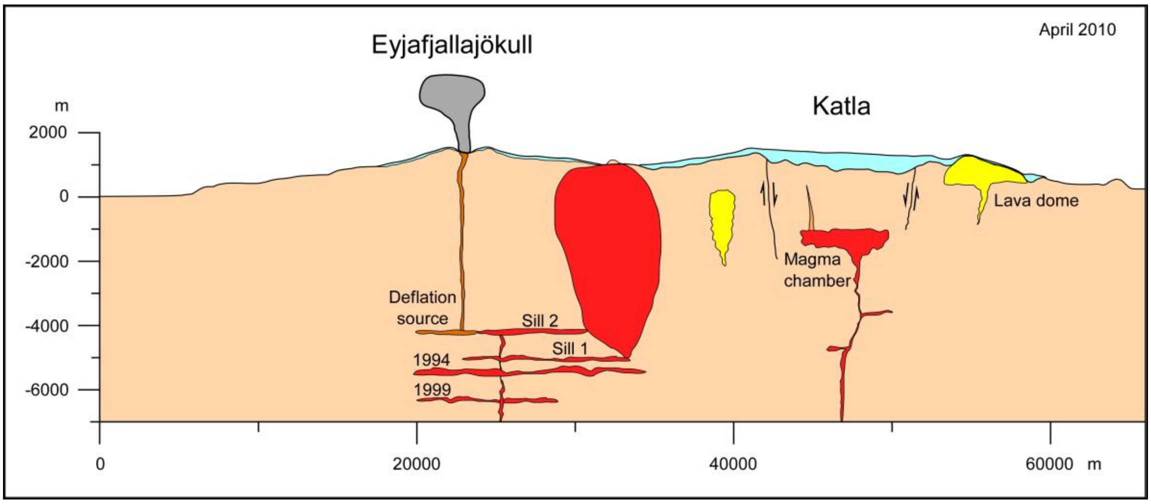
Structural map of Katla and Eyjafjallajökull, from Einarsson and Hjartardóttir (2015).

Eyjafjallajökull. This volcano is one of the oldest active volcanoes in Iceland. It is located in the volcanic flank zone of South Iceland, a few tens of kilometers off the nearest branch of the mid-Atlantic plate boundary. It is an elongated, flat cone of about 1650 m height. A 100-200 m thick glacier covers the upper part of the volcano and its elliptical 2.5–km-wide summit crater or caldera. Eyjafjallajökull products have an alkaline composition, similar to other off-rift volcanoes in Iceland. An E-W trending rift zone transects the volcano, most eruptive fissures and crater rows trend E-W, but occasional radial fissures are observed around the summit area. Eruptive fissures on the west flank are curved and tend to follow the topographic gradient. The E-W orientation of the rift zone suggests a tectonic control of a regional stress field with the least compressive stress oriented N-S. The strong influence of the topography suggests, however, that this intraplate stress field is weak.

There is only one well documented eruption in historic times, that of 1821-1823. One poorly documented eruption occurred in 1612-13 and geological evidence indicates eruptive activity around 920 AD, most likely in the Skerin ridge on the NW flank.

Eyjafjalljökull began showing evidence of re-awakening in 1992 and in 1994 there was a clear indication of a sill intrusion beneath the SE flank. Another sill was formed in 1999, also beneath the SE-flank. A third sill was formed in 2009. Towards the end of 2009 the volcano inflated for the fourth time and this time the activity was faster and more intense. Earthquakes showed how the volcano was intruded by magma from great depth. This led to a small lava eruption that began on March 20, 2010, on Fimmvörðuháls. The eruption produced a small lava flow into the gullies on the NE-flank of the volcano. The eruption ended on April 12. Apparently, however, the flow of magma from depth did not cease. It found its way into a batch of evolved magma that was sitting beneath the summit of the volcano, perhaps remains from the last eruptive episode in 1821-23. This magma then became eruptive, and an explosive eruption from the summit crater began on April 14. The ash from this eruption was unusually fine-grained, most likely the consequence of high viscosity and high gas content of the magma. The glacial cover in the summit caldera also added to the explosivity of the magma. Unusual weather conditions during the eruption furthermore amplified the effects of the ash. It was mostly carried by northwesterly winds to the European continent and caused an unprecedented closure of airspace. One of the many important lessons learned was that a volcano can have two very different eruptions within a short time, one triggering the other.

Connection between Eyjafjallajökull and Katla? The rather mild activity of Eyjafjallajökull stands in strong contrast to that of the neighbouring volcano Katla, which is one of Iceland‘s most active volcano. The distance between the two volcanic centers is 25 km and their magmatic sources appear to be chemically separated. Historical records, however, indicate a sympathetic behaviour of the two volcanoes. The only well documented historical eruption of Eyjafjallajökull, 1821-1823, was followed by a moderately small eruption of Katla in 1823. There is evidence for similar behaviour in 1612 and 920. Sill intrusion beneath Eyjafjallajökull in 1999 was followed by a magmatic event at Katla, most likely a small subglacial eruption and a period of slow inflation 1999-2004. The coupling mechanism between the volcanoes remains enigmatic. One volcano may be triggered by the other by direct dike or sill injection. Furthermore, stress induced in the crust by the activity of one volcano may affect the magmatic system of the other. Pressure perturbation in the mantle may also affect the magma sources of both volcanoes. At the time of writing (May 2013), there is no indication of unusual activity at Katla following the intrusive and extrusive activity of Eyjafjallajökull in 2009-2010.



An E-W section through the volcanoes Eyjafjallajökull and Katla, showing different magma bodies inferred from geophysical measurements. From Einarsson and Hjartardóttir (2015).

IV. The Eastern Volcanic Zone

Our observations near the eastern end of our area concern the products and processes in the Eastern Volcanic Zone. It is an axial rift zone that extends from the eastern end of the South Iceland Seismic Zone and about 100 km to the NE, to Central Iceland where it joins with the Northern Volcanic Zone and the Central Iceland Volcanic Zone in a triple junction. It is characterised by long, linear structures, eruptive fissures and normal faults. The fissure swarms of the volcanic systems are largely parallel to the zone itself and define a strong NE trend. Its structure is remarkably different from that of the Western Volcanic Zone. The most prominent structures in the Eastern Zone are constructional, i.e. volcanic fissures and their subglacial equivalents, long hyaloclastite ridges. In the Western Zone normal faults are most prominent. Volcanic fissures and hyaloclastite ridges exist but they are generally shorter and subordinate.

The Eastern Volcanic Zone appears to be young, taking over as the main rift in South Iceland from the receding Western Volcanic Zone in the last 3 million years. GPS-measurements demonstrate that elastic strain accumlation is in progress across the EVZ. In spite of that the seismic background activity is very low.

The central volcanoes of the EVZ are grouped in Central Iceland, to a large extent covered by the Vatnajökull glacier. They are connected to fissure swarms that issue from the glacier to the SW. Eruptive activity is very high, and large basaltic eruptions have occurred here in historic times, often on long fissures such as the Laki fissure active in 1783, the Veiðivötn fissure active in about 1480 AD, the Eldgjá fissure active in 934 AD, and the Vatnaöldur fissure active about 872 AD. All these historical eruptions were of large volume, 2-20 km^3. Lava shields are virtually unknown in this zone. The Grímsvötn volcanic system includes the Laki fissure, and the Bárðarbunga system comprises the Vatnaöldur and Veiðivötn fissures, as well as the Heljargjá graben. The Eldgjá fissure is a part of the Katla volcanic system that is located in the South Iceland Volcanic Zone south of the plate boundary. The large Holuhraun eruption of 2014-2015 was fed from Bárðarbunga by a dike propagating to the NE from the volcano.

The Laki eruption 1783-1784. Our trip takes us across two lobes of the Eldhraun lava flow, a product of the most destructive event in Icelandic history, the Laki eruption. The eruption began on June 8, 1783, preceded by three weeks of small earthquakes. The Skaftá river dried up on the third day, and one day later the lava flow emerged from its canyon and began to cover the lowland. This activity continued for 45 days and the western lobe of the lava covered 350 km^2 of land and destroyed 17 farms. On July 29 a new phase of the eruption began with heavy tephra fall. The river Hverfisfljót dried up on August 3 and lava began flowing out of its gorge, producing the eastern lobe of the Laki lava. This lobe covered 250 km^2 and destroyed 4 farms. Eruptive activity continued until February 7 the following year. The total volume of eruptive material is estimated at 15 km^3.

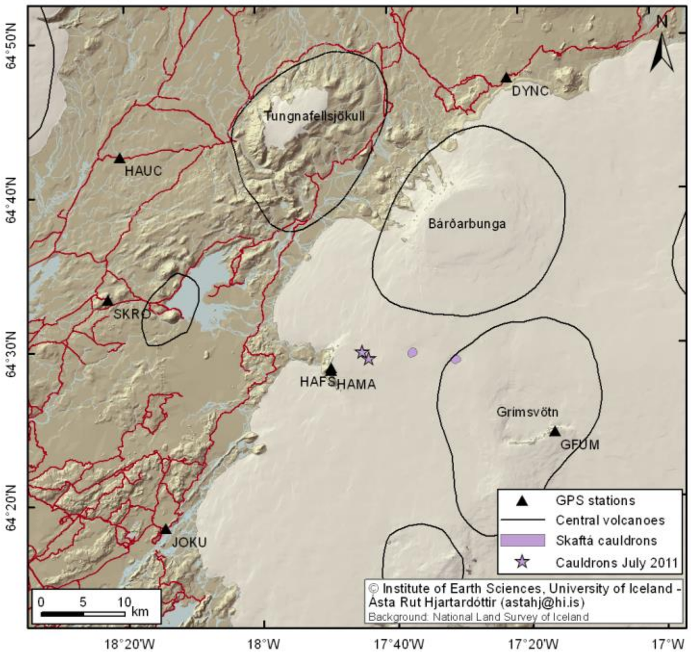
The lava issued from a 27 km long fissure extending from the SW edge of Vatnajökull glacier, along the Eastern Volcanic Zone. This fissure swarm is a part of the Grímsvötn volcanic system, and activity continued in Grímsvötn until at least May 1785. It is still debated whether the Laki eruption was fed laterally from the Grímsvötn central volcano, or directly from the mantle underneath the eruptive fissure. The activity apparently began at the southern end of the fissure and then gradually moved to the NE, a pattern similar to the activity during the Krafla events in North Iceland in 1975-1984.

The Laki eruption had serious consequences for the Icelandic population. The volcanic pollution following the enormous outpouring of lava stunted vegetation growth and eventually killed half of the livestock. The resulting famine decimated the population by an estimated 20%.

The haze produced by the Laki eruption had a global climate effect. It spread over the northern hemisphere and caused crop failure in continental Europe and North America. The following winter was one of the most severe on record. It has been suggested that disturbed climate conditions leading to famine in India and China were caused by Laki.

The Síða hyaloclastites have been a matter of great controversy for some time. It is a 700 m thick volcanic succession, dominated by 14 large-volume subaqueous hyaloclastite flows. Each flow typically consists of a columnar jointed lava grading upwards into cube-jointed lava, and then into well bedded lapilli tuff. A key exposure is seen at Keldunúpur. The thick hyaloclastite formation has columnar basalt at the bottom, with dike apophyses shooting up into basaltic tuff above.

Skaftárkatlar and jökulhlaups in Skaftá river. The river Skaftá that passes near our hotel is one of the main rivers flowing from the western side of Vatnajökull glacier, where it covers a part of the Eastern Volcanic Zone. Its catchment area includes a series of at least three geothermal areas, located on the Loki ridge extending NE from the Grímsvötn volcano. The geothermal activity leads to accumulation of water at the base of the glacier, contained by the pressure of the surrounding ice. The accumulated water is released about every 1-2 years, mainly from the two areas closest to Grímsvötn. The resulting floods, or jökulhlaups, are released into Skaftá and last a few days. An interestin aspect of these floods is the occurrence of seismic tremor shortly after the release of the water. The cause of the tremor bursts is enigmatic. Two plausable explanations have been put forward: 1) The tremor is due to a small volcanic eruption triggered by the sudden pressure drop at the base of the glacier. 2) The tremor is due to flash boiling within the geothermal system.



Volcanoes and geothermal cauldrons in the western Vatnajökull area.

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Appendix: Names and Etymology

Eyjafjallajökull. Contrary to common beliefs I like to maintain the opinion that Eyjafjallajökull is not a hard name for a volcano, no more than e.g. Popocatépetl, Llullaillaco, Piton de la Fournaise etc. And since this volcano is likely to be a conversation piece for quite some time we better clear up a few things.

There are mainly three things that seem to contribute to the misconception: the frequent appearance of the letter j, the sound of double l, and the sheer length of the word. Let us tackle these.

1. The Icelandic letter j is pronounced very similar to the German or Danish j, not like the English or French j. So the sound is that of y in yes.

2. The sound of double l in Icelandic is often like ddl in English, e.g. puddle, paddle, saddle. For practice, look at Dr Seuss (1965), Fox in Socks:
"When a fox is in the bottle where the tweetle beetles battle with their paddles in a puddle on a noodle-eating poodle, THIS is what they call...
...a tweetle beetle noodle poodle bottled paddled muddled duddled fuddled wuddled fox in socks, sir!"

3. Long words are common in Icelandic because of the habit of joining or concatenating short words into longer words. Each word usually has a meaning of its own. Eyjafjallajökull is thus composed of three words: Eyja-fjalla-jökull.
Eyja- is the plural genitive of the word ey, which means island. It is pronounced like a long a in English (A, B, C, D, ...). Many volcano enthusiasts recogize this word as the end of the names of Surtsey and Heimaey (Island of Surtur, Home-island), the volcanic islands off shore. In fact, Eyjafjallajökull is quite close and its name refers to these islands, the Vestmannaeyjar archipelago. This word also appears at the end of old English names of islands like Orkney, Jersey, Guernsey etc. The middle word, -fjalla-, is the plural genitive form of fjall, which means mountain. The name Eyjafjöll is used for the mountains on the southern flank and the inhabited district west and south of the volcano. The last word, -jökull, simply means glacier. The largest volcanoes are often capped by glaciers and the volcano usually takes the name of the glacier. This is common practice, both in Iceland and South America.

And just to make it clear; There is no way of shortening this name. Nobody will understand you if you ask where Eyja is. Some time ago we tried to take up the name Eyjafjöll for the volcano, but this attempt failed miserably. It did not work.

So the name Eyjafjallajökull is there to stay and means: “The glacier on the mountains next to the islands” and it is pronounced something like this:

A-yah-fyaddla-yoekuddl

Fimmvörðuháls: This frequently appearing name of the col between Eyjafjallajökull and Katla is also composite, Fimm-vörðu-háls. The last word, háls is a neck, same as col in French and used in the same sense in Icelandic, both for the part of the body and for a topographic feature in geography. Fimm is the number five, and vörðu is a plural form and genitive of the word varða, meaning a cairn, a pile of rocks used for marking a spot or path. So, Fimmvörðuháls is the Col of the Five Cairns.