South Iceland Excursion

Fljótshlíð, Gígjökull, Steinholtsjökull, Eyjafjallajökull, Sólheimajökull, Sólheimasandur, Mýrdalsjökull & Mýrdalssandur

May 11, 12 and 14, 2013

Glacial Geology & Glaciology Diary
of
Erica Massey

Glacial Geology (JAR407G)
Professor: Ólafur Ingólfsson
Faculty of Earth Sciences, University of Iceland

May 11, 2013

South Iceland

Subglacial volcanism in Iceland develops layers of pillow basalt, pillow breccias and lava caps. The southern lowlands of Iceland are either sandur fields or lava fields, the result of either jökulhaups or eruptions. The coastline is built out by over 4 km with coastal erosion at ~5-10 m/yr (1 km/100 year). Monitoring at coastal locations, Vik and Jökulsárlón, show that the balance of the coastline is maintained by volcanic eruptions. If glaciers disappear due to continued climate warming, it will diminish sediment transport to the coast, losing precious coastline as a result. Along the southern Iceland coast, ridges indicate previous higher sea levels where sea shells have been found. Sea levels change due to an interrelationship between loading of ice during glacial periods and isostatic rebound of the crust with glacial melt during interglacial cycles.

Figure 1. South Iceland coast.

Thórsmörk – Subglacial Volcanism and Hyaloclastite Ridges

The valley of Thórsmörk has an estimated 100 m of fill. Four major glaciations are represented in the Eyjafjallajökull volcano. The rocks exposed are mainly palagonite, which is tephra and volcanic glass that has been melted together to form hyaloclastite, volcanically produced sediments from subglacial or submarine eruptions. The rocks have pillow breccias at the base, typical for subglacial volcanism aged ~600,000 years. Subglacial eruption along a fissure was another event in Thórsmörk. A typical hyaloclastite mountain or ridge is fairly young, drowned in post- glacial sediments.

Figure 2. Hyaloclastite ridges in Thórsmörk valley, due to subglacial volcanism.

Figure 3. Thórsmörk valley.

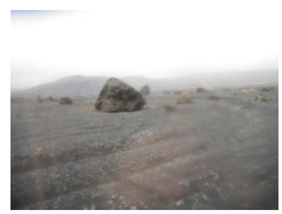

Figure 4. Boulders carried from jokulhlaup megafloods.

<u>Gígjökull</u>

Gígjökull was the first stop of the excursion, which is an ice fall on the west side of Eyjafjallajökull. It drops significantly from 1400 m.a.s.l. at the volcano crater down to 50 m, having more than a 1000 m drop. There have been major changes associated with the recent eruptions and subsequent jökulhlaups.

In front of Gígjökull, a MSc. student, Minny Sigurðardóttir, shared that the moraines we stood on were the largest in Iceland.

Figure 5. Standing on 4000-year old moraine, with view of 2010 moraine and Gígjökull.

Figure 6. Largest moraines in Iceland. ~ 4000 years old, from multiple advances.

In her research, she has concluded that multiple advances, possibly three, built up these moraines. The moraines are so large because the fast-flowing glacier has moved over easily eroded material. The huge lateral moraine is likely from neoglacial times and formed about 4000 years ago whereas a newer and smaller moraine closer to the glacier is thought to be from 2010. Sediment analysis indicates active transport, which means subglacial crushing action. Alternatively, passive transport refers to supraglacial or scree transport, which occurs in the Alps. Kettle holes were noticeable, pits where chunks of ice were emplaced that melted following the 2010 Eyjafjallajökull eruption and jökulhlaup.

Figure 7. Walking north along the ridge of the huge moraine.

In 1995, the moraine was ice cored and likely still is, although geophysical methods, i.e. gravity measurements, of analysis have not yet provided a conclusion. A very large glacier lagoon previously existed between Gígjökull and the massive moraines until the 2010 eruption and jökulhlaup. During this megaflood massive amounts of material have to go somewhere and were sent down the valley. In front of the glacier there is a hummocky moraine, now showing melting with kettle holes situated throughout.

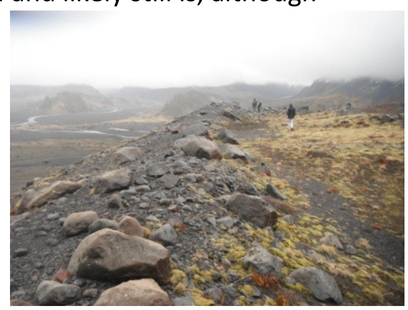

Figure 8. Further north on the large ice-cored moraine in front of Gígjökull.

Stratification and palagonization

During the Little Ice Age (LIA), the glacier filled up the entire basin. The top layer of material is since the LIA. Stratification has three main components, first, hyaloclastite, which is tephra and pumice with palagonite rock (aka the Icelandic term, moberg); second, a layer of pillow lavas and breccias; and third, interglacial lava flows when there was no glacier. Sediment horizons are typically a till, sediment, glaciolucustrine and fluvial complex. Different successions of sediments have different rates of erosion, for example, granite and gneiss are much more difficult to erode.

Figure 9. Hyaloclastite ridge in the distance, seen throughout South Iceland, (moberg), formed from subglacial volcanism. A rock in the foreground with altered yellowed palagonite. Photo at Sólheimajökull.

Pillow breccias occur when energy melts ice. Lava and water are in tubes that cool from the outside (pillows), until a difference in pressure is reached when the glacier melts. This blows the pillows apart producing fragments of pillow basalts. Palagonization is the low-temperature metamorphosis of the resulting three layers of pure ash on top, pillow breccias, and pillow basalt on the bottom layer. The sediment cover is ~ 50 m thick. The density of volcanic glass (hyaloclastites) is less than the density of basalt. Signs of metamorphosis are ice cracks from easily erodible bedrock and dead ice melting from multiple ice advances. Hummocky landslides resulted.

Tindfjoll volcano

Eruptions occurred on the western side of Thórsmörk valley across from Gígjökull and Steinholtsjökull long ago, with similar eruptive activity as Mt St. Helens, USA. The Tindfjoll volcano erupted ~ 40,000-50,000 years ago, producing a unique welded, acidic rock called ignimbrite, which is the result of a massive collapse of a volcanic ash cloud following an explosive eruption. Layers of the heavy, dense material become the ground layer, while the rapid-moving main pyroclastic flow settles on top. The top layer of ignimbrite consists of the light tephra from the ash cloud.

Figure 10. Ignimbrite, from Tindfjoll pyroclastic eruption ~ 50,000 years ago.

Steinholtsjökull Glacier Valley & the 1969 Jökulhlaup

Fissure eruptions ~ 20,000 years ago left lava dykes. Ignimbrite, a light-colored pyroclastic flow with crust above is left from the Tindfjoll eruption ~ 40,000 – 50,000 years ago.

Figure 11. Lava dyke.

In 1969, a major jökulhlaup occurred, bringing large boulders weighing over 100 – 200 ton with it onto the alluvial cone. Before 2010, the area was very sunny and vegetated, then became dead from the 5-10 cm thick tephra ash of the 2010 eruption. Jökulhlaups leave course-grained material. Levees consisting of fine-grained material have the highest velocity in the center of flow. Floods leave sediments on the side, as water flowing on the sides of the valley loses carrying capacity, thus leaving walls called levees.

Figure 12. Levees of sediment in jökulhlaup valley.

Hillocks are accumulations of sediment, not entirely understood, yet possibly from standing waves with high velocity in the flood that leave dune deposits around boulders. Waves make hillocks from a glacial event. Anti-dunes cause upstream erosion and downstream deposition. Mega flutes form as large stream ripples, like in a beach, from a jökulhlaup event.

Figure 13. Hillocks, in jökulhlaup valley.

Figure 14. Rock fall with fluvial erosion.

The cause of the 1969 jökulhlaup was a massive rock fall that catapulted onto Steinholtsjökull glacier, generating an earthquake. Consequently the weight brought the whole thing, ice, rock and water, flushing down the valley. It was an extreme jökulhlaup event that eroded, transported and produced sediments with a pattern of sediment sorting. The Eyjafjallajökull volcano, like other volcanoes, breathes with cycles of deflation and inflation, causing tension and

Figure 15.Hummocky terrain.

cracks in the mountain. There may be an earthquake pattern, crust loading, seismic unrest or an area where the glacier undercuts the mountain. Rockslides are known to generate earthquakes.

Steinholtsjökull Glacier

The Steinholtsjökull glacier previously had a depth of about 800 m, followed by melting 10,000-12,000 years ago. In the glacial forefront, there were recognizable glacial geology features. Three lateral moraines are situated to the west side of the glacier. A waterfall is flowing almost directly above and near the western area of the glacial front. Ash and sediment-covered dead ice is in front of a recessional moraine at the ice margin. Erratics randomly sit on the valley floor, along with well-rounded, angular and striated material, and silty clay visible throughout the geological features. Fluvial erosion and debris cones from the rock fall, sink holes and kettle holes are in the midst of the valley at the glacier's forefront.   A proglacial lake is forming with chunks of dead ice within.

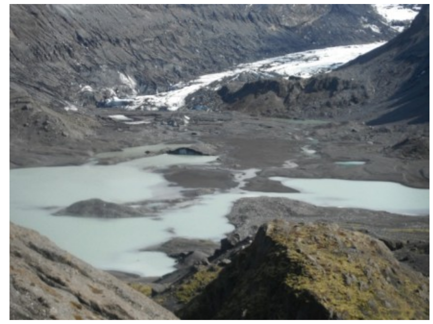
Figure 16. Steinholtsjökull glacier and forefront, from my viewpoint on a moraine ridge.

Erosion

The effects of frost are apparent in the rapid weathering, fracturing and fragmentation of rocks.


Figure 17. Beautiful erosion effects, from frost weathering and fragmentation.

South Iceland coast

Road 1 used to be a sandur area, which became an instantaneous sandur field of boulders, water-saturated sediments, glacial ice from major eruptions and megafloods. The South Iceland coastline is a glacial-volcanic complex featuring tuffs, breccias, basalt, palagonite, tillites and sediment horizons of fluvial, lake and lava origin.

Petersey, aka Peter's Island, was formed from subglacial volcanism that left a lava cap on top.
The Dyrhólaey area was a submarine eruption, similar to Surtsey, when the coastline was not as far out.

May 12, 2013 - Sólheimajökull

Glacial geology features

The Sólheimajökull glacier is 8 km long, draining from Mýrdalsjökull glacier situated over the 400 m deep caldera of Katla volcano.

Figure 18. Fúlilækur ("rotten river") river flowing from Sólheimajökull glacier.

It is quickly retreating 50-150 m/year and thinning. The river that flows southward from the glacier is referred to as "Fúlilækur", which means ‘sour-smelling’ or ‘rotten river’ in Icelandic, due to the high sulfur in the geothermal water around Katla volcano that is a contaminant and poisonous. The glacier retreats into a basin that is now below sea level where a glacier lagoon is forming since 2007. Yearly, new landforms are exposed.

Figure 19. Illegal tourist parking lot, in a dangerous location Jökulhlaups can occur rapidly without warning.

When the road was constructed for tourists about 4-5 years ago, it destroyed many beautiful things in the subglacial landscape. A catastrophic flood occurred without any warning in 1999 and could happen again with tourists in the parking lot. The Ministry of Environment should be monitoring this in Iceland, yet are not. The municipal people who gave the authority do not have such authority, as all land deglaciated after 1995 is protected, state land. The parking lot is illegal and nobody has done anything about it. The owners of the coffee shop built a road with a caterpillar, a gross violation of the environment. The law is broken to facilitate tourists all while destroying new landscape emerging from the glacier and putting lives in danger.

Figure 20. Sólheimajökull café. Destruction of important glacial landforms from unregulated and illegal permission for access.

A large ice-cored esker lies beside a pitted terrain and proglacial lake forming with dead ice floating in and around the lake. Kame terraces run along the eastern flank, where water would have run along when the glacier was much more advanced at greater depth. Lateral moraines, end moraines, annual and recessional moraines from the Little Ice Age (LIA), 1995 and more recently, were pointed out. The large lateral moraines on the mountains east of Sólheimajökull are dated to around AD 600 (Bjiis 2011).

Figure 21 Proglacial lake and insulated dead ice.

Figure 22 Pitted terrain.

Hill-hole pairs are situated on either side of some moraines, where drumlins are also noticeable. Solheimjökull sandur is not a braided river but exists from jökulhlaups.

Figure 23. Englacial 1918 Katla volcano ash in glacial ice margin. 2010 Eyjafjallajökull ash and sediment insulating ice melt.

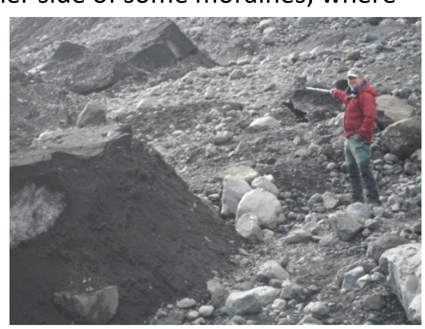

Figure 24 Ólafur pointing out ice margin features.

Figure 25 a) walking up lateral moraine, east side. B) hill-hole pairing on either side of moraines. C) jökulhlaup debris.

Figure 26. Crags & Tails. A short stubby flute.

Sólheimajökull Glacial Walk and Research

After fittings for crampons and ice picks, we set out for a hike on Sólheimajökull with Glaciology professor, Gudfinna Aðalgeirsdóttir, and Master's students, Helga María Heiðarsdóttir and Sverrir Aðalsteinn Jónsson. Dirt cones from insulation of ash, a medial moraine, moulins and small supraglacial streams were noticeable on the glacier. Our class chose two locations on the glacier to put wires down holes in the ice to measure glacial melt by the end of the 2013 summer season. First, we boiled water with propane, then with a hose gently pointed downwards to create a hole ~ 12 m deep was melted, in order to put a long steel wire, that attaches to a metal apparatus that will stay on the ice surface for location.

Figure 27. Crampon fitting.

Figure 28. Medial moraine on glacier.

Figure 29. Glaciology class walking up Sólheimajökull.

Figure 30. Hot water hose made ~ 12 m deep holes in the ice for a wire that will measure summer of 2013 melt.

Figure 31. A former frozen-looking moulin in the ablation zone.

Figure 32. Dirt cones on glacier, made by ash insulating ice, protecting ice from melt.

Figure 33. Pyramid-shaped ice covered in ash and sediments at ice margin.

Faulting occurs, bringing ash layers from the 1918 Katla eruption to the front of the glacier. If it is folded, it can be on the scale of 100's of meters and many ash layers from folding of one layer can occur. Shear movement causes ash to move up and be thrusted. Basal sediment has different lithology , with volcanic glass always present. In 1796, a naturalist wrote the book, "*Book of Glaciers*", a recommended read.

May 14, 2013 – Mýrdalssandur

Mýrdalssandur is located just east of Vik, and is very susceptible to erosion and dust storms as the sediments and ash are fine. Alaska lupine has been planted to prevent desertification of the sandur field. A massive megaflood and jökulhlaup in 1918 occurred as a result from the Mýrdalsjökull glacier-covered Katla volcano eruption that brought a wall of water having an estimated discharge rate of ~ 200,000 m^3/s. As much or more discharge than the Amazon river! This most powerful event carried and placed a rock we estimated to be over 1000 tons! In the field, there seemed to be a ripple effect along the sediments, although it was quite faint. Water erosion at high velocity would have been able to move large objects and have standing waves. Significant erosion and deposition of sediments powerfully flowed southwards into the Atlantic Ocean, leaving behind the Mýrdalssandur field.

Figure 34. A striated rock weighing an estimated 1000 tons brought down to Mýrdalssandur by the power of a jökulhlaup.

Figure 35. Vik beach. Columnar basalt columns formed while cooling. An old lava dyke still uneroded in the ocean.

__May 15, 2013__

While hiking high up on the eastern flank of the field on my last day, I observed what looked to be a lava dyke and further up the ridge was columnar basaltic columns. Holocene sediments along the east flank were loaded during glacial advancement, causing dyke intrusion (Le Heron and Etienne 2005).

Figure 36. Lava dyke, east side above glacier forefield.

Figure 37. Columnar basalt columns, near and above the lava dyke.

Hyaloclastite ridges flanked the Sólheimajökull glacier and the proglacial field. Subglacial volcanism is prominent in Iceland and represented in the Sólheimajökull system.

In Ari Trausti Guðmundsson's book, *Living Earth: Outline of the Geology of Iceland*, it helpfully explains that subglacial eruptions were common 130,000 to 2 million years BP when acid eruptives characterized volcanic centers, along with hyaloclastites and lava layers. About 170,000 years ago, subglacial volcanism under the ice shield made pillow-lava formations and hyaloclastite (moberg), at the height of the penultimate glaciation period, Saale. An interglacial period followed at about 13,000 – 130,000 years BP, when hyaloclastite (moberg) mountains became visible in the newly ice-free landscape. Lava then flowed freely on top of the moberg and other sediments. The Weichselian was the last glacial period with temperature lows between 70,000 and 22,000 years ago, completely covering Iceland with one ice cap that reached further out to the sea-shelf floor around the island. During the glacial maximum about 20,000 years ago, huge hyaloclastite (moberg) mountains were formed under the ice from subglacial eruptions. The warmer Bolling period that followed until the cooling Older Dryas period 12,000 years ago. Isostatic adjustment of the crust is thought to support volcanism, creating the oldest Pleistocene hyaloclastite (moberg) mountains in the warm Alleroid period 11,000 years ago. The cooling Young Dryas lasted 500 – 700 years about 10,500 years ago, when glacial re-advancement occurred until the warming of the first 3000 years of the Holocene. At 9800 years ago, a cold cycle caused two-thirds of the country to be covered in ice. Young Pleistocene volcanoes often erupted subglacially, creating the recognizable serrated hyaloclastite ridges made of moberg or palagonite tuff and breccias (Guðmundsson 2011).


Figure 38. Hyaloclastite (moberg) ridges surround Sólheimajökull glacier.

It was interesting to find out, while researching online, that hyaloclastite ridges are a prominent feature in Iceland and British Columbia, where I am from (Wiki 2013). This will be an interesting study that I intend to pursue further, to better understand the unique interrelationship of subglacial volcanism and its geological features.


Figure 38. Flying over Greenland's ice shelf and ice bergs the day after the excursion. May 16, 2013.

A further note…
The following afternoon, May 16, 2013, from the field excursion I flew over Greenland, Northern Canada and south over the Rocky Mountains to home in British Columbia. I could not help but see in a new way the Greenland ice shelf and icebergs floating in the North Atlantic, the endless expanse of white snow of Northern Canada, then the jagged,

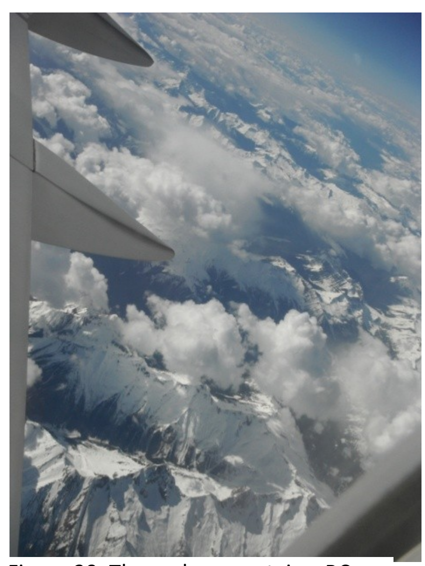
Figure 39. The rocky mountains, BC, Canada. Different landscapes!

rough, snow-covered mountains of BC. What are the processes that change the landscape? Over 90% of the Earth is greater than 1000 degrees C, yet its crust protects us from these molten temperatures. It is fascinating that the interrelationship of volcanoes and glaciers can exist at the surface where life is possible for us.

I have gratitude for my professors at the University of Iceland for giving me such perspective that I would never have had if I didn't spend the past 8 months studying geology, geophysics, crustal movements, geothermal energy, and best of all, glacial geology, glaciology and volcanology. Thank you, Ólafur Ingólfsson, for the most excellent field excursion I have ever experienced. It was an inspirational and terrific learning experience of South Iceland's glacial geology that also taught us how to operate during research in the field. Thank you, too, to the students I worked beside that taught me so much by just learning with them and of their unique perspectives, cultures and bright minds.

Iceland, its raw, young nature and beauty, along with its people, will always be in my heart.
Bless. Bless.

Leaving with an image taken while walking off Sólheimajökull glacier.

End of diary.
For now…

Figure 40. Glacial Geology field excursion class 2013 with professor, Ólafur Ingólfsson, and supervisors, Sverrir Aðalsteinn Jónsson and Minney Sigurðardóttir.. Photo courtesy of Ólafur Ingólfsson.

Figure 41. Scene while walking off of Sólheimajökull glacier. What a lovely site!

References:

Friis, Bjarki. (2011) Late Holocene Glacial History of Solheimajokull, Southern Iceland, *Master's thesis, Faculty of Earth Sciences*, University of Iceland, pp. 100.

Guðmundsson, A.T. (2011) Living Earth: Outline of the Geology of Iceland. *Florlagid*. Pgs. 378-387.

Le Heron, D.P. & Etienne, J.L. (2005)A complex subglacial clastic dyke swarm, Sólheimajökull, southern Iceland. *Sedimentary Geology* 181, 25-37.

Wikpedia. (2013) Hyaloclastite: BC and Iceland. Website accessed: May 15, 2013. http://en.wikipedia.org/wiki/Hyaloclastite.