NORNAHRAUN LAVA MORPHOLOGY AND EMPLACEMENT: A NEW TERRESTRIAL ANALOGUE FOR PLANETARY LAVA FLOWS. G.B.M. Pedersen[1], A. Höskuldsson[1], M.S. Riishuus[1], I. Jónsdóttir[1], M.T. Gudmundsson[1], F. Sigmundsson[1], B.V. Óskarsson[1], T. Dürig[1], V.J.P.B. Drouin[1], C. Gallagher[1], R. Askew[1], W.M. Moreland[1], S. Dumont[1], A. Davies[2], L. Keszthelyi[3], C.W. Hamilton[4], and Þ. Þórdarson[1], [1]NORDVULK, Institute of Earth Sciences, University of Iceland, Sturlugata 7, 101 Reykjavík, Iceland (gro@hi.is), [2]JPL, M/S183-501 4800 Oak Drive, Pasadena, CA 91109 USA, [3]USGS Astrogeology Science Center, 2255 N. Gemini Dr., Flagstaff, AZ 86001 USA, [4]LPL, University of Arizona, Tucson, AZ 85721 USA.

Introduction: The ongoing Nornahraun eruption is the largest effusive eruption in Iceland since the Laki eruption in 1783–84 A.D., with an estimated lava volume of ~1 km^3 covering an area of ~83.1 km^2 (as of 3 Janurary 2015). The lava has had discharge rates ranging from 60–400 m^3/s, which is one of the highest observed with modern monitoring techniques. The lava has also interacted with water/ice as it advanced into one of Iceland's main rivers, Jökulsá á Fjöllum, and onto snow and ice. This eruption is actively producing an exquisite analog to many of the large lava flows seen on Mars, especially within the Elysium and Tharsis Volcanic Provinces, and potentially to lava flows on Jupiter's moon Io [1–5]. Here we report on the lava morphologies and emplacement styles—observed to date in the field and from remote sensing platforms—to help inform the study of analgous large channelized ʻaʻā and transitional flows on other planetary bodies.

Geologic Setting and Overview of Events: An intense seismic swarm began beneath the ice-covered Bárðarbunga Volcano on 16 August 2014. The activity concentrated along a lineament and lengthened sequentially 45 km to the NE over the next 11 days along 8 segments, terminating on the floodplain, Flæður, 10 km N of the outlet glacier Dyngjujökull [6–7]. At midnight on 29 August, a small 4-hour-long fissure eruption took place eruption through the cone row of 1797 A.D. Holuhraun I event. The vents were reactivated and lengthened on August 31 (04:00 local time) and continue to erupt at the time of writing (6 January 2015). A new small fissure eruption took place September 5–6 along two new vent segments 2 km further to the south. The initial discharge rate on the 31 August were ~400 m^3/s, and subsequently declined to 200–100 m^3/s in the weeks that followed. The eruption is characterized by high and slowly declining magma discharge, estimated at 60–70 m^3/s at the end of December, after four months of continuous eruption.

Monitoring Methods: On-site eruption monitoring was carried out almost daily during the first three months, but transitioned to a mostly remote sensing perspective during the winter season. Tracking of the lava advancement, morphology, and thickness of the margin has been performed by Global Positioning System (GPS) measurements and GoPro cameras installed in 4×4 vehicles. Visible wavelength and thermal video footage have been particularly useful in documenting mechanisms lava emplacement. Along with the field observations, aerial, and satellite data have provided complimentary observations throughout the eruption. Of particular importance for lava morphology observations are 1–12 m/pixel airborne Synthetic Aperture Radar (SAR) images (X- and C-band). A complete field tracking of the lava margins was carried out until 7 September where the lava reached the river Jökulsá á Fjöllum. After that only the northern and western lava margins were readily accessible to the field teams. Hence, aerial observation became essential to monitor the flow's evolving morphology.

Lava Morphology: The Nornahraun lava flow field exhibits a diverse assembly of lava morphologies, which have varied temporarily and spatially. Figure 1 shows the primary morphologies, comprising a continuum from pāhoehoe to ʻaʻā, with multiple transitional morphologies present.

Slabby pāhoehoe lava is characterized by a flow top of crustal slabs and a pāhoehoe base. The slabs are up to several meters across and a few centimeters to decimeters thick. This morphology is produced when pulses of lava disrupt and break up incipient pāhoehoe crust, forming slabs that are rafted and pile up [8–10].

ʻAʻā lavas have brecciated flow tops and bases. The breccia consists of jumbles of blocky lava and irregular-shaped clinker formed by viscous tearing of the chilled lava crust, which subsequently is rafted towards the flow front where it is dislodged from the front in caterpillar-track motion.

Rubbly pāhoehoe lava is a flow characterized by a flow top of pāhoehoe crustal rubble and a pāhoehoe base. The crustal rubble is up to several decimeters in size and has previously been suggested to form when pulses of lava disrupt the mature crust of a pāhoehoe flow, that is brecciated and the transported on top of the flow [3,11].

Spiny pāhoehoe lava is a flow with smooth, coherent crust at meter scale and with a spinose surface characterized by longitudinal grooves and ridges. The appearance of this morphology is uncertain but was first reported 5 weeks after the onset of eruption.

Shelly pāhoehoe has been observed, but only to a minor extent close to the vents. However, it was the primary morphology during the small fissure eruptions.

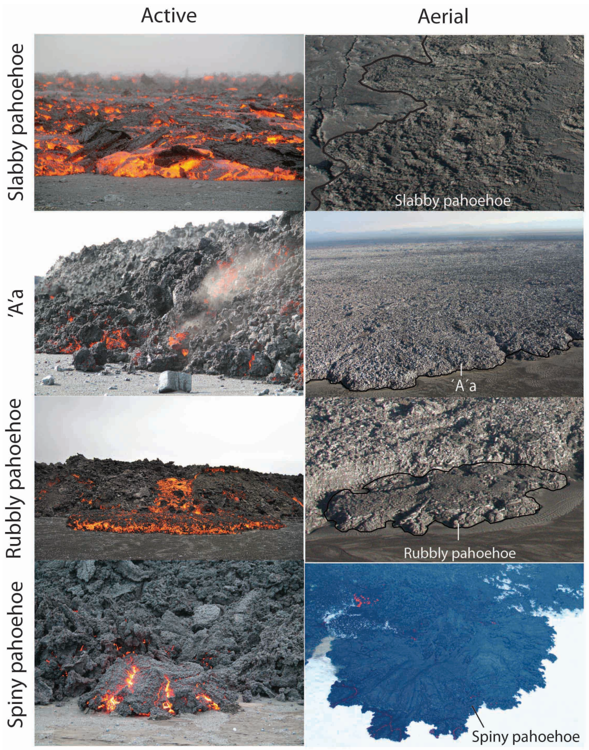

Figure 1 Illustrations of the four dominant flow morphologies (rows) showing images taken during active flow emplacement and from the air (columns).

Lava Emplacement: At the onset of the eruption the August 31 lava flows advanced rapidly (400–800 m/hr) from the 1.5 km long fissure as large slabby pāhoehoe sheet lobes 100–500 m wide and 0.3–1 m thick at the flow fronts. The lobes slowed down with radial spreading and cooling and subsequently began to inflate, but were overridden by new lobes. Minor phreatic explosions were observed on the night of the August 31 as the slabby pāhoehoe advanced over the wet flood plain. By early on the 1st of September, the flows began channeling towards the NE constrained by the older Holuhraun I lava field and the topography of flood plain itself. A 20- to 80-m-wide central open channel developed, feeding a 1–2 km wide active ʻaʻā frontal lobe that advanced 1–2 km/day. In addition to its own caterpillar-motion, the frontal lobe advanced in a series of 30–50 m long breakouts dominated by slabby and rubbly pāhoehoe morphologies. These breakouts have initial velocities of 10–30 m/hr and reached their full length within tens of minutes and subsequently inflated over hours. With the continuous brecciation and steepening of the ʻaʻā flow front, the breakouts were incorporated into the advancing ʻaʻā flow fronts and seldom preserved. At the margins of the frontal lava lobe, the breakouts were more sporadic, but dominantly rubbly pāhoehoe and slabby pāhoehoe, as at the flow front. The lava flow advanced into Jökulsá á Fjöllum the 7 September, resulting in passive steaming of the river water and forcing the river to migrate to the East. Steam explosions were observed the 8 September as the lava reached one of the larger river channel. This flow front came to halt on 12 September 18 km from the source vent. It is likely that at this time the lava had reached its critical length [12]. Subsequently, a new lobe broke out S of the first lobe and migrated NE until it came to a halt at a slightly shorter distance, corresponding to a modest drop in magma discharge. This process repeated 3–4 times from mid-September to mid-October. SAR images reveal that these early lobes have similar morphology, displaying central lava channels, levees with sheared edges, linear grooves formed by flow around obstacles and sporadic lava ridges. Inflated margins have been observed from aerial photographs from around 20 September. Around 15 October, a ~0.8 km^2 lava lake developed east of the fissure. This lake has been a persistent feature throughout 2014 though diminishing in size. Also since mid-October, the flow field has expanded more slowly via spiny pāhoehoe breakouts from close to the vent. In November the main lava channel partly crusted over and by the end of November a series of insulated flows were overriding the previous emplaced flows, changing transport system from an open to closed lava pathways.

Discussion: The current Nornahraun eruption provides an unprecedented opportunity to study the processes that form large channelized ʻaʻā and transitional flows, which are among the most common lava types on Mars [2,3,13,14]. The data collected to date will also provide new insight into (1) the relationship between magma discharge, lava rheology, and flow length; (2) the transition from open channel to insulated transport in thick ʻaʻā flows; (3) the formation of rubbly pāhoehoe and associated transitional lava surfaces; (4) the formation—and eventually demise of—a lava lake; and (5) the interaction between thick lava flows and groundwater.

References: [1] Theilig and Greeley (1986) *JGR*, 91, E193–E206. [2] Keszthelyi *et al.* (2000) *JGR*, 105, 15027–15050. [3] Keszthelyi *et al.* (2004) *GGG*, 5, Q11014. [4] Haack *et al.* (2006) *JGR*, 111, E06S13. [5] Hauber *et al.* (2009) *JVGR*, 185, 69–95. [6] Gudmundsson *et al.* (2014) *BV*, 76, 869. [7] Sigmundsson *et al.* (2014) *Nature*, doi:10.1038/nature14111. [8] Macdonald (1967) NY Wiley, 1–61. [9] Swanson (1973) *GSAB*, 84, 615–626. [10] Thordarson (2000) *Surtsey Res. Prog. Rep.*, XI, 125–142. [11] Guilbaud *et al.* (2005) *Geol. Soc. Am. Spec. Pap.*, 396, 81–102. [12] Thordarson and Höskuldsson (2008) *Jökull,* 58, 197–228. [13] Jaeger *et al.* (2007) *Science*, 317, 1709–1711. [14] Jaeger *et al.* (2010) *Icarus*, 205, 230–243.