Learning Science Through Research
Published by Keck Geology Consortium

Short Contributions
30th Annual Symposium Volume
29th April, 2017
ISBN: 1528-7491

NEW INSIGHTS AND EDUCATIONAL TOOLS THROUGH STORY MAPPING OF A GLACIOVOLCANIC TINDAR

CARL-LARS ENGEN, Beloit College
Research Advisor: Susan Swanson

INTRODUCTION

Lava erupting under ice takes on distinct morphologicals and geochemical characteristics. Glaciovolcanic sites frequently show examples of pillow lavas, fragmental deposits, and intrusive magma. Structures left behind by glaciovolcanics, such as tindars and flat topped tuyas, rise above post-glacial lava fields, and are more resistive than depositional glacial evidence. They can survive many episodes of glaciation and erosion (Edwards et al., 2009). A tindar is a linear volcanic landform fed by fissure eruptions, and a tuya is a flat-topped volcano, representative of a sequence of subaqueous pillow eruptions to a subaerial lava cap (Edwards et al., 2009). Under ideal circumstances, an abundance of paleo-environmental information can be extracted from these ridges including constraints on ice thickness at the time of the eruption (Hoskuldsson et al., 2006). Because of this, glaciovolcanics have recently been the subject of growing bodies of scientific literature (Bennett et al., 2009). They are keys to understanding the past climate of the Earth, as they are some of the only direct volcanic records of where extinct bodies of ice used to exist. Ice thickness constraints are a valuable tool for testing hypotheses of inferred past terrestrial ice volumes based on marine records (Edwards et al., 2009). For scientists reconstructing how fluctuations in climate have resulted in either global warming or cooling over the past 3 million years, the information recovered from glaciovolcanoes is critical (Edwards et al., 2009).

Relatively few studies have examined the formation of these glaciovolcanic features in detail, and even fewer have attempted to integrate stratigraphic, petrologic, and geochronologic data. (Edwards et al., 2011). As new information becomes available, and glaciovolcanics become more studied, there is an opportunity for the development and use of educational tools to assist undergraduate audiences in efficiently understanding glaciovolcanic processes and the structures they form. One way to do this is by using digital mapping technology.

Traditional maps have long been used in geoscience education; however, newer digital mapping applications, when available, have been found to quickly allow users to access data, whether those users are geology novices or professionals. A study using dynamic digital map technology found this was an effective way to bring exciting and relatively inaccessible field areas into a petrology classroom (Boundy and Condit ,2004). Significant gains were found in students' confidence in their own ability to do research and understand petrology. Furthermore, the authors claim dynamic digital mapping can be adapted to any sub-discipline of geology, for use in introductory courses, to research-based graduate programs (Boundy and Condit, 2004).

Another study of a Google Earth-based, multi-level maps package for the state of Virginia found that this new resource provided students with opportunities for custom map tours and inquiry based investigations. These involved presenting information along a sequence of geographic locations or "stops" along a tour. Some other advantages of this system are a user-friendly intuitive interface that enhanced the accessibility of geologic information to new students and the public, integrating map interpretations with individual outcrop and field data, and the ability to view multiple maps simultaneously and transition between maps by zooming or panning (Shufeldt et al., 2012).

Google Earth is not the only platform with which to create such tools. An undergraduate geography class in South Carolina found that Esri's Story Maps are an effective resource for undergraduate students to present their research. The Story Maps allowed the students to create dynamic, professional looking web mapping applications to present and support the results of their studies (Battersby et al., 2013). Point data might be displayed on a digital map, along with other geological data to support conclusions about a glaciovolcanic feature. The findings of these studies suggest that student understanding of glaciovolcanics might benefit from digital tools as well, and that Esri's Story Map template would be an effective tool to use.

One easily accessible glaciovolcanic site exists on the Reykjanes Peninsula, SW Iceland. Undirhlíðar ridge (see Figure 4, Pollock and Edwards, this issue) is a glaciovolcanic tindar formed by fissure eruptions under ice. It lies within the Reykjanes United Nations Educational Scientific and Cultural Organization (UNESCO) Geopark. UNESCO Geoparks are areas of global geologic significance that place an emphasis on a holistic management approach to education, protection, and sustainable development. Given the popularity of the park with many types of visitors, a need was identified for different educational tools suitable for casual hikers, geology undergrads, as well as interested professionals. This project's goal is to create ESRI Story Maps to allow interested hikers to gain an understanding of this ridge in a matter of two hours, rather than two weeks. The first Story Map is an overview of glaciovolcanics through the exploration of Undirhlíðar quarry in the north, summarizing the work of Pollock et al. (2014). A second Story Map synthesises data from studies on the ridge's central tephra cone, megapillow features, pillow morphology and geochemistry, as well as previous research in two nearby quarries. It creates a comprehensive overview of the entire geologic structure. By gathering data points to fill in key gaps, this project attempts to determine the magma transport and eruption dynamics of the ridge, and the sequence of eruptive events that formed it.

METHODS

Important features needing analysis on Undirhlíðar ridge include several dikes, megapillows, geologic contacts, and a partially eroded tephra cone. Feature positions were recorded using GPS and field mapping techniques. Erosional gullies provided the best exposures, so a majority of time was spent there. All locational data were uploaded into an ArcGIS geodatabase and the exported as a .zip file for use in ArcGIS Online. Photographs provide both close up views and larger picture views of features in the field. They range from vesicle patterns in a piece of basalt to the entire quarry wall to illustrate contacts between rock units. Because intrusions and contacts in the quarry walls can be difficult to see from a picture alone, Adobe Photoshop and Illustrator were used to trace these features to provide visual aid when needed.

In addition to field data, five samples were collected for geochemical analysis. Three are from pillow lavas, and two from tephra units. These were taken with the intention of filling in sampling gaps in concurrent studies of the ridge. X-ray Fluorescence (XRF) analysis for major and trace elements was performed at the College of Wooster using methods modified from Pollock et al. (2014). For samples 16CLE01 through 16CLE05, smaller amounts of whole-rock powder were used to make pressed pellets and glass beads, but the ratio of binder and flux to sample was the same as in Pollock et al. (2014; 0.13 +/0 0.01 and 0.7 +/- 0.01, respectively). ICP-MS analysis was also performed at Washington University to detect trace elements. These methods were used to create major and trace element plots, which are useful for correlating different lava outcrops that are related. Billets for thin sections were cut at the College of Wooster. The geochemical and petrographic data complement field photographs to provide a more complete geological analysis for the Story Maps.

RESULTS

Quarry Tour

This Story Map is designed to be an introduction to glaciovolcanics that are restricted to Undirhlíðar (UND) Quarry (Fig. 1). It includes information about features like pillows, dikes, and tephra to get a user acquainted with these specific terms as they apply to glaciovolcanic edifices. The quarry tour sequentially illustrates the complex polygenetic eruption history of that section of the ridge based on Pollock et al. (2014), and shows that the current model for understanding glaciovolcanic edifices needs to be expanded (Fig. 2). The tour can communicate this understanding to a student audience in a relatively short amount of time, without the need to actually travel there.

The tour begins with introductions to pillow lavas and intrusive dikes. While there are several dikes and hundreds of pillows exposed in the quarry, the tour provides an example of each and their locations in case visitors want to examine them up close in person. The Story Map then proceeds to the central wall (Fig. 1), where sequential layers of interbedded pillows and lapilli-tuff are visible in cross section. A section is devoted to the basal pillow units, Lp1-2, before the tour moves on to two dikes (Ld1-2). These dikes are located on the south wall, and it is there that the tour directs visitors next. The final stop is the southeast wall, where a third dike (Ld3), a third pillow lava unit (Lp3), and a tuff-breccia (TB2) are exposed. Several sections are dedicated to illustrating how Ld3 cuts through unit TB2 to feed pillows above, forming Lp3. The last section of the Story Map recaps the journey and presents the sequence of eruptive events from Pollock et al. (2014).

Figure 1. Aerial view of Undirhlíðar (UND) quarry with walls labeled.

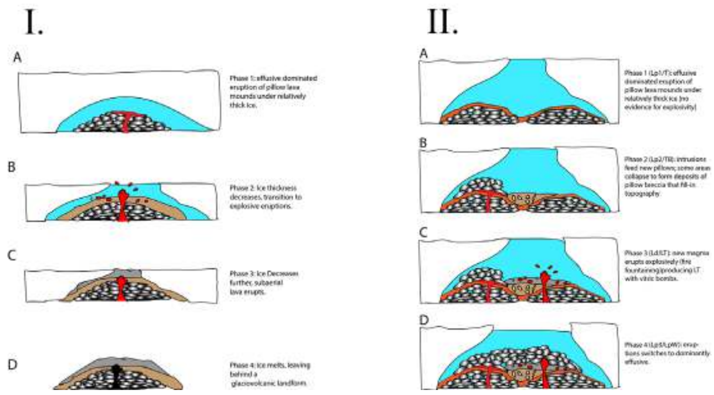

Figure 2. Simple model for the eruption of glaciovolcanic edifices on the left, as described in Pedersen and Grosse (2014), followed by the expanded model for Undirhlíðar (UND) quarry from Pollock et al. (2014) on the right.

Ridge Tour

The purpose of this Story Map is to synthesise multiple concurrent studies to get a more complete understanding of this particular ridge (Fig. 3). Major conclusions from these concurrent studies include:

- An explosive eruptive event at the end of the ridge building process under thin ice resulted in the central tephra cone (Lembo, this issue).
- Megapillows are morphological variations of pillows, not intrusions (Heineman, this issue).

The ridge Story Map begins on the south end of the ridge. On approach, the road passes by Vatnsskarð (VAT) quarry (Fig. 3), and the first section of the Story Map calls attention to the pillow units there that can be seen from the road. This provides a broad cross section into the pillow dominated ridge before the next stop places the user in tephra. On the southernmost point of the mapped area, a vertical dike (sample 16CLE01) is the first stop in the walking portion of the tour. From here onwards, the Story Map follows the dashed red line, which avoids any particularly difficult terrain. The red line serves as a suggested walking route (Fig. 3); however, the Story Map also marks the location of sample 16RH11, an intrusion that is down a gulley and less accessible for those physically hiking the ridge. The tour visits two different megapillow outcrops and then proceeds to the central area of the tephra cone.

Here, various layers of tephra can be explored and the user can reference the stratigraphic column from a study specific of that area (Lembo, this issue). The next stop is another megapillow (sample 16RH02) near a well-constrained dike in the middle of the ridge, before the user visits this dike itself (sample 16MP03). The tour heads north across the pillow rubble and back towards UND quarry, stopping to explain the significance of scattered spots of glacial diamict. Finally, the last section of the Story Map recaps the information presented and displays an interpretation for the sequence of eruptive events that formed the ridge as a whole.

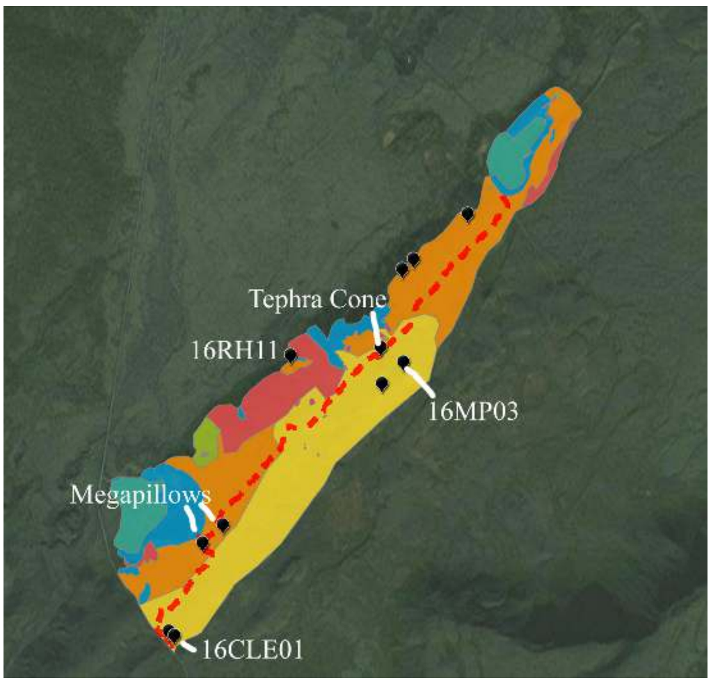

Figure 3. Satellite imagery of UndirhlíðarRidge with geologic units, tour walking route (red dashed line), and points (black points) with story map stops. White text displays sample locations.

The UND basal units (Lp1-2) and the UND upper units (Ld1-3, Lp3, Lpw) are thought to be from separate crustal melt chambers (Pollock et al., 2014). The way they separate into two groups in major and trace element plots is useful as an indicator for fingerprinting additional ridge samples. Different units on the ridge corresponded to either UND Quarry upper or lower units, depending on location. Displayed on the same CaO versus MgO plot as Pollock and Edwards (Fig. 3B, this issue), sample 16CLE01 (a dike) plots up with UND basal units (7.34 wt.% MgO, 12.41 wt.% CaO). 16MP03 (a dike) is a bit more of

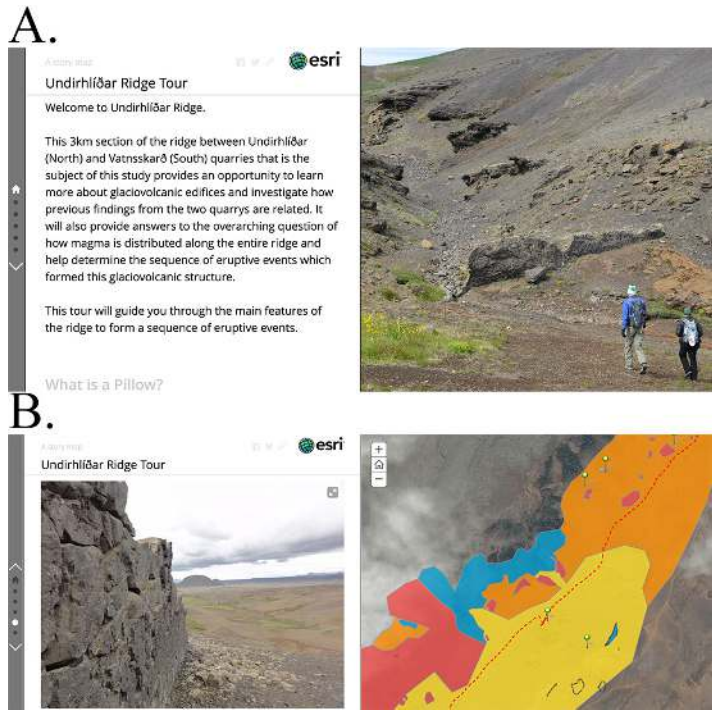

Figure 4. A, Introductory screen. B, Tour interface with a close up picture of a dike on the left, and the adjustable map on the right with geologic units.

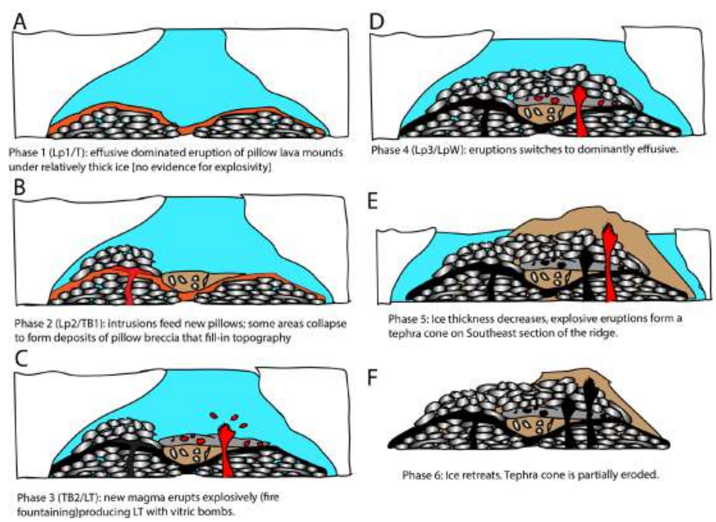

Figure 5. Expanded eruptive model for Undirhlíðar Ridge.

an outlier, but is much closer to the UND. upper units and VAT. pillows (6.96 wt.% MgO, 11.21 wt.% CaO). 16RH11 is a megapillow which falls away from either group (6.44 wt.% MgO, 11.82 wt.% CaO). The sample has about the same CaO as UND upper units and the megapillows, but lower magnesium than any of the other samples. Correlations observed in major element plots are also observed in the trace element analysis. Overlaying additional ridge data points to the same trace element plot as Pollock and Edwards (Fig. 3A, this issue), sample 16MP03 (a dike) plots closer to the UND upper units at (0.126 La_N/Sm_N, 2.235 Nb/Zr). 16RH11 (a megapillow) plots with the UND. basal units, at (0.139 La_N/Sm_N, 2.531 Nb/Zr). This intrusion was exposed at the bottom of a gulley. The megapillows, which all appeared higher in elevation up the ridge, corresponded geochemically to the UND upper units. Trace element data were not available for 16CLE01. Overall, low elevation samples correspond to low units and high elevation samples correspond to high units.

DISCUSSION

Undirhlíðar Ridge provides the opportunity to examine the formation of glaciovolcanic features in detail, by integrating stratigraphic, petrologic, and geochronologic data. These data are used to expand the eruptive model from Pollock et al. (2014) to apply to the whole ridge. Since the upper units in both quarries are pillow lavas, a geopark visitor might infer that these pillow units are continuous across the whole surface of the structure; however, the tour illustrates that this is not the case. There are a variety of geologic units including pillow breccia, glacial diamict, and a large central tephra cone. Multiple picture types are included so the user can see different perspectives of the geologic features (Fig. 4). Geochemical plots are also included to help determine which geologic units occur where.

Most of the ridge is built in an alternating sequence of effusive and eruptive events (Fig. 5). Effusive eruptions form pillow lavas along discrete ~km-long segments of the ridge. Based on their geochemistry and elevations, the basal pillow lavas from UND Quarry appear to have been erupted about 1 km farther south along the ridge at the same time. Dikes appear to be transporting magma along the ridge axis and feeding the pillow lava flows. Between the effusive events are explosive events that deposit fragmental units, like the lapilli-tuff that was observed in the quarries. In this way, the bulk of the ridge is built episodically, over time. Toward the end of the ridge building process, when overlying ice pressures are relatively low, an explosive event deposits tephra on the central and southeast portion of the ridge. The central ridge dike (sample 16MP03) intrudes into this tephra unit. Glaciers retreat, depositing sediment, obscuring some of the volcanic geology. Finally, some erosion of both tephra and glacial diamict occurred, leaving behind scattered patches of both these materials on top of the pillow rubble near UND Quarry, and exposing the central dike on top of the ridge. A user's understanding of this model is increased through its presentation through a Story Map.

The creation of two Story Maps required the assemblage of photographs, geologic evidence, and location data simultaneously. The map interface provides a useful spatial context to synthesize evidence. For example, the Story Map provides the full context for a sample such as 16RH11. This is a megapillow located midway down the ridge, with a location that is clearly marked on the map. A trace element graph on the righthand side panel is viewed with the map on the left, allowing the user to quickly understand that its magma fingerprint and location provide evidence for that magma batch erupting along the ridge axis.

CONCLUSIONS

The use of Story Maps to present the geologic features of Undirhlíðar ridge provided the opportunity to display more visual material than might be available in a simple geologic report. The stops contain multiple perspectives of outcrops, as well as hand samples, photomicrographs, and geochemical plots, which can be expanded to a larger size if the user chooses. By highlighting certain parts of a photo or geochemical graph at a certain stop, the user can make a conclusion about a certain outcrop or layer before the tour's text explicitly states it. This turns the experience into one of active involvement and learning. Further evidence presented in the tours from major and trace element analysis leads to the expansion of the previous eruptive model (Fig. 2), to a new model that encompasses the entire 3 km ridge section (Fig. 5).

ACKNOWLEDGEMENTS

This project was made possible through financial support from the Keck Geology Consortium, The

National Science Foundation (grant number NSF-REU1358987) and ExxonMobil Corporation. Thanks to Dickinson College for providing field equipment and The College of Wooster for summer housing and use of their lab facilities. Special thanks to project directors Meagen Pollock, and Ben Edwards, as well as faculty advisors James Rougvie, and Sue Swanson.

REFERENCES

Battersby, Sara M., Remington, Kevin., 2013 "Story Maps in The Classroom" Arcuser Magazine Spring 2013, p. 62-65

Bennett Matthew R., Huddart, David., Gonzalez, Silvia., 2009, "Glaciovolcanic landsystems and large-scale glaciotectonic deformation along the Brekknafjöll–Jarlhettur, Iceland." Quaternary Science Reviews 28 (2009) 647–676

Boundy, Theresa M., Condit, Christopher., 2004, "Bringing the Field into the Classroom by Using Dynamic Digital Maps to Engage Undergraduate Students in Petrology Research" Journal of Geoscience Education, v. 52, p. 313-319.

Edwards, B.R., Skilling, I.P., Cameron, B., Haynes, C., Lloyd, A., Hungerford, J.H.D., 2009, "Evolution of an englacial volcanic ridge: Pillow Ridge tindar, Mount Edziza volcanic complex, NCVP, British Columbia, Canada." Journal of Volcanology and Geothermal Research v. 185 (4), p. 251–275.

Edwards Benjamin, R., Russel, James K., Simpson, Kirstie., 2011, "Volcanology and petrology of Mathews Tuya, northern British Columbia, Canada: glaciovolcanic constraints on interpretations of the 0.730 Ma Cordilleran paleoclimate" Bulletin of Volcanology v. 73 p. 479–496 .

Pedersen, G.B.M. and Grosse, P., 2014. "Morphometry of subaerial shield volcanoes and glaciovolcanoes from Reykjanes Peninsula, Iceland: Effects of eruption environment." Journal of Volcanology and Geothermal Research v. 282, p. 115-133

Pollock, M., Edwards, B., Hauksdóttir, S., Alcorn, R., and Bowman, L., 2014. "Geochemical and lithostratigraphic constraints on the formation of pillow-dominated tindars from Undirhlíðar quarry, Reykjanes Peninsula, southwest Iceland." Lithos v. 200-201, p. 317-333

Höskuldsson, A., Sparks, R.S.J., and Carroll, M.R., 2006, Constraints on the dynamics of subglacial basalt eruptions from geological and geochemical observations at Kverkfjöll, NE-Iceland: Bulletin of Volcanology, v. 68, p. 689–701.

Shufeldt Owen P., Whitmeyer, Steven J., Bailey, Christopher M. 2012, "The new frontier of interactive, digital geologic maps: Google Earth–based multi-level maps of Virginia geology" The Geological Society of America Special Paper 492, 2012.