Aerial and Topographic Analysis of Quaternary Faulting at SP Crater Lava Flow, San Francisco Volcanic Field, Arizona, USA: Hightlighting Undergraduate Research in Geology

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Arizona Geological Survey | Scottsdale Community College

Students and faculty of Scottsdale Community College clinging to their data tethered to a helium-filled balloon; blocky SP aa lava flow (right) recent fault scarp (left)

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Aerial and Topographic Analysis of Quaternary Faulting at SP Crater Lava Flow, San Francisco Volcanic Field, Arizona, USA:

Hightlighting Undergraduate Research in Geology

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Introduction

Approximately 60,000 years ago SP Crater, situated in the north- central part of the San Francisco volcanic field between Flagstaff and Grand Canyon, Arizona, erupted and flowed into a structural graben bound by late Quaternary faults. SP Crater is one of about 610 cinder cone volcanoes and 8 large dome complexes in the volcanic field which were emplaced between 6 Ma and 900 years ago, covering an area of about 5,000 km^2 and volcanic volume of about 500 km^3 (Tanaka et al., 1986; Conway et al., 1998).

Recent published and unpublished research by faculty, students and geologists with Northern Arizona University (NAU), Arizona State University (ASU), U.S. Geological Survey (USGS), and Arizona Geological Survey (AZGS) have attempted to constrain the relative and absolute ages of the volcano, its flow and the fault that abuts the northernmost-toe of the flow (Pearthree, 1998; Billingsley, 2007; Rittenour et al., 2015). SP Crater is a monogenic, basaltic-composition cinder cone and blocky aa flow with a flow-volume of 3.3 x 108 m^3 (0.33 km^3) (Harburger, 2014). Harburger also measured the thickness of SP lava flow at 24 locations, ranging from 1 to 45 m, and averaging 18 ± 16 m.

Rittenour et al. (2015) reports an estimated age of SP Crater as 60,000 years, younger than the graben and faults. Age of faulting is late Quaternary; whether faulting has been active since eruption of the SP flow remains uncertain (Pearthree, 1998). The dating techniques and studies employed have not conclusively determined whether the SP lava flowed over an inactive or active fault zone. Did the SP lava flow essentially cover an inactive fault scarp, resulting in topography seen today, or did the lava flow cover an active fault scarp that eventually ruptured the flow?

This question was the focus of a geomorphological study and topographic survey by students and faculty from Scottsdale Community College (SCC) where SP flow intersects the fault at 35.644° North, 111.61° West (Datum NAD83, Zone 12 North). Our objective was to determine the relative age of SP flow and the most recent faulting. This was part of an introductory 2-credit Scottsdale Community College field based geology course, Special Topics in Geology: Geology of the Flagstaff Area (Figure 1). Geology of SP Crater and environs is shown in Figure 2, with the star indicating the study area.

Methods

Students collected original aerial imagery in order to conduct an aerial and topographic survey of the fault and flow.

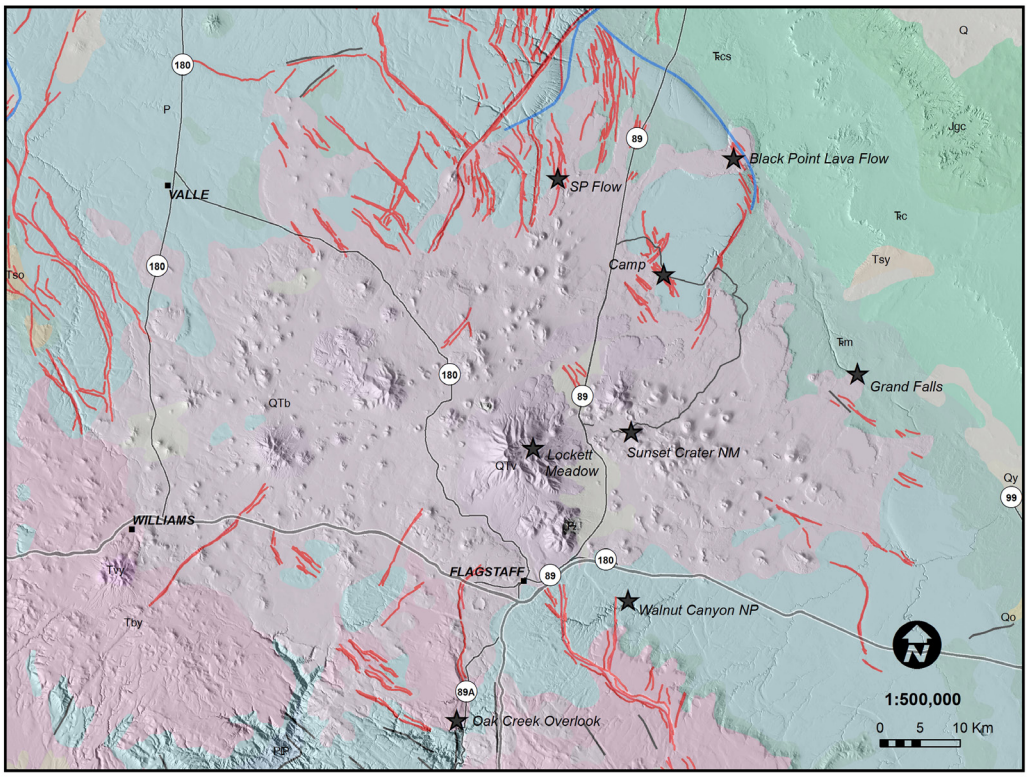

Figure 1. Geologic map of the San Francisco Volcanic Field showing locations of field trip stops for Scottsdale Community College GLG231 course, Fall 2015. Map adopted from Richard et al., 2000. QTb represents volcanic rocks in the volcanic field. Red lines represent young Holocene-age faults. A shaded relief DEM was used underneath geologic map.

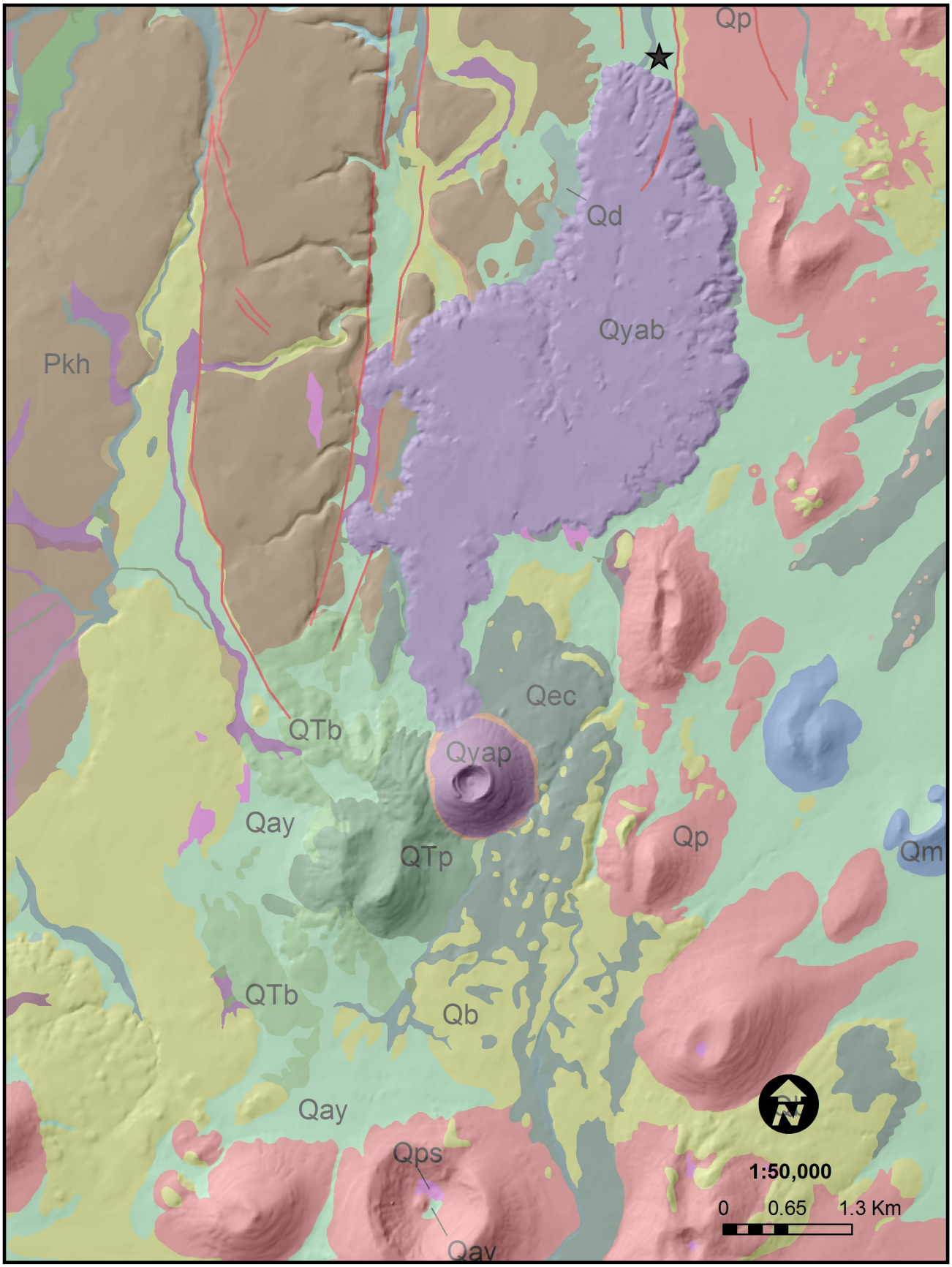

Figure 2. Geologic map of the SP crater and flow area, adopted from Billingsley et al., 2007. Shaded-relief DEM underneath geology layer. See reference for detailed explanations of map units. Red lines represent Quaternary-age faults.

In addition, teams of two to three student engaged in basic geologic/geomorphic mapping. The mapping exercises required students to observe and document changes in soil deposits and landscape morphology, such as slope-breaks, lineaments, streams, landslides, etc. They recorded their field observations on vellum sheets overlying a print from existing aerial imagery, e.g., Figure 3.

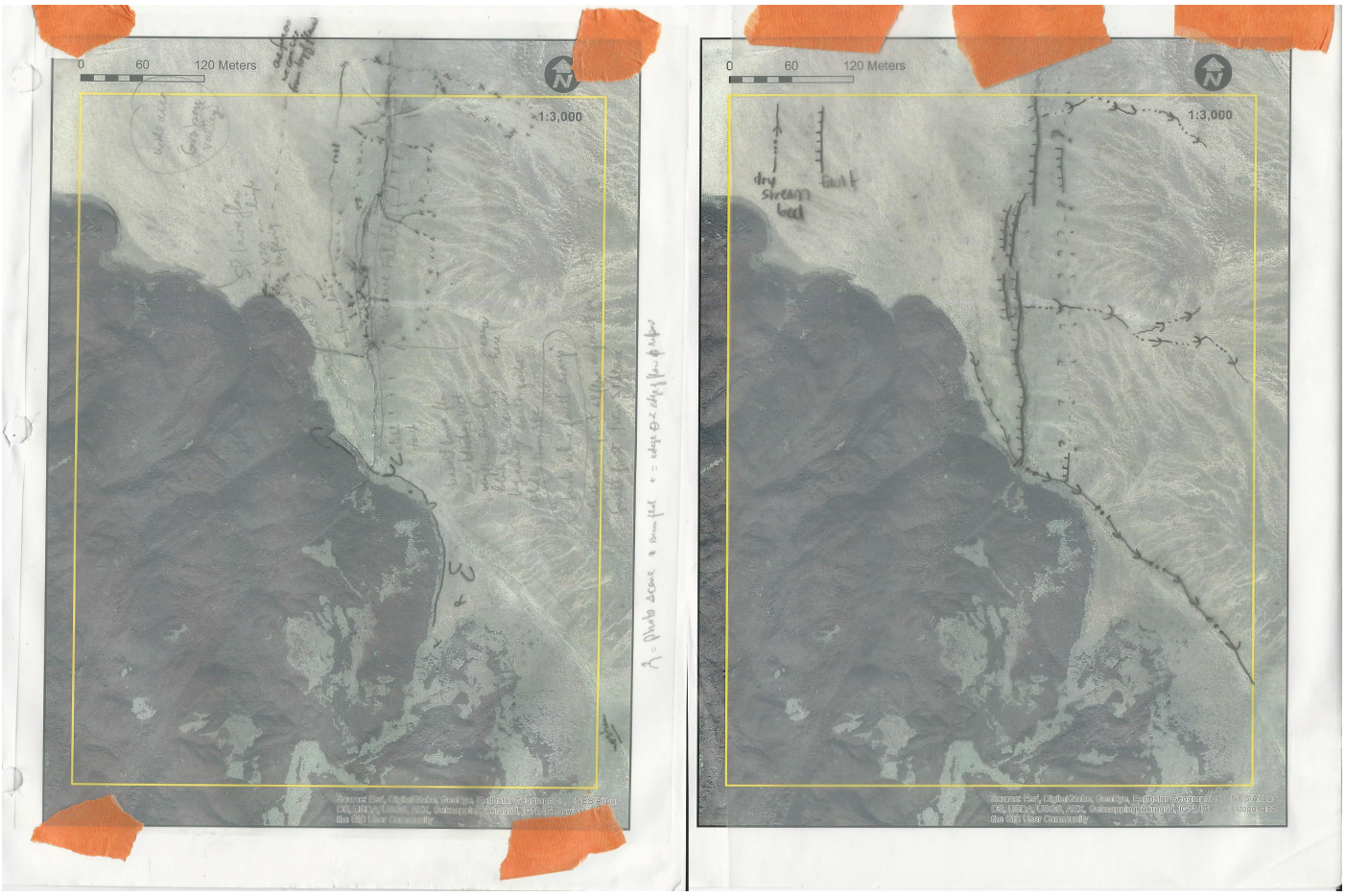

Figure 3. Two example student geomorphic maps on velum sheets overlying existing imagery. Examples of lines above (not clearly visible) include vegetation differences, toe collapse, fault and drainages.

Imagery for this survey was collected using a 2-meter diameter helium-filled weather balloon carrying a 16 megapixel digital camera, provided by ASU's Active Tectonics Group. This was tethered to 250 meters (m) of line connected to a hand-held reel. The balloon was raised between 35 and 100 m above the surface, recording images every 10 seconds. The goal was to collect approximately 2 hours of images (720 images) along the northeastern flank of the flow and along the fault scarp north of the flow. We used overlapping photos from varying altitudes and angles. Agisoft Photoscan software was used to process images and generate an ortho-aerial image of the landscape and digital elevation map (DEM). ESRI ArcMap was used to generate an artificial shaded-relief map from the DEM. All data are in WGS1984 Datum.

Results

Despite wind and rain, conditions at the site were ideal during aerial imagery data collection - overcast skies with winds 0 to 5 mph. This yielded excellent photos without casted shadows. Approximately two third of the way through the planned data collection the camera battery died, resulting in 30 minutes of lost imagery.

A total of 406 photos were taken over 67 minutes of flight time, with 317 of sufficient quality to be used in the image processing software to generate the ortho-aerial image of the landscape and digital elevation map (DEM). Ten ground control points were derived from ESRI ArcMap using an existing 10 m DEM.

Agisoft Photoscan identified over 1 million tie points from the 317 photos used, which allowed over 3.5 million projections for an adequately dense point cloud. Results from the airborne balloon photography are presented in Appendix 1, SP Flow Report v1.

The resulting aerial imagery yielded 19-cm per pixel resolution, with approximately 5.7 m of ground control error, meaning the high-resolution imagery is poorly constrained on the ground in actual space. Existing 10-m DEM maps derived from USGS topographic maps were replaced with a 7.8-cm per pixel (2-order magnitude) with about 160 points per square meter DEM, a substantial improvement. An orthographic aerial image was derived from Agisoft

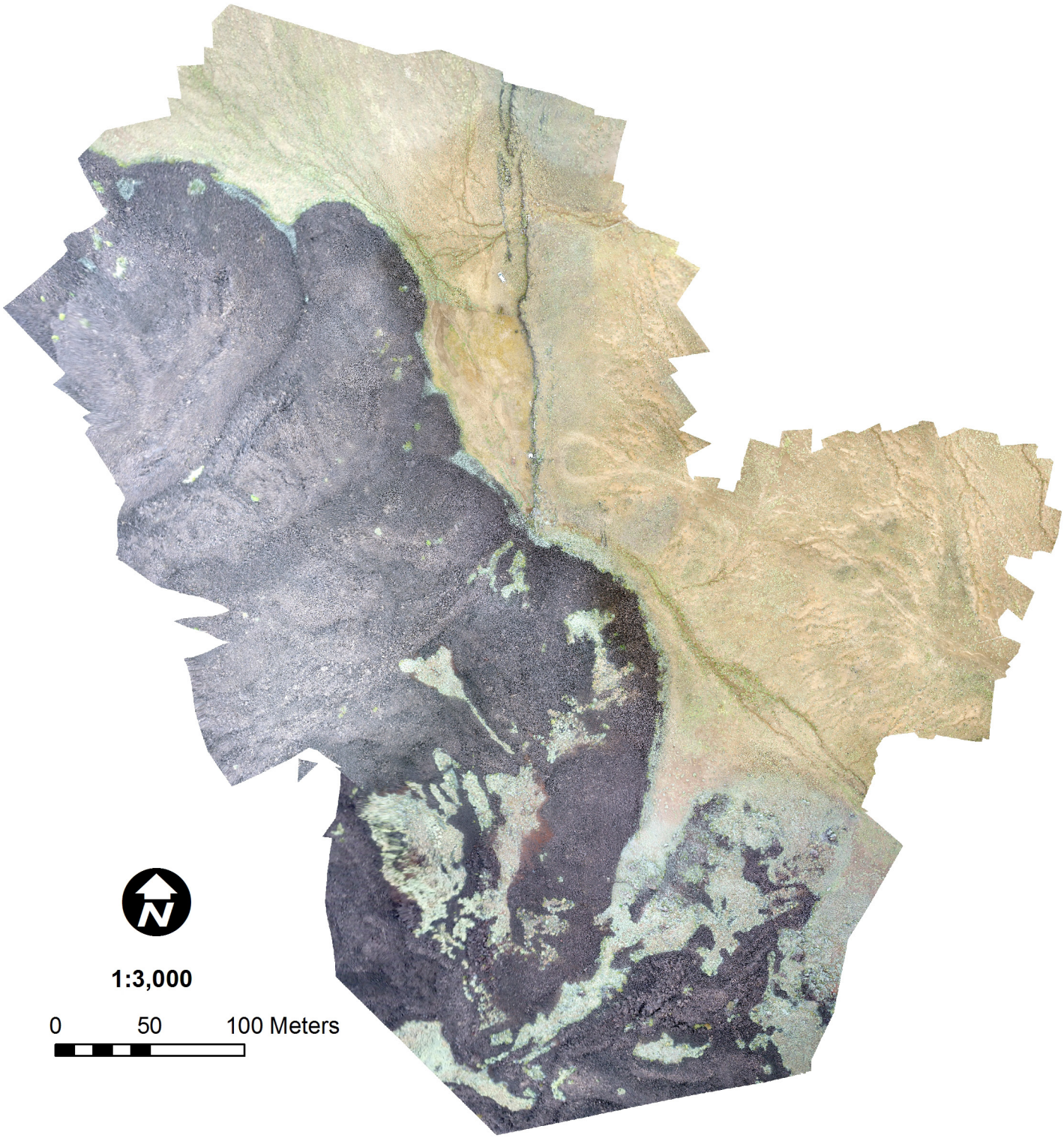

Figure 4. Orthographic aerial image of SP flow and fault. Notice white van near top of image, and white water tank near center.

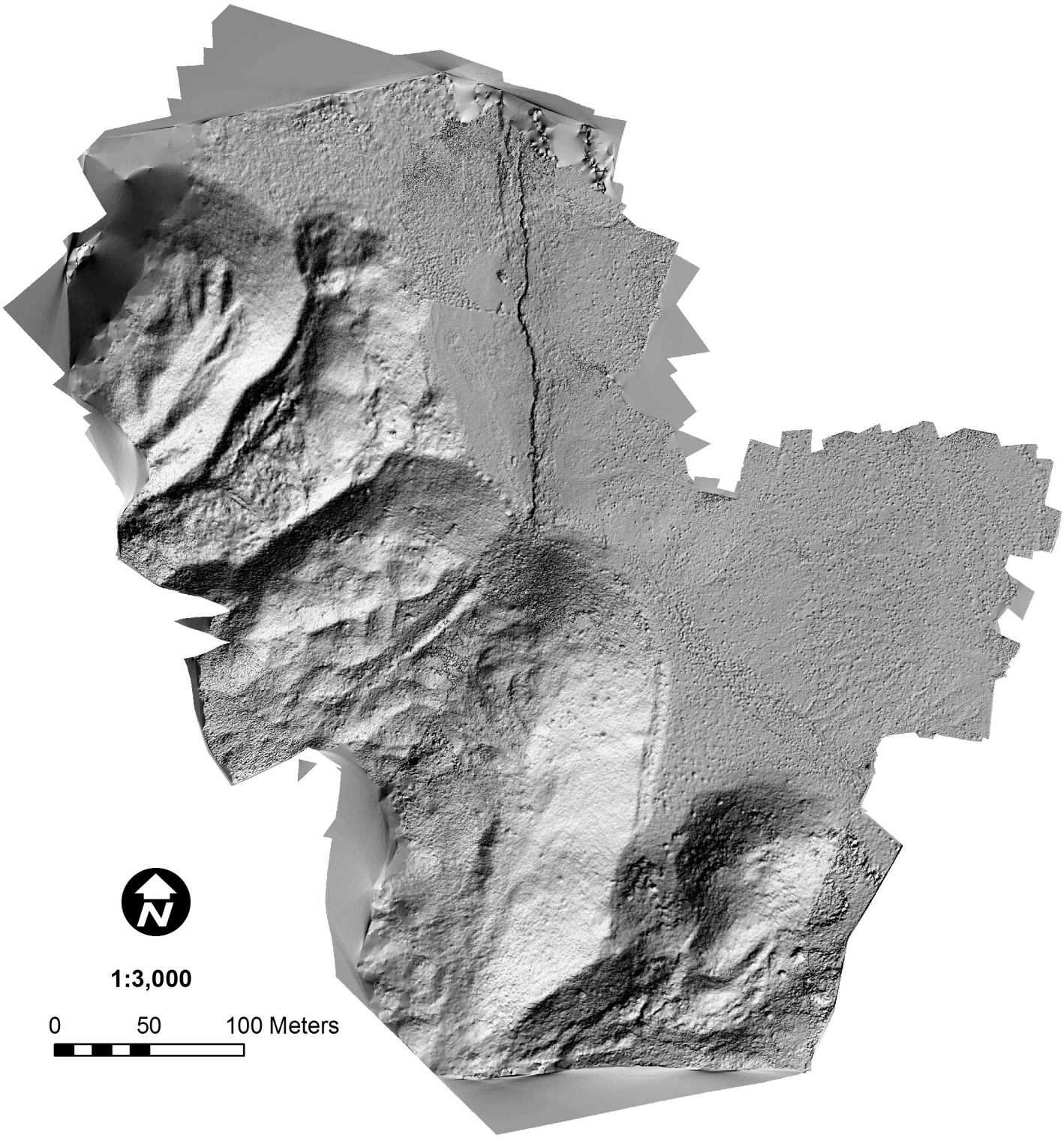

Figure 5. Shaded-relief digital elevation map illuminated from 135 degrees (southeast).

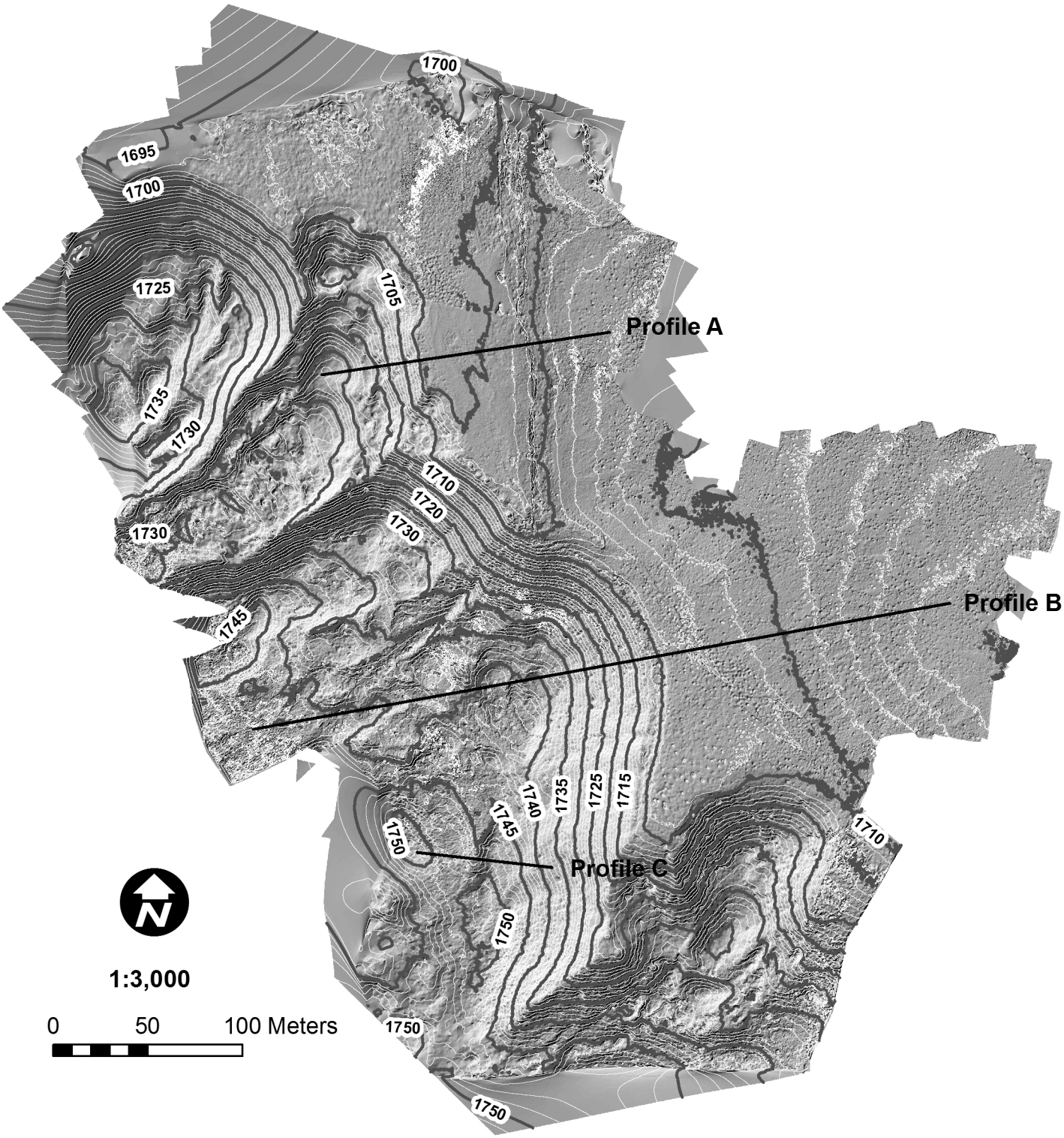

Figure 6. Elevation contour map with 1 m contours and 5 m index contours. Vertical error may be up to 5 m. Elevation profiles shown in Figure 7 .

Photoscan in "SP_Flow_orthophoto_20cm.tif", presented in Figure 4; the shaded-relief map from the DEM is presented in Figure 5. A topographic contour map and three topographic profiles are presented in Figure 6 and 7, respectively.

Geomorphic mapping by teams of students was successful at identifying stream channels, knickpoints along stream channels, slope breaks, changes in vegetation, the fault scarp, and toe collapses along the margins of the lava flow (Figure 3).

Findings and Discussion

The aerial survey successfully captured high-quality images for geomorphic analysis, although coverage of a broader area would be helpful, and could provide additional insight. From the student's geomorphic field maps and processed balloon aerial imagery, several features could be identified and studied.

- Imagery reveals more detail in the fault and smaller associated faults along its strike, outlining the fault zone to approximately 30-to 40-m wide (Figure 4). Kinematic indicators observed in the field at one local fault strand suggested a strike-slip component to otherwise normal dip-slip fault movement.
- Deformation of the north toe of the lava flow by the fault could not be discerned on the balloon imagery or derivative DEM.
- In general, tributaries form in the foot wall east of the fault, and distributaries form in the hanging wall west of the fault, clearly outlined by channels one or two feet wide.
- Channels east of the fault vary in their width-to-length ratio, and some appear to 'dead end' and be filled with sediment toward the fault scarp in the footwall.
- In the footwall immediately east of the fault, and at slightly higher elevations to the far east in Figure 4, erosion is exposing an underlying and older basaltic lava flow.
- Since the SP flow was emplaced, an active drainage has formed along its eastern margin, capturing local drainages.
- Soil color east of the fault varies from light brown to light reddish-brown, which may indicate latest Pleistocene soil development of eolian and argillic horizons, respectively.

The shaded relief map shown in Figure 5 reveals toe collapse outlining the margin of the flow, a characteristic mass-wasting process that forms during a flow event. This aspect of mass wasting raises questions about whether faulting has post-dated the flow or not. If the toe slumps were formed during the

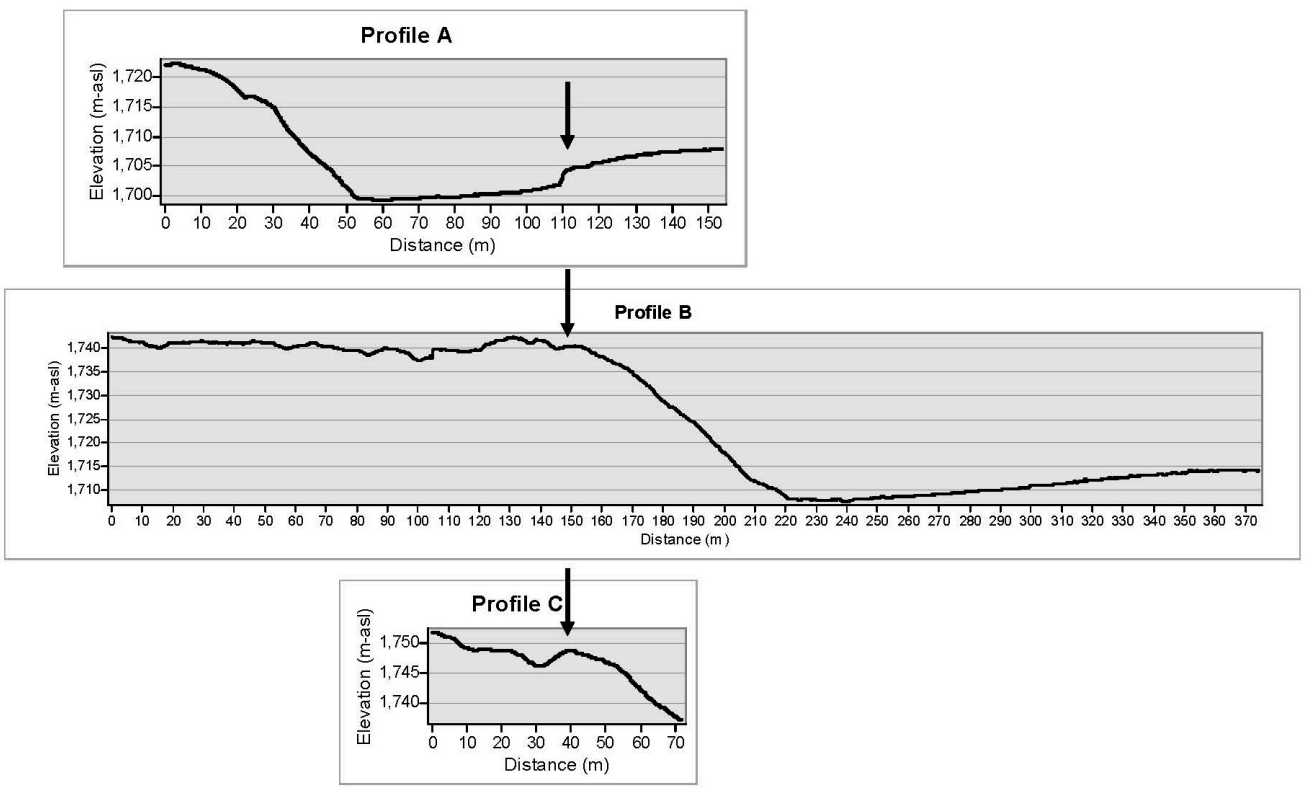

Figure 7. Profiles A, B and C, from north to south as shown in Figure 6. Profiles lined up along suspected strike of fault (black arrow).

Figure 7. Profiles A, B and C, from north to south as shown in Figure 6. Profiles lined up along suspected strike of fault (black arrow).

lava flow then the flow morphology is largely preserved and faulting doesn't seem likely to have occurred since then. If the toe slumps occurred after the flow then it is plausible that a faulted lava flow would have an obscured fault scarp. Given the relative freshness of the fault scarp through an older lava flow and its soil cap (north of SP flow's terminus), mass wasting processes both on and off the flow may not be adequate for comparison.

From the topographic map and profiles in Figure 6 and 7, the contour lines inflect or bend along strike with the fault. Profile A shows the character of the fault, with 3-to 4-m of vertical relief. This relief is not apparent in Profile B, yet may be in Profile C with a similar amount of relief, about 3 to 4 m. Given the ruggedness and variation in topography on the flow, it is not clear if the topographic step in Profile C represents a propagation of the fault into the flow. Additional imagery across the flow margins may be used to compare flow features such as individual lobes, surface roughness, and directionality to the fault zone and surrounding topography.

At the junction between the flow and fault the slump of debris similar to other areas characteristic of the flow is missing (see Profile A in Figure 7). This may be due to the proximity of the main wash and its floodplain adjacent to the flow's angle of repose. Whether this cove between the fault scarp and flow has aggraded with silt and sand over a toe slump, or if the toe slump was removed by erosion, is not clear.

Conclusions

The terrain surrounding SP crater and lava flow offer an excellent and world-class opportunity to study landscape geomorphology in a Quaternary volcanic field in an arid to sub-arid environment. While SP lava flow flowed into an existing fault-graben, our preliminary interpretation based on this survey is that the fault does not appear to have ruptured the SP lava flow.

The balloon-derived imagery produced derivative tools (e.g. high resolution DEM) adequate for analysis of subtle geomorphic features. Further field mapping and additional aerial imagery are needed at this site to adequately define age relationships and processes.

In regards to doing this type of research with a field-based introductory geology class:

- This approach to field-based research is cost effective, yields useful data, and works well with relatively inexperienced personnel. Moreover, it can be powerful reconnoitering tools for identifying areas for additional study.
- Results demonstrate that valuable data can be gathered with interested students under professional guidance.
- The precision of stereo-photogrammetry can be increased with the addition of more images. Because the images can be captured at more than one session, there is a potential for enlisting other researchers to capture and share data in an open-resource environment to enhance the quality of the stereo-photogrammetry output.
- This work suggests that partnerships with educational institutions can utilize personnel, student interest, and funding sources, to produce research materials that supplement and build on ongoing research.

Challenges and Future Work

Our efforts were limited to about 2.5 hours of work on-site, which leaves much room for more work and much more detail. Collection of high-precision ground survey points would have improved geospatial ground control useful for this kind of survey. While results of the DEM and orthoimagery were quite good, knickpoints with only inches to a foot of relief were not captured in this exercise. More detail along stream channels across the fault zone and into the footwall would be an area for further consideration. More time spent mapping subtle changes in vegetation and isolated outcrops could have generated a more thorough analysis. Models of seismic shaking and faulting across a flow like SP flow can help test our knowledge about the physical properties of a lava flow during an earthquake event.

The cognitive and affective impact of this type of field experience on introductory geology students needs study. Additionally, how can partnerships between 2-year community colleges, 4-year research institutions, tribal institutions and government agencies be nurtured to enhance future collaboration?

The results of this work can be used to continue collecting images and ground control for an improved suite of digital products, as well as continuing to map where SCC students last left off.

Acknowledgements

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Wolfe, E. W., Newhall, C. G., & Ulrich, G. E., 1987, Geologic map of the northwest part of the San Francisco volcanic field, north-central Arizona, scale 1:50,000, U.S. Geological Survey Miscellaneous Field Study Map, MF-1957.

Supplemental Data

SP Flow Report v1.PDF – Agisoft Photoscan summary report of SfM results, 5 p.

SP_Flow_orthophoto_20cm.TIF – GeoTIFF orthophoto, 20 cm pixel resolution.

SP_Flow_DEM.TIF – GeoTIFF DEM.

SP_Flow_shadedrelief.JPG – non-referenced shaded-relief image file.

SP Flow Model 500K faces.PDF – 3-Dimensional model, 3D PDF file.

SP_Flow_Points2.PDF – 3-Dimensional model of point cloud, 3D PDF file.

Photos: 318 photos taken from balloon.

Link to GLG231AC field course photos:
https://picasaweb.google.com/108846976427706520496/101515SCCGLG231GeologyOfFlagstaffArea?authuser=0&feat=directlink

Vimeo video of ASU's SfM project at SP flow, by Merri Lisa Trigilio: https://vimeo.com/96496263