USING AGISOFT PHOTOSCAN TO COMPARE TERRESTRIAL AND PLANETARY VOLCANIC FEATURES.

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Introduction: The Agisoft Photoscan software aligns images from multiple cameras and uses shape-from-motion (parallax) to create high-resolution digital terrain models (DTMs) [**1**]. It is commercially available, and can ingest photos from common consumer- or professional-grade handheld cameras, in addition to more mobile imaging systems (i.e. drones). We have tried some similar open-source programs, but none of them allowed as much manual control. We created several high-resolution DTMs of terrestrial volcanic features that are believed to be analogous to features on the Moon and on Mars. We explore the potential for using these DTMs to better understand these analogs by comparing profiles and roughness measurements.

Terrestrial DTMs: We created DTMs of three terrestrial cones (summarized in **Table 1**) in Photoscan using photos taken with some combination of smartphones, handheld semi-professional cameras, and a DJI Mavic Pro drone (all of which used 12-16 megapixel sensors). The two Arizona cones were chosen for geographic convenience, while the Hawaii cone was selected as an Earth analog for lunar volcanic features. The photos for each site were taken by 1-3 operators. To minimize changes in lighting, images at two of the three sites were taken over 1-2 hours; at Colton crater, images were taken over the course of a 4.5 hour hike around the crater (although this did not have an obvious effect on the resulting model). The photos were imported and aligned with spatial control information derived from the geolocation tags embedded in all images except those from one of the handheld cameras; from the aligned images, we created a point cloud, which was then used to generate the final DTM. Processing each DTM took ~2-4 hours of human interaction and ~1-3 days of computer time.

Our previous analysis indicated that scale errors of ~2-3% are expected in the absence of high-accuracy ground control points [**2**]. A physical scale bar in the SP model had a length error of $\lesssim$0.5%. In the Colton model, ground points from a consumer GPS (3-4 m reported uncertainty) suggested a ~2° clockwise rotation and a ~1-2% scale error. We have not yet done error analysis on the Hawaii model.

Planetary DTMs: We compared our terrestrial DTMs with DTMs of features on Mars and on the Moon, created, respectively, by the HiRISE team [**3**] and the LROC team [**4**], with pixel scales from 1 m to 5 m (**Table 1**). In addition to volcanic cones, two Copernican impact craters of a similar diameter to Colton Crater (terrestrial maar) were also included to see if they were quantifiably distinguishable from the volcanic features.

Analysis: We compared profiles and depth/diameter ratios of these features to show that Photoscan DTMs can be used as analogs to planetary DTMs.

Background. Previous studies have used DTMs, both planetary and terrestrial, to investigate the ages and internal structures of volcanic cones. Small lunar cones ($\lesssim$2km) have been considered similar to terrestrial cinder cones in terms of morphology; thus, our understanding of terrestrial formation processes has been used to interpret planetary cones [**5,6,7**]. Many authors [e.g. **7,8,9**] use DTMs to discuss differences in morphology, morphometry, and probable composition between cones on Earth, the Moon, and Mars, as well as implications for various models of small cone formation. Higher resolution DTMs on all bodies allow us to investigate the structure and composition of these cones and infer the eruption conditions that formed them. We now have high resolution DTMs on the Moon and on Mars [**3,4**]; the Agisoft Photoscan software allows us to quickly and conveniently create terrestrial DTMs of analogous features in order to make comparisons.

Methodology. Porter 1972 [**10**] characterized over 300 0.1-1.3km diameter cinder cones on Mauna Kea to establish typical ratios between cone width and depth, and between crater dimensions and cone size. Crater depth/crater width was found to be 0.14; however, this value represents a minimum depth only due to post-eruption filling, which can make them seem similar to terrestrial impact craters. Because our Photoscan DTMs are currently most complete over craters rather than entire cones, we used profiles taken over our 15 features (**Fig. 1**) to find crater depths and widths.

Comparison. We plotted crater depth and width for two terrestrial cones and one terrestrial maar, five martian cones, five lunar cones, and two lunar impact craters. **Fig. 2** shows that the terrestrial features were evenly distributed around [**10**]'s 0.14 ratio, while the lunar and martian cones had lower ratios, representing shallower/broader morphologies. The two impact craters fell above the line.

Conclusion: Photoscan provides a simple method of quickly producing very high-resolution DTMs of features, without requiring expensive and logistically difficult aerial photographic or LIDAR surveys.

The use of a drone in creating the model of SP crater significantly increased the quality of the DTM, by providing coverage of the flanks and a stable baseline of GPS coordinates, but was not necessary for modelling the interior of the crater. We found that modelling generally works best when there are images taken from within ~60° of the surface normal, so depressions can easily be mapped using handheld cameras. Flat surfaces and large positive relief features greatly benefit from the use of a low-cost drone to provide context and potentially tie together higher-resolution ground-level photography.

In addition to Earth analog sites, Photoscan can be used to model extraterrestrial surfaces using images from landed missions. Examples include route-mapping using images from the Mars Curiosity rover [**11**], and modelling the sampling trench dug at Shorty crater during the Apollo 17 mission [**2**].

References: [**1**] www.agisoft.com [**2**] Wagner et al. (2017) *3rd Planet. Data Wkshp.* #7023 [**3**] Kirk R. L. et al. (2008) *J. Geophys. Res., 113,* E00A24. [**4**] Henriksen M. R. et al. (2017) *Icarus 283,* 122-137. [**5**] Wood (1979) *Proc. Lunar Sci. Conf. 10th*, 3, 2815-2840 [**6**] Whitford-Stark and Head (1977) *Proc. Lunar Sci. Conf. 8th*, 3, 2705-2724 [**7**] Lawrence et al. (2013) *JGR Planets*, 118, 615-634, doi:10.1002/jgre.20060 [**8**] Stopar (2016) PhD dissertation, ASU [**9**] Brož et al. (2015) *JGR Planets*, 120, 1512-1527, doi:10.1002/2015JE004873 [**10**] Porter (1972) *GSA Bull.*, 83, 3607-3612 [**11**] Ostwald and Hurtado. (2017). *48th LPSC* #1787

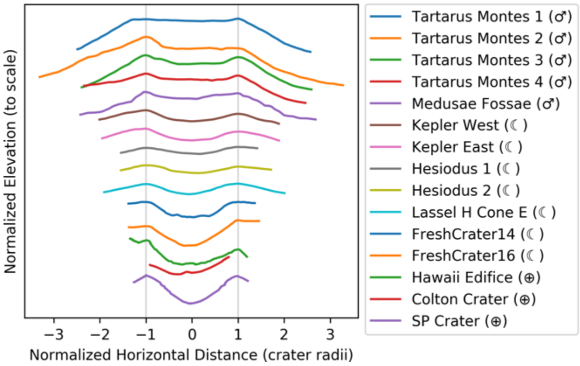

Figure 1: DTM profiles, normalized by peak crater radius. See **Table 1** for actual depths and diameters.

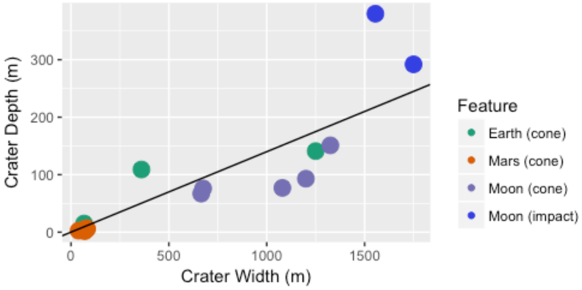

Figure 2: Plot of crater depth and width for the measured cones and impact craters. Line marks the 0.14 depth/diameter relationship found in [**10**] for terrestrial cinder cones.

Table 1: Terrestrial and Planetary DTM sites

Site	Planet	Camera(s)	Image Count	Scale (m/px)	Crater Widths (m)	Crater Depths (m)
Colton Crater	Earth	iPhone 7	52	0.23	1250	93
SP Crater	Earth	DJI Drone, iPhone 7, LUMIX DMC-LX100	434	0.12	360	109
Hawaii Edifice	Earth	Samsung Galaxy, Canon EOS 70D	496	0.08	65	15
Cone E of Lassell H	Moon	LROC NAC	-	3	1325	151
Fresh Crater 14	Moon	LROC NAC	-	3	1750	292
Fresh Crater 16	Moon	LROC NAC	-	5	1555	380
Hesiodus (two cones)	Moon	LROC NAC	-	3	1080, 1200	77, 93
Kepler (two cones)	Moon	LROC NAC	-	5	665, 675	67, 76
Cone near Medusae Fossae	Mars	HiRISE	-	1.01	40	2.6
Cones in Tartarus Montes (four cones)	Mars	HiRISE	-	1	70, 70, 80, 80	1.7, 5.3, 6.8, 5.3