LUNAR SURFACE GEODESY: LOCAL GEODETIC NETWORKS FOR A TECTONICALLY ACTIVE MOON T. Marshall Eubanks[1], W. Paul Blase[1], [1]Space Initiatives Inc , Newport, Virginia 24128 USA; tme@space-initiatives.com;

Introduction: The lunar surface is often assumed to be entirely static, except for tidal deformations and meteorite impact. However, recent work has shown a connection between at least some of the surface moonquakes and geologically young thrust faults on the Moon, with 7 of the 28 ALSEP events being within 60 km of an apparently young lobate scarp. Conventional crater-size / frequency dating indicates that these lobate scarps are <50 Myr old [1]. Another study [2] shows that geologically young lobate scarps and wrinke ridges are assocated with fresh boulder fields, with large numbers of 1 to 10 meter boulders on top of or beside ridges in the fault area. The rapid destruction of such boulder fields by meteorite impacts indicates that these areas must be very young (< 10 million years in some cases).

Activity in the Gruithuisen Dome Region: In an extensive search of the entire Dome region we found one location with evidence of recent tectonism, a depression (see Figure to the South of the Gamma Dome we call the Gamma Pit [3]. The Gamma Pit has many exposed boulders inside it, although there are almost none on top of the Highland Peninsula or in the adjacent mare region, a clear indication of recent activity. Almost all of the exposed boulders are on the mare side of the pit, and are presumably exposed by tectonic activity. We also found 5 boulder tracks within the pit (see Figure 2), a clear indication of recent activity. One hypothesis is that the pit results from the collapse of a lava tube or chamber [4], but if so this collapse is presumably still ongoing, and the chamber must have been very large and ∼1 km high. In any case, the Gruithuisen Gamma pit indicates that active tectonic regions on the Moon are not necessarily only associated with compressional faults at lobate scarps and wrinkle ridges. Active tectonic features such as this are high priority targets for future missions focused on lunar surface geodesy.

A Geodetic Network for Active Tectonic Areas: The seismic moment (M_W 4.1) of the largest observed shallow moonquake, together with an estimate of the fault size in that location [5] indicates that there could have been meter level ground motions for that event, and presumably for other such events, large enough to be both easily detected with geodetic measurements and also to present a danger for any astronauts working in the vicinity. Experience with terrestrial tectonics suggests that these regions likely also have centimeter level pre, post and a-seismic motions. Just as for the Earth, these motions can be observed on the Moon with geodetic instruments deployed in active tectonic regions. The combination of surface geodetic measurements and subsurface geophone observations will enable the correlation of subsurface and surface motions.

At Space Initiatives Inc (SII) we are developing a combined geodetic network, the Lunar Geodetic Observer (LGO), for deployment in tectonically active lunar regions on the near-side using Mote ballistic penetrators [6, 7]. The Motes (∼1.5 kg each) can be deployed from a CLPS Lander at and appropriate time in the landing sequence to fall into the center of the target area, while the CLPS lander proceeds to soft land anywhere from a few 100 m to a few km away. This deployment gives each Mote a velocity spread sufficient to produce a penetrator spread of up to ∼1 km on the surface, at velocities up to 300 m/s [7].

The LGO would deploy up to 12 Motes in an array up to 1 km across, providing a combination of Lunar Laser Ranging (LLR) retroreflectors [8], Very Long Baseline Interferometry (VLBI) COMPASS radio beacons [9], and 802.15.4 UltraWideBand (UWB) radio links on the surface providing cm-level position determinations between the deployed nodes, together with geophones carried beneaththe lunar surface (Figure 3). The LGO could thus provide cm-level determinations of local motions, allowing faults to be monitored (and fault motions compared to local seismology) even in the absence of large moonquakes on the instrumented fault. A km-scale LGO with multiple LLR retroreflectors would also support differential LLR measurements, thus enabling determinations of the local vertical to within 10's of μm [10]. With penetrator deployments down into the thermally protected levels ∼1 m below the lunar surface (Figure 4), the penetrator electronics would be protected from both extreme temperature swings and surface radiation. A local LGO network could also serve as a single node in the proposed Lunar Geophysical Network [11].

References: [1] T. R. Watters, et al. (2019) *Nature Geoscience* 12:411 doi. [2] A. Valantinas, et al. (2020) *Geology* 48(7):649 ISSN 0091-7613 doi. [3] T. M. Eubanks, et al. (2022) in *LPI Contributions* vol. 2678 of *LPI Contributions* 2918. [4] M. S. Robinson, et al. (2015) *Icarus* 252:229 doi. [5] P. S. Kumar, et al. (2019) *Geophys Res Lett* 46(14):7972 doi. [6] T. Eubanks, et al. (2021) in *AGU Fall Meeting Abstracts* vol. 2021 P11D–04. [7] C. J. Ahrens, et al. (2021) *The Planetary Science Journal* 2(1):38 doi. [8] V. Viswanathan, et al. (2020) *arXiv e-prints* arXiv:2008.09584. arXiv:2008.09584. [9] T. M. Eubanks (2020) *arXiv e-prints* arXiv:2005.09642. arXiv:2005.09642. [10] M. Zhang, et al. (2022) *Astron Astrophys* 659:A148 doi. [11] C. R. Neal, et al. (2021) in *2021 Annual Meeting of the Lunar Exploration Analysis Group* vol. 2635 of *LPI Contributions* 5039.

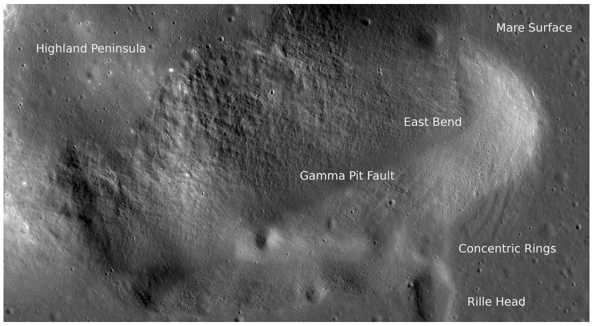

Figure 1: A portion of LROC NAC frame M135452859LC ∼4 km wide, showing a high incidence angle view of the Gamma Pit region including the "East Bend," an approximately right-angled feature that is the lowest visible part of the Highland Peninsula, ∼250 meters lower than the mare surface and ∼1 km below the peak of the Highland lava to the North. The Gamma Pit region is clearly geologically young; if it results from the collapse of a subterranean lava cave, the collapsed void was presumably several km long and up to 250 m high.

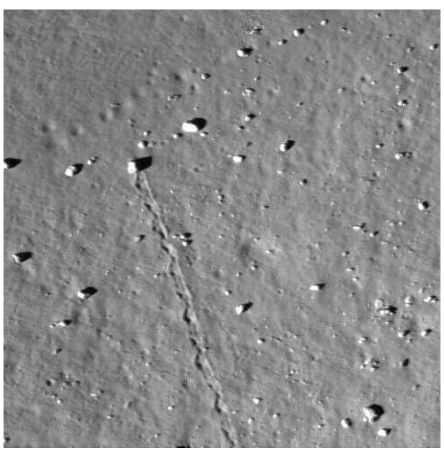

Figure 2: An enlargement of part of LROC NAC image M135452859LC at the bottom of the Gruithuisen Gamma pit. A boulder, with a diameter of about 5 meters, has rolled down to almost the Mare-Highland fault itself (visible here as a line of small pits, ∼10 m in diameter, trending almost perpendicular to the boulder track). This is one of several indications of recent activity in this depression, as described in [3]

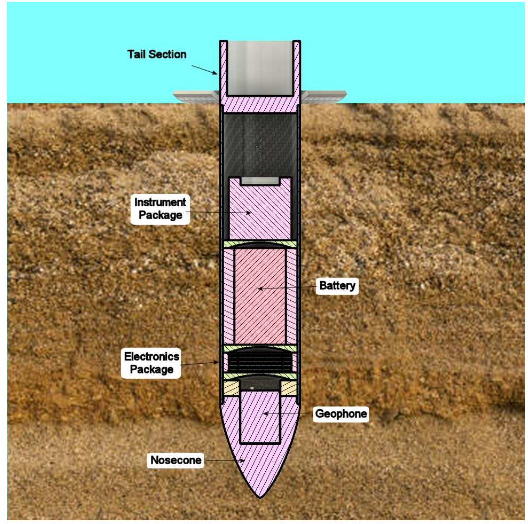

Figure 3: A Mote penetrator after deployment into the lunar regolith (shown in this artist's conception with a very shallow regolith penetration). The electronics and most of the scientific payload would be carried in the penetrator itself and would be automatically embedded below the lunar surface. Cameras, other instruments, and communication antennas are carried in the tail section left on the surface.

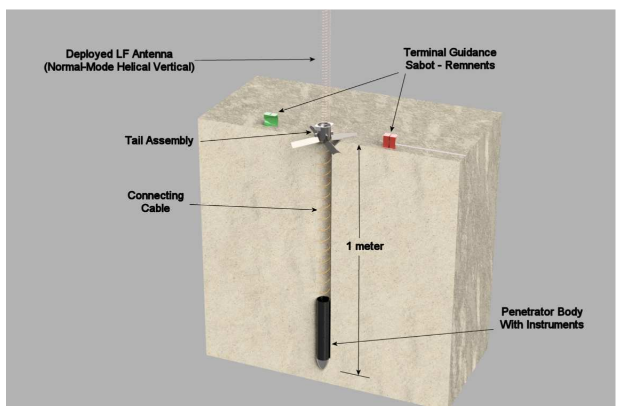

Figure 4: A Mote penetrator after deployment with a typical 1 meter penetration into the lunar regolith after deployment from a CLPS lander. The Mote electronics will be below the insulating surface layer of the regolith, and should remain at a constant temperature (about 250 K near the equator) throughout the entire lunar day.