NEAR-TERM LUNAR SURFACE GRAVIMETRY SCIENCE OPPORTUNITIES. Kieran A. Carroll, David Hatch[2], R. Ghent[3], S. Stanley[3], N. Urbancic[3], Marie-Claude Williamson, W.B. Garry[4], Manik Talwani[5] [1]Gedex Inc., 407 Matheson Blvd. East, Mississauga, Ontario, Canada L4Z 2H2, kieran.carroll@gedex.com, [2]Gedex Inc., [3]University of Toronto, [4]NASA GSFC, [5]Rice University.

Introduction: We describe a new-technology planetary surface gravimeter which is expected to have sub-milliGal repeatability on the Lunar surface. This instrument is small enough to be carried by several near-term Lunar rover missions, via which it could conduct Lunar surface gravity surveys in much the same way that gravity surveys are carried out on Earth. Concepts for such surveys are outlined for each of those missions, with a focus on scientific and Lunar resource exploration objectives that could be achieved by each survey.

VEGA instrument: Gedex is developing the VEGA (*VEctor Gravimeter for Asteroids*) planetary gravimeter instrument, which when used as a Lunar surface gravimeter is targeting a long-term repeatability of better than 1 milliGal. This is somewhat better than that of the Lunar Traverse Gravimeter that was used to conduct the only off-Earth planetary surface gravity survey to date, during the Apollo 17 mission [1]. VEGA's development is currently at the breadboard stage, and we plan to test-fly a prototype aboard a spacecraft by early 2017. The instrument's main specifications are: mass < 1.5 kg, volume < 1.5 litres, power consumption < 5 W, time per measurement ~ 10 minutes.

We have identified several near-term Lunar surface gravity survey opportunities, each with a significant scientific and/or resource exploration goal. Three of these are summarized below.

Surveying around pit craters to map sublunarean voids: The recent discovery of pit craters on the Moon has exposed the existence of voids below the Lunar surface [2], [3], [4], [5]. These voids may be localized impact melt ponds which have subsequently drained, or they may be lava tubes. In [6], we note that such voids will generate a low bouguer gravity signal at the surface above and near those voids, and that a surface gravity survey near a pit crater could thus map the extent, size and depth of the void into which it has made a skylight. For example, a 150 m radius lava tube 50 m below the Lunar surface could produce a gravity low above it as large as 5-10 milliGal, perhaps larger. Such a signal would be easily measurable by the VEGA instrument.

There is a near-term opportunity to conduct such a survey. The company Astrobotic plans to send CMU's "Andy" Lunar rover to the Moon in 2017 [7] to compete for the Google Lunar X-Prize. Their target is the partially-collapsed 230 m diameter pit crater in Lacus Mortis, at 44.96°N, 25.62°E, shown in Figure 1. This feature could be a skylight into a lava tube, or a collapse into a subsurface void from cooling of a melt pond. A local surface gravity survey, say within a 1 km radius around this crater, could distinguish between these possibilities, mapping the shape, extent and size of any void underlying this feature. This could help inform scientific understanding of the history and nature of Lunar impact melts and/or formation of lava tubes. It could also provide an initial reconnaissance of the subsurface void, in advance of future missions to descend into the void space and explore it from the inside.

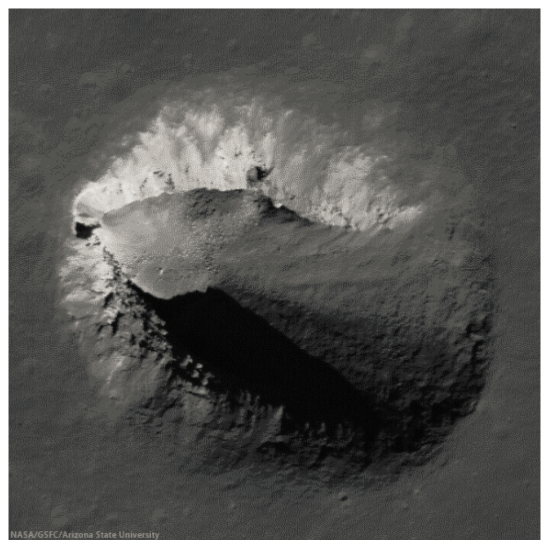

Figure 1: LROC Narrow Angle Camera (NAC) observation M126759036L, orbit 3814, April 24, 2010; 49.4° angle of incidence, resolution 0.5 meters from 45.56 km [NASA/GSFC/Arizona State University].

Surveying for ice deposits in permanently-shadowed polar craters: Numerous lines of evidence, developed since the Clementine bistatic radar experiment in 1994 and the Lunar Prospector Neutron Spectrometer experiment of 1998, have indicated that water ice might be present at both the north and south Lunar poles. Various conjectures have been mooted regarding the form that such ice deposits could take. Some of those forms could have a bulk density different from that of the Lunar regolith surrounding an ice deposit, thus producing a potentially-measurable surface gravity anomalous signal.

For example, ordinary Lunar regolith near the surface has an *in situ* porosity as high as 50% (cf. Table 9.5 in [8]), the voids in and between particles being "full of vacuum," thus having a bulk density (typically 1.5-1.7 g/cm^3) about half the specific gravity of the minerals comprising the particles. In permanently-shadowed polar regions, ice could potentially infiltrate these voids, thus forming diffuse frost-like ice deposits. The resulting bulk density of the regolith would then increase, to perhaps as high as 2-2.2 g/cm^3 if the voids were completely filled with ice.

Alternately, if ice deposits were found in the form of large slabs or lenses of pure water ice (perhaps buried beneath a surface layer of regolith), the density of such deposits would be 1 g/cm^3, considerably below the typical regolith bulk density of 1.5-1.7 g/cm^3.

A Lunar rover equipped with a sensitive enough gravimeter might detect an anomalous gravity high or low when traversing above such deposits, and provide a means for discerning the type and extent and thickness of a deposit. There is a potential near-term opportunity for carrying out such an investigation. NASA's proposed Resource Prospector mission plans to carry a rover to a region near one the Moon's poles, specifically to search for ice deposits [9], [10]. If a VEGA instrument were to be added to the baseline set of instruments already planned for that rover, it could potentially provide gravity data complementary to its neutron and NIR spectrometer remote sensing data, perhaps helping to find ice deposits accessible by the rover's drill, and providing context to help investigators interpret the signatures generated by the instrument s used to analyze the sampled brought up by the drill.

Follow-up gravity survey in the Taurus-Littrow valley: As described in [1], the Lunar Traverse Gravimeter instrument was carried on the Apollo Lunar lander, where it was used by astronauts Gene Cernan and Harrison Schmitt on their lunar rover to conduct a ~ 10 km traverse across the Taurus-Littrow valley floor, over which 22 gravity measurements were made at 9 stations, as illustrated in Figure 2. The general character of the resulting bouguer anomaly is a flattish profile across the valley, rolling off at either side, which one of us [1] interpreted to indicate a 1 km thick basalt slab beneath the valley floor.

However, there is also a 5-10 milliGal gravity low in the centre of the valley, at Station 5 of the survey, which remains unexplained. Assuming this is not a reading error, it could represent either local topographic effects (which we are currently investigating using the latest LOLA topography data), or some volume of anomalously low-density material in the subsurface near that location. While we have several conjectures regarding possible geological explanations for this gravity low, the relatively low spatial resolution of the original Apollo 17 gravity survey makes it difficult to resolve these. Higher-resolution gravity data would help us to pursue this question further.

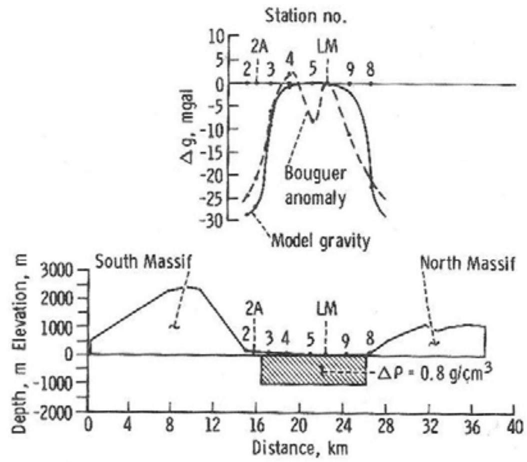

Figure 2: The Apollo 17 Lunar Traverse Gravimeter was used to infer the presence of a 1 km thick basalt block beneath the Taurus-Littrow valley floor [1].

There is a potential near-term opportunity to obtain just that data. The Google Lunar X-Prize team, Part-Time Scientists, plans to land their "Audi Lunar Quattro" rover near the Apollo 17 landing site in 2017, and to operate that rover over the course of a Lunar day in that vicinity [11]. If equipped with a VEGA instrument, that rover could carry out a higher-resolution follow-up gravity survey covering the area around Station 5 from the Apollo 17 gravity survey. The numerous scientific studies of the Taurus Littrow valley during and since Apollo 17 would provide excellent context for more-refined interpretation of the subsurface structure there, using new and better gravity data.

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