EXPLORING LUNAR SUB-SURFACE OBJECTS USING SURFACE GRAVIMETRIC SURVEYS. N. Urbancic[1] , S. Stanley[1], R. Ghent[1], K. A. Carroll[2], D. Hatch[2], M.C. Williamson[3], W. B. Garry[4] and M. Talwani[5], [1]University of Toronto, [2]Gedex Inc, [3]NRCan-Geological Survey of Canada, [4]NASA Goddard Space Flight Center and [5]Rice University.

Introduction: Surface gravity surveying is a well developed terrestrial geophysical technique, used to detect subsurface density variations, which in turn can reveal subsurface geologic features. Here we perform a feasibility study to determine what major science questions can be answered by a rover-mounted, highly compact gravimeter and gravity gradiometer being designed by Gedex Inc.; a Toronto-based geophysics company.

Several satellite and manned missions to the Moon have provided gravitational data. Most recently, the GRAIL (Gravity Recovery and Interior Laboratory) survey produced the highest resolution global gravity field from a satellite mission to date, of ~13km [1]. However, because the wavelength resolvable by these satellites is about equal to their altitude, even the highest resolution satellite gravity surveys are not sensitive enough to detect fine-scale sub-surface structures on the Moon. Therefore, many of the details about the lunar sub-surface geology have been derived primarily from the manned Apollo missions [2]. In particular, the Apollo 17 mission carried a gravimeter, which was used to measure the local gravity field near the landing site [3]. This was the first and only successful gravity survey on the surface of the moon. Now, with privatized space travel to the moon becoming more accessible than ever, and with advances in space gravimetry instrumentation, performing a high-resolution gravity survey on the surface of the moon is entirely viable.

Methods: Gedex Inc., is developing two types of gravity-measuring instruments suitable for use on Lunar rovers. The first of these is a compact (10x10x15 cm, 1.5 kg) gravimeter, able to measure the complete gravity vector with a repeatability target of 1 milliGal on the Moon. A breadboard of this instrument has been built and tested, and a flight-test version is under development. The second is a gravity gradiometer, designed to measure the full gravity gradient tensor, with a target repeatability of 1 Eotvos; that instrument is at a preliminary design stage. Gradiometers are much more sensitive to near surface features, whereas gravimeters are more effective at detecting deeper subsurface features.

With these estimates of repeatability for these instruments, we have conducted preliminary modeling to predict the magnitude of the gravity and gravity gradient signals produced in response to targets of interest in the lunar subsurface.

Results: The first target of interest is a single buried subsurface rock. We produced models of the gravimeter and gradiometer responses for various types of rocks, which were modeled as uniform density spheres. This provided limits on what parameters, such as depth, density contrast (between the target and the background) and size, are necessary for detection at the predicted sensitivity of the instruments.

Figure 1 shows the maximum gravity signal (vertical component) as a function of depth to the centre of the source, for a series of models each with a unique combination of density contrast and radius. The predicted repeatability of the instrument has been plotted as a yellow horizontal line and the coloured vertical lines each correspond to the minimum depth at which that radius sphere (labelled with the same colour) is buried.

The models that are detectable at the predicted repeatibility of the gravimeter, and correspond to rocks that are fully buried (depth > radius), have been outlined in green in the legend. For larger density contrasts, such as 6400 kg/m^3, e.g., corresponding to some sort of metallic ore, the radius of the sphere can be as small as 10m and be detectable by the gravimeter. However, for smaller density contrasts, closer in composition to the background material, such as 400 kg/m^3, the radius needs to be as large as 100m to be detectable by the gravimeter.

The results for the gravity gradient signals (in the vertical direction) for the same models as Figure 1 show that all of the density-contrast and radius combinations tested met the repeatability criteria of the instrument at some depth. This is as expected because the gravity gradient method is much more sensitive to small surface features.

These gravity gradiometer results provide an upper limit on the depth for detectability of certain density contrast and radius combinations using the gravity gradient method. For example, a sphere of radius 0.5m, can be buried up to ~3m depth for a 400 kg/m^3 density contrast, whereas it can be buried up to 5m deep for a 5400 kg/m^3 density contrast.

The next target of interest was that of two identical spheres separated by a various distances. Modelling this scenario helped determine at what separation the two spheres are discernible in the gravity gradient signal.

For each of the resulting gravity gradient profiles, we calculated the full-width-half-max (FWHM) of the profile, as well as the amplitude of the perturbation in the profile, using the ratio of the amplitude of the maximum peak to the amplitude of the dip. If there is any dip in the profile, due to the density low between the two separate spheres, this results in a ratio larger than unity.

We found that the ratio increased with increasing sphere separation, decreased with increasing depth, and stayed constant with increasing density contrast. The separation at which two spheres become discernable from a single sphere (when the ratio exceeded unity) is always approximately equal to the depth of the spheres, independent of the radius. The FWHM increased with increasing sphere separation and decreased slightly with increasing density contrast.

Conclusions and Future Work: These preliminary results for both the single-sphere and two-sphere configurations have helped constrain the approximate size and proximity of lunar subsurface features detectable at the predicted sensitivity of the Gedex gravimeter and gradiometer.

In our next phase we will investigate the feasibility of detecting features related to Lunar lava tubes. A target of particular interest is the apparently partially-collapsed pit crater in Lacus Mortis, at 44.96°N, 25.62°E, which is the target for CMU's "Andy" Lunar rover, which the company Astrobotic plans to send to the Moon in 2016 [4]. This feature could be a skylight into a lava tube, or a collapse into a subsurface void from cooling of a melt pond [5]. A local surface gravimetric survey could distinguish between these possibilities; analysis shows a lava tube whose size and depth is commensurate with this pit crater's 230 m diameter, could create a gravity low with a peak magnitude as high as -10 milliGal, easily within the expected detection capability of the gravimeter currently in development.

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Figure 1: Maximum gravity signal strength as a function of depth for various spheres with different density contrast and radius combinations. Horizontal yellow line represents the sensitivity of the instrument. The vertical coloured lines each represent when a sphere is at a depth (to the centre of the sphere) equal to its radius, and the lines are colour coordinated to match the models with a certain radius (i.e. blue vertical line represents a sphere of radius 1m). If a model has a density contrast and radius combination that allows its maximum gravity to exceed the sensitivity of the instrument (yellow line) at at a larger depth than it's radius, such that it is fully buried, it will be detectable by the gravimeter.