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The Search for Water in the Lunar Crust

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Abstract

There is evidence from several sources that water ice is present at a number of locations on the surface at the lunar poles. But there seems little agreement on the source of the ice with most suggestions being of external nature, such as impacts by ice-rich comets. Here we discuss the lunar crust as a possible source of the water ice and investigate whether there is any evidence from the recent GRAIL [1,2] and Lunar Reconnaissance Orbiter (LRO) [3] missions to support this possibility.

1. Introduction

GRAIL and the laser altimeter (LOLA) [4,5] on LRO have provided high resolution and high accuracy gravity and topography models of the Moon from which we have derived the Bouguer gravity anomaly field. These anomalies represent density contrasts within the Moon that provide information about its interior structure and composition. When Bouguer gravity is represented as a spherical harmonic series it can be analyzed by wavelength with the longer wavelengths representing deeper anomalies and the short wavelengths shallower features. In our analysis we focus on those wavelengths that represent the Bouguer gravity in the top 45 km, corresponding to the crust. Although gravity cannot be uniquely inverted to provide density it can provide some constraints on structure and composition.

2. Water ice signal

Water ice in the lunar crust can be manifest as either a positive or a negative Bouguer anomaly depending on how the ice is mixed in with the regolith. If the ice fills the pore space between the grains then there will be a small mass excess relative to surroundings that will produce a positive gravity signal. If the ice has displaced the grains of the regolith then because water ice is less dense than than compacted regolith we can expect a decrease in local density compared to the surrounding area, leading to a negative gravity anomaly. Our study indicates that the range of Bouguer gravity at the lunar south pole from latitude in a 10-degree radius cap centered on the pole is less than ± 50 mGal, which limits the mass of the material that is producing the density contrast that is causing the gravity anomaly.

One of the larger Bouguer anomalies coincides with the location of the Shoemaker crater at latitude 88S, which is also one of the locations that the LEND instrument [6] on LRO measures a significant decrease in neutrons that is interpreted to be caused by the presence of water ice in the top 1-meter of the surface of the crater floor. A simple model of this anomaly indicates it can be represented (though not uniquely) by a mass deficiency of ~ 10^{15} kg at a depth of about 25 km. If we assume the mass occupies a volume comparable to the size of the central region of the crater floor with similar thickness, then the required density contrast at 25 km mean depth is <200 kg/m^3, or ~8% of the estimated density of the crust. Further, since we can exchange depth for mass the equivalent mass required at 10 km depth is only ~25 kg/m^3, or ~1.5% density contrast. Thus, the Shoemaker Bouguer gravity anomaly could be explained by a few percent of water ice in an ice-rich layer below the surface of the crater, which incidentally is consistent with the indication from LEND of a few percent water in the top 1 meter.

Further, it is at least in principle possible to explain most of the gravity anomalies in the region of the south pole as being due to the presence of water ice in the upper crust. We do not suggest that this is the case but rather that the presence of water in the crust, instead of or in addition to chemical differences, could be at least part of the explanation of the observed Bouguer gravity signal, and might also explain the presence of surface ice seen by other instruments.

3. Conclusions

Analysis of the Bouguer gravity of the lunar south pole region indicates that the component that originates in the crust requires a density contrast of order 1 to 8%, depending on depth, which could, at east in part, be explained by the presence of water ice in the upper crust thereby bounding the amount of possible crustal ice.

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