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Remote estimation of dielectric permittivity of lunar surface regolith using compact polarimetric synthetic aperture radar data

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Abstract

A new model has been developed to estimate the dielectric permittivity of the lunar surface regolith using S-band hybrid compact polarimetric SAR data obtained from Mini-RF aboard LRO. The surface regolith is modeled as a random medium consisting of elementary ellipsoidal particles smaller than the incident wavelength of S-band. The data, available in the form of Stokes vector, are used to derive a coherency matrix, under the reflection symmetry condition, whose elements are used to calculate the particle anisotropy parameter. Since the anisotropy is bounded by the dielectric permittivity, its relationship with the latter is used for the required estimation. The method is applied to compute the dielectric permittivity of Apollo 17 landing site in Taurus-Littrow valley and to a part of Sinus Iridum. The estimated mean dielectric permittivity values (2.87 ± 0.31) and (3.04 ± 0.31), respectively, are consistent with the previous estimates. The dielectric permittivity values have also been used to discern different units of regolith in both the regions. The advantage of our model is that it does not require any a priori knowledge about the density or composition of the regolith. The available data in the form of Stokes parameters are sufficient for the computation. The model predicts a thin layer of low density, porous fine grained dust on the lunar surface.

Keywords: Lunar regolith; Dielectric permittivity; Compact polarimetry; LRO Mini-RF; Stokes parameters; Anisotropy

1. Introduction

The lunar bedrock is covered by ‘megaregolith’, a variably thick global layer of chaotically mixed crater ejecta derived by the impact cratering of the lunar crust during the period of heavy meteoritic bombardments (~3.8–3.9 Ga) (Hiesinger and Head, 2006) (Fig. 1). The seismic evidence indicates that the megaregolith becomes increasingly more compact with depth – its lower-most layer comprises large blocks of crustal material displaced by impact-generated subsurface movements – and eventually merges with fractured in situ crust beyond the depths of >10 km. The top layer of the megaregolith, termed ‘surface regolith’ (Hiesinger and Head, 2006), is a heterogeneous mixture of fine powder, agglutinates and rock fragments that are largely derived locally from the underlying ejecta-blankets, although there is a minor exotic component sourced from distant areas. The thickness of the surface regolith varies from 4–5 m over the maria to 10–15 m over the highlands, and the grain size is less than 1 cm, averaging between 60 and 80 μm (McKay et al., 1991). The surface regolith derives from the in situ gardening or turning over by the repeated impacts of micro-meteorites, solar wind and galactic cosmic rays during the post-heavy-bombardment period. Since most regolith components have not been transported for distances greater than a few crater diameters, the surface regolith cover over a lunar region can be assumed to be representative of the underlying bedrock even though the chemical composition

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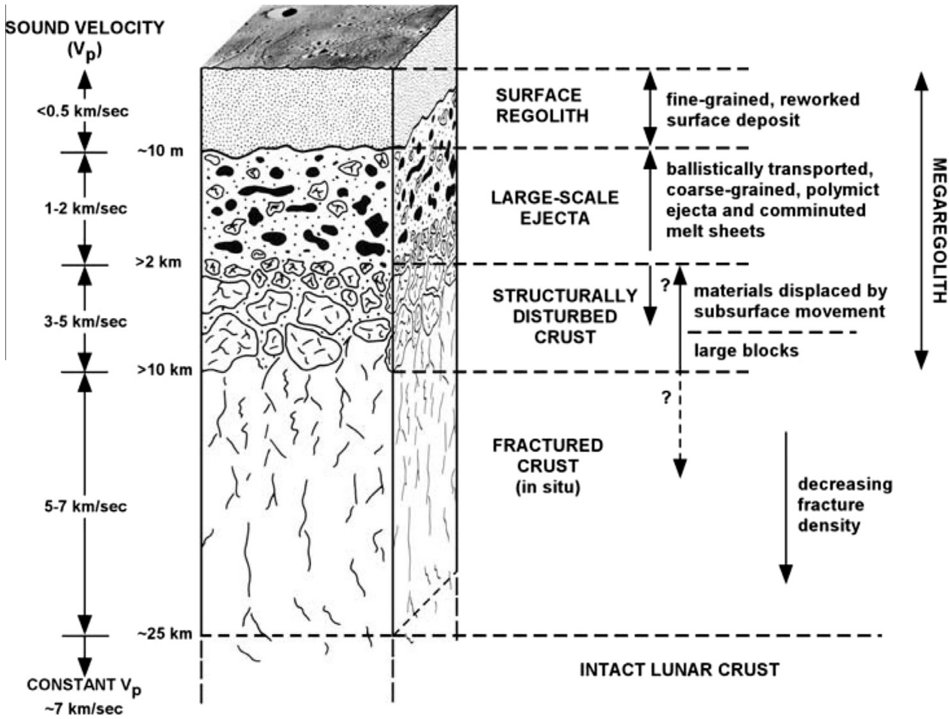

Fig. 1. Idealized profile of the lunar megaregolith. (Source: H. Hiesiner and J. Head, New views of lunar geoscience: an introduction and overview, Reviews in Mineralogy and Geochemistry. 2006, v.60, p. 1–81). The LRO Mini-RF senses only the uppermost few meters of the lunar surface, the surface regolith.

and physical properties of the regolith components are being continuously modified by the influx of micrometeorites and charged particles derived from the solar wind and galactic cosmic radiation.

Laboratory studies of the samples returned by various Apollo and Luna missions and the in situ experiments conducted during these missions have led to a detailed characterization of the chemical, physical and mechanical properties of the surface regolith (McKay et al., 1991); however, these studies are limited to the areas in the vicinity of the landing sites and cannot be interpolated over large distances to map the spatial variability of the surface regolith. Orbital remote sensing provides synoptic and unbiased coverage of the entire lunar surface, and therefore better suited for global characterization of the lunar surface regolith.

Short (visual and infrared) wavelength orbital remote sensing data particularly from the Clementine, Lunar Reconnaissance Orbiter (LRO) and Chandrayaan missions have been used for chemical and mineralogical mapping of the lunar surface at high resolutions and for detecting hydroxyl/hydration signatures (Pieters et al., 2009; Greenhagen et al., 2010; Yan et al., 2010; Feldman et al., 1998; Feldman et al., 2001; Lucey, 2004, 2000) at the surface. Long wavelength (4 and 13 cm) microwave radiation produced by space-borne synthetic aperture radar (SAR) systems such as Miniature Radio Frequency (Mini-RF) instrument aboard LRO can penetrate several meters ($\sim$1–10 m) into the lunar regolith (Spudis et al., 2010, 2013). This system senses only the uppermost few meters of the lunar surface, the Surface Regolith (Fig. 1). Long (cm to meter) wavelength microwave data can also be used to estimate physical parameters of the lunar regolith such as dielectric constant, density, grain-size, and thickness or depth to the bed rock (Campbell and Ulrichs, 1969; Hagfors, 1970; Campbell et al., 1997; Shkuratov and Bondarenko, 2001; Campbell, 2002). Nevertheless, it can be expected that the solar wind and galactic cosmic rays does not modify the bulk dielectric constant of the uppermost few meters of the lunar regolith.

In this paper, we present a new model for estimating the real dielectric permittivity of the lunar regolith from space-borne, high-resolution, S-band (13 cm) compact polarimetric (CP) SAR data from the Mini-RF aboard LRO. These data are available in the form of Stokes vector which is used to derive the 3×3 coherency matrix under reflection symmetry condition. The elements of the coherency matrix are used to calculate the anisotropy parameter which, in turn, is then used to determine the dielectric permittivity. The method does not require a priori or ancillary information about the density, compactness or composition of the lunar regolith. The model is applied to the Apollo 17 landing site and a part of the Sinus Iridum.

2. Dielectric permittivity

The response of a medium to an incident electromagnetic wave particularly in the microwave region is a function of its dielectric permittivity. The dielectric property of a material is responsible for the attenuation of an electric