The Mini-SAR imaging radar on the Chandrayaan-1 Mission to the Moon P. D. Spudis[1], D.B.J. Bussey[2], B. Butler[3], L. Carter[4], J. Gillis-Davis[5], J. Goswami[6], E. Heggy[7], R. Kirk[9], T. Misra[6], S. Nozette[1], M. Robinson[8], R. K. Raney[2], T. Thompson[7], B. Thomson[2], E. Ustinov[7] 1. Lunar and Planetary Institute, Houston TX 77058 (spudis@lpi.usra.edu) 2. Applied Physics Laboratory, Laurel MD 20723 3. NRAO, Socorro NM 4. NASM, Washington DC 5. Univ. Hawaii, Honolulu HI 96822 6. ISRO, Bangalore, India 7. JPL, Pasadena CA 8. ASU, Tempe AZ 9. USGS, Flagstaff AZ

The possible existence of ice in the polar cold traps of the Moon continues to be debated [1]. The Clementine spacecraft conducted a bistatic radar experiment in 1994, which supported the idea of an ice deposit within Shackleton crater, near the south pole [2]. However this result generated controversy [3,4] and there is still disagreement whether the observed polarization anomalies are due to ice [5]. However there is little argument related to the discovery by Lunar Prospector of enhanced hydrogen levels in the polar regions [6]. The question is whether this hydrogen is in the form of water ice [1]. By determining the backscatter properties inside the dark areas near the poles we will constrain the nature and occurrence of water ice deposits on the Moon.

While no remote measurement can definitively answer the question of whether ice exists at the lunar poles, an orbiting SAR provides the most robust method of obtaining a positive indication of ice deposits. With an orbital SAR, ALL areas on the Moon can be seen. The 6° inclination of the Moon's orbital plane around the Earth means that large areas of permanent shadow that might contain water ice can never be seen from Earth and all polar areas that can be seen from Earth are viewed at high incidence angles, which reduces the coherent backscatter predicted for ice deposits. However all permanently shadowed regions will be imaged multiple times by an orbiting radar with incidence angles favorable for determining their scattering properties.

The Mini-SAR instrument is a lightweight SAR radar flying currently on the Indian Space Research Organization's Chandrayaan-1 mission; a modified version of this instrument will fly on NASA's Lunar Reconnaissance Orbiter mission in 2009. Mini-SAR uses a different analytical approach to look for ice. Traditionally, the key parameter used to determine if ice is present is the circular polarization ratio (CPR). This quantity is equal to the magnitude of the same sense (i.e. the left or right sense of the transmitted circular polarization) divided by the opposite sense polarization signals that are received. Volumetric water-ice reflections are known to have CPR greater than unity, while surface scattering from dry regolith has CPR less than unity [1]. Mini-SAR uses a hybrid dual polarization technique, transmitting a circular polarized signal (either Right or Left Circular Polarization) and then receiving coherently the linear Horizontal and Vertical polarization signals. This hybrid architecture preserves all of the information conveyed by the reflected signals [7]. From these data, we will determine the four Stokes parameters of the backscattered field. The Stokes parameters offer a very powerful tool to investigate the nature of lunar radar backscatter. In addition to calculating the magnitude of both circular polarizations, and therefore also the circular polarization ratio [7], it will also be possible to ascertain other scattering properties which should help to distinguish between multiple surface reflections versus volume scattering. This characterization is critical to determine if the returned signal is caused by an ice-regolith mixture, or simply dry rocks on the lunar surface. Examples of such derived properties include the Degree of Linear Polarization [7].

The Mission: The Mini-SAR is currently flying on the Chandrayaan-1 mission, launched from India on October 22, 2008 [8]. This polar lunar orbiter will conduct a detailed analysis of the lunar surface using eleven instruments over the course of the two-year nominal mission from an altitude of 100 km. The principal goal of Mini-SAR on Chandrayaan-1 is to conduct systematic mapping polewards of 80° latitude for both poles. Mini-SAR uses S-band (2380 MHz), has an illumination incidence angle of 35°, and image strips have spatial resolution of 75 meters per pixel. During the observation opportunities given to the instrument, it will image in SAR mode both poles every 2-hr orbit, covering both polar regions in a single 28-day mapping window. However, because the instrument looks off-nadir, there will be a gap in SAR coverage within a couple of degrees of latitude around both poles. These regions close to both poles contain some of the most promising sites for potential water deposits. There are a couple of options for exploring these polar areas. Because the Moon's spin axis is inclined 1.5° to the ecliptic, the orbital plane of Chandrayaan-1 will vary slightly.. The orbit will naturally drift between 90° (pure polar orbit) and approximately 91° on a 14 day cycle. By operating Mini-SAR during orbits of maximum inclination, we will be able to obtain SAR strips of permanently shadowed regions within 2° latitude of both poles.

The second option involves operating the instrument in a scatterometry or "vertical SAR" mode. In this mode, the Chandrayaan-1 spacecraft is rolled 35° so that the antenna is oriented to point to nadir. The advantage of this mode is that we can completely map the polar areas between 85° and 90° in 14 days, thus filling in the entire polar SAR gap; the disadvantage is that you lose high spatial resolution in the range direction. Essentially what is acquired is a radar profile, with 10 km width and 1 km along-track resolution. However, because of large overlap between consecutive strips, we can process this scatterometry to greatly improve spatial resolution, possibly to sub-kilometer levels. If Chandrayaan-1 operates in an extended mission in a 50 km orbit, Mini-SAR will be able to obtain true SAR strips of the poles.

Our data products will include complete maps of both polar regions of the Moon at 75 m/pixel. These images will consist of opposite sense image mosaics (to reveal the terrain of the dark areas near the poles), images of Stokes parameters, and derived maps of CPR and other Stokes "daughter" products, including degree of linear polarization [7]. All raw data as well as processed data including higher order products such as mosaics will be made available to the scientific community, both through the international portal of the Indian Space Science Data Center and through the Geosciences node of the NASA Planetary Data System.

The Mini-SAR instrument was activated on November 17, 2008 and acquired SAR images of both poles during a commissioning test (Fig. 1). The instrument performed as specified. Our first systematic mapping season is currently scheduled to begin in mid-January, 2009. We will have three additional data taking periods during 2009, allowing us to map both poles in SAR from both directions and also providing opportunities to fill in missing data gaps and acquire high-incidence polar gap-filling SAR images.

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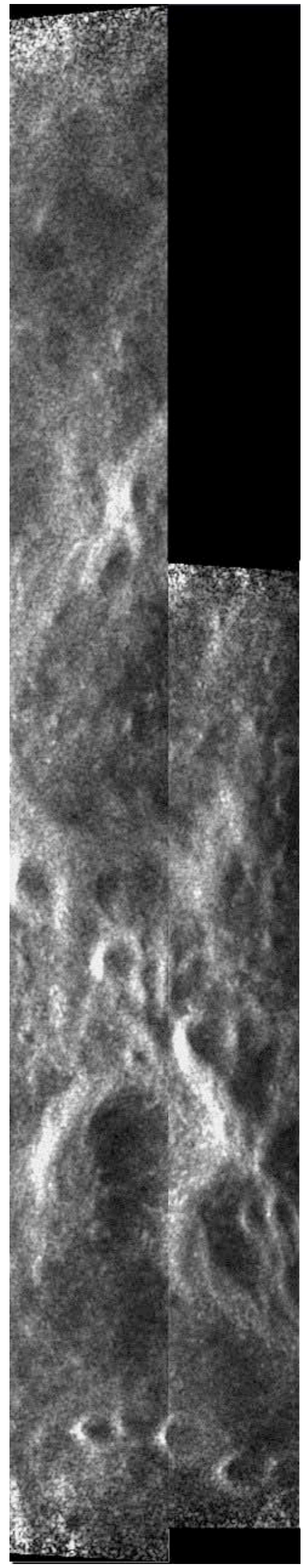

Figure 1. Mini-SAR image strip covering the western rim of the crater Seares (110 km dia.; 73.5° N, 145.8° E), obtained on November 17, 2008.