EXPLORING YOUNG HIGH-TI BASALTS WITH CHANG’E-3 ROVER. Y. Z. Wu¹, X. Z. Cui², W. X. Peng³, J. S. Ping⁴, C. R. Neal⁵. ¹School of Geographic and Oceanographic Sciences, Nanjing University, Nanjing, 210023, China (wu@nju.edu.cn), ²Institute of High Energy Physics, Chinese Academy of Sciences (CAS), Beijing 100049, China, ³National Astronomical Observatories, CAS, Beijing 10012, China, ⁴Dept. of Civil & Env. Eng. and Earth Sciences, University of Notre Dame, Notre Dame, IN 46556, USA.

Introduction: The unsampled Eratosthenian basalts, which were mostly in Imbrium and Oceanus Procellarum, provide unique information for understanding the late stage evolution of the Moon. On December 14 2013, the Chinese CHANG’E-3 (CE-3) spacecraft landed in Mare Imbrium (44.12°N, 19.51°W). The landing site is near the eastern boundary of the Eratosthenian high-Ti basalts and ~9 km north to the site is Imbrian low-Ti basalts (Fig. 1). The in situ exploration of landing site by the ‘‘Yutu (Jade Rabbit)’’ rover was performed for 2 months and results are reported here.

Fig. 1. M³ image shows the CE-3 landing site.

Payloads: Four payloads were on board the Yutu rover (Fig. 2). The VIS/NIR Imaging Spectrometer (VNIS) was designed to identify minerals. It uses acousto-optic tunable filters (AOTFs) as dispersive components and consists of a VIS/NIR imaging spectrometer (0.45–0.95 μm), a shortwave IR (SWIR) spectrometer (0.9–2.4 μm), and a diffuse panel for in orbit calibration [1]. The Alpha Particle X-Ray Spectrometer (APXS) was designed to deduce elemental abundances. It consists of a sensor head mounted on the rover arm, an in-flight calibration target and a radioactive heat unit (RHU). The calibrated energy range of APXS is 0.4–22 keV, and the energy resolution is about 135–142eV@5.9 keV@ 20°C [2]. The Lunar Penetrating Radar (LPR), operating at frequencies of ~500 MHz and ~60 MHz, examined the subsurface to a depth of lunar soil of 30 meters and a depth of 100 meters [3]. The fourth, which is consisted of two Panoramic Cameras (PCAM), acquired high-resolution stereo images for three-dimensional imaging and used to assess the lunar surface morphology and geology [4].

Results: During the period that Yutu was mobile, four measurements (sites 5, 6, 7 and 8; Fig. 3) were made for VNIS, three measurements for APXS at two sites (6, 8). The LPR acquired 10171 and 19934 track data for the first and second channels during its 277 minutes performance. The PCAM took 28 panorama images each circle with 12.8°/image at three sites (6, 7, 8) for both horizon and tilt viewing.

Fig. 2. Image shows the locations of the four payloads.

The VNIS observed at a 45° with phase angles between 85°-108°. No current photometric models match well its forward scattering. For an initial comparison, the Lambert albedo spectra acquired by the VNIS and orbital data [6-8] normalized to the common VNIS solar angle (~60°) is shown in Fig. 4. The VNIS in situ reflectance of the undisturbed regolith (site 8) is larger than orbital reflectance. The VNIS reflectance decreases as the rover moved further away from the lander, reflecting the spectral effects of rocket exhaust. The increase in reflectance (>17%) of the regolith disturbed by the rocket exhaust measured by the VNIS is much larger than that derived from orbital remote sensing data (3–12% [9]). The differences between in situ and orbital reflectance are due to the maturity, shadow, phase angle, roughness, etc.

Fig. 3. LROC NAC image [5] shows the track of the rover and the locations of the four measurements for VNIS. Image width is ~200 meters.
Smoothing of the macroscopic roughness has been suggested as the main cause of the reflectance increase of regolith affected by rocket exhaust [9-11], while exposure of less mature soil was rejected since the rocket exhaust did not excavate regolith to depths that would be needed to expose significant changes in maturity [12]. The images acquired by the VNIS and PCAM show that the macroscopic roughness does not increase from site 5 to site 8. On the contrary, the PCAM images show that the regolith disturbed by rocket exhaust contains a “winnowed structure” and appears rougher than the undisturbed regolith (Fig. 5). The band depth and the visible slope (Fig. 4) suggest that the disturbed regolith (sites 5, 6, 7) is more immature than the undisturbed soils (site 8). The difference of the absorption depth and absolute reflectance among the four sites cannot be due to differences in chemical composition because the APXS demonstrated a uniform regolith composition at the CE-3 landing site [2, 13]. These results from the instruments onboard the Yutu rover suggest that exposure of less mature soil is the major effects accounting for the reflectance increase rather than smoothing of the surface.

**Fig. 4.** Comparison of the Lambert albedo spectra derived from VNIS with those from orbital data [6-8].

The VNIS spectra show wide and long 1 μm absorption and very weak 2 μm absorption implicating that the unit CE-3 landed on is rich in olivine. The colour picture of basaltic boulder captured by PCAM shows relatively large amounts of plagioclase, which is consistent with the relatively high Al abundance in the regolith [2]. Regolith major element composition along the rover track is essentially constant, suggesting the regolith is locally derived from the underlying basalt flow(s). More detailed discussions are presented at this conference [13].

To derive the thickness of regolith we only used the CH2 LPR band. The time delays of the radar echo signal to the lunar surface is 28.203 ns. The thickness changes from 6.5 m through 8.5 m, with a mean depth of ~7.5 m. Note that regolith thickness is rather than simple definition but highly dependent on radio frequency of LPR radar or of microwave receiver, where longer wavelength can penetrate deeper than shorter wavelength in the regolith-base rock boundary. The thickness of the regolith estimated from two crater, which penetrated through the regolith (D~16 m, B in Fig. 3) and not penetrated through the regolith (D~10 m, A in Figs. 3 & 5), could be between 1-1.5 m. However, the CE-3 landing site is on the blanket of a 450 m crater, which complicated the estimation of the regolith thickness. The new result from the LPR is in processing.

**Implications:** The unit CE-3 landed on is mare basalt not returned by the Apollo and Luna missions. In the Eratosthenian Period, the Moon had cooled meaning melting would only occur if there were low melting point components in the source, consistent with late stage lunar magma ocean (LMO) cumulates. This would explain the relatively high Ti nature of the basalts at the CE-3 landing site as ilmenite was a late stage LMO crystallizing phase. However, the relatively high abundance of olivine represents a conundrum, as olivine was an early LMO crystallizing phase. This may be resolved by the fact that olivine can also be a late stage (>65% crystallization) LMO cumulate phase depending upon the starting composition (e.g., [14])

**Fig. 5.** PCAM image (taken at site 6) showing increasing roughness (*winnowed structure*) of the disturbed regolith caused by the rocket exhaust (arrows). A is the ~10 m crater that did not penetrate through the regolith.