REGIONAL GEOLOGY OF THE CHANG'E-3 LANDING ZONE. Y.Z. Wu[1, 2],, J.W. Head[3], C.M. Pieters[3], A.T. Basilevsky[4], L. Li[2], A.R. Tye[3]. [1]School of Geographic and Oceanographic Sciences, Nanjing University, Nanjing, China (wu@nju.edu.cn), [2]Department of Earth Sciences, Indiana University-Purdue University, Indianapolis, IN 46202, [3]Dept. Geological Sciences, Brown University, Providence, RI 02912 USA, [4]Vernadsky Institute of Geochemistry and Analytical Chemistry Russian Academy of Sciences, Moscow, Russia.

Introduction: On the basis of our long-term interest in lunar impact basins, their filling with the volcanic deposits of a variety of compositions and emplacement styles comprising the lunar maria, and their loading and related lithospheric deformation, we have undertaken a tri-lateral (Russia-China-USA) study of the northwest Mare Imbrium/Imbrium basin centered on Iridum crater (Figs. 1, 2) [1]. We utilize 1) a variety of orbital remote sensing data (topography, morphology, chemistry, mineralogy/spectroscopy, gravity) and 2) in situ exploration from surface landers and rovers (Luna 17/Lunokhod 1 and Chang'E 3/Yutu) (L1-CE3). The goal of our trilateral analysis is to provide a regional context for the history of the Imbrium basin, and to document the nature and evolution of the geologic units that it contains. We place particular emphasis on the role played by the merging of orbital remote sensing information and surface traverse observations and analyses. This detailed analysis will provide important input into future planning for optimizing lunar surface mission payloads, traverse planning and operations, and returned sample missions.

Regional Geology [1]: Northwest Imbrium lies in the Procellarum-KREEP Terrain (PKT) and its geology and history is dominated by the formation of the Imbrium basin, and the emplacement of the ejecta deposit, the Fra Mauro Formation, defining the base of the Imbrium System. Although not exposed at the surface in this region, significant volumes of impact melt were generated by Imbrium event and ponded in the basin interior; in the smaller, 930 km Orientale basin, melt may have exceeded 15 km in thickness. Very shortly following basin formation, several large impacts (Iridum and Plato craters) formed; Iridum, a probable peak-ring basin, heavily modified the rim and ring structure of the NW Imbrium basin. Subsequent to the Iridum impact (and perhaps somewhat before) viscous domes of silicic composition were emplaced in the Gruithuisen region, to the SW of Iridum crater. Over the next hundreds of millions of years, the Imbrium basin was filled by lava flows that built up a complex stratigraphy in the interior. To the NW of the basin, basalts flooded the basin back slope and depression. Emplacement of the interior mare deposits resulted in loading and flexure of the basin, lithospheric flexure, graben and wrinkle ridge formation, and subsidence of the basin interior. The youngest lava flows, on which the L1-CE3 spacecraft landed, show evidence of being guided by this topography, and then also subsequently deformed. As shown in Figs. 2a and 2b, the mare filling can be divided into an early widespread phase, and a later high-Ti phase much of which appears to have emanated from the SSW margin of the Imbrium basin.

The regional geology of NW Imbrium [1] raises many questions that are subject to current and future exploration. Among these are: 1) What are the elemental abundances in the young high-Ti basalt? 2) How do these compare to those seen in the Apollo 11 and related basalts? 3) How much contamination is in the mare soils from the surrounding highlands? 4) What is the thickness of the young high-Ti basalt unit? 5) Are there multiple units in the high-Ti basalt unit or was it emplaced in a single flood? 6) How do the results of the L1 mission and the CE3 mission compare? 7) If the L1 mission and CE3 landing sites are in the same units, is their surface geology different or similar? 8) What do these similarities and differences tell us about future mission planning and sample return exploration strategies?

Remote Sensing Data: Initial integrated analyses of the Iridum crater and northern Imbrium basalts have been undertaken for the L1-CE3 landing sites [1]. A mosaic of M^3 data for the region is shown in Fig. 2c. To allow direct comparison with other Imbrium and Procellarum basalts, we use the same color composite used previously [2]. Although several hundred km apart, the L1-CE3 sites appear to be in approximately similar settings: a young medium-high Ti basalt with older low-Ti basalts nearby [e.g., 3]. However, their other elemental abundances are different [4], and the two sites are not considered the same unit. The highland crust at Iridum is feldspathic (blue in Fig. 2c) and exhibits numerous exposures of small noritic (light blue) and olivine bearing (purple) regions [1]. Example M^3 spectra for the CE3 region are shown in Fig. 3. A small 350 m fresh crater a few km to the southwest of the site was selected to represent the mineralogy of the Ti-rich basalt (red spectrum). A similar small crater to the north of the site represents the low-Ti basalt (purple spectrum). At the CE3 landing site, spectra were obtained from the wall of the 450 m crater close to the CE3 site (green) as well as the landing site itself (light blue). The landing site crater (green), exhibits the same features as the SW crater (red), but is slightly more weathered. We interpret the CE3 landing site basalt to be olivine-rich based on the strength and shape of the 1 μm band and the weakness of the 2 μm band for the two craters in this unit. This is consistent with extensive young, Ti-rich basalts observed further to the west in Procellarum [2]. Based on the size of the two craters, the thickness of the Ti-rich basalt at the site should be more than 40 m.

Luna 17/Lunokhod 1 Geologic Exploration: Luna 17, with Lunokhod 1 onboard, landed on November 17, 1970, in the NW coastal part of Mare Imbrium about 40 km SW from Heraclides Promontorium [5-7]. Coordinates of the landing site updated with LROC NAC analysis are 38.328°N, 325.002° E [8]. In the vicinity of the landing site the surface is typical mare plains peppered with small impact craters. The boundary between the equilibrium and non-equilibrium parts of crater population is at ~100 m. Lunokhod 1 travelled ~10,500 m, made >50,000 images by navigation cameras, >200 TV panoramas, conducted >500 soil mechanics tests, and made XPFS analyses in 15 places along the route. Numerous measurements of the spatial density of craters of decimeters to a few meters in diameter made through analysis of TV panoramas showed that the $N_{>D}(D)$ function varies around the equilibrium equation $N_{>D} = 10^{10.9} D^{-2}$ [9-10]. The observed rock fragments were classified into four morphological types (irregular shape, pyramidal, prismatic, and coplanate) and three morphologic classes (angular, angular-rounded and rounded). It was found that in association with fresh craters are observed more rock fragments than in association with the subdued ones and that the function $n = kd^{-\alpha}$ is more steep for the subdued. The Lunokhod-1 XRF analyses showed that the regolith chemical composition was nearly constant: 20±3 - 22±2 wt.% Si, 9±1 - 12±1 wt.% Fe, 7±1 - 8±1 wt.% Al, <4 wt.% Ti, <1 wt.% K. These abundances are typical for mare basaltic regolith [11 and refs.].

Chang'E 3/Yutu Geologic Exploration: The four experiments on board the CE-3 rover will help to address some of the questions listed above [12]. The dual-frequency Ground Penetrating Radar (GPR), operating at frequencies of 500 MHz and 60 MHz, will examine the subsurface to a depth of lunar soil of ~30 meters and a depth of at least ~100 meters. The thickness of the regolith and the young basalt flows can be addressed via the GPR. The Alpha Particle X-Ray Spectrometer (APXS), with the energy range of 0.5-20 keV, will measure elemental chemistry of regolith, and can provide comparisons with Lunokhod 1 and orbital measurements. The AOTF type VIS/NIR Imaging Spectrometer (VNIS) will be used for identifying minerals. The VNIS includes two channels, a V-NIR hyper-spectral imager covering a spectral range of 0.45 to 0.95 μm and a SWIR spectrograph covering a spectral range of 0.90 to 2.4μm [13-14]. The fourth experiment, which consists of two Panoramic Cameras, will acquire high-resolution stereo images for three-dimensional imaging that can be used to assess the lunar surface morphology and topography around the rover, as well as the trafficability and operations, with comparisons to L1 traverses in the same general unit.

Summary: The results of this tri-lateral study will be useful for optimizing the findings of the Chang'E 3 mission and planning for future international exploration, including sample return and human exploration site selection and traverse planning.

References: 1. Y. Wu et al., 2014 in preparation. 2. M. Staid et al., 2011, JGR, 116. 3. D. Wilhelms 1997, USGS PP. 1348. 4. T. Prettyman et al., 2006, JGR. 5. Florensky C.P. et al. (1971) In: Mobile laboratory on the Moon. Nauka press. 96-115. 6. Florensky C.P. (1972) Space Research XII, Akademie-Verlag. Berlin. 107-121. 7. Florensky C.P. et al. (1978) In: Mobile laboratory on the Moon. V. 2. Nauka press. 102-135. 8. Plescia J.B. (2010) EPSC Abstracts. Vol. 5, EPSC2010-724. 9. Trask N.G. (1966) Ranger VII and IX Tech. Rept. 32-800. Pasadena. 249-338. 10. Morris E.C. et al (1968) In: Surveyor Project Final Report. Part 2. 32-1265. Pasadena. 11. Abdrakhimov A.M. (2009) LPSC-40. Abs. # 2547. 12. http://www.spaceflight101.com/change-3.html 13. He Z.P. et al. (2011) Proc. of SPIE, 819625. 14. Liu B. et al. (2013) Res. Astron. Astrophys. 13 862.

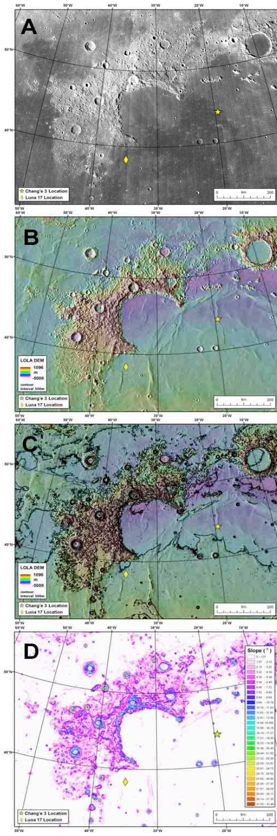

Fig. 1 Background image and topography of Sinus Iridum and the landing sites of Luna 17 (diamond filled in yellow) and Chang'E 3 (diamond filled in yellow). (A) LROC WAC global mosaic. (B) LOLA DEM. (C) LOLA DEM with 500m contours. (D) LOLA-derived slope map, baseline ~2km.

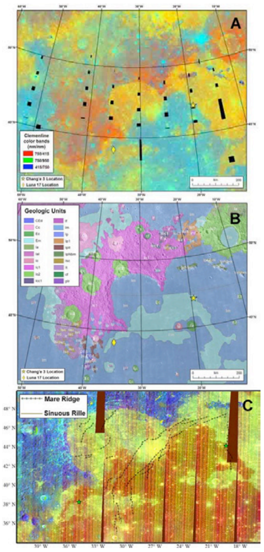

Fig. 2. (A) Clementine color data (R = 750nm/415nm, G = 750nm/950nm, B = 415nm/750nm. (B) Area geology from [Wilhelms, D.E. & McCauley, J. F., 1971, USGS Map I-0703]. (C) Color composite of M3 mosaic for the Sinus Iridum and northern Imbrium region containing Chang'E3 and Luna 17 landing sites (R=integrated band strength 1000 nm; G=integrated band strength 2000 nm; B=reflectance at 1580; mare ridges and sinuous rilles mapped).

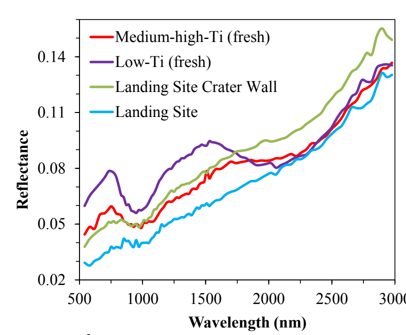

Fig. 3. M^3 spectra of the Chang'E 3 landing site. Two nearby fresh craters represent the two basalt types of the region. The landing site is in an olivine-rich, medium high-Ti basalt.