AN UNUSUAL GEOLOGY OF MARE IMBRIUM AND IMPLICATION TO THE GLOBAL EVOLUTION. Y. Z. Wu, X. Tang, X. M. Zhang, Y. Chen, W. Cai. School of Geographic and Oceanographic Sciences, Nanjing University, Nanjing, 210023, China (wu@nju.edu.cn).

Introduction: On December 14 2013, Chang'E-3 (CE-3) spacecraft landed in the Eratosthenian basalts in northern Mare Imbrium, which are spectrally unique and umsampled. To interpret CE-3 data and its local geology, we started pre-research before CE-3 lanunched cooperated with Brown University and Vernadsky Institute of Geochemistry, Russia. During the research we noted that for understanding the local geology it is important considering the regional geology or even the whole Moon. This paper reported our multiyear research for north Imbrium and the extended geology of the whole Moon and the scope spans both composition and technology [1].

Unusual highlands: The highlands surrounding Imbrium exhibit elevated concentrations of Fe and radioactive elements, and abundant exposures of low-Ca pyroxene and olivine bearing lithologies (e.g., Fig. 1). Actually, as shown in the global integrated band depth (IBD) image the highlands surrounding even PKT have more mafic minerals than farside highlands (Fig. 2). The elevated Fe and reduced Al from CE-1 IIM data [2] also show the mafic anomaly. The mafic characteristic of highlands is explained that a huge impact forming Imbrium basin has removed much of the feldspathic lunar crust and exposed the lower mafic-rich crust.

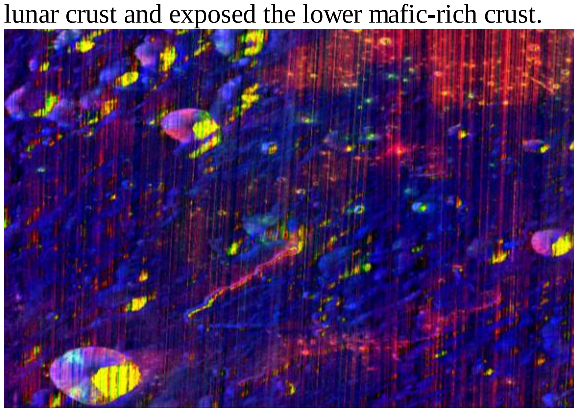

Fig. 1. The M^3 IBD color composite (R-1000 nm IBD, G- 2000 nm IBD, B- reflectance at 1580 nm) showing the mineralogy diversity of northwest highlands of Imbrium. The pink of the walls of crater and sinuous rille are associated with troctolite. The green is associated with the unusual spectra. The cyan is commonly associated with LCP rich rocks. The blue indicates lack of mafic minerals similar with farside (Fig. 2).

Unusual Mare Basalts: A scatter plot of 1 vs 2 μm band positions for the basaltic units of north Imbrium and synthethic pyroxenes is shown in Fig. 3. The Eratosthenian basalts (Em3, CE-3 unit) fall above the pyroxene trend. A similar trend was also found for the Eratosthenian basalts in Oceanus Procellarum [3]. The spectra of the young Eratosthenian units exhibit longer center of wide 1 μm absorption, strong 1.3 μm absorption and very weak 2 μm absorption, consistent with olivine-rich basalts.

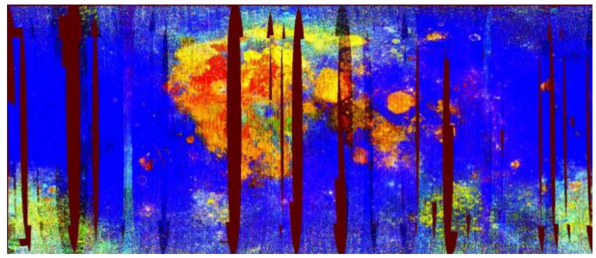

Fig. 2. The M^3 IBD of whole Moon illustrating that the highlands surrounding Imbrium and much of the whole PKT are different from the farside highlands with more mafic absorption features.

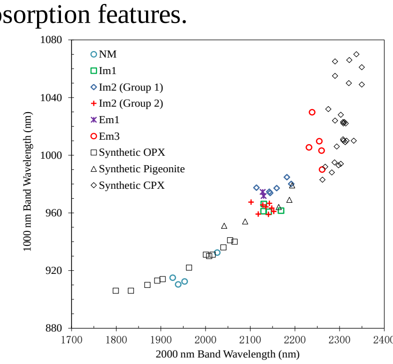

Fig. 3. Comparison of the 1 μm vs 2 μm band positions for fresh craters of highlands and mare basalts with synthethic pyroxenes [4].

Structure 1—ridges: Large numbers of volcanic and tectonic structures such as vents, sinuous rilles, wrinkle ridges and rupes exist in this area, and more found than previously reported. Compared with the latest Lunar Rille Catalog [5], 22 rilles are newly identified and mapped. Compared with the latest Lunar Wrinkle Ridges Catalog [6], more ridges are newly identified (Fig. 4). The rilles distributed in both highlands and mare basalts. The ridges also distributed in both highlands and mare basalts. CE-3 landed on NS ridges in Imbrium, which are among the youngest ridges of the Moon. Fig. 5 shows an example that a young crater (~50 m.a.) that was disturbed by ridge. Moreover, the age of young ridges has been estimated as late-Copernican [7] or even 5 Ma [8]. According to our global survey (Fig. 4), young ridge is mostly inside of Imbrium. They represent very recent tectonic activity of the Moon and suggest that Mare Imbrium is an important area for understanding the late evolution of the Moon.

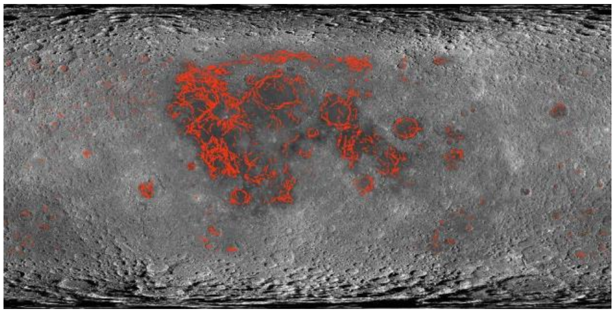

Fig. 4. Global distribution of lunar wrinkle ridges. Note that they distributed in both mare and highlands.

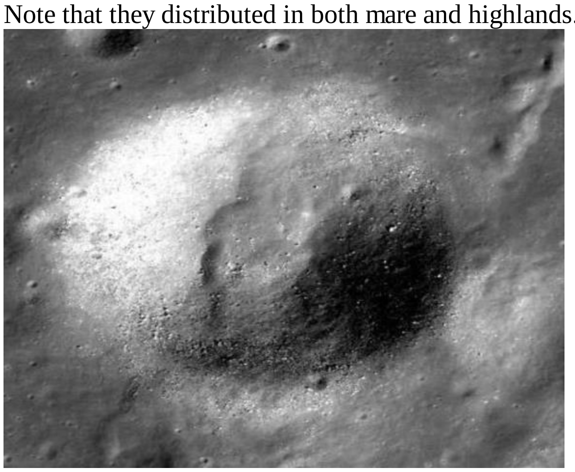

Fig. 5. Example showing young ridges inside Imbrium disturbed a crater with age of ~50 m.a.

Structure 2—ripple and mound: In addition to ridges, two other types of structure widely distributed around CE-3 landing site and other places. The ripple structure has once been called dune-like ridge and interpreted as the result of mechanical interactions of the moving debris with pre-existing topography[9]. We named it as “ripple” rather than “dune” considering its forming mechanism related to endogenic activity rather than moving debris. To demonstrate this several evidences are listed here. The formation, density and amplitude of ripple are related to the diameter of crater and the property of the substrate rocks. Only craters larger than the critical size, usually ~550 m, have ripples while less than the critical size no ripple. The ripples are mostly in mare basalts while very few in highlands. A crater on the right rim of Lick caused ripples on the floor of Lick while no ripples on the ejecta blanket (Fig. 6). The ripple cuts the radial ejecta of crater indicating that it formed after the impact (e.g., arrow in Fig. 7a). The ripple structure explains the reason forming the rugged/hummcky topography around Le Verrier and other craters. Note that a 3.6 km crater on its south rim has mound (bulge in the floor or wall of crater), indicating the development of ripple. Similar situation can be found for CE-3 region showing young ridges and mounds (Fig. 7b). The mound also reflects the endogenic activity and has the same mechanism as ridges and ripples, i.e., tectonism due to the contraction/shrinking of the Moon or subsidence of the basin. For ripples, the impact produced vermiculate fractures surrounding crater and these fractures are channel for materials uplift caused by later contraction/shrinking of the Moon. Although ridges, ripples and mounds have different apparent forms, their formation mechanism is similar. This study suggests that the Imbrium basin, including mare and highlands, and even the whole PKT is an important region for exploring the evolution of the Moon.

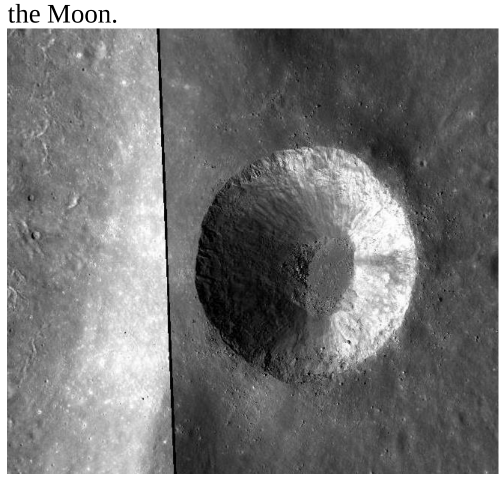

Fig. 6. a crater on the right rim of Lick showing that the crater floor of Lick has ripples while the ejecta blanket has no ripples.

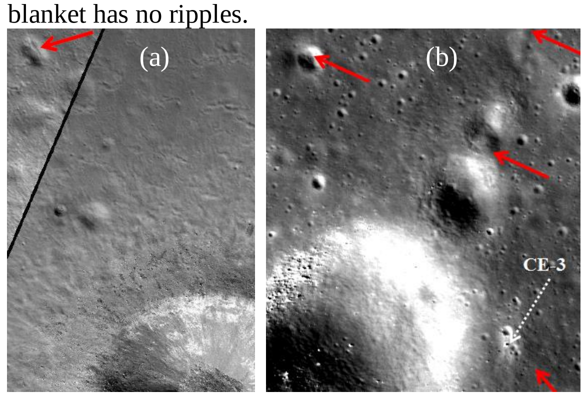

Fig. 7. (a) Ripples disturbed crater indicated by red arrows. (b) Ridges passed the CE-3 landing site.

References: [1] Wu, Y. Z. et al.(2016) LRO Special Issue, *Icarus, submitted*. [2] Wu, Y. Z. (2012) *Geochim. Cosmochim. Acta*, 93, 214-234. [3] Staid M. I. et al. (2011) *JGR,116*, E00G10, doi:10.1029/2010JE003735. [4] Klima R. L. et al. (2011) *JGR*, 116(E6). [5] Hurwitz, D. M. et al. (2013) *Planet Space Sci*., 79, 1-38. [6] Yue, Z. et al. (2015) *JGR*, 120, 978-994. [7] Xiao, Z. et al. (2014) *Macao Univ. Sci. Technol.* [8] Xiao Z. Y. et al. (2014) *LPS XLV*, #1719. [9] Oberbeck V. R. (1975) *Rev. Geo.,* 13, 337-362.