POSSIBLE CRUSTAL BOUNDARY EXPOSED AT LUNAR COPERNICUS CRATER. T. Arai[1] , M. Ohtake[2], A. Yamamoto[3], T. Sugihara[4], T. Hiroi[5], R. Nakamura[6], N. Namiki[1], K. Wada[1], S. Yamamoto[7], T. Matsunaga[7] and J. Haruyama[2], [1]Planetary Exploration Research Center, Chiba Institute of Technology, 2-17-1 Tsudanuma, Chiba 275-0016, Japan, tomoko.arai@it-chiba.ac.jp, [2]Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, [3]Remote Sensing Technology Center of Japan, [4]Department of Geological Sciences, Brown University, Providence, RI, [5]Japan Agency for Marine-Earth Science and Technology, [6]National Institute of Advanced Industrial Science and Technology, Tsukuba, Japan [7]National Institute of Environmental Studies, Tsukuba, Japan .

Introduction: Copernicus crater (95 km in diameter) in the central nearside (9.5^{o}N, 20^{o}W) has several important aspsects in lunar science. Since it has a fresh, bright ray, the crater has been extensively studied by ground-based telescopes [1-3] and with Clementine visible (VIS)-near infrared (NIR) reflectance spectra [4]. It resides within the Procellarum KREEP terrane (PKT) [5], where prolonged, thermal (magmatic) activities occurred. Copernicus crater contains several massive, blocky central peaks, which is probably uplifted from an original depths of ~ 10 km [1]. The central peakes are known for olivine-rich composition [e.g. 1-3], which suggests possible exposure of deep-seated crustal or mantle materials [2]. Despite the location within the central PKT, the Th concentration is low inside of the crater compared with the surrounding [6], which implies that the possible presence of low-Th crustal bedrocks. Since purest anorthosite (PAN) [7] has not been reported in the PKT, it is unclear whether PAN crust globally (including PKT) formed from a primordial magma ocean. Since Copernicus can be a window to a deep-seatd crust (or mantle) in the most thermally active area of the Moon, it is the best target for us to (1) investigate crustal material and origin of the PKT (PAN or not), (2) understand an origin of the Th-rich material in the PKT and (3) evaluate whether PAN crust exist in the PKT. We study mineral distribution and geology of the Copernicus with VIS-NIR reflectance spectra of Kaguya Multiband Imager (MI).

Analytical methods: MI multiband spectra (415, 750, 900, 950, 1000, 1050, 1250, 1550 micron) are used for band images and reflectance spectra in this study. The MI data are calibrated with a method presented in [7]. Photometric correction with detailed topography were made for band images and all spectra presented here. Pyroxene can be easily distinguished from olivine and plagioclase due to its sharp absorption at 900 nm and/or 950 nm. In contrast, plagioclase has a very weak and broad absorption near 1250 nm. Similar absorption can be caused by olivine, which has a broad absorption centered 1050 nm. To better differentiate between olivine and plagioclase, two kinds of images are presented (Fig. 1b and c).

Results: Distribution of pyroxene, olivine and plagioclase in the Copernicus crater is presented in Fig. 1. Detection of plagioclase absorption at 1250 nm requires that the abudance of plagioclase is nearly 100 vol%. [7]. Thus, blue areas indicate the presence of purest anorthosites [PAN] [7]. Since an absorption coefficient of pyroxene is far greater than that of olivine and plagioclase, a few to several vol% of pyroxene masks absorptions of olivine and plagioclase. Red areas indicate that pyroxene abundance is greater than several vol%, with possible co-existence of olivine and plagioclase. Green areas are olivine-rich with minor amount of pyroxene (less than a few vol%), and minor or moderate amount of plagioclase, of which abundance is hard to be determined. Therefore, green areas can be dunite or troctolite.

Central peaks, western crater floor and wall are abundant in olivine without pyroxene. Olivine-rich nature of the central peaks are consistent with previous studies [1-3]. Eastern crater floor and wall consists of PAN. The contrast between olivine-rich western floor and plagioclase-rich eastern crater floor is sharp and linear across the crater (Fig. 1c). A digital elevation model created by MI dataset indicates that the eastern floor is about 100 m higher in alititude than the western floor. Southern crater wall and terrace are rich in pyroxene. The pyroxene-rich materials continuously occurs outside of the southern crater rim, showing a radial distribution, while they are not present on and ourside the northern crater rim. A pyroxene-rich area is also present from north of the large westernmost central peak to northern wall on the olivine-rich floor.

Discussions: Complex and asymmetric occurrence of multiple lithologies in the Copernicus is likely resulted from a complex geology of the target site and an oblique impact. Pyroxene-rich materials in the southern crater rim, wall and surroundings are likely surface materials that was originally covered on the Copernicus impact site. An oblique impact may have caused an asymmetric distribution of the pyroxene-rich surface materials. The surface materials are probably a high-Th, pyroxene-rich matters commonly present in the PKT, and the Copernicus impact excavated them, exposing a Th-poor crustal rock buried underneath. The lower Th content inside the Copernicus crater relative to the outside [6] is consistent with the above implication.

PAN is present at Copernicus. The rare occurrence of PAN in PKT is likely due to the high-Th pyroxene-rich surface materials (possibly Imbrium ejecta), which mask PAN crust both physically and spectroscopically.

An original depth of central peaks is generally greater than that of floor and wall. PAN on the eastern crater floor and olivine-rich rocks at the centeral peaks indicate that the olivine-rich rocks originally occur below the PAN crust. The olivine-rich western floor may also represent a deeper portion of the crust than the PAN crust revealed in the eastern floor. An occurrence of olivine-rich western floor and plagioclase-rich eastern floor with a sharp and linear boundary across the crater is unlikely a product of the impact, but likey represents a pre-Imbrium crust. The co-existence of two distinct lithogies with a clear boundary suggests a crustal boundary or a boundary within a layered intrusion. Yet, the linear border of about a crater diameter (95 km) seems favor of the former case. The crustal thickness in the Copernicus area of about 40 km (Y. Ishihara, pers. comm.) infers that PAN and the olivine-rich lithology likely represent an upper PAN crust and lower (probably troctolitic) crust. Copernicus impact site is located 100 km south of Imbrium basin ring, where a pre-Imbrium crust was uplifted. The cratering event excavated the crust underneath the pyroxene-rich Imbrium ejecta. A mechanism to expose a boundary of an upper and lower crust is to be further studied.

Plagioclase and olivine are major constituents of the crust in the Copernicus. Olivine is also present in other craters located on and around the Imbrium basin [8]. Olivine may be a major mafic minerals in the feldspathic crust in the PKT, and possibly in the global FHT. The apparent paucity of olivine in the FHT may be attributed to the lower detectability of olivine relative to pyroxene due to the smaller absorption coefficiency smaller than that of pyroxene. General occurrence of troctolite clasts in the feldspathic lunar meteorites [9-12] is in line with the above inference.

A magma ocean composition has been estimated to crystallize low-Ca pyroxene and plagioclase [13], because a noritic crust has been generally assumed [e.g. 14]. However, a magma ocean needs to be more aluminious by a factor of two or three than the previous estimation, when a troctolitic crust with olivine and plagioclase is assumed.

References: [1] Pieters C. M. et al. (1982) *Science 215,* 59-61. [2] Pieters C. M. and Wilhelms D. E. (1985) *PLPSC 15th, JGR 90,* C415-C420. [3] Pieters C. M. et al. (1994) *Science 266*, 1844-1848. [4] Lucey P. G. et al. (1991) *GRL 18,* 2133-2136. [5] Jolliff B. L. et al. (2000) *JGR 105,* 4197-4416. [6] Lawrence D. J. et al. (2007) *GRL 34,* CiteID L03201. [7] Ohtake M. et al. (2009) *Nature 461,* 236-240. [8] Yamamoto S. et al. (2010) *Nature geosciences 3,* 533-536. [9] Korotev R. L. et al. (2003) *GCA 67,* 4895-4923. [10] Korotev R. L. et al. (2006) *GCA 70,* 5935-5956. [11] Takeda et al. (2006) *EPSL 247,* 171-184. [12] Arai T. et al. (2008) *Earth Planet Space 60,* 433-444. [13] Longhi J. (2003) *JGR 108,* doi:10.1029/2002JE001941. [14] Hawke B. R. et al. (2003) *JGR 108,* DOI:10.1029/2002JE001890.

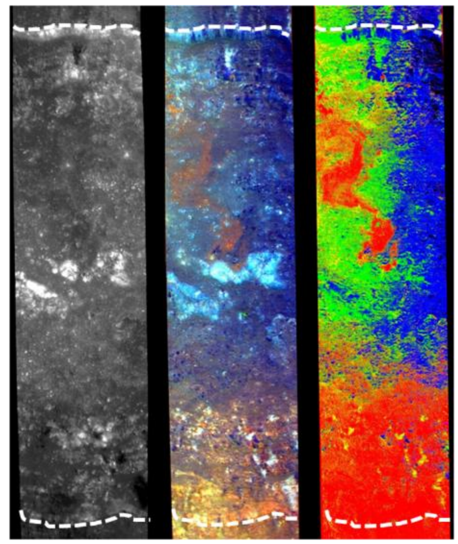

Fig. 1. MI images of a masaic strip including central peaks of Copernicus crater. (a) 750 nm band reflectance. (b) Color-composite image. Red for absorption depth (AD) at 950 nm (pyroxene), green for that at 1050 nm (olivine), and blue for that at 1250 nm (plagioclase). (c) Color-composite image. Red: areas with AD_{900} >AD_{1050} and AD_{1250} . Green: areas with (AD_{1050}/AD_{1250}) >1. Blue: area with (AD_{1250}/AD_{1050}) >1.

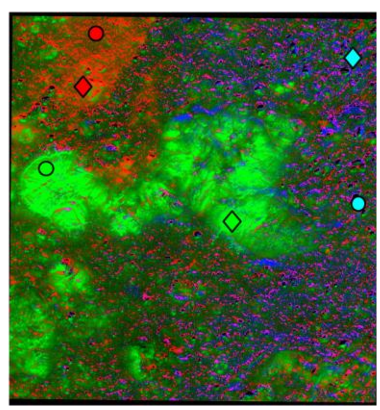

Fig. 2. Blown-up image of Fig. 1(c) for the westernmost central peak. Red for pyroxene-rich areas, green for olivine-rich areas, and blue for plagioclase-rich area. Solid circles and diamonds indicate the points for the spectra which are shown in Fig. 3.

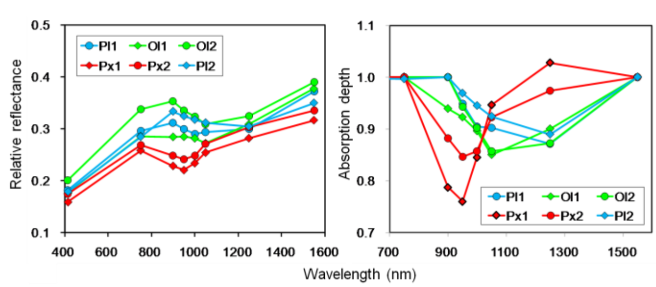

Fig. 3. (a) MI eight band spectra for points given in Fig. 2 (b) the spectra of (a) after the continuum removal.