EVIDENCES OF MULTIPHASE MODIFICATION OVER THE CENTRAL PEAK OF TYCHO CRATER ON MOON FROM HIGH RESOLUTION REMOTE SENSING DATA. P. Chauhan[1], N. Srivastava[2], P. Kaur[1], S. Bhattacharya[1], Ajai[1], A. S. Kiran Kumar[1], J. N. Goswami[2] & R. R. Navalgund[1] [1]Space Applications Centre, (ISRO), Ahmedabad 380 015, India**;** [2]Physical Research Laboratory, Ahmedabad 380 009, India.

Introduction: Crater Tycho (diameter ~102 km; 43.4^0S, 11.1^0E) is a unique dark haloed impact crater in the southern highlands on the near side of Moon. It is a Copernican crater due to its well developed bright ray pattern and intact crater morphology exhibiting conspicuous central peak, wall, rim and ejecta blanket. Its central peak exhibits a peculiar compositional assemblage, comprising of high - Ca pyroxene bearing lithology of plausibly gabbroic nature and anorthositic rocks [1,2,3,4,5] and an average titanium content >1wt% [6]. Due to the young age of Tycho (~100 m.y.) [7] and its considerable distance from nearby mare basalts, possibility of mafic ejecta cover from an adjacent younger impact event is quite unlikely. Similarly, presence of a crypto mare unit at a depth of ~ 10 kms in the pre-impact lithological sequence, estimated from standard depth-diameter relationship, is a remote possibility. With regards to volcanism, identification of a small irregular pond at the summit, in one of the Lunar Orbiter V images have been put forward to apprehend possibility of the central peak to be entirely of volcanic origin [8].

Here we report results of an integrated morphological and compositional analysis of the central peak of Tycho crater using high resolution panchromatic data from Terrain Mapping Camera (TMC) onboard Chandrayaan-1, Narrow Angle Camera (NAC) images of Lunar Reconnaissance Orbiter camera (LROC), and Multi-band Imager (MI) data onboard SELENE/Kagua mission, to understand processes involved in its formation and evolution. Our investigation, brings out, clear evidences of late stage volcanic activity leading to modifications of the central peak of Tycho crater. Volcanic vent, domes, pyroclastics, lava ponds and channels showing distinct cooling cracks and flow fronts have been identified on the central peak using TMC and LROC data. Compositionally, from the Kaguya's high resolution MI data, the lava pond and channels have been found to be high Ca –pyroxene rich, whereas, consistent with recent findings, the host rock in the central peak is anorthositic in nature [9].

Data used and methodology. TMC of Chandrayaan-1 has captured central peak of Tycho crater at 5 m spatial resolution using three different stereoscopic views separated by $\pm 26^0$. DTM for the Tycho region was generated using stereoscopic pairs of the TMC data, using a methodology developed at Space Applications Center, (ISRO), India [10]. Additionally, Tycho's central peak and crater floor coverage's from LROC NAC datasets and obtained from LROC WMS web site (http://wms.lroc.asu.edu) have been used. Whereas, TMC-DTM has provided the perspective view of the central peak (Fig. 1a&b), essential for the study of geologic settings and identification of volcanic features, LROC NAC data has enabled us to have a closer look at them from various phase angles, at a very high spatial resolution of 0.5 meters (Fig. 2b & 3b). For compositional studies, level-1b spectral dataset from multi-band Imager (MI) onboard SELENE/Kaguya mission has been used.The MI level 1b radiance data set have been converted into apparent reflectance values by normalizing it with incoming solar flux data corresponding to different MI spectral band pass filters.

Results and Discussions. Figure 1 (a) shows mosaic of TMC data strips covering Tycho crater and figure 1 (b) shows three dimensional view of the central peak, generated by draping the TMC panchromatic image over the DTM of the central peak. The entire central peak area has been found to be covered with several patches of pyroclastic materials. Two lava ponds [marked as (1) and (2) in figure (1b)], respectively, have been identified on the central peak of Tycho. Figure 2 (a & b) of Lava pond (1), from TMC and LROC NAC data, show signatures of flow patterns

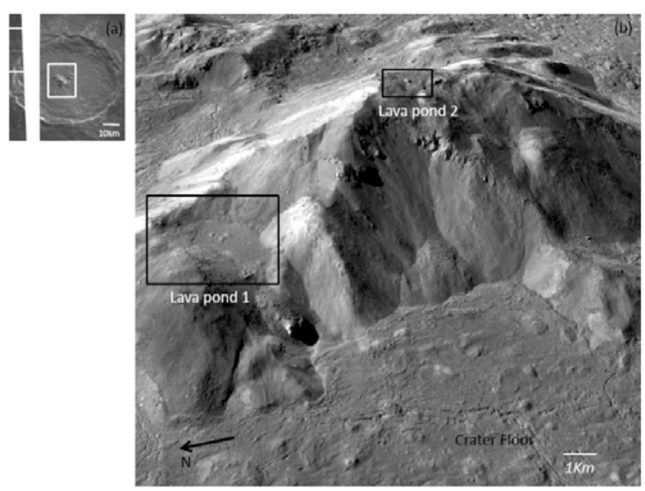

Figure 1: (a) Chandryaan-1 TMC data mosaic of Tycho crater, (b) three dimensional image of Tycho central peak with vertical exaggeration factor of 5.0 showing two distinct lava ponds.

associated with viscous fluids, pyroclastics and slightly raised inclined volcanic vent (figure 2a), surrounded by high density of pits and boulders. Though, only a single vent could be clearly seen in the TMC derived DTM, possibility of presence of multiple vents in the area exists due to enormous amount of pyroclastic material seen in the area.

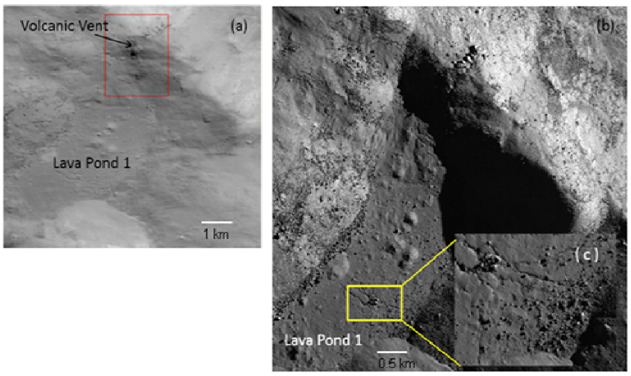

Figure 2: (a) High resolution view of lava pond 1using Chandrayaan-1 TMC data, (b) LROC NAC image of the lava pond 1, showing morphological evidences of LROC NAC data showing varied flow & pyroclastic relationships. (c) blow up of LROC NAC data showing varied flow & pyroclastic relationships.

Figure 3 (a) shows false color composite of MI data (RGB combination of 950, 750 & 415 nm) and figure 3 (b) shows the apparent reflectance (I/F) curves for the regions associated with lava pond 1, lava pond 2, crater floor and basement rocks of the central peak. Except basement rocks, spectral reflectance data obtained for lava pond 1, lava pond 2 and crater floor show spectral characteristics of high- Ca bearing rock type, indicating compositional similarity.

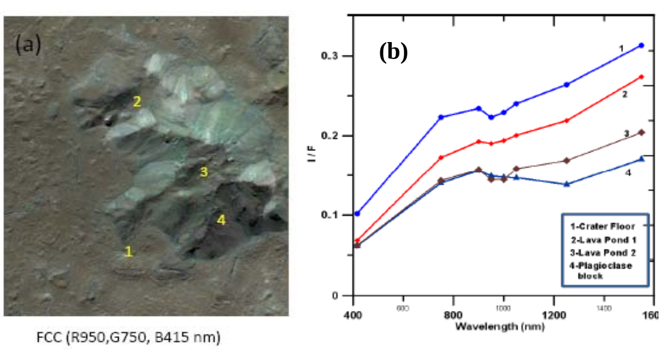

Figure 3: (a) SELENE MI FCC for the Tycho central peak, (b) spectral reflectance curves of the lava pond 1 & 2 along with spectra of Tycho crater floor and plagioclase rich blocks.

Earlier, plausibility of volcanism on central peak of lunar craters was hypothesized on the basis of photogeological investigations of high resolution lunar orbiter photographs. In the case of Tycho, late stage volcanic activity in and around the crater was reported by identifying and mapping plausible lakes and channels in Orbiter V images [8,11]. Crater counting of these volcanic units have revealed them to be younger than the crater's age. Based on these morphological and chronological evidences, it was apprehended that volcanism associated with Tycho crater might have been triggered by a large impact which tapped a shallow subsurface source of magma and it continued in phases. Significantly, the central peak was thought to be entirely of volcanic origin and channels on the crater's wall were traced down to the floor suggesting a feeding relationship. More recently, crater counting using very high resolution LROC NAC data have also revealed similar development of Tycho, though there are differences in the absolute time scales. The lakes have been found to be much younger than the ejecta blanket outside the crater [12].

Our very high resolution photo geological & compositional study of volcanic activity on topographically varied locations of the central uplifts, reported here provide conclusive evidences of extensive volcanic activity on the central peak of Tycho crater, otherwise located in the highland area. It may be appropriate to term mafic high-Ca bearing rock types on the central peak of Tycho as "basalts", instead of the popularly used term "Gabbro", its plutonic equivalent.

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