MORPHOMETRY, MORPHOLOGY AND TOPOGRAPHY OF VOLCANIC CONES IN MARIUS HILL, THE MOON. S. Wan, L. Qiao and Z. C. Ling*, Shandong Key Laboratory of Optical Astronomy and Solar-Terrestrial Environment, Institute of Space Sciences, Shandong University, Weihai Shandong 264209, China (zcling@sdu.edu.cn).

Introduction: Volcanism is one of the major geological processes of the Moon. Studying the surface geological characteristics of lunar volcano takes great importance and reflects the geological and thermal evolution history of the Moon. Lunar volcanic cones are conical shaped mounds occasionally with summit pit craters. Lunar cones, typically $2-3 \mathrm{~km}$ across at the base with summit craters $0.5-1 \mathrm{~km}$ in diameter [1], are among the most common volcanic landforms on the Moon. Lunar volcanic cones have been previously identified mainly from orbital photographs [e.g., 1-4]. However, due to the small topographic nature of lunar volcanic cones, many of them are not easily identified or are otherwise obscured, especially for areas where images obtained at very low Sun illumination (for example near terminator and in earthshine [5]) are not available. Newly-obtained global lunar topographic data, like the Kaguya/SELENE-TC (Terrain Camera) + LRO-LOLA (Lunar Orbiter Laser Altimeter) merged topography (SLDEM2015) with $\sim 60 \mathrm{~m}$ spatial sampling and $\sim 3-4$ $m$ vertical altimetric accuracy [6]), provide an unprecedented tool for identifying and characterizing geomorphic features on the Moon, including volcanic cones.

Lunar volcanic cones are generally interpreted to be composed of pyroclastic materials [2]. The cones formed on the Moon are broader and lower than those formed on Earth because of the low gravity and lack of atmosphere [7].

We initiated a comprehensive search campaign for volcanic cones in Marius Hill, plotting their distribution, local and regional clustering, range of characteristics (diameter, height, volume). Marius Hill is the largest single concentration of volcanic features on the Moon and includes volcanic domes, cones, rilles, and depressions (e.g., $[2,3]$ ). We employ the SLDEM2015 topography, with assistance from other multi-source topography (e.g., Kaguya TC DTM, LOLA) to (1) evaluate each volcanic cones identification in previous investigations and (2) search for new volcanic cones features. We then characterize each catalogued volcanic cones further by calculating morphological parameters.

General Characteristics and Identification Criteria of Volcanic Cones in Marius Hill: A preliminary survey of previously-catalogued volcanic cones [1-4] reveals some of their fundamental characteristics. A typical well-developed volcanic cone is characterized by a conical raised structure with a generally convexshape and relatively steep $\left(>10^{\circ}\right)$ topographical slopes
and a (quasi-)circular or elliptical outline with rough surface. Some cones have summit pit craters, while many lack them, possibly being filled up by the last eruptions. The development of the volcanic cone is sometimes affected by pre-existing topography or subsequent impact events; in these cases, the outline of the cone will be poorly defined.

Evaluations of Previous Volcanic Cones Identifications in Marius Hill: There are three prior dedicated volcanic cones identification contributions in this region, and each is re-visited as follows:
(1) Weitz and Head [3] identified 46 volcanic cones in Marius Hill using Lunar Orbiter mosaic of images.
(2) Whitford-Stark and Head [2] identified 59 volcanic cones in Marius Hill also using Lunar Orbiter images.
(3) Lawrence et al [4] identified 93 volcanic cones in Marius Hill using new data sets from LRO including the Lunar Reconnaissance Orbiter Camera (LROC).

Identification of Volcanic Cones in Marius Hills: Using the new SLDEM2015 topography and other new data sets, we conducted a systematic search for volcanic cones features in this region. In total, we identify 339 volcanic cones and 56 mare domes in Marius Hill. Considering the influence of subjective factors, we determinate the reliability of each cone and dome identification, which can be divided into four categories: class A: The characteristics are obvious and can be confirmed basically; class B: There are partial characteristics and can be confirmed roughly; class C : The characteristics are weak and the possibility is low; D: There are no characteristics. Excluding class D, we finally determined 321 volcanic cones and 50 domes in Marius Hill (Fig. 1). These observations prove that Marius Hill contains one of the highest densities of volcanic cones across the Moon.

Characteristics of Volcanic Cones in Marius Hills: We recognized the shape of each cone, which is divided into six categories: 29 cones for $C$-shape, 63 for elliptical-shaped, 173 for irregular-shape, 4 for linearshape, 32 for rounded-shape, 20 for unrecognizedshape. Using morphometric parameters and morphometric ratios, the cones morphology is summarized and quantified [8]. The morphological parameters we used include the basal width $\left(\mathrm{W}_{\mathrm{co}}\right)$, height $\left(\mathrm{H}_{\mathrm{co}}\right)$, eccentricity, volume, slope (mean slopes of the cone) and mean rock abundance (RA). For the cones with summit craters, the diameter $\left(\mathrm{W}_{\mathrm{cr}}\right)$ and depth of summit crater $\left(\mathrm{D}_{\mathrm{cr}}\right)$ are also
measured. The morphological ratios we used include the ratio of height to basal width $\left(\mathrm{H}_{\mathrm{co}} / \mathrm{W}_{\mathrm{co}}\right)$ and the ratio of summit crater width to basal width. We used histograms to show the distribution of morphometric parameters and morphometric ratios of volcanic cones with different shapes and utilized scatter plots to explore the potential relationship between different morphometric parameters. The partial results are shown in Fig. 2. We found that the dimension of volcanic cones in Marius Hill are generally small compared with terrestrial cones (e.g. the cone fields of Mauna Kea or Lanzarote [9]). In addition, the ratio of height to basal width and mean slope revealed the low overall steepness of volcanic cones in Marius Hill, which may be related to the lunar gravitational environment, the weathering degree of volcanic cones or other geological events.


Fig. 1. Identification of Volcanic Cones in Marius Hills
On-going and Future Work: We are trying to compare the volcanic cones in Marius Hill with other volcanic structures on the Moon and terrestrial cones. We are also working on constraining the regional volcanism in Marius Hill with the previous dating results.

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Fig. 2. The histograms and scatter plots of volcanic cones' morphometric parameters and morphometric ratios in Marius Hills.

