NONMARE VOLCANISM ON THE MOON: CHARACTERISTICS FROM THE CLEMENTINE DATA.
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In this work we study visible and near-IR spectra of nonmare volcanic domes on the Moon using Clementine data and consider some spectrally analogous formations on the Moon.

Introduction: Hansteen α, Gruithuisen γ, and Gruithuisen δ formations on the Moon were supposed to be volcanic features formed by viscous lavas with some pyroclastics [1–4]. These formations are isolated domes, which elevate over the surrounding mare surface. Their material appears to be brighter and more fresh-looking than that of nearby highland areas. The surface texture also differs from that of the lunar highlands. The domes have remnants of something resembling summit or flank craters. The Gruithuisen structures are more regular-looking domes, while the Hansteen α formation is a triangular-shape hill. Another supposed volcanic feature, Mairan T is a regular cone with a summit depression [2]. KREEP basalts or more acidic compositions have been proposed for these features [2, 4].

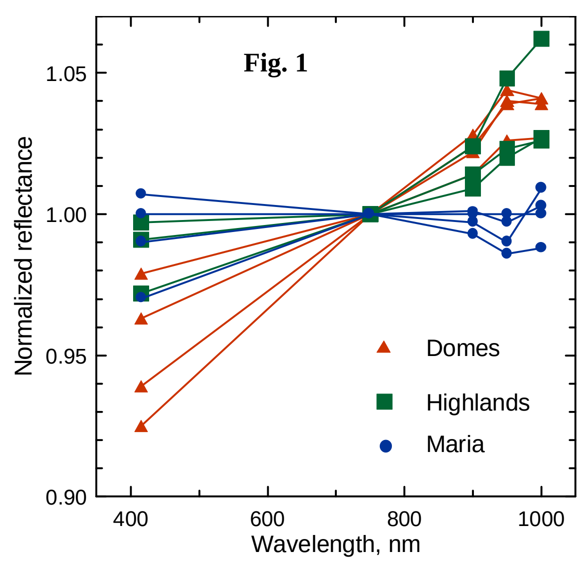
Visible - near IR spectra: We selected a few typical areas of 20x20 pixels within Hansteen α, Gruithuisen γ, and Gruithuisen δ domes in raw Clementine UVVIS camera images. We tried to avoid craters and steep slopes with probably immature regolith. Calibrated reflectance averaged over the selected areas gave us the albedo values for the 5 UVVIS filters. We compared these reflectance spectra with some typical spectra of lunar terrains extracted in the same way. Fig. 1 shows some of these spectra normalized by the red filter and by the standard site MS-2. Apollo-16 landing site and two sites just to the west of Oceanus Procellarum are shown as examples of highland spectra. Some sites in Oceanus Procellarum, Mare Imbrium and Mare Serenitatis are taken as mare samples. It is seen that the domes display steep continuum slope and a specific signature in the near IR filters, namely, a convex form of the spectrum. In addition, the domes are brighter than typical highlands.

We made composite images of these specific characteristics for Hansteen α (α, Fig. 2), Gruithuisen γ and δ (γ and δ, Fig. 3), and Mairan T (T, Fig. 4). The images were derived from coregistered and calibrated raw UVVIS images in filters A (415 nm), C (900 nm), D (950 nm) and E (1000 nm). The blue channel denotes the inverse albedo in filter C. The green channel denotes a combination of albedo and slope of the continuum: $4*C - C/A$ (the letters denote albedo in the corresponding filters). This combination is actually the inverse continuum slope roughly corrected for general albedo-color trend for highlands. The red channel denotes a combination of three near IR filters: $D^2/(C{\cdot}E)$, a measure of spectral curvature in the near IR. Specific spectral features of the domes mean less blue (high albedo), less green (steep continuum), and more red (reflectance in D is higher in comparison to C and E). Thus, the typical dome material appears in reddish shades in the composite images (see Fig. 2 – 4).

Interpretation of spectral features: High albedo and steep red spectral slope of mature regolith on the volcanic domes suggest Fe and Ti content lower than for any mare soil [2] and probably favor non-basaltic composition of the domes. Though observed unusual combination of high albedo and continuum slope put some constraints on mineralogy of the features, the great diversity of spectra of lunar samples did not allow us to propose any candidate with a confidence.

The specific near-IR spectral feature, that is the convex form of the reflectance spectrum, is not typical for lunar regolith. Among lunar samples, the orange glasses can be considered as a probable component of the regolith of the domes. The orange glasses have pronounced convex form of spectrum in 900-1000 nm band. Formation of the domes with viscose magma supposes some amount of pyroclastic materials in these sites. Presence of the orange glasses in the pyroclastic material is plausible.

We applied a spectral mixing model [5] to simulate admixture of the orange glasses (RELAB spectra



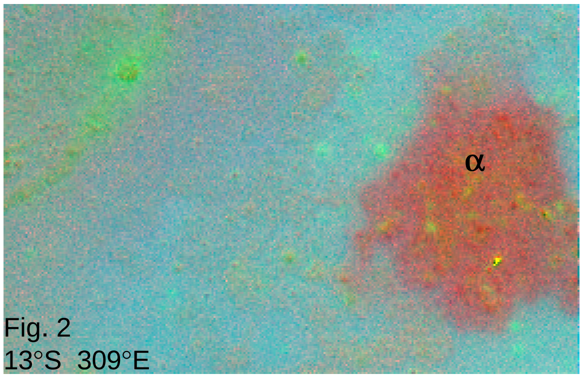


Fig. 2
13°S 309°E

of an Apollo-17 sample) to typical highland regolith (spectra of Appolo-16 samples). We found that 20% – 50% orange glasses in the regolith provides the observed values of the spectrum curvature parameter $D^2/(C{\cdot}E)$.

Other sites. A dome-like highland peninsula (D in Fig. 4) near Mairan T cone (T, Fig. 4) shows similar spectral signature as Gruithuisen γ and δ domes. This points to possibility of pyroclastic material here.

Mons La Hire usually had been treated as a part of an inner Imbrium basin rim protruding through mare basalts [1]. In [6] it was supposed that Mons La Hire was formed by extrusion of magma that utilized a major fault to rise. The composite image (Fig. 5) shows that part of Mons La Hire has the spectral signature typical for volcanic domes. For comparison, Fig. 6 shows Delisle β, a neighboring island in the mare basalts with no such signature. The mare surface near Mons La Hire (Fig. 5) is contaminated with the spectrally peculiar material. Probably, this contamination is pyroclastics deposited by explosive eruption from a main pit crater.

Discussion: Morphological freshness of dome surfaces indicates their relative youth and thus rather late lunar volcanism. Among the factors controlling dome formation, the eruption viscosity has been rather important and connected with composition of erupted materials together with eruption temperature, rate and type. An approach, which involves the study of eruption styles together with compositional constraints from spectra, would contribute to study of the volcanic domes and their role in the lunar geological history.

Forthcoming completion of the global Clementine UVVIS mosaics will enable a systematic search for features possessing the spectral signature typical for the volcanic domes. This would give a new insight into this peculiar type of volcanism on the Moon.

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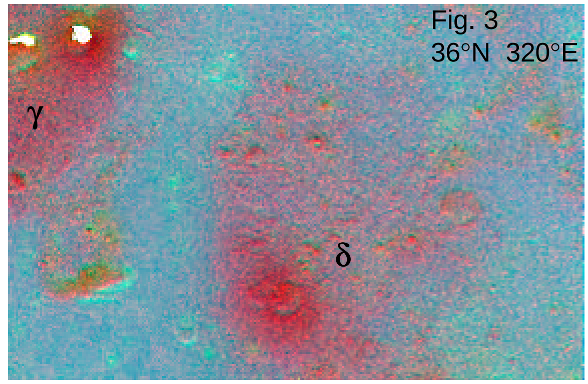

Fig. 3
36°N 320°E

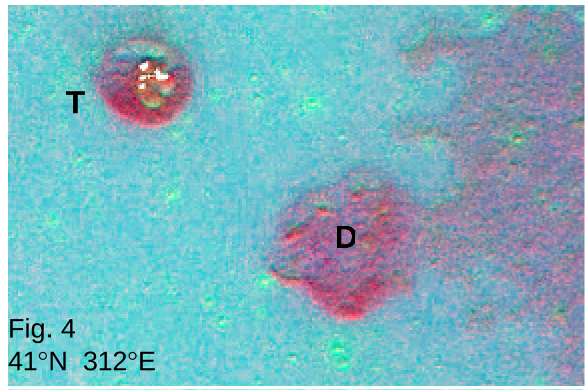

Fig. 4
41°N 312°E

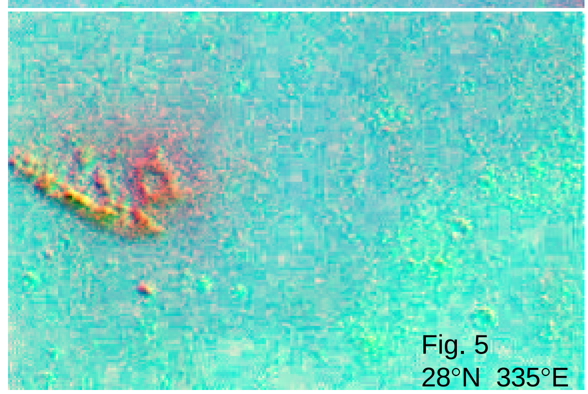

Fig. 5
28°N 335°E

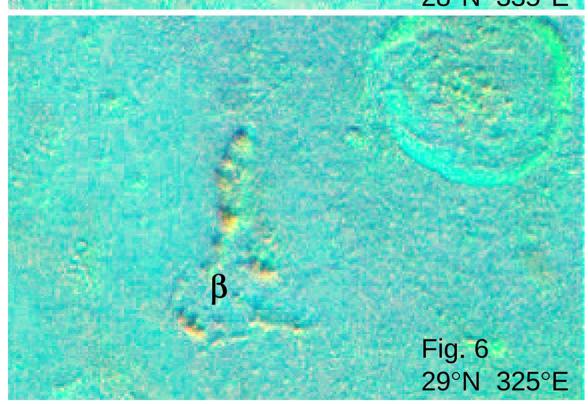

Fig. 6
29°N 325°E