IDENTIFICATION AND CHARACTERISATION OF POTENTIAL LUNAR ANALOGUES WITHIN INDIA K. Durga Prasad, Megha Bhatt, P. Kalyana Reddy, Janmejay Kumar, N. Srivastava, D. Ray, Abishek Verma, A.D. Shukla, Varun Sheel and Anil Bhardwaj, Physical Research Laboratory, Ahmedabad 380009, India (durgaprasad@prl.res.in)

Introduction: Lunar samples from Apollo missions have provided us a detailed characterization of the lunar soil. Any terrestrial soil that has physical, chemical, mineralogical, and geotechnical properties similar to that of the lunar soils can be termed as a lunar analogue or simulant [1]. However, there may be certain exceptions depending on the kind of analysis/studies planned on the target analogue. Global remote sensing analysis of morphology, chemical composition and physical characteristics of the lunar surface by recent missions now provide us a handle to mimic diverse lunar surface and stratigraphies for carrying out various studies under simulated lunar environment. Considering future lander/rover missions and human exploration to the Moon, representative lunar analogues for both mare and highland regions have been identified within India [2-4]. Detailed physical and chemical characterization of these samples have been carried out to establish their potential as lunar analogue samples. For the first time, identification and characterization of mare analogue within India has been reported in this work. Characterisation of already reported highland simulant from Sittampundi Anorthosite Complex from India is also included using the same analytical tools for a comparison.

Terrestrial Analogues of Lunar Soils: Samples returned from the Moon are limited and they represent only a specific part of the Moon and do not represent the heterogeneity on the global scale revealed from remote sensing studies and lunar meteorites. Further, the lunar samples are scarce and precious, therefore lunar analogues are ideal for conducting long-term surface experiments considering diverse and representative locations of the Moon. In this scenario, a first-hand global understanding of various lunar surface properties and processes can be obtained by conducting laboratory experiments on analogue samples in a simulated lunar environment [5]. Conducting these experiments demand a relatively large amount of samples (~few gms to kgs). This necessitates the identification, collection and characterization of appropriate terrestrial analogue samples. Although, several lunar soil simulants like JSC-1, JSC-1A, MLS, FJS-1, FJS-2, FJS-3 are available globally, they are scarce, and their accessibility is limited. Keeping in view the scarcity of lunar soils and simulants, terrestrial analogues representing samples for both mare and highland soils of the Moon have been identified within India for carrying out such studies. While anorthosite rocks from Sithampundi of Tamilnadu were identified and used as a potential highland simulant [2,3], basaltic rocks from Dhinodhar area of Kutch, Gujarat, India, have been identified and characterised as suitable Mare analogues and reported in the present study.

It was initially identified through X-ray fluorescence analysis that basalt rocks from Dhinodhar have the potential of using them as analogues of lunar mare basalts. Validation of the samples as lunar analogues for carrying out various studies has been done through their detailed physical and chemical characterization [6].

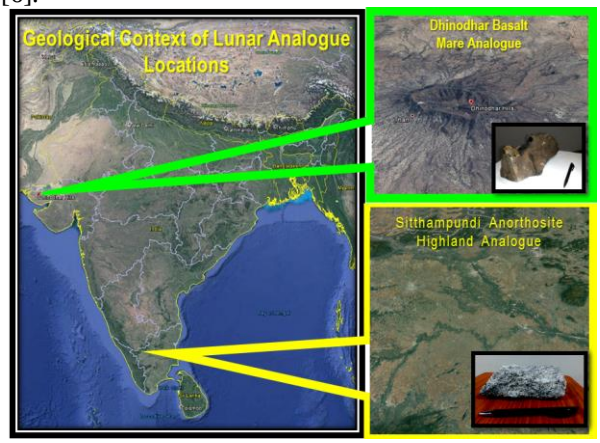

Figure 1. *Contextual map of analogue locations and sample collection area (Image courtesy: Google Maps). Samples can be seen in inset.*

Terrestrial Analogue for Lunar Basalt: Lunar basalts found in mare regions are characterized by low silica content, greater concentration of TiO_2, FeO and have higher CaO/Al_2O_3 ratio when compared to the highlands. Lunar basalts are mainly composed of pyroxenes, olivines, and metal oxides such as ilmenite, armalcolite and spinel [7]. Terrestrial basalt differ from having greater silica content, low Ti & Fe contents. From Literature [8] and also from the present study it seems the basalts from Dhinodhar area of Kutch, Gujarat, India, have a chemical composition similar to that of lunar basalt.

Terrestrial Analogue for Lunar Anorthosites: Lunar anorthosites are mainly found in highlands which are early formed igneous rocks rich in Ca and Al [7]. Analogous composition of highland soil has been found in terrestrial anorthosites. Sittampundi Archean

anorthosite (Namakkal district, Tamilnadu) is analogue for lunar anorthosite, which is dominated by relatively pure calcic anorthosite (An80-An100) with less than 10% mafic minerals [9]. Anorthosite returned from Apollo mission contain greater than 90% Ca- rich plagioclase as well as pyroxene and minor amount of olivine, which is Fe rich [7]. On the basis of the mineralogical characteristics and relative percentage of major oxides, Sittampundi anorthosite is established as a lunar highland analog [2].

Sample collection and preparation: The contextual image showing the sample collection region for highland and basalt simulants is shown in figure 1. The identified mare analogue is derived from basalt rock sample of Dhinodhar (DH) area of Kutch. The sampling area is Dhinodhar hill (23°27'1"N, 69°20'7"E), which has been estimated to be a Late Cretaceous (69 - 65 My) volcanic plug formed by solidification of magma inside an abandoned and eroded volcano. The lunar highland analogue is Anorthosite rocks from Sittampundi Complex. Sittampundi is located in Nammakal district (Lat. 11°10- 11° 25 N and Long. 77° 50 – 76° 05 E) of Tamil Nadu.

The samples collected from field are rock fragments. They are prepared in the form of fine-grained powders sorted in different grain sizes such that physical properties: density, porosity, stratigraphy, thermal and electrical, can be replicated as desired. Before attempting any modification to the rock sample, a slice is preserved from the sample for petrographic analysis.

Sample Analysis and Discussion: The following detailed characterization is carried out on the samples and the results are compared with those from the returned samples, JSC-1A simulant and literature [8].

1. Visual inspection & Microscopy
2. Reflectance Specroscopy (for mineralogy)
3. X-Ray Flourescence (for chemistry)
4. X-Ray Diffraction (for identifying crystalline structure)
5. Thermophysical properties
6. Electrical properties

The results obtained from all the above analyses showed a very good agreement with the data obtained for lunar soils, JSC-1A and literature. It can be seen from figure 2 that the measured chemical composition of identified analogue samples compare well with lunar soils and simulant data. Results from all other analyses also show a similar agreement.

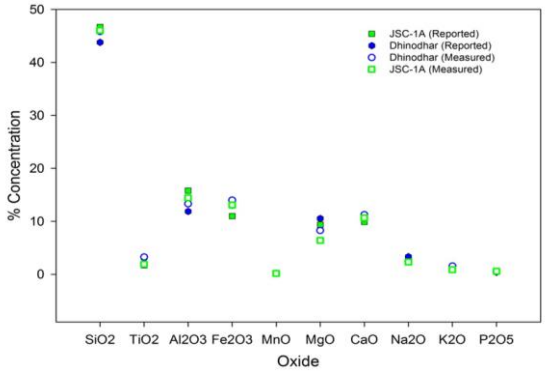

Figure 2. *Comparison of the chemical composition of basalts used for this study with other lunar analogues*

Summary: Because of the scarcity of lunar soils and simulants, and in view of future lunar exploration, terrestrial analogue rocks for lunar basalts and Anorthosites have been identified within India and collected from Dhinodhar, Kutch, Gujarat and Sittampundi,Tamilnadu, areas. Powdered samples of different grain sizes were prepared from the rock sample by following a specific sample preparation procedure involving cleaning, cutting, grinding, and powdering. Validation of the samples as lunar analogues has been done by carrying out a detailed characterization and comparing the results with that of lunar soils and simulants. A very good agreement shown in the comparison qualifies the identified samples as potential lunar analogues.

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References: [1] Sibille et al., (2006), NASA/TP—2006–214605 [2] Anbazhagan and Arivazhagan, (2012), J.ISRS, 40(1) [3] Anbazhagan et al., (2021), Icarus, 366(114511) [4] Durga Prasad, (2016), PhD Thesis[5] Durga Prasad and Murty, (2013), Acta Astro., 89(149) [6] Durga Prasad and Murty,(2020), PSS, 191(105038) [7] Heiken et al., Lunar Source Book, Camb., 1991 [8] Paul et al., (2008) Lithos, 102, 237[9] Ashwal, L.D. , Anorthosites springer, Verlag, Berlin; 1993, p. 422