Automatic Production of the Geologic Classification Map of the Moon based on the Kaguya/SP data.

Taisei Shibakura[1], Yoshiko Ogawa[1], Makiko Ohtake[1] and Uday Kiran Rage[1], [1]University of Aizu (m5261159@u-aizu.ac.jp, yoshiko@u-aizu.ac.jp, makiko-o@u-aizu.ac.jp, udayrage@u-aizu.ac.jp)

Introduction: A geological map is an important information for understanding a terrestrial body. The VIS-NIR reflectance spectra of the Moon include key information of the distributed minerals. A global lunar classification map of absorption spectra by K-means was proposed by Hareyama et al. (2019) [1]. However, this map assumes the best number of clusters is 7, based on the independent information of major geologic areas.

This study aims to generate and update a global lunar geologic map based on hyperspectral data in future. This report proposes the optimal number of clusters based on Elbow K-means results. We focus on the two areas: mare and SPA on the Moon in this report.

The mare clustering results are compared with the Unified Geologic Map [2]. The SPA results are compared with the reports of [3] and Uemoto et al. (2017) [4].

Data and Method:

Kaguya/SP data

The SP data were collected by the Spectral Profiler (SP) onboard the lunar orbiter Kaguya, which has 296 bands of reflectance spectra at VNIR wavelengths (513-2588 nm). In this study, we used the same 160-band SP data as Hareyama et al. (2019) [1]. They are averaged every 0.5 grid of lat/lon. The two areas on the Moon: mare and SPA are focused in this report. The mare regions are defined and provided by Nelson et al. (2014) [5]. SPA region is defined as 0°-90°S, 120°E-120°W.

Clustering

Fuzzy K-means is non-hierarchical clustering, so we need to determine the number of clusters in advance. The advantage of Fuzzy K-means over K-means is flexible and allows an object to belong to more than one cluster. The optimal K value is determined based on the result of the Elbow K-means, which plots WSSE (Within-cluster Sum-of-Squared Error) values in relation with clustering number [e.g.,].

These clustering algorithms are applied using the clustering tool RasterMiner [6].

Results:

Mare

Based on the results of elbow K-means method (Fig. 1), the optimal K value appears to be around 3 or 4. Therefore we applied the Fuzzy K-means method to the mare data set, where K = 3, 4, and 5 are adopted, respectively Fig. 2 shows the resultant geologic classification map of mare regions for the case of K = 4. In Fig. 3, the centroid spectra for each cluster displayed in Fig. 2 are plotted. The total number of data used in mare regions is 31208.

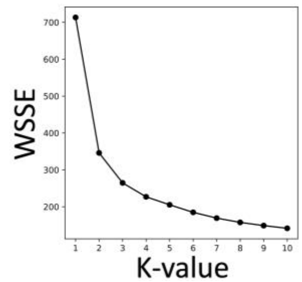

Fig. 1: The result of applying elbow K-means to the lunar reflectance spectra in the mare regions. The WSSE value drops sharply around K =3 or 4.

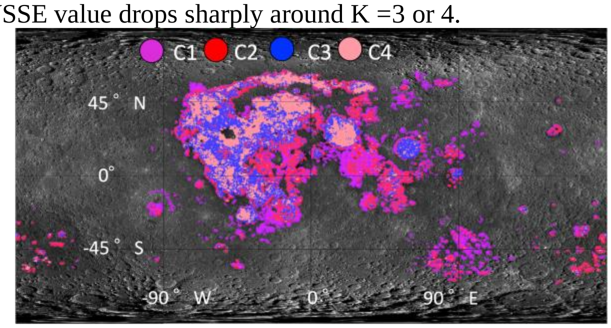

Fig. 2: Fuzzy K-means classification results (K = 4) in mare region.

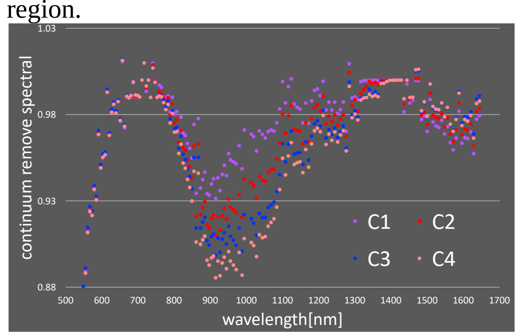

Fig. 3: Continuum-removed spectra representing each class (K=4) in the mare regions. C1 to C4 are in descending order of reflectance value around 950 nm for clarification.

SPA

Based on the results of elbow K-means method (Fig. 4), the optimal K value appears to be around 4 or 5. Therefore we applied the Fuzzy K-means method to the mare data set, where K = 4, 5 and 6 are adopted, respectively.

Fig. 5 shows the resultant geologic classification map of SPA regions for the case of K = 5. In Fig. 6, the centroid spectra for each cluster displayed in Fig. 4 are plotted. The total number of data used in SPA regions is 43621.

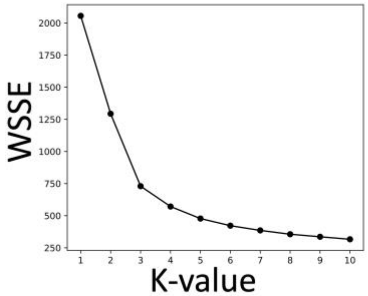

Fig. 4: The result of applying elbow K-means to the lunar reflectance spectra in the SPA regions. The WSSE value drops sharply around K = 3, 4, 5.

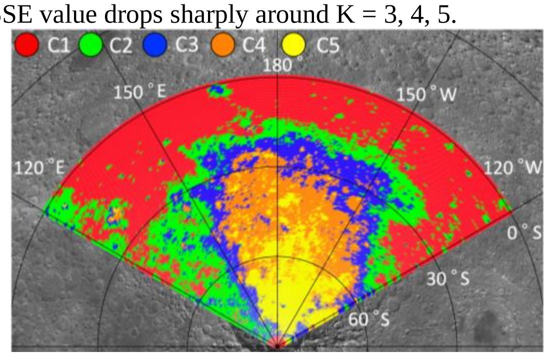

Fig. 5: Fuzzy K-means classification results (K=5) in the SPA Region.

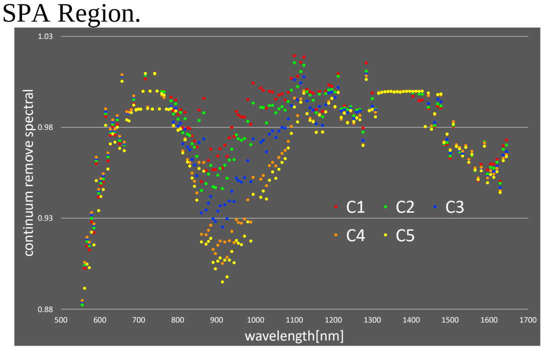

Fig. 6: Continuum-removed spectra representing each class (K=5) in the SPA regions. 1-μ m band absorption is clearly observed.

Discussion:

As for mare regions, the classification results for each K-value were compared to the unified geologic map [2]. The close-up of the Mare Australe region is shown in Fig. 7. For the case of K = 3, 4, The red and purple clusters correspond to the "lm1" (Lower Mare Unit) and "lm2" (Upper Mare Unit) units on unified geologic map [2]. For the case of K = 5, 6, a new cluster is generated (green colored) with no correspondence with the described geological unit. This appears to be over-classified.

In SPA, the distribution of C2 (green) is consistent with the distribution of "FeO-rich low-Ca pyroxene-dominated mantle material" reported by Ohtake et al. (2014) [3]. The clustering results in SPA shows good agreement with the lithology map, especially Anorthosite exposure area, reported by Uemoto et al. (2017) [4] (Fig. 8).

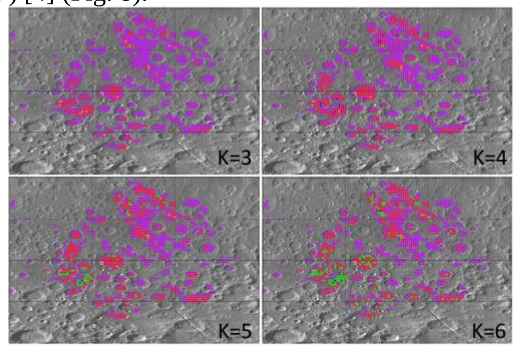

Fig. 7: Close-up of the Mare Australe. Red cluster for the case of K = 4 is divided into smaller clusters for the case of K > 5.

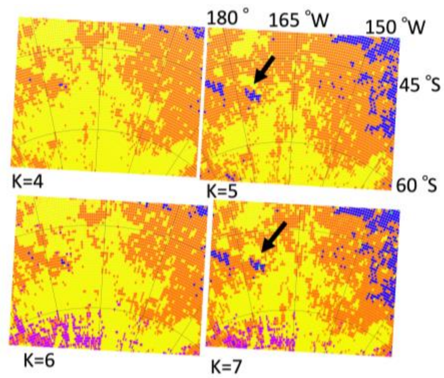

Fig. 8: Close-up of the part of SPA. The blue clusters indicated by the black arrows correspond to the distribution of anorthosite [4].

Conclusion:

In this work, elbow K-means and fuzzy K-means were applied to the averaged Kaguya/SP data sets in the two regions of the Moon: mare and SPA. The clustering results were compared with existing geologic maps. The consistency between them is discussed.This work tried to produce the geologic classification map of the Moon automatically and optimally based on the Kaguya/SP data, which seemed successful for the two major regions. Future tasks include extension of the area and quantitative evaluation toward the goal of updating the global lunar geologic map.

References: [1] Hareyama, M. et al. (2019) Icarus, 321, 407-425. [2] Fortezzo, C. M. et al. (2020) 51st LPSC, #2760. [3] Ohtake, M. et al. (2014) Geophy. Res. Lett., 41, 2738–2745. [4] Uemoto, K. et al. (2017) J. Geophys.Res., 122, 1672– 1686. [5] Nelson, D. M. et al. (2014) 45th LPSC, #2861. [6] Rage, U. K. (2021), ICDAR , #1.