STATISTICAL CLASSIFICATION OF APOLLO 16 IMPACT MELT USING MAJOR ELEMENT COMPOSITIONS.
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Introduction: Lunar rocks record a history of heavy bombardment called the Late Stage Heavy Bombardment (LHB). Lunar impact melt rocks have shock ages clustering around 4.1–3.8 Ga [e.g. 1-3]. However, the age clustering might include a sampling bias; for example, some rocks could record the same impact event. Therefore, attempting to identify and characterize individual impact events is important to understand LHB. Lunar rocks from Apollo 16 landing site have a wide variety of impact melts, and thus could provide important clues to further unravel the impact history of the moon. Apollo 16 impact melt rocks and fragments have thus far been petrologically and geochemically investigated in an attempt to identify their origin [e.g. 4-5]. Norman et al. (2006) [5] reported at least 4 different melt-producing events during 3.96–3.75 Ga based on impact age, bulk composition, and petrography for rock-scale impact melt.

Bulk chemical composition of impact melt rocks give us important information on the variation of pre-impact target rocks, because impact melt yields a nearly average composition of the melted target materials. Korotev (1994) [4] classified rock-scale Apollo 16 impact melts into 4 major types (Groups 1-4) using trace element compositions, in particular Sc and Sm concentrations. Though smaller-sized impact melt fragments in lunar rocks (less than centimeter) exist, they are rarely measured for trace element composition because of their small mass. Therefore, it is hard to compare among multiple impact melt rocks to identify the origin of the melt according to Korotev's method.

As such, we have developed a new method for classifying impact melt rocks by only using major element composition, as well as classification by trace element data. Our technique informs on the variation of target materials even using the smaller-sized samples. This includes performing statistical investigation of the bulk chemical composition of Apollo 16 impact melt rocks with a resultant new classification scheme by only using major element composition.

Data and method: We have compiled 330 published data of major, minor, and trace element compositions of Apollo 16 impact melt rocks and clasts [e.g. 4-9]. These compositional data have been obtained by various techniques which include INAA, XRF, and DBA. Most of the samples were not classified using the Korotev method because of the lack of trace-element compositional data. We selected samples which have 9 element data (Si, Ti, Al, Fe, Mg, Ca, Na, K, and Cr) and have been already classified using trace element information (95 total data).

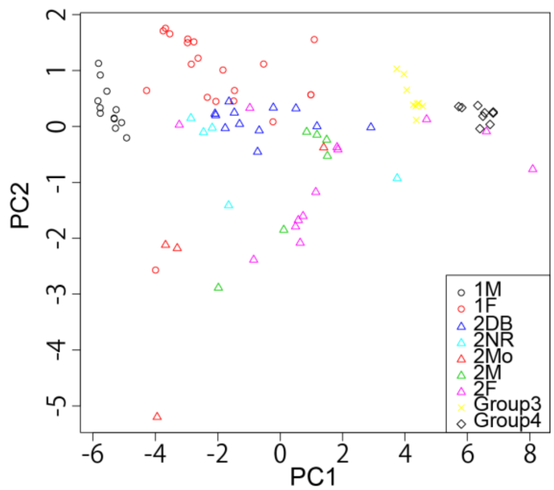

Figure 1. PC1 vs. PC2 plot. Major 4 groups were separated in PC1. PC2 separate subgroups of Group2 impact melt.

We conducted principal component analysis (PCA), a method of dimension reduction of data set, to identify and interpret compositional variations and obtaining PC scores. The first principal component (PC1) explains maximum variation, followed by second (PC2) and third (PC3) components. PCA has already been applied for meteorite classification using major element compositions, with positive results indicating that it can be used to classify meteorite types [10].

Results and discussion: The PCA results are displayed in Fig. 1. The first component (PC1) separated the analyzed impact melts into four distinct groups with increasing PC1 score correlative with increasing group number (i.e., Group 4 representative of the maximum PCA score). Group 1 melt is characterized as incompatible trace element (ITE) rich and both CaO- and Al_2O_3-poor impact melt [4]. On the other hand, Group 4 is ITE-poor, aluminous-rich impact melt [4]. Two sub-types (1M and 1F) of Group 1 melt are clearly separated by PC1, although 1F and Group 2 melts spatially overlap. 1M has lower Al and MgO abundances than 1F. Therefore, these PC1-based groupings indicate a distinction between mafic and felsic impact melt rocks.

Group 2 impact melts have wide ranging PC1, and sub-groups are roughly distinguishable, although all types spatially overlap in the PC1 plot. Sub-type of Group 2 impact melt, which includes dimict breccia (2DB), North Ray Crater VHA basalt (2NR), 2M, and 2F, displays a higher aluminous value than Group 1 melt. 2M and 2F could be a mixture of both 2DB and feldspathic melt [4]. Therefore, the variation displayed by PC2 is wide for this group, especially highlighted by 2M and 2F.

Group 3 has a lower ITE concentration and high in Al concentration when compared to Groups 1 and 2, as well as a PC2-determined greater ferroan composition than Group 2 melt.

Our PCA results not only are consistent with conventional-classification-based results using the trace elements, but also statistically indicate a difference between mafic and felsic impact melt rocks, although sub-types of Group 2 melt are widely distributed. Classification of Apollo 16 impact melt using major 9 element compositions by PCA is thus useful to classify impact melt rocks, along with conventional methods that use Sc and Sm compositions [4].

As explained above, most importantly PC1 distinguishes between mafic and felsic impact melt; more specifically, felsic melt is distinct from mafic melt relatively rich in Fe and/or Mg and poor in Al, Na, and K (wt.%). These elemental compositions have good correlation with PC1 (correlation coefficients are -0.98

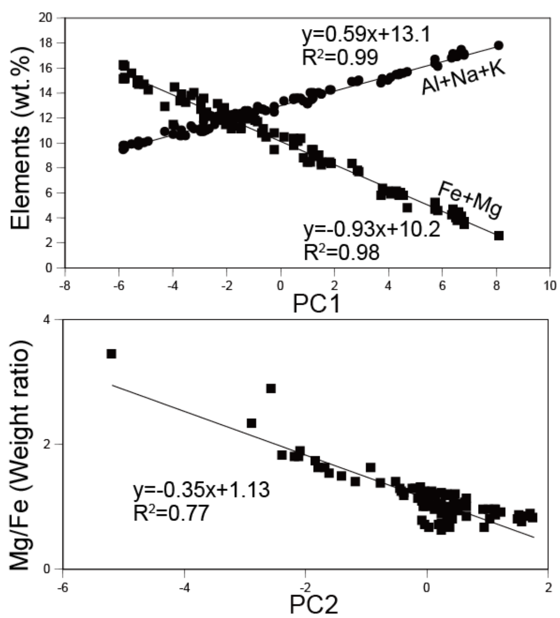

Figure 2. Correlation between PC score and elemental compositions. PC1 shows negative correlation with Fe+Mg and positive correlation with Al+Na+K.

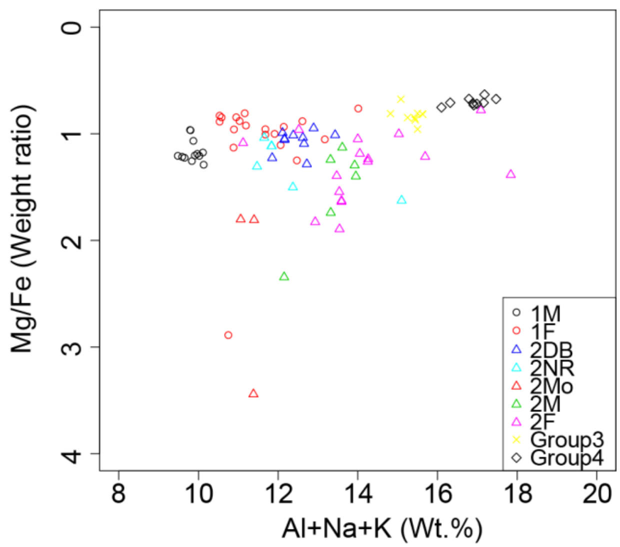

Figure 3. Al+Na+K vs. Mg/Fe (weight ratio) plot. This plot shows similar geometry with PCA.

and 0.99 respectively for Fe+Mg and Al+Na+K; Fig. 2). In addition, our work shows PC2 results correlating with the Mg/Fe weight ratio (correlation coefficient is -0.81; Fig. 2).

We plotted Al+Na+K (wt. %) and Fe/Mg (weight ratio) of Apollo16 impact melt rocks in Fig. 3. This plot has similar trends when compared to the PCA-based trends, although the y axis is slightly different. Hence, this plot is also useful in the identification of impact melt types using only 5 major elements (Al, Na, K, Fe, and Mg).

Summary: Our PCA results indicates that Apollo 16 impact melt rocks can be statistically classified by using only 9 major elements, as well as trace element abundances. Moreover, our results indicate that impact melts can also be classified by using 5 elements; this includes finding that Al+Na+K and Fe+Mg have good correlation with the PC1 scores. By plotting Al+Na+K and Mg/Fe, we obtained a figure similar to that yielded by the PCA analysis.

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