

# Analysis of the correlation relationship between chemical components in different ancient glass artifact

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**Abstract.** To compare the differences in chemical composition correlation between high potassium glass and lead barium glass. Firstly, the Spearman correlation coefficient was used to observe whether there is a correlation between different chemical components. If there is a correlation, the degree of correlation has been indicated. At the same time, principal component analysis was used to reduce the dimensionality of 14 chemical composition indicators for high potassium glass and lead barium glass. The principal components corresponding to the characteristic values with a cumulative contribution rate of over 80% have been taken, and the meanings represented by these principal components have been explained. The specific differences in the correlation between the chemical composition content of different types of glass products have been studied, revealing the differences in the production processes of high potassium glass and lead barium glass.

**Keywords:** High Potassium Glass, Lead Barium Glass, Spearman Correlation Coefficient, Principal Component Analysis.

## 1. Introduction

The Silk Road was a channel for cultural exchange between China and the West in ancient times, and glass was a valuable material evidence of early trade exchanges. Early glass was often made into bead shaped ornaments in West Asia and Egypt and introduced to China.[5][6] After absorbing its technology, ancient Chinese glass was made locally, making it similar in appearance to foreign glass products, but with different chemical compositions.[7][8]

The main raw material of glass is quartz sand, and the main chemical component is silicon dioxide ( $\text{SiO}_2$ ). Due to the high melting point of pure quartz sand, in order to reduce the melting temperature, combustion aids need to be added during refining. The combustion aids commonly used in ancient times included Wood ash, natural soda, saltpeter and lead ore, and limestone was added as a stabilizer. After calcination, limestone was converted into Calcium oxide ( $\text{CaO}$ ). [1] The main chemical composition varies depending on the added flux. For example, when lead ore is added to lead barium glass as flux during firing, the content of lead oxide ( $\text{PbO}$ ) and Barium oxide ( $\text{BaO}$ ) is high, and it is generally considered as the glass variety invented in List of Chinese inventions. [2][3] Potassium glass is fired with substances with high potassium content, such as Wood ash, as combustion promoter. It is mainly popular in Southeast Asia, India and other regions.

This article reveals the differences in the production processes of high potassium glass and lead barium glass by analyzing the correlation between the chemical composition in high potassium glass and lead barium glass. [4]The data in this article has been taken from relevant data on ancient Chinese glass products. Archaeologists have classified these cultural relics into two types based on their chemical composition and other detection methods: high potassium glass and lead barium glass. The data includes the content of 14 chemical components ( $\text{SiO}_2$ ,  $\text{Na}_2\text{O}$ ,  $\text{K}_2\text{O}$ ,  $\text{CaO}$ ,  $\text{MgO}$ ,  $\text{Al}_2\text{O}_3$ ,  $\text{Fe}_2\text{O}_3$ ,  $\text{CuO}$ ,  $\text{PbO}$ ,  $\text{BaO}$ ,  $\text{P}_2\text{O}_5$ ,  $\text{SrO}$ ,  $\text{SnO}_2$ ,  $\text{SO}_2$ ) from 58 different cultural relic sampling points.[9][10]

## 2. The basic fundamental of analysis models

### 2.1. Observing whether there is a correlation between different chemical components using Spearman correlation coefficient

First, a level to the data was assigned. The rank of a number is the position of the number in a column sorted from smallest to largest. For example, for high potassium glass, there are 18 samples, and the samples under each chemical composition are assigned a level of 1-18 based on the size of the number. The smaller the number, the lower the level. If some values are the same, their positions will be averaged by arithmetic.

Second, the Spearman correlation coefficient was calculated:

$$r_s = 1 - \frac{6 \sum_{i=1}^n d_i^2}{n(n^2 - 1)}$$

Among them,  $d_i$  is the level difference between  $X_i$  and  $Y_i$ , and  $n$  is the amount of data contained in a set of data.

Third, Hypothesis test of Spearman correlation coefficient. The data were tested for significance. The original hypothesis  $H_0$  was  $r_s = 0$  and the alternative hypothesis  $H_1$  was  $r_s \neq 0$ . When the original hypothesis was true, the statistics  $r_s \sqrt{n-1}$  obeyed the standard Normal distribution, so the test value was calculated and the corresponding value  $p$  was compared with 0.05. For example, if we calculate the value  $r_s = 0.4646$  between silicon dioxide and Potassium oxide, we can get the test value  $z^* = 0.4646 \times \sqrt{67-1} = 3.7744$ . Since  $p$  is far less than 0.05, we reject the original hypothesis and think that silicon dioxide is significantly related to Potassium oxide.

Fourth, observing the correlation between various chemical components based on the Spearman correlation coefficient.

a) High potassium glass

Significant correlation at 0.01 level:

SiO<sub>2</sub>-K<sub>2</sub>O, K<sub>2</sub>O-Na<sub>2</sub>O, CaO-SiO<sub>2</sub>, CaO-Na<sub>2</sub>O, CaO-K<sub>2</sub>O, Al<sub>2</sub>O<sub>3</sub>-SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>-MgO, Fe<sub>2</sub>O<sub>3</sub>-SiO<sub>2</sub>, Fe<sub>2</sub>O<sub>3</sub>-Al<sub>2</sub>O<sub>3</sub>, CuO-Fe<sub>2</sub>O<sub>3</sub>, PbO-Al<sub>2</sub>O<sub>3</sub>, P<sub>2</sub>O<sub>5</sub>-MgO, SrO-MgO.

Significant correlation at 0.05 level:

Na<sub>2</sub>O-SiO<sub>2</sub>, MgO-SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>-K<sub>2</sub>O, Al<sub>2</sub>O<sub>3</sub>-CaO, Fe<sub>2</sub>O<sub>3</sub>-CaO, Fe<sub>2</sub>O<sub>3</sub>-MgO, BaO-MgO, BaO-Al<sub>2</sub>O<sub>3</sub>, BaO-Fe<sub>2</sub>O<sub>3</sub>, BaO-CuO, P<sub>2</sub>O<sub>5</sub>-SiO<sub>2</sub>, P<sub>2</sub>O<sub>5</sub>-Al<sub>2</sub>O<sub>3</sub>, P<sub>2</sub>O<sub>5</sub>-Fe<sub>2</sub>O<sub>3</sub>, SrO-SiO<sub>2</sub>, SrO-Al<sub>2</sub>O<sub>3</sub>.

b) Lead barium glass

Significant correlation at 0.01 level:

Na<sub>2</sub>O-SiO<sub>2</sub>, CaO-SiO<sub>2</sub>, CaO-Na<sub>2</sub>O, Al<sub>2</sub>O<sub>3</sub>-SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>-K<sub>2</sub>O, Al<sub>2</sub>O<sub>3</sub>-MgO, Fe<sub>2</sub>O<sub>3</sub>-CaO, Fe<sub>2</sub>O<sub>3</sub>-Al<sub>2</sub>O<sub>3</sub>, CuO-SiO<sub>2</sub>, CuO-Fe<sub>2</sub>O<sub>3</sub>, PbO-SiO<sub>2</sub>, PbO-Al<sub>2</sub>O<sub>3</sub>, BaO-MgO, BaO-Al<sub>2</sub>O<sub>3</sub>, BaO-Fe<sub>2</sub>O<sub>3</sub>, BaO-CuO, P<sub>2</sub>O<sub>5</sub>-Si<sub>2</sub>O<sub>5</sub>, P<sub>2</sub>O<sub>5</sub>-Na<sub>2</sub>O, P<sub>2</sub>O<sub>5</sub>-CaO, SrO-Si<sub>2</sub>O<sub>5</sub>, SO<sub>2</sub>-MgO, SO<sub>2</sub>-Al<sub>2</sub>O<sub>3</sub>, SO<sub>2</sub>-Fe<sub>2</sub>O<sub>3</sub>, SO<sub>2</sub>-CuO, SO<sub>2</sub>-BaO.

Significant correlation at 0.05 level:

K<sub>2</sub>O-SiO<sub>2</sub>, MgO-K<sub>2</sub>O, MgO-CaO, PbO-Na<sub>2</sub>O, PbO-K<sub>2</sub>O, PbO-CaO, P<sub>2</sub>O<sub>5</sub>-PbO, SrO-CaO, SrO-PbO, SnO<sub>2</sub>-CaO, SnO<sub>2</sub>-Al<sub>2</sub>O<sub>3</sub>, SnO<sub>2</sub>-Fe<sub>2</sub>O<sub>3</sub>, SnO<sub>2</sub>-CuO, SO<sub>2</sub>-SiO<sub>2</sub>, SO<sub>2</sub>-Fe<sub>2</sub>O<sub>3</sub>.

### 2.2. Using Principal Component Analysis to Reduce Dimensions of 14 Chemical Component Indicators

Using principal component analysis to reduce the dimensionality of indicators can reflect the specific relationships between each indicator, making it easier to analyze.

If there are now  $n$  samples and  $p$  evaluation indicators, it can form a  $n * p$  sample matrix.

$$x = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1p} \\ x_{21} & x_{22} & \cdots & x_{2p} \\ \vdots & \vdots & \ddots & \vdots \\ x_{n1} & x_{n2} & \cdots & x_{np} \end{bmatrix}$$

First,  $x$  was standardized.

Calculate the mean  $\bar{x}_j = \frac{1}{n} \sum_{i=1}^n x_{ij}$  and standard deviation  $S_j = \sqrt{\frac{\sum_{i=1}^n (x_{ij} - \bar{x}_j)^2}{n-1}}$  of each column to obtain standardized data  $X_{ij} = \frac{x_{ij} - \bar{x}_j}{S_j}$ . The original sample matrix is normalized to:

$$X = \begin{bmatrix} X_{11} & X_{12} & \cdots & X_{1p} \\ X_{21} & X_{22} & \cdots & X_{2p} \\ \vdots & \vdots & \ddots & \vdots \\ X_{n1} & X_{n2} & \cdots & X_{np} \end{bmatrix} = (X_1, X_2, \dots, X_p)$$

Second, the Covariance matrix of the standardized sample was calculated.

$$R = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1p} \\ r_{21} & r_{22} & \cdots & r_{2p} \\ \vdots & \vdots & \ddots & \vdots \\ r_{n1} & r_{n2} & \cdots & r_{np} \end{bmatrix}$$

Among it,  $r_{ij} = \frac{1}{n-1} \sum_{k=1}^n (X_{ki} - \bar{X}_i)(X_{kj} - \bar{X}_j) = \frac{1}{n-1} \sum_{k=1}^n X_{ki} X_{kj}$ .  $R$  also known as the sample correlation coefficient matrix.

Third, the Eigenvalues and eigenvectors of the matrix  $R$  were calculated.

Characteristic value:  $\lambda_1 \geq \lambda_2 \geq \cdots \geq \lambda_p \geq 0$ .

Feature vector:

$$a_1 = \begin{bmatrix} a_{11} \\ a_{21} \\ \vdots \\ a_{p,1} \end{bmatrix}, a_2 = \begin{bmatrix} a_{12} \\ a_{22} \\ \vdots \\ a_{p,2} \end{bmatrix}, \dots, a_{14} = \begin{bmatrix} a_{1p} \\ a_{2p} \\ \vdots \\ a_{pp} \end{bmatrix}$$

Forth, the principal component contribution rate and cumulative contribution rate were calculated.

$$\text{Contribution rate} = \frac{\lambda_i}{\sum_{k=1}^p \lambda_k} (i = 1, 2, \dots, p), \text{ cumulative contribution rate} = \frac{\sum_{k=1}^i \lambda_k}{\sum_{k=1}^p \lambda_k}$$

Fifth, the principal components were written.

Due to the fact that high potassium glass has 18 samples and 14 evaluation indicators (i.e. 14 different chemicals),  $x_1$  is an 18\*14 matrix.

Due to the 49 samples and 14 evaluation indicators of lead barium glass, it is a 49\*14 matrix.

I take the first, second, third, and fourth principal components corresponding to the eigenvalues with a cumulative contribution rate exceeding 80%, and calculate the eigenvalues, corresponding eigenvectors, and contribution rate of the correlation coefficient matrix of high potassium glass. The

principal components corresponding to eigenvalues with a cumulative contribution rate exceeding 80% are taken as follows.

The first principal component,

$$F_1 = -0.40X_1 + 0.10X_2 + 0.30X_3 + 0.28X_4 + 0.31X_5 + 0.37X_6 + 0.35X_7 + 0.21X_8 + 0.18X_9 + 0.23X_{10} + 0.27X_{11} + 0.29X_{12} - 0.04X_{13} + 0.12X_{14}. \quad (1)$$

The second principal component,

$$F_2 = -0.18X_1 + 0.49X_2 + 0.28X_3 + 0.43X_4 - 0.27X_5 + 0.01X_6 - 0.13X_7 + 0.05X_8 + 0.14X_9 - 0.23X_{10} - 0.36X_{11} - 0.34X_{12} - 0.20X_{13} + 0.11X_{14}. \quad (2)$$

The third principal component,

$$F_3 = -0.08X_1 - 0.14X_2 + 0.18X_3 + 0.07X_4 + 0.22X_5 - 0.02X_6 + 0.03X_7 - 0.11X_8 - 0.53X_9 - 0.47X_{10} + 0.05X_{11} - 0.02X_{12} + 0.24X_{13} + 0.55X_{14}. \quad (3)$$

The fourth principal component,

$$F_4 = -0.07X_1 + 0.31X_2 + 0.25X_3 - 0.08X_4 + 0.10X_5 + 0.13X_6 - 0.22X_7 - 0.52X_8 + 0.14X_9 - 0.13X_{10} + 0.04X_{11} + 0.20X_{12} + 0.55X_{13} - 0.34X_{14}. \quad (4)$$

According to the same method, the principal component analysis equation for lead barium glass can be obtained,

First principal component,

$$F_5 = -0.46X_1 - 0.19X_2 - 0.16X_3 + 0.12X_4 - 0.20X_5 - 0.35X_6 - 0.15X_7 + 0.30X_8 + 0.30X_9 + 0.34X_{10} + 0.24X_{11} + 0.27X_{12} - 0.17X_{13} + 0.28X_{14}. \quad (5)$$

Second principal component,

$$F_6 = 0.22X_1 + 0.28X_2 - 0.13X_3 - 0.47X_4 - 0.37X_5 - 0.16X_6 - 0.32X_7 + 0.21X_8 - 0.27X_9 + 0.26X_{10} - 0.35X_{11} - 0.15X_{12} - 0.19X_{13} + 0.09X_{14}. \quad (6)$$

Third principal component:

$$F_7 = -0.03X_1 - 0.09X_2 + 0.35X_3 + 0.14X_4 + 0.06X_5 + 0.31X_6 + 0.13X_7 + 0.28X_8 - 0.41X_9 - 0.43X_{10} + 0.01X_{11} - 0.06X_{12} + 0.35X_{13} - 0.02X_{14}. \quad (7)$$

Fourth principal component:

$$F_8 = -0.08X_1 + 0.53X_2 - 0.13X_3 - 0.02X_4 + 0.39X_5 + 0.26X_6 - 0.4X_7 + 0.1X_8 - 0.02X_9 - 0.01X_{10} + 0.04X_{11} + 0.54X_{12} + 0.13X_{13} - 0.02X_{14}. \quad (8)$$

Fifth principal component:

$$F_9 = 0.14X_1 + 0.06X_2 - 0.42X_3 + 0.15X_4 + 0.22X_5 + 0.06X_6 + 0.13X_7 + 0.27X_8 - 0.40X_9 - 0.03X_{10} + 0.49X_{11} - 0.23X_{12} - 0.43X_{13} - 0.01X_{14}. \quad (9)$$

Sixth principal component:

$$F_{10} = -0.03X_1 + 0.22X_2 + 0.68X_3 - 0.04X_4 + 0.23X_5 - 0.15X_6 + 0.01X_7 - 0.10X_8 + 0.01X_9 - 0.01X_{10} + 0.04X_{11} + 0.02X_{12} - 0.61X_{13} + 0.16X_{14}. \quad (10)$$

### 3. Results

#### 3.1. Analyze the significance of principal component representation based on coefficients

##### a) High potassium glass:

In the first principal component,  $K_2O$ ,  $CaO$ ,  $MgO$ ,  $Al_2O_3$ ,  $Fe_2O_3$ ,  $BaO$ ,  $P_2O_5$ , and  $SrO$  have approximately equal positive loads, and there is a larger load on  $SiO_2$ . It can be known that  $SiO_2$  has stable chemical properties, while  $K_2O$ ,  $CaO$ ,  $MgO$ ,  $Al_2O_3$ ,  $Fe_2O_3$ ,  $BaO$ ,  $P_2O_5$  and  $SrO$  have unstable properties and are prone to react with water. Therefore, the first principal component is called the water component (stability when encountering water).

In the second main component,  $Na_2O$ ,  $K_2O$  and  $CaO$  account for a large positive load.  $SiO_2$ ,  $MgO$ ,  $Fe_2O_3$ ,  $BaO$ ,  $P_2O_5$ ,  $SrO$  and  $SnO_2$  have approximately equal load loads.  $Na_2O$ ,  $K_2O$  and  $CaO$  are easy to react with acids, but not with bases.  $SiO_2$  is an Acidic oxide, and generally does not react with acids.  $MgO$ ,  $Fe_2O_3$ ,  $BaO$ ,  $SrO$  and  $SnO_2$  do not react with acids as vigorously as  $Na_2O$ ,  $K_2O$  and  $CaO$  do with acids.  $P_2O_5$  is easy to react with bases, but not with acids. So the second principal component is called the acid component (stability when encountering acid).

In the third principal component,  $PbO$  and  $BaO$  occupy a large load,  $SO_2$  occupies a large positive load, lead oxide can gradually absorb carbon dioxide in the air, Barium oxide is very easy to absorb water and carbon dioxide in the air to generate Barium carbonate, while sulfur dioxide generally does not react with carbon dioxide. So the third principal component is called carbon dioxide component (stability in case of carbon dioxide).

In the fourth principal component,  $SnO_2$  has a relatively high positive load,  $Na_2O$ ,  $K_2O$ , and  $SrO$  have a moderate level of positive load,  $CuO$  has a relatively high load,  $Fe_2O_3$  and  $SO_2$  have a moderate level of load,  $SnO_2$ ,  $Na_2O$ ,  $K_2O$ , and  $SrO$  are white or light yellow solids,  $CuO$  is black, and  $Fe_2O_3$  is reddish brown. So the fourth principal component is called the color component.

##### b) Lead barium glass

In the first principal component,  $SiO_2$  and  $Al_2O_3$  account for a large proportion of the load,  $Na_2O$ ,  $K_2O$ ,  $MgO$ ,  $Fe_2O_3$ , and  $SnO_2$  account for a moderate proportion of the load, and  $CuO$ ,  $PbO$ ,  $BaO$ ,  $P_2O_5$ ,  $SrO$ , and  $SO_2$  account for approximately equal positive loads. Due to the fact that  $SiO_2$  and  $Al_2O_3$  are essential materials for glass products, while  $PbO$  and  $BaO$  are the main combustion aids used for burning glass in lead barium glass, and they are relatively higher than potassium glass. Since  $K_2O$  is not used as a combustion aid material, the content of  $K_2O$  is relatively low. So the first principal component is called the combustion aid component.

The second principal component,  $CaO$ ,  $Fe_2O_3$ ,  $MgO$ , and  $P_2O_5$ , has a relatively high specific gravity load.  $CaO$  has hygroscopicity, but it is not easy to react with water.  $P_2O_5$  has strong water absorption and dehydration properties, making it a powerful desiccant. Therefore, the second main component is called a hygroscopic component.

In the third principal component,  $PbO$  has a higher specific gravity load, while  $K_2O$ ,  $BaO$ ,  $SO_2$ , and  $Al_2O_3$  have a higher specific gravity positive load. Due to the fact that lead oxide is a yellow or slightly red yellow powder or small crystalline flake that easily changes color when exposed to light, while  $K_2O$ ,  $BaO$ , and  $Al_2O_3$  are white powders that do not react with light. the third principal component is called a photochromic component.

In the fourth principal component,  $Na_2O$  and  $SrO$  have a higher specific gravity positive load, while  $Fe_2O_3$  has a higher specific gravity load.  $Na_2O$  is non flammable and melts when dark red is hot.  $SrO$  has a high melting point of  $2430^\circ C$ . And  $Fe_2O_3$  has obvious combustion phenomenon. So the fourth main component is called the combustion component.

In the fifth principal component,  $P_2O_5$  accounts for a significant proportion of the positive load, while  $K_2O$ ,  $SnO_2$ , and  $PbO$  account for a significant proportion of the load.  $P_2O_5$  has strong oxidizing properties, while  $K_2O$ ,  $SnO_2$ , and  $PbO$  have reducing properties. So the fifth principal component is called an oxidizing component.

In the sixth principal component,  $K_2O$  accounts for a significant proportion of the positive load, while  $SnO_2$  accounts for a significant proportion of the load. Tin (IV) oxide is especially suitable for

melting flint glass, barium flint, barium crown, and heavy crown glass, and does not pollute the glass. When Potassium oxide is used as combustion supporting agent when the glass is burned, a large amount of impurities will be produced. Therefore, we call the sixth main component pure.

### **3.2. Analyze the correlation between chemical components based on principal component analysis and the results of testing using Spearman coefficients.**

First, in the principal component analysis of high potassium glass, four principal components are extracted from the high potassium glass sample, namely water component, acid component, carbon dioxide component, and color component. The first three principal components can be collectively referred to as stability components, solving the problem of the impact of different chemical component contents on the storage process of glass products by external environmental factors. The fourth principal component addresses the impact of different chemical composition contents on the quality of glass products.

Second, in the principal component analysis of lead barium glass, six principal components are extracted from the lead barium glass sample, namely the combustion aid component, hygroscopic component, photochromic component, combustion component, oxidizing component, and purity component. The first principal component addresses the influence of the selection of combustion aids on the basic component (silicon dioxide) content during the glass firing process. The second principal component addresses the sensitivity of glass products to moisture content in the air. The third and sixth principal components can be collectively referred to as quality components, which address the impact of chemical composition selection on the quality of glass products. The fourth principal component addresses the issue of whether this glass product is combustible and whether it is easily diffused during combustion. The fifth principal component addresses the impact of highly oxidizing compounds (sulfur dioxide) in glass products on their stability in environments with high carbon dioxide concentrations.

Third, in the correlation test of 14 different compounds, the chemical components with significant correlation in high potassium glass are mainly concentrated among silicon dioxide, Calcium oxide, Potassium oxide, magnesium oxide, aluminum oxide, Barium oxide, iron oxide, Phosphorus pentoxide, and Strontium oxide. The chemical components in lead barium glass with significant correlation are mainly concentrated among silicon dioxide, Calcium oxide, aluminum oxide, lead oxide, Barium oxide, Phosphorus pentoxide, tin oxide and sulfur dioxide.

### **3.3. Comparing the differences in chemical composition associations between different categories**

First, in the production process of lead barium glass and high manganese glass, great attention is paid to the environmental resistance of glass products to different chemical components in the glass, that is, whether the glass products can be kept intact for a long time. At the same time, the influence of different chemical component contents on the color of glass products is also important. However, in the production of lead barium glass, the factors considered are more comprehensive than high manganese glass, and the amount of chemical components used is also finer than that of high manganese glass. For example, certain chemical components may change color when exposed to light, some have strong hygroscopicity and can be used as desiccants on the surface of glass products, and some chemical components cannot guarantee the safety of glass products, which are easy to burn and have diffusion properties, etc.

Second, there are fewer "impurities" in lead barium glass than in high potassium glass, almost every chemical component in lead barium glass is related to at least one other chemical component, while in high potassium glass, tin oxide (SnO<sub>2</sub>) and sulfur dioxide (SO<sub>2</sub>) are not related to other chemical components, equivalent to "impurities". Here, "impurities" refer to chemical components that are useless for glass processing.

Third, the correlation between different chemical components of lead barium glass is stronger than that of high potassium glass. There are a total of 40 pairs of chemical components with strong

correlation in lead barium glass, of which 24 pairs have strong correlation. In high potassium glass, there are a total of 32 pairs of related chemical components, of which 14 pairs have strong correlation. So it can be explained that lead barium glass is made more finely than high potassium glass.

#### 4. Conclusions

The article reveals the specific differences between ancient high potassium glass and lead barium glass by analyzing the correlation between their chemical composition. It can be seen that lead barium glass has higher purity, better environmental stability, brighter color, stronger safety, and stronger practicality than high potassium glass.

The article is logically rigorous and mainly uses principal component analysis to reveal the secrets of the production of ancient glass products, which can better indicate the correlation between different chemical components. However, at the same time, due to the subjectivity of the interpretation of principal components, drawing conclusions may not be professional and rigorous enough.

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