Application of cluster analysis and discriminant analysis in quality grading of jadeite red

Xin Pan, Ying Guo, Ziyuan Liu, Zikai Zhang and Yuxiang Shi

School of Gemology, China University of Geosciences, Beijing 100083, China

Email: guoying@cugb.edu.cn

Abstract. A more effective grading standard for jadeite-jade red was established through combining gemology with statistics. 120 jadeite-jade (red) samples were tested by X-Rite SP62 integral spherical spectrophotometer under standard light source D65 to quantify the lightness ($L^*$), hue ($h_{ab}$) and chroma ($C_{ab}^*$) of jadeite-jade red based on CIE 1976 $L^*a^*b^*$ uniform color space theory. K-Means clustering analysis method in SPSS 22.0 statistical analysis software was used to grade the color of red jadeite-jade. Fisher discriminant analysis method was used to verify the feasibility of the classification and to find an objective and effective color grade evaluation method. Finally, the jadeite-jade red was divided into five grades: Fancy Vivid, Fancy Deep, Fancy Intense, Fancy dark and Fancy.

1. Introduction

Jadeite-jade is a fibrous mineral assemblage composed of pyroxene and omphacite [1, 2]. It is called the “King of Jade” in China. Currently, the international gemstones color evaluation focuses on high-quality gemstones, e.g., Diamonds, Rubies, Sapphires, Emeralds, etc. Since color is one of the most important quality evaluation elements for jadeite-jade [3-5], the development of jadeite-jade color evaluation system has attracted considerable research interest in the industry. Color grading of jadeite was empirically summarized and subjectively described by the industry [6]. The national standard GB/T 23885 2009 Jadeite Grading was introduced by China in 2009 to solve this problem, where, purple and yellow-red jadeite-jades are graded according to the green jadeite-jade standard, and no standard was established for jadeite (red) [7]. According to Guo Ying, K-means cluster analysis and Fisher discriminant analysis are suitable for color grading for colored gemstones, which has been verified in green jadeite-jade and red tourmaline [8-17]. Color evaluation of red jadeite-jade was performed in this paper to establish a scientific, reasonable, objective and effective grading standard.

2. Material and methods

One hundred and twenty natural red jadeite jades with good texture, well purity and polished surface were selected and prepared in size of 5mm *6mm to 7mm *8mm, which varies in color from orange red to brownish red with continuous change of color hue and lightness.

X-Rite SP60 portable spherical spectrophotometer was used to collect the reflection signals from jadeite surface by integrating sphere.

Color space CIE 1976 $L^*a^*b^*$ is the closest to the actual effect of human eyes and homogeneity of individual color index is better than other color spaces, which can better reflect the psychological effect of object color. It is also the most widely used international color measurement system in the
world [18]. Hence, CIE1976 L*a*b* color space was chosen to quantify the color parameters of jadeite [19, 20].

Standard light source box is used as the experimental environment. The standard light source D65 (PHILIPS MASTER TL-D 90 De Luxe E/965, color temperature 6504 K, Holland) is selected as the grading light [21-24].

3. Results and discussion

3.1. Color parameter

Firstly, the color data of jadeite-jade samples measured under standard light source D65 were arranged. Results show that under the standard light source D65, the parameters of jadeite-jade (red) samples can be summarized as followings: lightness (L*): 37.06, 52.82, the chromatic (a*): 13.05, 28.18, (b*): 8.19, 30.02, hue angle (h°): 22.64°, 57.66°, chroma (C*): 15.95, 38.33. Hence, the color of jadeite-jade samples is mainly concentrated in the reddish area with yellowish hue. It is commonly medium lightness, but varies in red saturation, which is consistent with the naked eye color perception [11].

To visually show the distribution of the sample color under the standard light source D65, the data is projected into the L*a*b* three-dimensional color space, as well as the a*b* chromaticity plots, as shown in Figure 1, the horizontal axis represents the a* axis (red and green direction) and the vertical axis represents the b* axis (yellow and blue direction).

![Figure 1. Jadeite red L*, a*, b* three-dimensional plots and a*b* chromaticity plots under the standard light source D65.](image)

3.2. Color grading of jadeite-jade red

3.2.1. K-Means cluster analysis. K-Means cluster analysis is applicable to cluster analysis of massive samples, where the distance can be used as a marker of affinity degree between samples, which quickly divides observations into various types in progressive integrating and analyzing process. Specifically, the cluster objects are initially classified into two categories, while one category is defined as points close to the central. In such discrimination, the final cluster analysis results are obtained by adjusting them step by step [6, 8].

Three independent color parameters, e.g., L*, a*, b*, were used for cluster analysis based on the international classification scheme of gem color, while the number of cluster categories is odd to ensure one type for one color. Clustering was begun from the classification number 7 that was followed by 5 and 9, and their significant difference was analyzed. It is found that the clustering
performed best for the classification number 5 with uniform distribution of each category. Also, the Sig value of the clustering result is less than 0.001 (as shown in Table 1), indicating that the classification is valid. Therefore, color data of 120 red jadeite-jades samples were classified into 5 categories.

### Table 1. Jadeite-jade red clustering analysis table (5 categories).

| Classification Mean Square | Error Mean Square | F | Significance (Sig.) |
|----------------------------|------------------|---|---------------------|
| L * 285.231 4 | 2.707 115 | 105.379 | 0.000 |
| a * 172.356 4 | 3.418 115 | 50.424 | 0.000 |
| b * 463.983 4 | 3.190 115 | 145.457 | 0.000 |

### 3.2.2. Fisher's discriminant analysis

Discriminant analysis is one of the important multivariate statistical analysis methods. Information provided by samples of known categories can be used to summarize classification regularity, establish discriminant formula and discriminant criterion, distinguishing the group of individuals [6, 8].

The discriminant functions for five types of jadeite-jade colors can be established using discriminant analysis, and thereby the color data can be verified by this expression, so as to conform the correctness and feasibility of the classification scheme [25].

\[
F_1 = 22.417 L^* + 10.690 a^* - 9.536 b^*
\]

\[
F_2 = 23.384 L^* + 12.586 a^* - 7.723 b^*
\]

\[
F_3 = 23.033 L^* + 11.648 a^* - 8.605 b^*
\]

\[
F_4 = 24.546 L^* + 11.623 a^* - 6.833 b^*
\]

\[
F_5 = 23.864 L^* + 10.854 a^* - 7.966 b^*
\]

The L *, a *, and b * values of 120 jadeite-jade samples were input into five Fisher discriminant functions for discriminant analysis. The verification results are shown in Table 2. The correct rate is as high as 100%, indicating ideal prediction accuracy. The model can work well in grading jadeite-jade red.

Coordinated point display is performed for classified colors (Figure 2), showing significant independence between different color type and large distance between each group. All these evidences suggest that the cluster analysis and discriminant analysis are applicable for the classification, which lays a solid foundation for the quality grade evaluation of the jadeite-jade red [26].

### Table 2. Fisher's discriminant analysis of jadeite-jade red color.

| (%) | 1 | 2 | 3 | 4 | 5 | The Total |
|-----|---|---|---|---|---|----------|
| 1   | 100.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 2   | 0.0 | 100.0 | 0.0 | 0.0 | 0.0 | 100.0 |
| 3   | 0.0 | 0.0 | 100.0 | 0.0 | 0.0 | 100.0 |
| 4   | 0.0 | 0.0 | 0.0 | 100.0 | 0.0 | 100.0 |
| 5   | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | 100.0 |
3.2.3. Quality grading of jadeite. After classifying the jadeite-jade red using cluster analysis and discriminant analysis, the colors of the red jadeite-jade are graded according to the commercial value and the international standard of fancy diamond grading.

Currently, high-quality red jadeite-jade in the market is characterized by pure color, bright and uniform distribution, thus, chroma (C*) and lightness (L*) were used to evaluate color. If the lightness is high, the color of the jadeite-jade will be light. If the lightness is low, the color will be dark. Consequently, with the same chroma, the quality of jadeite-jade with middle lightness is regarded as high quality.

Therefore, according to the difference of lightness (L*) and chroma (C*) of jadeite-jade, the colors were divided into 5 levels. Colors data of five levels were plotted using lightness and chroma as two coordinate axes, and zones are divided based on color data, as shown in Figure 3. The simulated color of each level and its division category are shown in Table 3.
Table 3. Quality evaluation of color chips of jadeite-jade color red.

| Level (N) | Color | Quality            | Cluster center          | Simulation color |
|----------|-------|--------------------|-------------------------|------------------|
| 1 (N=18) | V     | Fancy Low lightness| L*=39.9533, a*=17.4483, b*=13.0089 |
|          |       | Low chroma         |                         |                  |
| 2 (N=20) | I     | Fancy Vivid        | L*=44.4260, a*=24.7825, b*=21.7480 |
|          |       | Middle lightness   |                         |                  |
|          |       | High chroma        |                         |                  |
| 3 (N=31) | III   | Fancy Intense      | L*=42.5819, a*=21.0958, b*=17.6732 |
|          |       | Middle lightness   |                         |                  |
|          |       | Middle chroma      |                         |                  |
| 4 (N=23) | II    | Fancy Deep         | L*=49.4848, a*=21.5452, b*=25.6935 |
|          |       | High lightness     |                         |                  |
|          |       | High chroma        |                         |                  |
| 5 (N=28) | IV    | Fancy dark         | L*=46.2618, a*=18.4232, b*=20.4250 |
|          |       | High lightness     |                         |                  |
|          |       | Middle chroma      |                         |                  |

Figure 4. Jadeite-jade red color solid model.
Consequently, Jadeite-Jade with hue range (22.64°, 57.66°) is divided into five levels, Fancy vivid, Fancy deep, Fancy intense, Fancy dark and Fancy, respectively. A three-dimensional model of jadeite-jade red is established accordingly, as shown in Figure 4, specifically, the lightness of Fancy Vivid range (L*): 35-47, the chroma range (C*): 30-40, the lightness of Fancy Deep range (L*): 47-53, the chroma range (C*): 30-40, the lightness of Fancy Intense range (L*): 35-44, the chroma range (C*): 24-30, the lightness of Fancy Intense range (L*): 44-53, the chroma range (C*): 24-30, and the lightness of Fancy Intense range (L*): 35-53. The chroma range (C*): 15-24.

4. Conclusions
A practical grading standard for jadeite-jade red was established by combining gemology with statistics in this paper. 120 jadeite-jade(red) samples were tested using X-Rite SP62 integral spherical spectrophotometer under standard lighting sources D65 to quantify the lightness (L*), hue (h°) and chroma (C*°) of jadeite-jade red based on CIE 1976 L*a*b* uniform color space theory. K-Means clustering analysis method was performed using SPSS 22.0 to classify jadeite-jade red, and Fisher discriminant analysis method is used to verify the feasibility of classification. The Sig value of the variance analysis determined by clustering is less than 0.001, and the correct rate of return generation is as high as 100%, indicating ideal prediction accuracy. Finally, jadeite-jade with hue range (h°) of 22.64°-57.66°is divided into five levels according to lightness and chroma, namely Fancy vivid, Fancy deep, Fancy intense, Fancy dark and Fancy. Consequently, a three-dimensional model of jadeite red color is established. This research may contribute to study in related field in future.

Acknowledgments
This paper thanks the Gem Research Laboratory of Gemmological Institute of China University of Geosciences (Beijing) for its strong support for the Colorimetric Experiment. It also thanks Xue-ding Wang and Ze-ting He for their suggestions and help in colorimetric research.

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