Color grading of Emerald green based CIE 1976$L^*a^*b^*$

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Abstract. This paper illustrated how to grade the color of emerald on the basis of CIE1976 L*a*b* uniform color space. In order to test the stability of Color i5 color photometer, sample average color variation was calculated by utilizing CIEL*a*b*color difference formula and the result revealed that it is reliable. Tone of emerald was classified through comparing GemDialogue colorimetric method and instrumental measurement; in addition, merits and demerits of GemDialogue colorimetric were also illustrated during this process. The result showed that GemDialogue colorimetric method has certain fuzziness and subjectivity in color grading and the corresponding suggestions are also supposed. The green tone of emerald was classified into 4 parts by combining sample tone measurements with the drifting of its UV visible spectrum peak (10nm) under uniform color space. Finally, the color of emerald was graded.

Introduction

Emerald is known as “champion of green gems” due to its attractive velvet viridis and rarity; and it is listed into the world four precious stones together with diamond, ruby, and sapphire. Emerald is the birthstone of May as well as the memorial stone for 55th wedding anniversaries and symbolizes hopeful spring, vitality, safety and happiness.

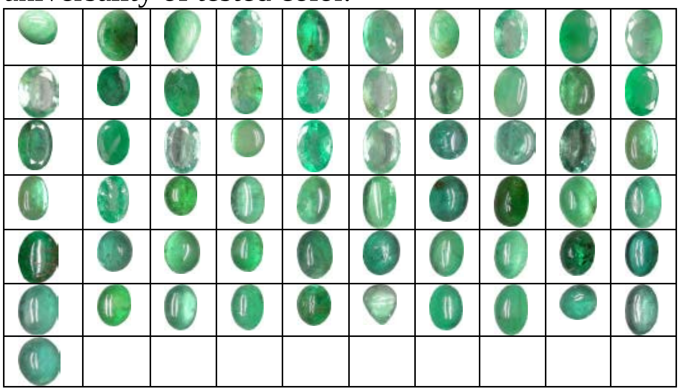
Truly superior emerald is very rare and the principle grading element is color, followed by neatness, weight, cutting origin and so on. The charming green in emerald is because of chrome or vanadium element and there are some subtle differences among the tone of emerald produced in different areas；Whereas, the development of emerald market is blocked by the following aspects. Firstly, the emerald is very expensive with big grade differences, which cannot be distinguished by common consumers. Secondly, the phenomenon of artificial synthesis and optimizing process in emerald market spreads unchecked. Thirdly, there is no authorized and detailed evaluation criteria for the green color which is most featured in emerald; while color grade occupies 2/3 in quality ranking system of emerald. At present, visual test is the main way of grading emerald, such as using master stone or color card; however, the subjective factors in visual test undermine its objectivity, science and uniformity. What’s more, in the qualitative evaluation for the color of emerald, people always cite some abstract professional words such as ivy shimmer ink, viridis, and blue-green, which lack of specific professional standard and reference system.

There was researches on emerald in the past. For example, Liangting(1998) compared the color of emerald produced in Yunnan with that from Columbia on the basis of their gemological characteristics. As natural emerald, synthetic emerald, and light green beryl's bsome similarities in terms of composition and appearance, comparison of the three gemstones were made to explore the color and composition difference of these gemstones. Besides, common gemological testing methods and modern testing technology like electron probe micro-analysis (EPMA) and LA-ICP-MS were adopted to analyze the girdle of Yunnan emerald. Qugang ［1］utilized CIE1931XYZ color system to quantitatively analyze visible absorption spectrum of Yunnan emerald. Although he primarily analyzed the difference of visible absorption spectrum for various green hues (location of absorption peak, width of absorption band and absorption strength), he did not do the systematic research. In the research, he pointed out that Cr^{3+}, V^{3+} and Fe^{3+} all can make the emerald takes on green; and emerald tends to be yellowish green when the C_r/V value is bigger; while, it tends to be blue green when C_r/V value is smaller. Whereas, the relationship between the content of Cr^{3+} and Fe^{3+} and each green index was unclear. At the earlier period, the problem of controlled crystallization of emerald single crystals from a fluxed melt, its color characteristics and optic parameters were discussed. But these researches on color features and color-causing mechanism stalled at colorimetric quantitative description and qualitative analysis［2-9］. In contrast, the research on emerald abroad focused on mineral deposit and crystal［10-18］.

Quality evaluation for emerald color arouses jewelry researchers' increasing attention. Most of the evaluations adopt qualitative or half quantitative method; and there has yet unified standard up to now. It is necessary to have objective and quantitative evaluation for the color of emerald from the perspective of gemology; so mass experimental studies are required. According to previous research, this study takes colorimeter COLOR i5 as the tool and adopts GemDialogue system and ultraviolet --visible spectrum to make grade classification for emerald color on the basis of colorimetric. Moreover, the study primarily discusses the objective and quantitative evaluation of emerald color, which provides the foundation for getting rid of subjectivity and fuzziness during color assessment and for the realization of objective and quantitative evaluation and finally set the grading standards for emerald color.

Sample& Experiment

The experiment selected 61 emeralds as samples and numbered them to ensure the representative ness and universality of tested color.



Photographed the samples of emerald under illuminant D_{65} and the number of pictures is more than 60. Firstly, test the color of emerald samples with Color i5 color photometer, analyze and summarize; then divide the green tone of emerald using GemDialogue system, record and analyze the information.

Discussion on Results

Firstly, select emerald samples numbering 38, 39, 46, 50 and 54 to do Color i5 color photometer stability test, the selected 5samples are with broad representative ness because of the striking differences in their size, thickness and color. Measure the selected 5samples separately with color photometer each 5minutes, gaining the value of L, a* and b* measured each time, and calculating its mean. Take the mean of L, a* and b* as the reference value, then calculate the aberration with actual metrical data each time and this reference value. For example, test the stability of Color i5 photometer for #39 samples, the value of L, a* and b* of #39 sample measured at first time with color photometer is 53.91, -31.13 and 16.15 respectively, and the mean of L*, a* and b* of #39 sample is 53.9, -31.07 and 15.51 respectively measured after 10 times; take the mean of the value of L, a* and b* of #39 sample as guide sample to calculate the aberration of this two with color difference formula of CIE L, a* and b*: $\triangle E^*=\sqrt{(\Delta L)^2+(\Delta a^*)^2+(\Delta b^*)^2}$, and the value is 0.21.

Calculate the value of #39 sample with the same way in the second measurement.

Measure the value of L, a* and b*, the aberration of them with guide sample is 0.19,……,finally Gain the mean of 10 value of chromatist, namely (0.21+0.19+0.18+0.17+0.2+0.21+0.2+0.18+0.14+0.17+0.18)/10=0.18, which can represent the stability of Color i5 color photometer. Similarly, the average value of chromatist of the rest of samples can be calculated. Specific data refers to Table 1-1.

Table 1-1 average chromatist calculated

	Time	1	2	3	4	5	6	7	8	9	10	AVG
46	L	57.26	56.46	56.17	56.26	56.83	56.88	56.89	56.88	56.9	56.26	56.68
	a*	-21.52	-20.63	-20.31	-21.33	-21.44	-21.64	-21.73	-21.75	-21.77	-21.33	-21.23
	b*	-1.32	-1.24	-0.79	-0.82	-0.86	-0.89	-0.86	-0.87	-0.87	-0.82	-0.97
	△E*	0.67	0.50	1.19	0.49	0.16	0.33	0.42	0.43	0.46	0.46	**0.52**
54	L	54.02	53.97	54.17	54.21	54.2	54.07	54.04	54.02	54.01	54.04	54.09
	a*	-28.76	-28.66	-26.99	-26.94	-27.56	-28.03	-28.18	-28.19	-28.23	-28.27	-27.91
	b*	7.8	7.7	6.84	6.83	7.1	7.39	7.39	7.39	7.38	7.42	7.31
	△E*	0.92	0.79	1.10	1.16	0.49	0.09	0.22	0.23	0.27	0.31	**0.56**
50	L	54.39	54.41	54.39	54.38	54.37	53.43	53.45	53.44	53.45	53.44	53.44
	a*	-22.25	-22.25	-22.38	-22.49	-22.52	-23.44	-23.44	-23.46	-23.45	-23.53	-23.53
	b*	-1.62	-1.64	-1.63	-1.64	-1.64	-2.85	-2.83	-2.84	-2.84	-2.8	-2.80
	△E*	1.03	1.02	0.94	0.87	0.72	0.94	0.92	0.94	0.93	0.96	**0.93**
39	L	53.91	53.89	53.87	53.88	53.89	53.91	53.89	53.9	53.89	53.9	53.90
	a*	-31.13	-31.23	-31.26	-31.3	-31.33	-30.94	-31.01	-31.05	-31.08	-31.07	-31.07
	b*	16.15	16.19	16.23	16.3	16.29	16.41	16.51	16.52	16.48	16.51	16.51
	△E*	0.21	0.19	0.18	0.17	0.20	0.21	0.20	0.18	0.14	0.17	**0.18**
38	L	41.69	41.67	41.66	41.67	41.66	42.69	42.66	42.67	42.67	42.66	42.05
	a*	-12.5	-12.53	-12.56	-12.53	-12.52	-12.21	-12.26	-12.2	-12.33	-12.29	-12.41
	b*	9.77	9.79	9.76	9.78	9.79	8.79	8.86	8.85	9.01	9.04	9.42
	△E*	0.65	0.68	0.68	0.68	0.69	0.78	0.70	0.73	0.60	0.59	**0.67**

Notes: △E* as every time between the measurement and average chromatist

Learn from Table1-2 that the mean of △E* of 5 emerald samples is 0.52, 0.56, 0.926, 0.18 and 0.67 respectively. The mean of △E* of #50 sample is larger than others, reaching 0.93, the reason is probably that the small grain size caused the smaller displacement after fixed for a long time. Results show that the stability of Color i5 color photometer is good since the total mean of △E* of 5 samples is less than 1, its analysis precision can meet the measured requirement for parameter of color measure, and also the accuracy rating can satisfy the tolerance of color analysis. Consequently, all analytical data measured by Color i5 color photometer is effective and reliable.

Then calibrate the color of samples by GemDialogue RHscc, and divide the tone category. Identify the castellation on La*b* chromaticity coordinates with different color for each tone category.

Table1-2 GemDialogue system sample color describe

Number	Color	Number	Color	Number	Color	Number	Color
1	G 20/10 Black	17	G 10	33	Y2G 40/10 Black	49	B2G 40
2	G 30/10 Black	18	B2G 15	34	B2G 15	50	G2B 20
3	G 40/20 Black	19	B2G 5	35	G 20	51	G2B 5
4	G 10	20	G 50/10 Black	36	G 15	52	Y2G 50
5	G 30	21	B2G 30/40 Black	37	G2B 10	53	B2G 5
6	G 20	22	G 60/20 Black	38	Y2G 30/10 Black	54	G 15
7	G 15	23	B2G 5	39	G 20	55	G 30/20 Black
8	G 10	24	Y2G 20	40	B2G 15	56	G 30/20 Black
9	G 30/10 Black	25	Y2G 20	41	B2G 50/20 Black	57	B2G 20
10	G 15	26	G 20/10 Black	42	G2B 10/5 Black	58	B2G 10
11	B2G 10	27	G2B 10/5 Black	43	G 20	59	G2B 10/5 Black
12	B2G 30/20 Black	28	G2B 10/5 Black	44	G 20	60	G2B 10/5 Black

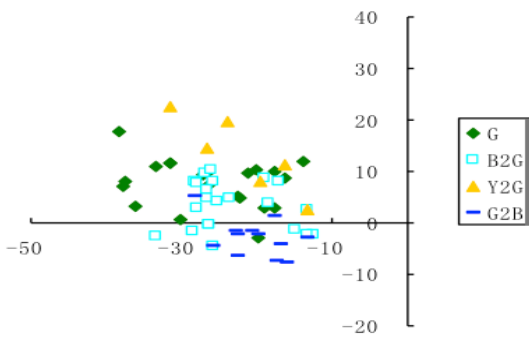
13	B2G 40/20 Black	29	G2B 20	45	G2B 10	61	G2B 10/5 Black
14	B2G 20/10 Black	30	B2G 15	46	G2B 10/5 Black		
15	B2G 30	31	B2G 15	47	B2G 10/5 Black		
16	Y2G 5	32	G 40	48	B2G 10		

To sort the samples color is tonal, can divide sample green color is divide into four categories，immediate Y2G、G、B2G、G2B，each type of including specimen in table1-3

Table1-3 Sample color GemDialogue hue classify

Colors hue	**sample**											
Y2G	19	24	33	38	52							
G	1	2	3	4	5	6	7	8	9	10	17	20
	22	32	35	36	39	43	44	54	55	56		
B2G	11	12	13	14	15	18	21	23	30	31	31	34
	37	40	41	45	47	48	49	53	57	58		
G2B	16	27	28	29	37	42	46	50	51	59	60	61

Color measurement instrument measured the emerald color data and in L*a*b* on the chromaticity coordinate projection. With different color of the samples on the different GemDialogue color categories are identified, such as yellow said Y2G specimens of emerald hue .Figure2-1



Seen from Graph 2-1 that the boundary of the area where the samples with tone of Y2G &G2B located is clearer, while the boundary of the area where the samples with tone of G& B2G located has the crossing and mixing situation. This indicates that it has certain feasibility to divide the sample tone with GemDialogue system, but it is only for the green tone of emerald; the defect is that when divides the tone of gemstone color of small difference, it will be vague.

The following improved solution is arisen aiming at the deficiency (cannot tell the secondary tone well) of measuring the green tone of emerald with GemDialogue system: equip with the several transparent color mask of secondary tone with different saturation for mass tone. For example, for green gemstone, the secondary tone of yellow and blue is easy to appear in green tone, although the Gendialogue RHscc also sets the different color cards for different green tone, these color cards are far from enough to be used to describe the green color. So if equipped with the transparent color mask of yellow and blue with different saturation for green color card, the distinguishing degree of GemDialogue RHscc to green tone will be increased greatly, and thus enhance the application of GemDialogue RHscc. Transparent color card of secondary tone is advised to cooperate with color mask, and set the order of use for the color card of mass tone, color card of secondary tone and color mask for the sake of refining the color tone.

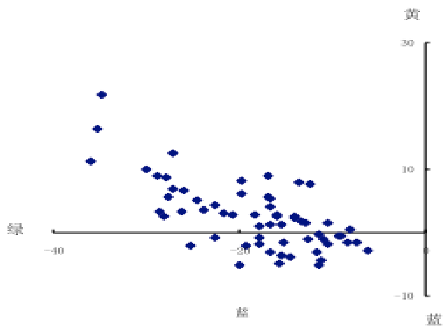
Based on the above discussion, Color i5 color photometer is accordingly used to measure the tone in order to divide the green tone of emerald scientifically, objectively and accurately, and the green tone of emerald is divided in uniform color space.

Applied with the colorimetry knowledge, select the CIE976La*b* as the color space of quantitative classification for emerald green tone, and employ the CIE976La*b* as the color appearance system of quantitative classification for emerald green tone ［19-31］.

Experimental scheme: (1) measure the ho of samples with color photometer, and map under La*b* chromaticity coordinate. (2) Divide the measured ho at 5°as a interval, then use the ultraviolet spectrophotometer.

Measure the peak wavelength of UV vis absorption spectrum of the samples in each small interval, observe the drifting level of UV vis absorption spectrum peak of samples in each small interval; thus the category of the green tone of samples is divided by merging the small intervals with 10nm as the limit. Finally, arrange and classify the samples, inspecting the tone of color visually for the purpose of verifying the rationality of the classification.

Measure the ho of samples with color photometer, the cultellation graph of measured ho under La*b* chromaticity coordinate refers to Graph 2-2:



As shown in the figure, all the tone angle of specimens fall into the green interval (135°, 225°). The specific tone angle data are as shown in table1-4:

Table1-4 Emerald hue angle

	1	2	3	4	5	6	7	8	9	10
ho	152.26	161.54	147.78	204.18	175.02	182.52	162.93	176.73	181.07	173.64
	11	12	13	14	15	16	17	18	19	20
ho	183.88	174.84	171.28	175.80	184.44	192.32	172.11	170.10	157.27	184.76
	21	22	23	24	25	26	27	28	29	30
ho	171.26	172.46	189.52	154.97	181.86	183.14	194.38	197.35	185.98	190.89
	31	32	33	34	35	36	37	38	39	40
ho	165.81	174.84	147.74	168.67	162.62	162.88	190.57	149.40	161.52	185.34
	41	42	43	44	45	46	47	48	49	50
ho	169.61	185.81	162.37	165.81	171.10	195.2	168.08	171.11	175.60	192.69
	51	52	53	54	55	56	57	58	59	60
ho	201.58	155.08	173.43	168.97	162.37	165.86	171.78	171.59	185.41	204.09

As shown in the figure, all the tone angle of specimens fall into the green interval (135°, 225°). The specific tone angle data are as shown in table 1-4:

According to the above data, Specimen 33 has the minimum tone angle 147.74°, and Specimen 4 has the largest tone angle 204.18°, the tone angles of all specimens are concentrated into the range (147.74°, 204.18°). The interval of tone angle range is extended to (145°, 205°) for easy classification.

He angle interval was subdivided with 5°as a unit, and the data are as shown in table 1-5:

Table1-5 Emerald hue angle subdivide

(145，150)	38	33	3

(150，155)	24													
(155，160)	1	19	52											
(160，165)	39	2	55	43	35	36	7							
(165，170)	44	31	62	47	34	54								
(170，175)	18	45	48	21	13	58	57	17	22	53	10	32	12	41
(175，180)	49	14	5	8										
(180，185)	9	6	25	20	15	26	11							
(185，190)	29	42	59	23	40									
(190，195)	50	37	27	61	30	16								
(195，200)	28	46												
(200，205)	51	60	4											

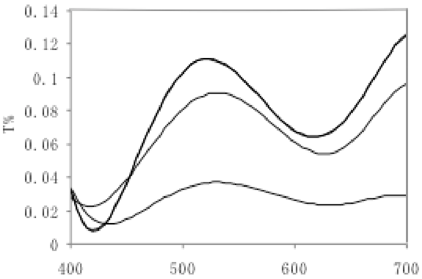
UV -Visible absorption spectra of specimens at each small interval are measured, and refer to table 1-6 for the data:

Table 1-6 UV visible absorption peak of emerald

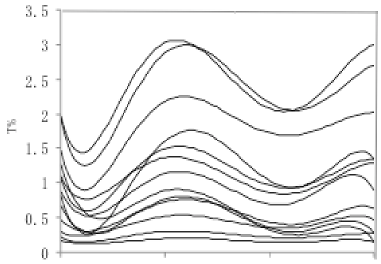
ho **section**	**sample**	**Peak** nm	**sample**	**Peak** nm	**sample**	**Peak** nm	**sample**	**Peak** nm	**sample**	**Peak** nm	**sample**	**Peak** nm
(145，150)	38	522	33	522	3	536						
(150，155)	24	516										
(155，160)	1	514	19	515	52	519						
(160，165)	39	510	2	512	55	519	43	509	35	512	36	518
	7	512										
(165，170)	44	510	31	500	62	508	47	514	34	508	54	514
(170，175)	18	502	45	500	48	496	21	509	13	497	58	498
	57	507	17	502	22	508	53	499	10	492	32	493
	12	506	41	503								
(175，180)	5	501	49	510	14	505	8	496				
(180，185)	9	508	25	503	6	505	26	501	11	507	15	494
	20	503										
(185，190)	40	492	59	500	42	496	29	496	23	497		
(190，195)	37	493	30	489	16	497	50	492	27	494	61	488
(195，200)	46	508	28	493								
(200，205)	51	496	60	490	4	502						

When the peak of UV visible absorption spectrum shifts 10nm, human’s eyes will clearly fell the changes of color tone, so small intervals with UV visible absorption spectrum peak shifting within 10nm can be merged into a large interval to represent the same color tone. See figure 2-3.

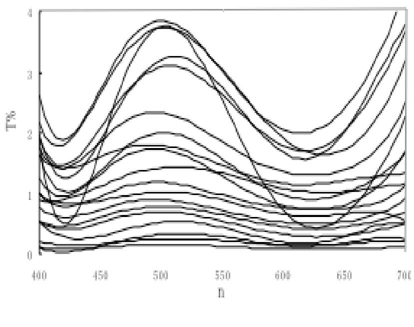
$h_o \in$ (145°，150°)



$h_o \in$ (150°，170°)



$h_o \in$ (170°，185°)



$h_o \in$ (185°，205°)

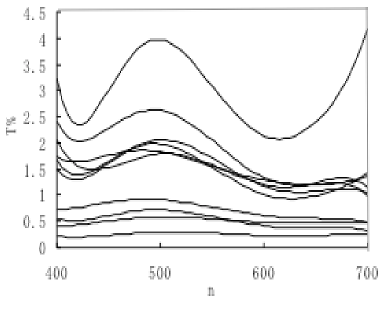


Figure 2-3 UV Visible spectra of each ho interval

According to table 3-6 and figure 3-4: when ho falls in interval ((145°, 150°), the wavelength of UV-Visible absorption spectrum peak will be greater than 520nm and the color is greenish and yellowish; when ho in interval (150°, 170°), the wavelength of UV-Visible absorption spectrum peak is (505, 515) and the color is greenish and a slightly yellowish; when ho in (170°, 185°), the wavelength of UV-Visible absorption spectrum peak is (495, 505）, and the color is green; when ho in (185°, 205°）, the wavelength of UV-Visible absorption spectrum peak is (485，495), and the color is greenish and a little bluish.

This experiment divides the tone of emerald into 4 kinds. When ho falls in （145°, 150°）, the tone is greenish and slightly yellowish; when ho is in （150°, 170°）, the tone is greenish and slightly yellowish; when ho in (170°, 185°), the tone is green; when ho in (185°, 205°), the tune is greenish and a little bluish.

Main Conclusions

Conclusions can be drawn based on the above-mentioned studies that Colori5 color measurement instrument has high stability; GemDialogue color chart can distinguish the principle tones of emerald green (a value corresponds well), but cannot tell auxiliary tones (yellowish tone or bluish tone) which have smaller differences and can be identified by human eyes, therefore, it is suggested to combine auxiliary tone transparent color chart with color correction mask, and determine the order of principle tone chart, auxiliary tone chart and color correction mask to increase color combinations and refine color tone; by measuring the tone angles of emerald and UV Vis spectral peak shift (10nm) in the uniform color space, the tones of emerald can be divided into 4 kinds: When ho falls in （145°, 150°）, the tone is greenish and slightly yellowish; when ho is in （150°, 170°）, the tone is greenish and slightly yellowish; When ho in (170°, 185°), the tone is green; when ho in (185°, 205°), the tune is greenish and a little bluish.

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