COLOR OF MOLDAVITES MEASURED BY COLORIMETRY. Lenka Dziková[1], Petr Dzik[2], Jana Fürstová[3] and Roman Skála[4, 5], [1]Department of Geological Sciences, Faculty of Sciences, Masaryk university, Kotlářská 2, CZ-61137 Brno, Czech Republic, e-mail: lenka.dzikova@seznam.cz, [2]Brno University of Technology, Faculty of chemistry, Purkyňova 118, CZ-61200 Brno, [3]Institute of Computer Science, Academy of Sciences of the Czech Republic, Pod Vodárenskou věží 2, CZ-18207 Prague 8, Czech Republic, [4]Institute of Geology, Academy of Sciences of the Czech Republic, Rozvojová 269, CZ-16500 Praha 6, Czech Republic, [5]Institute of Geochemistry, Mineralogy and Raw Materials, Faculty of Science, Charles University, Albertov 6, CZ-12843 Praha 2, Czech Republic.

Introduction: The problem of moldavite color was first addressed by [1]. Six distinctive color shades – pale green, light green, bottle green, „poisonous" green, olive green and brown were identified in this work. These categories were established based on empirical subjective observation of moldavite samples. The perceived color of every moldavite strongly depends, however, on its unique shape, size, internal structure and surface morphology.

Moreover, other color shades of moldavites have been reported later (including grass green, olive-brown, yellowish olive green, intensive green) [2]. Furthermore, other (brownish green) color is abundant in many moldavite samples and some very special colors (dark brown, yellowish brown) have recently been observed in the Muong Nong type of moldavites [3].

Having realized this inconsistence and the subjectivity of observer, we decided to utilize a colorimetric approach to measure the moldavite color quantitatively. Utilizing the statistical cluster analysis, we were able to define objective color groups and assign individual studied moldavites into them. Next, we correlated the macroscopically observed color of raw moldavite samples with the objective colorimetric discrimination into the clusters.

Samples and method: Eighty six samples of moldavites from the entire Central European Tektite strewn field were studied. Moldavites were cut and polished into plates of thickness 0.1 mm. The sample set consisted of 55 South Bohemian moldavites, four moldavites from the Radomilice area, 7 moldavites from the Cheb area, 19 moldavites from the Moravian area, and 1 moldavite from Lusatia.

Spectral colorimeter Gretag Macbeth Spectrolino was employed for the measurement of reflectance/transmittance spectra. This device covers spectral range between 380 and 730 nm with a 10 nm resolution, features measuring geometry of 0/45º and the diameter of measuring aperture is 4 mm. Since the samples were cut into very thin slides, their color, when observed in transmitting light, was very faint. In order to intensify the observed and measured color, the samples were places onto a flat white, uniformly diffusive support. In this arrangement, the incident light passed through the sample, was reflected by the white support, passed again through the sample and eventually the light was measured. The spectra were recorded in a relative measuring mode, i.e. the instrument was zeroed to reflectance spectrum of the white support and thus only the measured moldavite sample contributed to the spectral composition of reflected light. Each sample was measured randomly over its whole area 10-15 times, depending on its size, and the measured spectral values were averaged.

The recorded spectra were then used for calculation of colorimetric values. Standard observer of 2° and a lightsource of 5000 K was used for our calculations.

The three coordinates L*a*b* of CIELAB represent the lightness of the color (L* = 0 yields black and L* = 100 indicates diffuse white; specular white may be higher), its position between red/magenta and green (a*, negative values indicate green while positive values indicate magenta) and its position between yellow and blue (b*, negative values indicate blue and positive values indicate yellow). Because of different ranges of the variables L*a*b* they were renormalised by the z-score function (so that they have zero mean and unit variance). The Ward cluster analysis method [4] was applied to the renormalized data.

Results and discussion: The L*a*b* values represent a three-dimensional problem. Dimensionality can be reduced, however, to 2D considering the plot in Fig. 1.

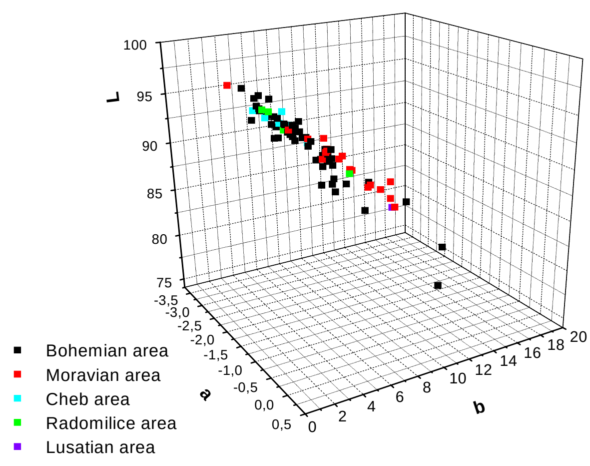

Fig. 1: *Measured color coordinates of studied samples plotted in L*a*b* color space.*

It shows statistically significant (R^2 = 0.92) linear dependence of the variables L*, a*, b*. Resulting least-square plane has an equation $L^* = c_0 + c_1a^* + c_2b^*$, where c_0 = 98.50 with confidence interval (97.69, 99.31), c_1 = 0.58 with confidence interval (-0.88, -0.28), c_2 = -1.24 with confidence interval (-1.32, -1.16). All confidence intervals are quoted at the significance level of 0.05. Consequently, results were projected onto L* a* plane. This allowed much more straight-forward representation of the data and helped to resolve color association to particular partial strewn fields, as shown in Fig. 2.

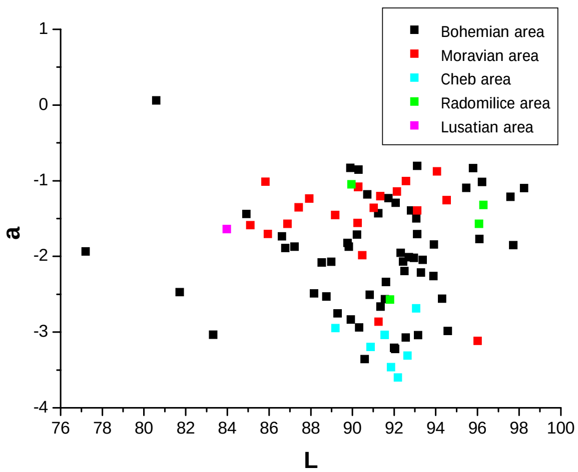

Fig. 2: *Representation of measured data in L*a* plane*

For the cluster analysis, the optimum cluster number is such that no measurement is single in a cluster and the total variability of the L*a*b* values in the clusters is minimal. The application of this rule yields 7 clusters in our case (Fig. 3). Next, we have identified the most frequent visually determined colors in each of these clusters. The results are following: cluster 1 – olive green (7 matches of 12 samples), cluster 2 – bottle green (7/13), cluster 3 – brown (2/3), cluster 4 – brownish green (6/9), cluster 5 – pale green (7/10), cluster 6 – bottle green (15/21) cluster 7 – brownish green (9/18). The obtained match ratio is 53 out of 86.

Conclusion: Quantitative characterization of color distribution among 86 moldavites showed seven statistically distinct groups. This number is in fair agreement with previously empirically determined color scale [1]. Considering all drawbacks of empirical color determination for raw moldavite samples the percentage of sample discrimination into individual statistically defined clusters is relatively good. Nevertheless, caution should be taken when describing color in large or deep-colored moldavites.

Acknowledgements: This work was funded by the grants of the Czech Science Foundation (GAČR) No. 205/09/0991 and falls within the research plans AV0Z30130516 of the Institute of Geology AS CR and MSM 0021620855 of the Ministry of Education.

References: [1] Bouška V. and Povondra P. (1964) *GCA, 28,* 783–791. [2] Bouška V. and Ulrych J. (1984) *JNCS 67,* 375–381. [3] Švardalová L. (2007) MSc. thesis, MU Brno. [4] Ward J. H.. (1963) *JASA, 58 (301),* 236–244.

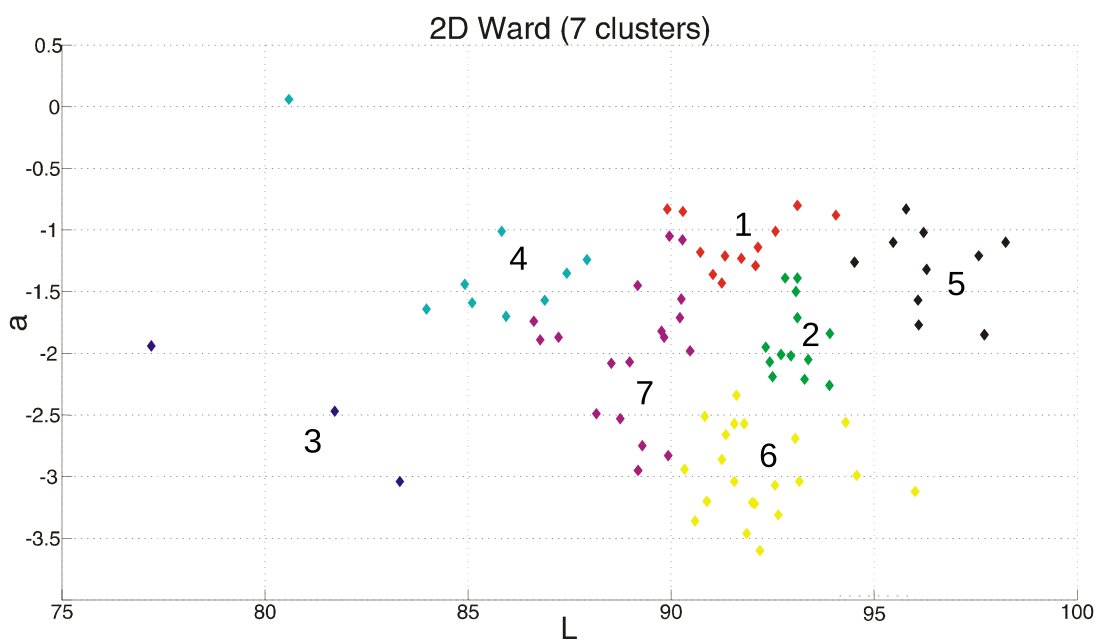

Fig. 3: *Results of hierarchical clustering projected onto L*a* plane. Seven clusters are clearly resolved.*