A CATHODOLUMINESCENCE STUDY OF IMPACT MELTS AND ROCKS FROM EL'GYGYTGYN: A METHOD TO DISTINGUISH IMPACT AND VOLCANIC MELTS? L. Pittarello[1] and C. Koeberl[1,2], [1]Department of Lithospheric Research, University of Vienna, Althanstrasse 14, 1090-Vienna, Austria; lidia.pittarello@univie.ac.at, [2]Natural History Museum, Burgring 7, 1010 Vienna, Austria; christian.koeberl@univie.ac.at.

Introduction: Cathodoluminescence (CL) is the electromagnetic emission in the field of visible light (400-700 nm) from a body bombarded with high energy electrons. Emission intensity and color are mainly controlled by the nature of the material, but can be influenced also by temperature and pressure. The presence of some elements results in characteristic enhancement or inhibition of the emission, providing information on the material composition, growth, and provenance. The use of the scanning electron technology (SEM-CL) coupled with spectral analysis expanded the use of CL in planetary science. For a review of the method, see [1]. In shocked materials, CL observations were generally limited to a single shocked phase (e.g., quartz: [2], [3], [4]; feldspar: [5]), but also impact glass were investigated (e.g., [6]).

Here we present optical and quantitative SEM-CL investigation on shocked and unshocked volcanic rocks and glasses from the El'gygytgyn impact structure, central Chukotka, Russia. El'gygytgyn represents the only known impact structure on Earth that is mostly excavated in felsic volcanic rocks [7]; this implies an intrinsic difficulty to distinguish between impact and volcanic melts. Several approaches were tried, such as optical and electron microscopy, geochemistry, and quantitative petrography ([8] and reference therein), but none of them has allowed a unequivocal interpretation. We show here that CL might help in such a distinction, because of some characteristic features of the investigated rocks.

Samples and methods: The 3.6 Ma old El’gygytgyn impact structure, central Chukotka, Russia, is a depression 18 km in diameter, largely filled by a lake with 170 m maximum depth, excavated in Late Cretaceous volcanic rocks, which include lava, tuffs, and ignimbrites of rhyolites, dacites, andesites, and locally some basalts [7],[9-11]. Although the ejecta blanket around the crater is extensively eroded, bomb-shaped impact glasses, redeposited after the impact event, occur in lacustrine terraces within the crater [12] and recently new samples were studied [13].

The structure has been drilled in 2009 in a project sponsored by the International Scientific Continental Drilling Program (ICDP), reaching the impactites underlying the lacustrine sediments [14]. The lower section (~316-517 m below the lake bottom) of the drill core includes: ~85 m of suevite and impact breccia, ~ 20 m of slightly shocked to unshocked rhyolitic-dacitic tuffs and basalt, and ~95 m of unshocked rhyolitic-dacitic ignimbrite [15].

Three polished 35 µm-thick thin sections from the impact glasses and melt rocks collected at the crater [13] and three from the suevite in the drill core [8] were selected for a CL study. Optical CL was performed with a LUMIC HC5-LM machine, operated at 14 keV beam energy and ~0.20 mA beam current, and images were acquired with a KAPPA DX 40 C camera, at the Dept. of Lithospheric Research, University of Vienna. Further CL analysis was performed with a GATAN MiniCL camera attached to a JEOL JSM-6610LV SEM operated at 15 kV accelerating voltage and 0.2 nA beam current at the Natural History Museum of Vienna. Analytical SEM (EDX) for major element qualitative compositions was also used.

Results:

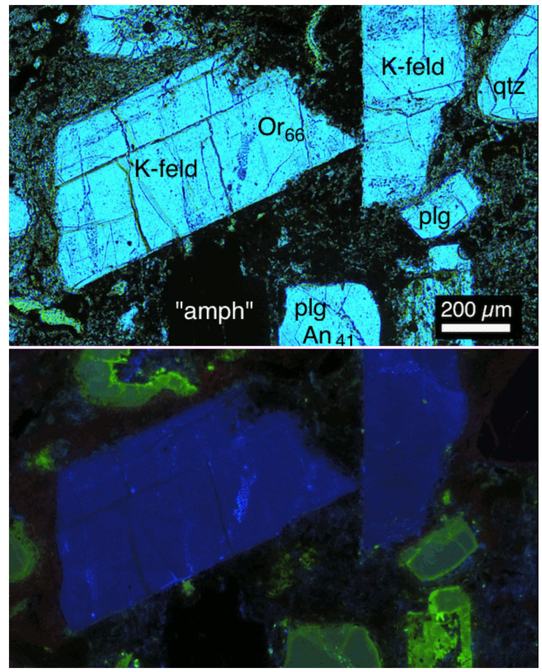
Volcanic rocks. Unshocked and slightly shocked volcanic fragments, embedded in impact glasses and melt rocks, have generally a microcrystalline matrix with bright CL emissions. In the case of cryptocrystalline or melt matrix, a distinction by composition is possible with SEM-CL and EDX in feldspathic-normative (CIPW) and quartz-normative glasses, which are brighter and darker, respectively. There is a clear correlation between the shock stage and the CL emission: the less shocked the fragment is, the brighter the matrix appears, commonly with a bluish color that is consistent with a feldspathic-normative composition. Spherulites, formed in the matrix at phenocrysts edge, have also emissions in the field of blue. Phenocrysts have characteristic emissions that are treated separately.

Impact melts. Impact glasses, as defined in [13], have generally dark emissions, obliterating flow and structural features, such as *schlieren*. As the intensity of the emission depends strongly on the amount of Fe in the matrix components, flow structures and *schlieren* marked by compositional variations are locally recognizable. A further distinction is possible if microlites have crystallized. Microlite-poor areas, which are generally quartz-normative in composition, have low emission, with dark brownish color and locally dark-reddish spots. Alternatively, microlite-rich areas display different response to CL depending on microlite composition. Aggregates of Fe-bearing microlites, such as of biotite or pyroxene, appear blackish and unresolvable with optical CL, whereas plagioclase microlitic aggregates have a pale bluish-violet color. CL-SEM allows a better distinction between the microlite-rich and -poor areas, even in the case of unresolvable microlites with the optical microscopy: regardless the composition of microlites, the higher the content of crystalline material, higher is the intensity of the emission. *Schlieren*, well recognizable in transmitted light as different color layers, are generally barely distinguishable by optical CL, whereas a weak difference in emission intensity is detected with CL-SEM.

Mineral grains. Unshocked mineral grains, present as phenocrysts in volcanic rocks or clasts in impactites, are well recognizable with optical CL. Plagioclase has generally a greenish-yellowish color. Locally a compositional zoning is indicated by gradational emission intensity, with a darker Ca-rich core with respect to the more albitic rim. K-Feldspar has a characteristic blue color. In these rocks, quartz has very low emissions, regardless the shock experienced. Mafic minerals are dark because of the Fe content. Generally, a reduction in luminescence intensity is observed in shocked grains.

Suevite in the drill core. Observations in the suevite are partially hampered by the widespread alteration. In particular, the presence of secondary calcite obliterates the emission of the neighbor phases because its high intensity reddish emission. On the other hand, the crystallization of secondary albite along glassy layers allows the identification of compositional *schlieren* also with optical CL. The rough relationship between shock and CL response, observed in impact glasses and melt rocks as described above, is confirmed in the suevite, even if it is more difficult to identify. Shocked grains (quartz and plagioclase) are equally dark under CL, but some reddish luminescence along planar fractures is observed. Alternatively, bluish response can mark fractures filled by secondary or matrix minerals.

Discussion and conclusions: An unambiguous criterion to distinguish impact and volcanic melts in felsic rocks was a major research challenge at El'gygytgyn. Despite CL was already used for description of impact glasses, the study was limited to ejecta and has allowed only a partial correlation with shock temperature [6]. In the investigated rocks, it seems that a relationship between shock and CL intensity is present, having the unshocked to slightly shocked volcanics a crystalline or devitrified matrix that generally shows a brighter emission intensity than the low emission intensity of fresh impact glass. A possible explanation of this behavior is that, due to the fast quenching, impact melts are generally fresh and with low crystallinity. This determines a poor organization of luminescence centers, resulting in low emission intensity due to the competing effect. When microlites occur, their composition and abundance might result in increased emission intensity. We have not observe the relationship between emission and shock intensity described for K-feldspar in [5], as K-feldspar, even when featureless, has a bright bluish emission. Shock features in quartz (e.g., [3] and [4]) were also undistinguishable because of a very low emission intensity of all the investigated grains, regardless the shock experienced. A quantification of CL spectra is planned, for a better correlation between emission and shock.



Plane-polarized light (top) and CL (bottom) image of a lithic fragment, likely unshocked volcanic, in impact melt rock. The fragment consists of feldspar, quartz and mafic grains in a microcrystalline matrix. The matrix is pervasively altered but exhibits a dark bluish emission, suggesting high feldspathic content. The mafic mineral, likely amphibole (amph), is completely altered, whereas feldspars are not. CL shows that plagioclase (plg, greenish-yellowish) and K-feldspar (K-feld, bluish, note the brighter spots related to in-plane fluid inclusions) seem to be not affected by shock. Quartz (qtz) displays very low dark reddish-brownish emissions of ambiguous interpretation. The mafic phase appears dark because of the high Fe-content.

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References: [1] Cathodoluminescence and its application in the planetary sciences. Gucsik A. Ed., Springer, Berlin (2009). [2] Gratz A. (1984) *J.Non-Cryst.Sol., 67,* 543-558. [3] Boggs S. at al. (2001) *Meteoritics&Planet.Sci., 36,* 783-791. [4] Hamers M.F. and Drury M.R. (2011) *Meteoritics&Planet.Sci., 46,* 1814-1831. [5] Kayama M. et al. (2012) *JGR, 117,* E09004. [6] Gucsik A. et al. (2004) *Meteoitics&Planet.Sci., 39,* 1273-1285. [7] Gurov E.P. et al. (1979) *LPS, 10,* 479 481. [8] Pittarello L. et al. (subm.) *Meteoritics&Planet. Sci.* [9] Dietz R.S. and McHone J.F. (1976) *Geology, 4,* 391-392. [10] Layer P.W. (2000) *Meteoritics&Planet.Sci., 35,* 591-599. [11] Stone D.B. et al. (2009) *Stephan Mueller Spec.Publ.Ser., 4,* 243–260. [12] Gurov E.P. and Koeberl C. (2004) *Meteoritics&Planet. Sci., 39,* 1495-1508. [13] Pittarello L. and Koeberl C. (2013) *Meteoritics&Planet.Sci.* [14] Melles M. et al. (2011) *Sc.Drilling, 11, 29-40.* [15] Koeberl C. et al. (2013) *Meteoritics&Planet.Sci.*