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Chemistry of Tertiary sediments in the surroundings of the Ries impact structure and moldavite formation revisited

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Abstract

Moldavites, tektites of the Central European strewn field, have been traditionally linked with the Ries impact structure in Germany. They are supposed to be derived mainly from the near-surface sediments of the Upper Freshwater Molasse of Miocene age that probably covered the target area before the impact. Comparison of the chemical composition of moldavites with that of inferred source materials requires recalculation of the composition of sediments to their water-, organic carbon- and carbon dioxide-free residuum. This recalculation reflects the fact that these compounds were lost almost completely from the target materials during their transformation to moldavites. Strong depletions in concentrations of many elements in moldavites relative to the source sediments (e.g., Mo, Cu, Ag, Sb, As, Fe) contrast with enrichments of several elements in moldavites (e.g., Cs, Ba, K, Rb). These discrepancies can be generally solved using two different approaches, either by involvement of a component of specific chemical composition, or by considering elemental fractionation during tektite formation. The proposed conceptual model of moldavite formation combines both approaches and is based on several steps: (i) the parent mixture (Upper Freshwater Molasse sediments as the dominant source) contained also a minor admixture of organic matter and soils; (ii) the most energetic part of the ejected matter was converted to vapor (plasma) and another part produced melt directly upon decompression; (iii) following further adiabatic decompression, the expanding vapor phase disintegrated the melt into small melt droplets and some elements were partially lost from the melt because of their volatility, or because of the volatility of their compounds, such as carbonyls of Fe and other transition metals (e.g., Ni, Co, Mo, Cr, and Cu); (iv) large positively charged ions such as Cs^+, Ba^{2+}, K^+, Rb^+ from the plasma portion were enriched in the late-stage condensation spherules or condensed directly onto negatively charged melt droplets; (v) simultaneously, the melt droplets coalesced into larger tektite bodies. Steps (iii)–(v) may have overlapped in time. The still melted moldavite bodies reaching their final size were reshaped by further melt flow. This melt flow was related to moldavite rotation and escape (bubbling off) of the last portion of gaseous volatiles during their flight in a low-pressure region above the dense layer of the atmosphere.

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1. INTRODUCTION

Tektites are a type of distal impact ejecta produced during hypervelocity impacts of relatively large extraterrestrial bodies (with a diameter of at least several hundreds of meters) on the Earth's surface. They are usually several centimeters in size and consist of natural silica-rich glass. The idea that tektites are generally formed by rapid fusion of near-surface terrestrial sediments during the impact process (Spencer, 1933; cf. also Schwarcz, 1962) has been widely discussed. The four known major tektite strewn fields encompass (in order of decreasing formation age) the North American, the Central European, the Ivory Coast, and the Australasian tektite strewn fields. The known spatial extent of the Central European strewn field is the smallest among the known tektite strewn fields. Most probably, tektites can be formed most effectively during oblique impacts (30–50° from horizontal; Stöffler et al., 2002). In these cases, hypervelocity ejection of near-surface terrestrial materials is favored by the impact geometry. In addition, numerous occurrences of tektite-like materials are related to impact events (Libyan Desert Glass, Aouelloul glass, Darwin glass, glasses of Elgygytgyn impact structure, Zhamanshin impact structure, and many others; see Koeberl, 2014, for a review).

Moldavites, tektites of the Central European strewn field (Fig. 1) genetically linked to the Ries impact structure in Germany, are found in several areas of the Czech Republic (Trnka and Houzar, 2002) and rarely also in adjacent areas of Austria (Koeberl et al., 1988), Germany (Lange, 1995, 1996), and Poland (Brachaniec et al., 2014). The Ries was first proven to be an impact structure by Shoemaker and Chao (1961). Moldavites were genetically connected with the Ries for the first time by Cohen (1961) and the synchroneity in K–Ar ages of the Ries glasses and moldavites was introduced by Gentner et al. (1963) shortly thereafter. More recent dating of the Ries event was published by Abdul Aziz et al. (2008), Di Vincenzo and Skála (2009), Buchner et al. (2010), and Rocholl et al. (2011). Buchner et al. (2013) compiled all the existing K–Ar, Ar–Ar and U–Pb ages for the Ries and combined them with paleomagnetic data. These authors concluded that the Ries event occurred within the age interval of 14.80 ± 0.20 Ma. This age was confirmed by Schwarz and Lippolt (2014) at 14.75 ± 0.20 Ma.

Numerous detailed studies compared the chemistry of moldavites with that of possible target materials sampled within and around the Ries (e.g., Philpotts and Pinson, 1966; Engelhardt, 1967; Bouška et al., 1973; Delano and Lindsley, 1982; Luft, 1983; Engelhardt et al., 1987; Delano et al., 1988; Meisel et al., 1997; Engelhardt et al., 2005; Řanda et al., 2008; Skála et al., 2009). A consensus of these studies was that moldavites can be derived neither from the impactor matter, nor from the Mesozoic sediments and/or crystalline basement rocks. The only type of material that has suitable chemistry for the formation of moldavite glass is represented by the Middle Miocene unconsolidated sediments of the Upper Freshwater Molasse (Obere Süßwassermolasse; hereafter referred to as OSM), which probably covered a substantial part of

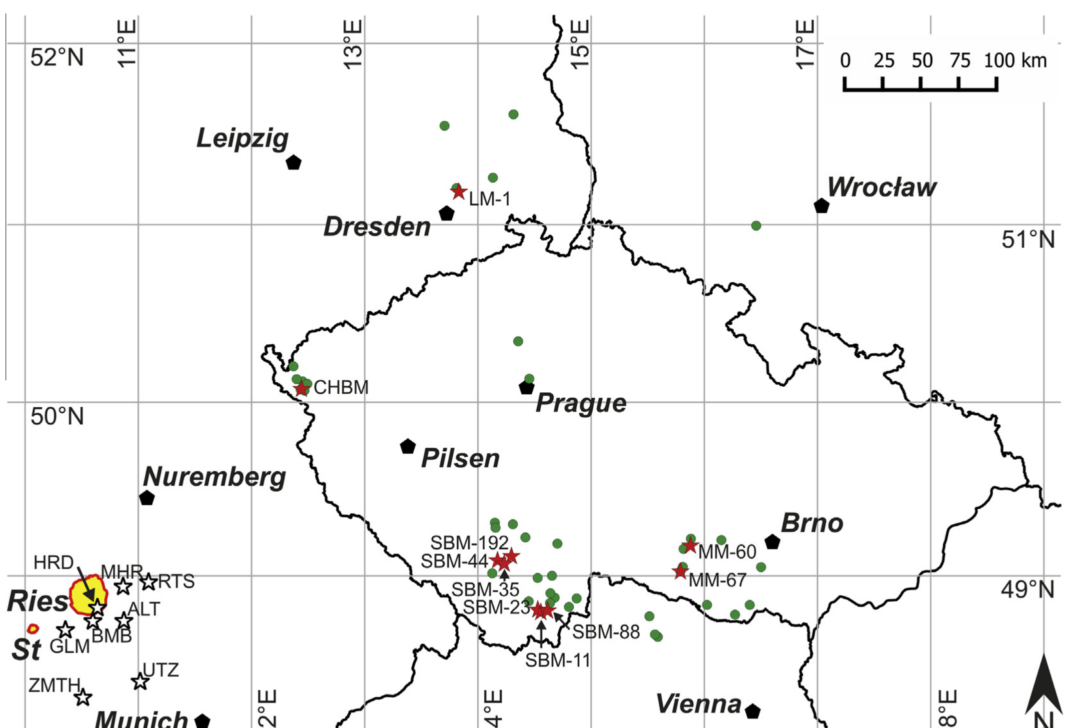

Fig. 1. The location of the studied samples of sediments (white stars) and moldavites (red stars). Also shown are positions of the Ries and Steinheim (abbreviated St) impact structures (red-outlined yellow areas) and selected important moldavite localities (green dots). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)