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Extremely P-rich olivine from a prehistoric sacrificial burning site (Goldbichl, Igls, Tyrol, Austria)

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Prehistoric sacrificial burning sites have been studied in the Alpine area for the past 40 years. The study of Weiss (1997) on burning sites from Bavaria shows that due to the lack of surfacial characteristics, these burning sites are very hard to identify and indeed their identification mostly happens accidentially. Although Krämer (1966) already described 25 possible sacrificial burning sites from the Alpine region, Weiss (1997) discusses about 120 burning sites from an area extending between the Alps and the Danube. These sites were identified based on the presence of pottery-, metal- and bone fragments and none of these sites has ever been investigated from a mineralogical point of view.

Two burning sites, where the link to ritual fires has firmly been established in Tyrol are the prehistoric burning sites at the Goldbichl near Innsbruck and in Ötz in the Ötztal approximately 50 km W of Innsbruck. Before their anthropogenic origin was recognized, the slags were variably interpreted as products of volcanic activity, meteorite impacts, lightning strikes or forest/bogfires (Heißel, 1938). Von Chlingensperg (1904) was the first to interpret the burning sites as localities where ritual immolations took place, based in part on the abundant presence of bone fragments of domestic animals such as cow, sheep, goat and pig (Weiss 1997).

In this study we report extremely P-rich olivines from partially molten quartzphyllites from the presumably La-Tène (450-15 B.C.) age sacrificial place at the Goldbichl, near Innsbruck, Northern Tyrol, Austria, where immolation of ritual offerings took place. During partial melting, foamy patches of dark glassy material formed at the surface of the rocks and also as layers within the rocks. The pyrometamorphic rocks contain the mineral assemblage olivine + orthopyroxene + plagioclase + spinel + glass. Phosphorus-rich olivine was found in an apatite-rich domain, coexisting with graftonite $(Fe, Ca, Mg, Mn)_3(PO_4)_2$ and shows a wide range in composition with P ranging from 0.3 to 0.55 apfu, which corresponds to up to 21 wt.% P_2O_5! This are th highest P-contents in olivine reported from rocks so far! The systematics of Mg, Fe, Si, and P concentrations in olivine indicates that phosphorus is incorporated into olivine via the coupled substitution $2P + (r)M_{1,2} \Leftrightarrow 2Si + (Mg, Fe)M_{1,2}$. Olivine forms by incongruent melting of biotite at $T>1000^{\circ}C$ through the reaction biotite + quartz = olivine + Ti-magnetite + K-rich melt.or by breakdown of chlorite along the reaction Chlorite = Olivine + Spinel + H_2O. P was provided to olivine either from added bone material to the fire or by mineral reactions involving apatite from the protolith rock. To place constraints on the temperature of the firing processes, melting experiments at 1 bar will be conducted in a box furnace similar to the investigation of Tropper et al. (2006). To be as close as possible to the observations, we conducted simple experiments, where fO_2 is either not constrained or only approximated to the CCO buffer but not fixed. The experimental investigations on natural quartzphyllites and differential thermal analysis of biotite and chlorite also suggest that temperatures in excess of 1000˚C and strongly reducing conditions are necessary for the formation of phosphoran olivine in burning sites. In summary, chemical and experimental data presented above point to rapid olivine growth under disequilibrium conditions, which is a prerequesite for the incorporation of large amounts of P into olivine (e.g. Tropper et al., 2006; Boesenberg et al., 2004). This is also consistent with conditions of formation obtained from the rare natural occurrences of phosphoran olivine.

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