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Phosphorus-bearing phases as archaeopetrogenetic indicator for possible bone-rock interactions in pyrometamorphic slags from ritual immolation sites

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Although 200 ritual immolation sites occur throughout the Eastern Alps only 2 have been investigated from a mineralogical/petrological point of view. The investigated sites (Oetz, Goldbichl/Igls) are located on hill-tops and show abundant ceramic and bone fragments. In these sites pyrometamorphic slags occur (in Oetz only little, at the Goldbichl, massive amounts). The textures within these slags indicate strongly disequilibrium conditions. Investigations of slags from two ritual immolation sites in the Eastern Alps, the La-Tène (450 – 15 B.C.) age site in Oetz and the Bronze-Age site at the Goldbichl/Igls yielded the occurrence of phosphorus-rich olivines and phosphates such as whitlockite (Oetz) and stanfieldite (Goldbichl). Temperatures derived from the slags are >1000-1100°C under highly reducing (QFM) conditions. On the other hand bone apatite crystallinity of calcinated bones yields much lower temperatures this might be due to their position in "cooler" spots of the fire (e.g. at the surface). The high temperatures deduced from the slags are compatible with core temperatures (>1100°C) of large bone fires with a possible wind-driven air circulation. Experimental investigations using DTA-TG to study chlorite breakdown verify these temperatures. In order to verify the presence of P-bearing phases during bone-rock interactions experiments were carried out at 1100-1300°C and highly-reducing conditions in graphite crucibles. Experiments concerning the interaction of bone material and three different rock types such as paragneiss, quartzphyllite and granite led to the formation of whitlockite and P-bearing olivine. Olivine contains 0-4.6 wt.%, P2O5 where the highest P-contents were observed in the quartzphyllite experiments. The occurrence of P-rich olivine and whitlockite in the quartzphyllite experiments is therefore diagnostic for bone-rock interaction at high temperatures.
Based on the mineralogical observations from the two sites P-rich minerals which indicate the presence of a P-source (bone or detrital apatite) in the fire are the following: whitlockite, P-rich olivine, P-rich clinopyroxene and stanfieldite. The following mineral assemblage has experimentally shown to be associated with bone-rock interactions is: P-rich olivine ± P-rich clinopyroxene only when coexisting with whitlockite, which was found in the Oetz site. On the other hand P-rich olivine, P-rich clinopyroxene and stanfieldite form by decomposition of detrital apatite in the slags of the Goldbichl and no bone material is involved in their formation. The archaeological implications for the Goldbichl site points towards the implication that the massive slags probably represent the last firing event of the immolation site and hence the ritual „closing" of the site by an enormous fire. Therefore the occurrence of the mineral whitlockite in pyrometamorphic slags from ritual immolation sites could be diagnostic for bone-rock interactions if one considers archaeological, petrological and experimental data. The occurrence of P-bearing olivine and/or clinopyroxene alone is not diagnostic of bone-rock interactions.