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Microbially Influenced Formation of Lüneburgite in a Closed Basin Evaporitic System, Central Anatolia (Türkiye)

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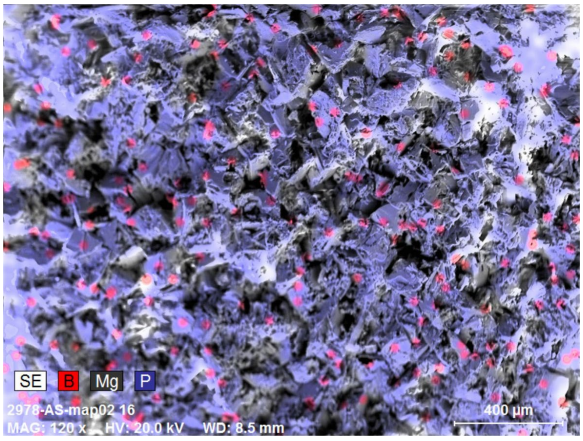



Lüneburgite ($Mg_3[B_2(OH)_6(PO_4)_2]\cdot 6H_2O$) is a rare mineral, and the origin of its main components, boron, magnesium, and especially phosphorus, is of considerable geochemical importance. The study area is situated in the Polatlı–Sivrihisar Basin of Central Anatolia, Türkiye, and is characterized by Late Miocene–Pliocene evaporitic units. The geochemical characteristics of lüneburgite occurring within evaporitic and clay rich units are examined, and its phosphate component is evaluated as organic or inorganic in origin based on $\delta^{18}O_{PO_4}$ isotopic data, together with the processes controlling its incorporation into the depositional basin. In addition, $\delta^{11}B$ and $\delta^{18}O_{SO_4}$–$\delta^{34}S_{SO_4}$ isotope data from associated gypsum samples are used to characterize the evaporitic depositional environment and to distinguish between different evaporitic settings. Mineralogical studies (XRD, SEM, EPMA) reveal that lüneburgite occurs in association with gypsiferous and clay-rich units and is crystallized in triclinic system, while gypsum exhibits granoblastic and tabular textures with local anhydrite occurrences. Whole rock geochemistry shows that lüneburgite is characterized by 23.8–24.2 wt. % MgO, 13.94–14.07 wt.% B_2O_3, and 26.7–26.9 wt.% P_2O_5, whereas gypsum is enriched in CaO (30–32 wt.%). The variability of Sr concentrations in both lüneburgite and gypsum suggests changing salinity conditions during mineral formation. The $\delta^{11}B$ isotope values of lüneburgite range between −20.97‰ and −21.77‰, whereas gypsum samples yield values from −21.87‰ to −22.05‰, corresponding to those reported for nonmarine evaporitic and groundwater derived sources. In addition, gypsum displays $\delta^{18}O$ values of +16.9‰ to +21.2‰ and $\delta^{34}S$ values of +18.9‰ to +23.5‰, overlapping with the isotopic field characteristic of marine evaporite sulfates. $\delta^{18}O_{PO_4}$ values of lüneburgite (+25.8‰ to +26.7‰) are significantly higher than typical volcanic or guano-derived phosphates, indicating formation from a phosphate pool subjected to extensive microbial cycling under highly evaporative conditions. Overall, the combined isotopic signatures point to lüneburgite formation in a microbially influenced, evaporatively concentrated closed basin system after gypsum deposition. The systematically elevated $\delta^{18}O$ values in phosphate, borate, and sulfate minerals provide additional support for this model.