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Water-Rock Interaction in Karst Systems: Experimental and Modeling Insights into Mg and Sr Release

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Karst systems are dynamic environments where water-rock interactions play a crucial role in shaping the geochemical composition of dripwaters and, ultimately, speleothems. These mineral deposits serve as valuable archives for reconstructing past climate conditions, with trace element ratios such as Mg/Ca and Sr/Ca often used as proxies for aridity and hydrological changes. However, the transfer of trace elements from bedrock to speleothems is influenced by a complex interplay of processes, including bedrock composition, water residence time, and dissolution dynamics. This study combines laboratory experiments, geochemical modeling, and field data to explore the factors controlling the release of major (Ca, Mg) and trace (Sr) elements during carbonate rock dissolution.

In the first part of the study, six types of limestone from the Moravian Karst (Czech Republic) were dissolved under controlled conditions. The results revealed that dissolution rates were 1–3 orders of magnitude slower than expected based on previously published values, with no clear correlation between dissolution dynamics and limestone microstructure (micrite/sparite composition). The study highlights the importance of incongruent dissolution, particularly for Mg-calcite and dolomite, and the role of preferential leaching of trace elements (Mg, Sr) from fresh mineral surfaces. A dynamic model was developed, incorporating fresh surface dissolution, non-stoichiometric leaching, and calcite precipitation, showing that trace element ratios (Mg/Ca, Sr/Ca) in karst waters are influenced by bedrock composition and the extent of rock-water interaction.

The second part of the study examines dolomitic rocks from the Demänovská Dolina (Slovakia) and Bozkov Cave (Czech Republic). Laboratory experiments demonstrated slower dolomite dissolution rates compared to limestone, with significant variations in Mg/Ca and Sr/Ca ratios depending on rock composition. The study emphasizes the importance of considering non-ideal stoichiometry in dolomite and the presence of Mg in calcite for accurate geochemical modeling. The experimental data were used to calibrate a theoretical model, which, while effective under laboratory conditions, did not fully replicate expected field conditions.

The studies underscore the complexity of karst water chemistry and the need to consider non-climatic factors, such as bedrock composition and water-rock interaction, in paleoclimatic reconstructions as well as in studies assessing rock weathering and denudation.