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Hydrochemistry and $^{87}Sr/^{86}Sr$ ratios as tracer for groundwater origin and discharge in crystalline basement

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Introduction

The construction of tunnels through mountain ranges requires a detailed understanding of the hydrogeological situation. In order to prevent large-scale water inflow into the tunnel system a detailed prognosis of groundwater discharge is of high significance. Groundwater discharge is affected by the geological, tectonic and lithological conditions in the catchment area. Because crystalline rocks are generally less permeable, the occurrence of groundwater in such lithologies is normally limited to fractures, lineaments, joints, and cleavages. However, layers of highly soluble rocks, e.g. carbonate rocks may be intercalated in crystalline sequences resulting in local karst formation that may not be recognizable on the surface. Therefore, the main goal of this investigation is the assessment of the usability of various tracer methods including hydrochemical and isotope tracers to find indications of such layers. In this study, we employ $^{87}Sr/^{86}Sr$ isotope ratios as a natural tracer to distinguish groundwater that has been influenced by carbonates dissolution from groundwater that is solely affected by silicate weathering in crystalline catchment areas. Here we present preliminary data from the Koralm tunnel project in southern Austria.

Fig. 1: Planned Koralm railway line (Vavrovsky et al., 2001), simplified geological map showing the major lithologic units, the trace of the tunnel (Graf et al., 2001) and tunnel heading and loading machine.

Geological and hydrogeological settings

The Koralm massif consists of a polymetamorphic crystalline basement. The crystalline basement is constrained by major fault zones, which have generated Tertiary basins on both sides of the mountain range. Mylonitic gneisses and micaschists are the predominant lithologies. Occasionally, marbles, amphibolites and eclogites are intercalated. Because of the low permeability of the crystalline schists, the area of the Koralm massif is mainly characterized by surface runoff and numerous small springs. The occurrence of deep circulating groundwater is limited to fractures, lineaments, joints and cleavages. The magnitude of the water circulation is a function of the intensity of these structures especially in the marble units. These units are intercalated in the gneisses and mica schists but show a limited extension and a low degree of karstification due to the high degree of crystallization. However, fractures in the marble layers represent very important pathways for fluids in the crystalline basement. Large-scale water inflow into the tunnel can occur when the tunnel excavation progresses in short distance from low permeable crystalline layers to high permeable zones (e.g. fault structures which are connected to karstified marbles).

Methods

Spring water samples were collected at representative sites across the mountain range. Water samples were filtered through 0.45 µm cellulose-acetate filters and stored in acid-washed PE bottles prior to the analysis of major cations and anions by ion chromatography (Joanneum Research) and ICP-OES (TU Graz). Samples of dissolved inorganic carbon (DIC) are prepared by injecting an aliquot of spring water into 10 mL helium-flushed Labco exetainer (which contain a few droplets of phosphoric acid). DIC samples are analyzed using using an on-line, continuous-flow system (Gasbench II) linked to a Finnigan DELTA^{plus}XP mass spectrometer (Joanneum Research). The distribution of strontium isotopes in dissolved Sr^{2+} was determined using TIMS. Strontium was purified by ion chromatography on a cation resin (AG50 x8), using 2.5N HCl as the eluent. $^{87}Sr/^{86}Sr$ isotope ratio measurements were carried out on a Finnigan MAT 262 at Stanford University. Samples were loaded onto out-gassed Ta-filaments. Saturation indices were calculated using the computer code PHREEQC-2 (Parkhurst & Appelo 1999).

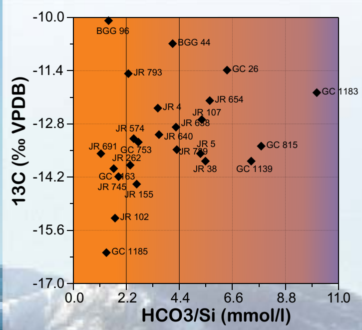

Fig. 2: Molar ratio of HCO_3/Si concentration vs. delta ^{13}C values for spring water. The change in color from orange to blue indicates the increasing influence of carbonates in the recharge area of the springs.

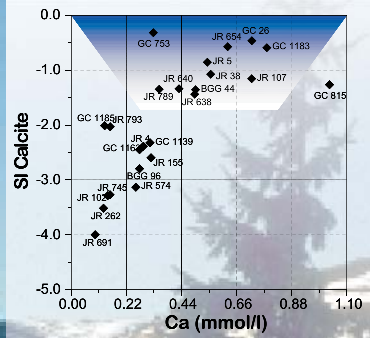

Fig. 3: Calcium concentration vs. saturation index of calcite for spring water. The blue-colored area indicates the influence of carbonates in the recharge area of the springs.

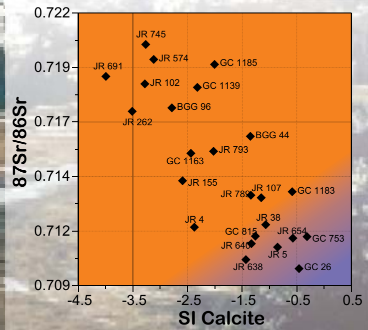

Fig. 4: Saturation index of calcite vs. $^{87}Sr/^{86}Sr$ ratio for spring water. The change in color from orange to blue indicates the increasing influence of carbonates in the recharge area of the springs.

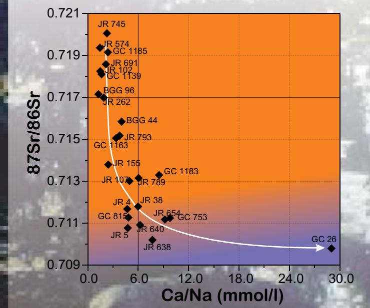

Fig. 5: Molar ratio of Ca/Na concentration vs. $^{87}Sr/^{86}Sr$ ratio for spring water. The change in color from orange to blue indicates the increasing influence of carbonates in the recharge area of the springs.

Conclusion

Based on saturation indices for calcite and $^{87}Sr/^{86}Sr$ ratios, the influence of dissolving calcium carbonate and mixtures between crystalline and carbonate waters can be identified easily. $^{87}Sr/^{86}Sr$ ratios vary from 0.7098 to 0.7200 with lowest values reflecting carbonate dissolution and highest values associated with the weathering of silicate minerals. $^{87}Sr/^{86}Sr$ ratios support the results from other hydrochemical parameters analyzed in this study.

The results of this study clearly demonstrate that the combination of hydrochemical investigations and $^{87}Sr/^{86}Sr$ ratios provide very useful information about the geochemical evolution of groundwater in crystalline basements. Moreover, it is possible to distinguish between different lithologic settings in the crystalline recharge areas.

References

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