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Field experiment to trace gas exchange and excess air formation in the quasi-saturated zone under natural conditions

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The concentrations of atmospheric gases dissolved in groundwater are usually found to exceed the respective atmospheric solubility equilibrium concentration. As the composition of the dissolved gas excess is often similar to that of atmospheric air the supersaturation is called “excess air”. Environmental tracer methods using dissolved trace gases of atmospheric origin (e.g. for groundwater dating and climate reconstruction) are strongly affected by the presence of excess air. To apply these methods in subsurface hydrology it is necessary to identify the excess air component reliably. Although excess air in groundwater is a well-known phenomenon its formation is still poorly understood and an appropriate physical description is lacking. Only recently, Holocher et al. (2002) were able to generate reproducible excess air in laboratory experiments using sand columns.

However, to our knowledge the formation of excess air has never been studied in natural aquifers including a sound physical description of the processes involved. To this end, we carried out an irrigation experiment in order to study the formation of excess air under natural conditions (Tomonaga 2004). A steep slope of a drumlin was selected as field site. The slope consists of ground moraine with low permeability and is equipped with a 9 m wide and 2 m deep shaft at its bottom that collects all the subsurface runoff water. The site was irrigated during about 8 hours, whereby the water volume corresponded to $\sim$10 mm/h. The first subsurface runoff was observed in the

shaft 4 hours after starting irrigation. Water samples for noble gas analysis have been collected in time intervals of 10 to 30 min beginning from the water breakthrough. These samples were analyzed for their excess air content. The measured neon concentrations exceed the atmospheric equilibrium concentration by 5 to 10%. This reflects the excess air, which was produced during water infiltration by gas exchange with air bubbles entrapped in the soil matrix.

A physical model that describes the dissolution of entrapped air bubbles beneath the water table (kinetic bubble dissolution (KBD) model) was developed in order to simulate the formation of excess air (Holocher et al. 2003). The KBD model was adapted for the required field situation, and was then used to simulate the excess air formation in the irrigation experiment. The experimental data agree well with the modeled values. The mean deviations between modeled and measured concentrations are less than 5% for all noble gases.

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