

The upper water table: a reactive interface between ground water and surficial biogeochemical processes in a shallow alluvial aquifer

R. Groffman
L. J. Crosse

Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, New Mexico 87131 USA

C. S. Fellows

Department of Biology, University of New Mexico, Albuquerque, New Mexico 87131 USA

In shallow phreatic aquifers the upper water table represents a zone of active biogeochemical exchange among multiple reservoirs. Fluxes of gases and solutes between atmosphere, vadose zone and ground water reservoirs modify the chemistry to different degrees. Due to the open nature of these systems, chemical fluxes are strongly influenced by seasonal cycles, especially infiltration events such as spring snow melt. Infiltration events cause the phreatic surface to fluctuate and flood the overlying vadose zone defining a zone of intermittent saturation (ZIS). Within the upper water table and ZIS, carbon sources, nutrients and terminal electron acceptors (TEAs) are more available than at depth. Our research focuses on biogeochemical activity in the upper water table and the response to imports and exchange from adjacent reservoirs.

We are characterizing biogeochemical responses by measuring redox-sensitive trace elements, nutrients, major cations and anions in ground water and sediments throughout the aquifer at the Rio Calaveras research site. Instrumentation includes over 200 wells, 12 suction lysimeters, two flumes and a meteorological station. The site is located approximately three kilometers northwest of the Valles Caldera in the Jemez Mountains of northern New Mexico at an elevation of 2475 meters (8300 ft). A first order stream with a gradient of 1.3 percent drains an area of approximately 3,760 hectares. Valley floor sediments are comprised of two to three meters of poorly sorted colluvial and fluvial material (90 percent sand 10 percent silt) that together form a matrix-supported aquifer structure.

Using dialysis cells and a DMLS[®] high resolution ground water sampling system we have defined vertical concentration gradients of the biogeochemically sensitive TEAs oxygen, sulphate, nitrite, nitrate, iron, and manganese at multiple locations in the aquifer over seasonal cycles. We have sampled

aquifer sediments anaerobically and aseptically during well installation to evaluate mineral products in the same vertical context. Monitoring TEAs in ground water gives insight into microbially mediated processes in the aquifer (Loveley and Chapelle, 1995). These processes partially control redox and mobility of many trace elements in ground water.

Laboratory methods include anion and organic acids analysed with a Dionex-500X ion chromatograph and AS14 and AS11 columns respectively (precision of $\pm 5\%$ anions and $\pm 10\%$ for OA); cations were analysed by Perkin Elmer model 303 flame atomic absorption (precision of $\pm 5\%$).

Figure 1 shows a vertical profile of biogeochemical constituents sampled in early July of 1997. Soluble iron is elevated in the upper 80 cm of the aquifer and decreases with depth while sulphate is low in the upper aquifer and increases with depth. Dissolved oxygen, measured down hole with a probe (YSI-50B), is below 0.5 mg/L (the analytical detection limit of the instrument) indicating suboxic to microaerophilic conditions through the entire profile. Concentrations of low molecular weight organic acids (LMWOA) (acetate, formate and oxalate) are elevated in the upper 40 cm of the aquifer and decrease with depth. Acetate concentration is particularly high (approximately 15.58 mg/L (264 μ M)), an unusual occurrence in both diffusion and advection dominated environments. We postulate the presence of high concentrations of LMWOA in the upper aquifer are due to transport of organic acids or more complex forms of carbon from the overlying vadose zone by infiltration associated with storm events. An alternative hypothesis is that acetogenesis in the upper water table is producing acetate under microaerophilic conditions degrading allocthonous carbon derived from the vadose zone. Residence times of acetate in most natural environments are short, i.e. hours in marine sediments

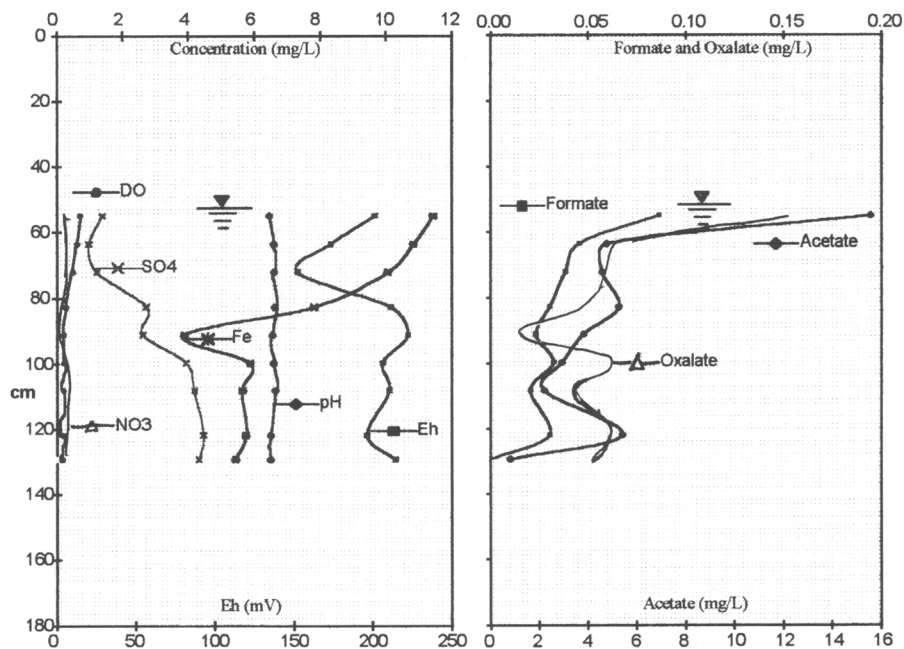


FIG. 1. Biogeochemical parameters at MLS-3, Rio Calaveras, New Mexico.

(Middelburg, 1989). Baker (1998) measured background acetate concentrations up to 2.4 mg/L (40 μ M) in the upper aquifer at Rio Calaveras.

Iron and sulphate reduction appear to be robust in the upper aquifer during summer/autumn base flow conditions (Fig. 1) but decrease during late winter and spring as dissolved oxygen increases during spring infiltration of snow melt. These events shift redox to suboxic/oxic conditions and may stimulate aerobic microbial activity in addition to reacting with ferrous iron resulting in ferric iron phases (oxidation products) coating aquifer sediments.

The distribution of amorphous iron, nonsilicate iron and amorphous manganese from vadose and aquifer sediments show elevated concentrations in the ZIS (up to 1.2 wt.%) with decreasing concentrations at depth providing evidence for a reactive interface at the phreatic surface during portions of the year. The accumulation of reactive oxidation products on sediments at the top of the water table is significant because 1) amorphous iron and manganese phases represent a labile reservoir of electron acceptors for bacterially-mediated iron and

manganese reduction, 2) their presence suggests oxygen is transported across the ground water interface and 3) these phases are excellent sorption surfaces for trace elements in ground water.

Sediment incubations utilizing ambient microbial populations, organic carbon and ground water are currently in progress to assess the role of abiotic versus biotic mechanisms affecting iron and manganese mobility in the aquifer.

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