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Salinity of pore waters in sedimentary basins under geothermal gradients

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The pore waters in sedimentary basins are crucial in the control of diagenesis, sediment-hosted ore formation, and generation and transport of hydrocarbons. The chemical and hydrological properties of the pore waters are therefore of importance in the understanding of these geological phenomena. An increasing number of studies reported that the pore waters often have higher salinity than seawater, and the salinity generally increases with the increase of the depth (e.g., Kharaka and Hanor, 2003). Such salinity distribution has been often attributed to infiltration of brines from underlying halite beds. However, the downward salinity increase is observed also in basins that are lacking halite beds (e.g., Xie et al., 2003). Therefore, more general mechanisms may exist for the formation of the salinity distribution.

In this study, I demonstrate on the basis of thermodynamics that the chemical equilibrium of the saline water in a sediment column under gravity and the pressure and geothermal gradients results in the downward salinity increase. The chemical potential of solute is the function of pressure, temperature, concentration, and gravity potential. The pressure term increases with increasing the depth, whereas the temperature term and the gravity potential decrease. The sum of these terms generally decreases with the increase of the depth. In the final equilibrium state, the chemical potential should be constant along the column. Therefore, we consider that the concentration term increases to keep the chemical potential constant, leading to the downward salinity increase. Assuming that the pore water is the NaCl-H2O mixture, I calculated the concentration of NaCl in the solution using the model of Pitzer et al. (1984) and Rogers and Pitzer (1982). The calculations showed that the salinity increased from 32 to 208 g/L in the 2000 m-thick sediment column under the geothermal gradient of 0.05 K/m. Such a salinity increase is in the same order to those observed in many sedimentary basins. In an isothermal case, the salinity increased only weakly, and it reached 36 g/L. This result is consistent with the conclusion of Mangelsdorf et al. (1970) that gravity alone does not explain the observed enrichment of salinity. If we set the salinity at the top of the column at 1 g/L, it increased to 24 g/L under the identical condition. Therefore, the high-salinity waters are generated in fresh to brackish environments.

This study showed that the simple chemical equilibrium along the sediment column resulted in the downward salinity increase. The method proposed here may be applicable to studies of fluids in other geological systems, such as in mantle, crustal rocks, hydrothermal environments, and magmatic systems.

Keywords: pore waters, salinity, sedimentary basins