

The origins of deep groundwaters in Cumbria, northwest England: hydrochemical constraints

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Introduction

In order to determine groundwater flow paths it is essential to characterise the origins of the waters and their dissolved solute load. This is often easier for shallow groundwaters in relatively permeable sedimentary cover sequences than it is for deep groundwaters in less permeable crystalline basement rocks. Deep waters will usually have longer residence times within the geosphere than shallower waters, and often will have undergone extensive water/rock interactions. At localities where cover rocks overstep basement rocks, groundwater origins and residence times are influenced by the possibility of hydraulic connectivity between the cover and the basement. Such a locality occurs at the eastern margin of the East Irish Sea Basin (EISB), at Sellafield, northwest England (Figure 1). Here, relatively permeable Carboniferous to Triassic sedimentary cover rocks are underlain by less permeable Ordovician volcanic basement rocks of the Borrowdale Volcanic Group (BVG). Data for deep (up to 1.7 km) groundwaters at this location have been produced recently during the investigation of the site for a potential nuclear waste repository, which

is being undertaken by U.K. Nirex Ltd. Additionally, analyses of porewaters from bottom sediments in a freshwater lake, Derwentwater, to the northeast of Sellafield (Figure 1), have been reported. The purpose of this paper is to assess these new hydrochemical data in order to characterise the relationship between groundwaters in the cover and basement rocks of the area.

Two main types of groundwater occur in the Sellafield area (U.K. Nirex Ltd, 1993): 1. shallow, dilute ($< c. 500 \text{ mg l}^{-1}$ Total Dissolved Solids (TDS)) Ca-HCO₃ and Na-Ca-HCO₃ dominated waters; and 2. deeper, more saline, Na-Cl dominated waters. In the EISB, waters of the first type occur only in the cover, and in the very top of the basement towards the basin margin in the east. Waters of the second type occur at depth both in the cover and in the basement, and their salinities increase from $c. 30000 \text{ mg/l}$ Total Dissolved Solids (TDS) in the east, to $c. 180000 \text{ mg/l}$ towards the basin centre in the west. The first type of water is interpreted to have been recharged relatively recently and to have acquired its salinity mainly through water-rock interactions involving carbo-

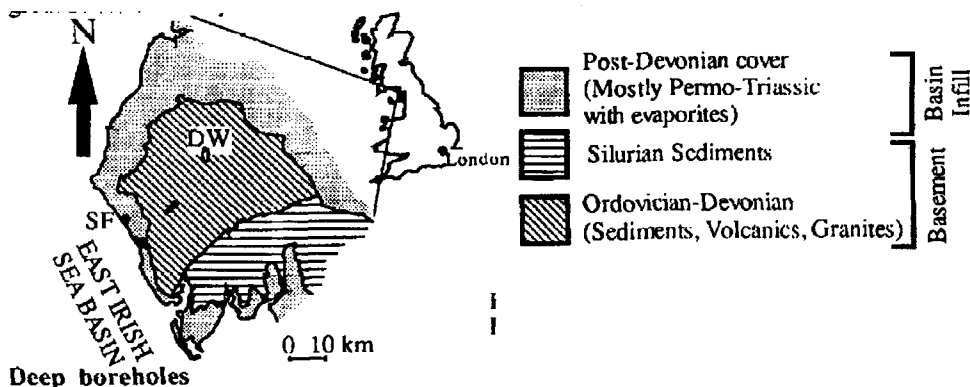


FIG. 1. Simplified geological map of northwest England. SF is Sellafield; DW is Derwentwater.

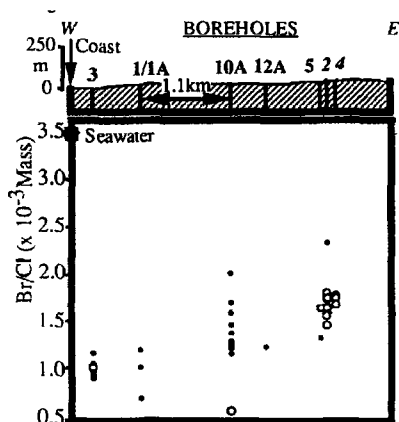


FIG. 2. Variations in Br/Cl for deep groundwaters in the Sellafield area. Solid circles = cover waters; Open circles = basement waters.

nates within the host rocks. In contrast, the available evidence suggests that there may be two distinct components comprising the NaCl dominated waters. For example, Br/Cl ratios increase from west to east (Figure 2). This implies that waters with relatively low Br/Cl ratios which originate in the west may be mixing with waters with higher Br/Cl ratios which originate in the east.

Lake sediment porewaters

Hamilton-Taylor *et al.* (1988) reported concentration gradients in porewaters from Derwentwater sediments. Porewater salinities were found to increase uniformly to *c.* 6900 mg/l. TDS at *c.* 6 m below the lake bed, and the deepest samples had a Ca-Na-Cl dominated chemistry. These observations were considered to reflect the upwards diffusion of saline waters that originate in the underlying basement rocks. Analytical data from saline springs in the area were used to support this conclusion. However, no Br data were obtained. Recently, new analyses of these porewater samples have suggested that the deep saline waters have high Br/Cl ratios, greater than that of seawater (Figure 3; seawater Br/Cl (mass) = 3.5×10^{-3}). As Cl concentrations increase above *c.* 500 mg/l the Br/Cl (mass) ratios of the Derwentwater porewaters converge towards a value of *c.* 4.0×10^{-3} (Figure 3). This is probably close to the Br/Cl ratio of the saline basement water because, when two waters of contrasting salinity mix, the mixture will have a composition reflecting the chemistry of the most saline water. This can be appreciated from a theoretical line illustrating Br/Cl variations during mixing between the sample with the highest

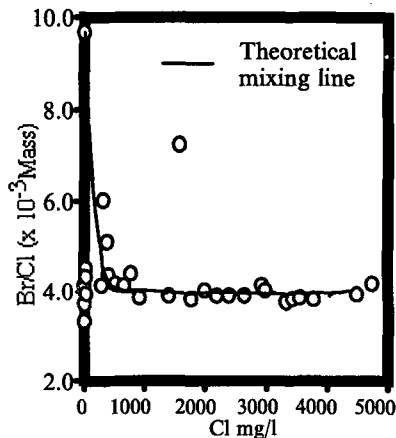


FIG. 3. Br/Cl versus Cl for Derwentwater sediment porewaters and saline springs in the east of the area underlain by basement.

Br/Cl ratio and the sample with the highest salinity (Figure 3).

Discussion and conclusions

Ratios of Br:Cl are commonly used as indicators for the origins of groundwater salinity. The Br/Cl ratios of the deep Sellafield groundwaters are all much lower than that of seawater (Figure 2). This suggests that the Na-Cl dominated groundwaters did not acquire their salinities from seawater. However, halite accommodates relatively small amounts of Br within its structure. Thus, halite dissolution in the Permo-Triassic evaporites which occur in the cover sequence is a plausible origin for the salinity of the postulated low Br/Cl groundwater endmember. The second putative Na-Cl dominated endmember is the saline basement water encountered in the Derwentwater sediments. Mixing between these two endmembers could explain the observed eastwest increase in Br/Cl ratios in the Sellafield area. Ranges of Br/Cl ratios vary laterally (Figure 2) indicating that salinity sources have mixed throughout the district, both in the cover and in the basement.

Acknowledgements

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References

- Hamilton-Taylor *et al.* (1988) *Geochim. Cosmochim. Acta*, **52**, 223-7.