Isotopic and geochemical evidence for old groundwaters in a granite on the Canadian Shield

M. Gascoyne

Applied Geoscience Branch, Whiteshell Laboratories, Pinawa, Manitoba R0E 1L0, Canada

Introduction

Groundwaters have been sampled from depths of up to 1000 m in permeable fractures and faults in the Lac du Bonnet granite batholith, southeastern Manitoba, Canada, as part of AECL's geoscience research for the Canadian Nuclear Fuel Waste Management Program (Dormuth and Gillespie, 1990). The batholith is being studied to develop site characterization methods and to understand geologic and hydrologic processes in fractured rock to assist in the eventual selection of a site for nuclear fuel waste disposal on the Canadian Shield. This paper summarizes the isotopic and geochemical evidence indicating the presence of Pleistocene and pre-glacial groundwater in the batholith.

Methods

Groundwaters in permeable fractures in the Lac du Bonnet granite have been obtained from over 100 boreholes drilled to depths of up to 1000 m at several locations on the batholith and from various levels of AECL's Underground Research Laboratory (URL), near the southern margin of the batholith. Analyses for a suite of dissolved species are made on representative groundwater samples obtained after contaminating groundwater (from drilling, open-borehole flow, etc.) has been removed or minimized by pumping.

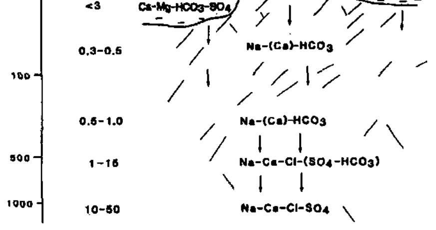

FIG. 1. Evolution of groundwater composition with flow (arrowed) through fractures in the Lac du Bonnet granite.

Results

Ionic composition. Groundwater salinity (ie. dissolved salt content) in the batholith generally increases with increasing depth or with distance along the flow path (Fig. 1). Upland areas of recharge have relatively dilute groundwaters (total dissolved solids (TDS) about 0.4 g/L) at depths of up to 400 m whereas lowland areas, where discharge is occurring, contain relatively saline (TDS about 2 g/L) groundwaters at depths of about 50 m. Ionic composition evolves with depth from dilute, near-neutral, Ca-HCO_3 waters at shallow depths in recharge areas, to more alkaline, (pH 8–9) Na-(Ca)-HCO_3 waters at greater depth. As groundwater is sampled further down-gradient in the direction of flow, salinity increases so that between 500–1000 m, groundwaters are typically Na-Ca-Cl-SO_4 in composition and range from 5 to 50 g/L TDS. This pattern of chemical evolution is similar to that observed at numerous sites across the Canadian Shield and is indicative of continued rock-water interaction in which groundwater salinity is qualitatively related to residence time.

Isotopic composition. The tritium content of groundwaters in the batholith decreases to < 1 TU below about 200 m indicating that most groundwaters below this depth were recharged at least 40 years ago. Deuterium (^2H) and ^{18}O data fall on or close to the global meteoric water relationship (Fig. 2*a*) indicating a meteoric source for all groundwaters including the most saline samples (indicated in Fig. 2*a*). Modern precipitation and shallow groundwaters are typically $\delta^{18}O$ = −13 to −14.5 ‰ but a number of deeper, brackish and saline groundwaters are significantly depleted in ^{18}O (and ^2H), by up to 7‰ (Fig. 2*b*). The depleted groundwaters are at depths ranging from 50 to 400 m with the shallower samples occurring in groundwater discharge areas. The distribution of these groundwater types is clearly seen at the URL (Fig. 3) where the largest number of samples have been obtained. These results indicate that a pulse of cold-climate recharge, probably derived from Pleistocene glacial events, is slowly moving through the intermediate depth flow system and, in some cases, is now being discharged at the surface. Most of the deeper, more saline ground-

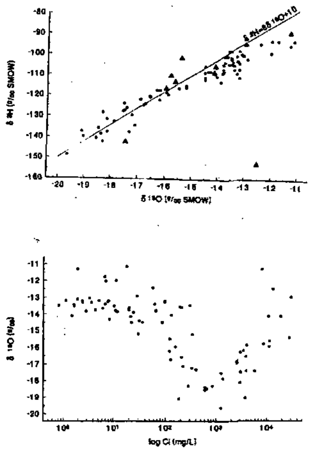

FIG 2. Variation of a) δ^2H and $\delta^{18}O$ and relationship to the meteoric water line (triangles indicate groundwaters with TDS > 10 g/L), and b) $\delta^{18}O$ with Cl concentration, for groundwaters in the Lac du Bonnet granite.

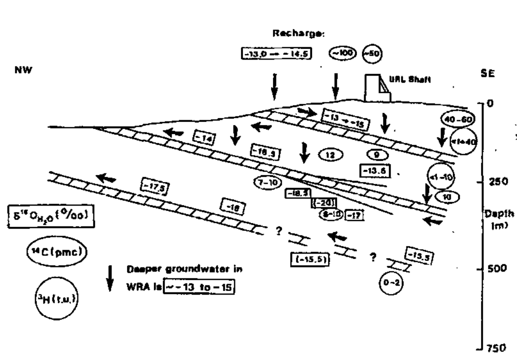

FIG. 3 Summary of H, C, O isotopic data for groundwaters in fracture zones (cross-hatched) in the area of the AECL's Underground Research Laboratory, Manitoba. Flow directions are arrowed.

waters in the area are not significantly depleted in ^2H and ^{18}O and indicate recharge occurred during a mild to warm climate similar to modern conditions.

Carbon-14 data are available for groundwaters that have sufficient bicarbonate alkalinity and values as low as 3 PMC (percent modern carbon) have been obtained so far on brackish waters at 270 m depth (Fig. 3). These data are consistent with a Pleistocene age for recharge of these groundwaters.

Discussion

The major ion compositions and H, C, and O isotopic data all indicate groundwater recharge in upland areas, predominantly where bedrock is exposed, with relatively rapid movement through the upper ~200 m of well-fractured granite to discharge locations in adjacent lowland areas. Below this depth, groundwater movement is slower and occurs mainly through a network of widely spaced fracture zones. Only a small proportion of the shallow recharge water penetrates into this flow regime as indicated by the absence of a 'bomb-pulse' of ^3H in these waters. Salinity (as Cl and SO_4 salts) of these groundwaters increases along the flow path and groundwater residence times may be at least 10,000 years. Of note are the more saline groundwaters, at depths of 400–1000 m in the batholith, which have δ^2H and $\delta^{18}O$ values similar to modern groundwater, yet underlie or are hydrogeologically upstream of the $^2H/^{18}O$-depleted waters. The deep, saline groundwaters clearly recharged during a warm climate similar to modern but, because of their salinity and location in the hydrogeological flow path, probably recharged prior to Pleistocene times (> 106 years ago). These long residence times are consistent with predictions from a hydrogeological particle-tracking model derived from fracture permeabilities and hydraulic head data (Gascoyne and Chan 1992).

Summary and conclusions

Major ion and H, C, O isotopic data for groundwaters, from depths of up to 1000 m in the Lac du Bonnet granite, Manitoba, have shown an internally consistent geochemical evolution along flow paths through the granite. Residence times of > 106 years are indicated for saline groundwaters underlying brackish Pleistocene recharge waters. External consistency has been demonstrated through independent estimates of groundwater residence time from groundwater flow models. The combined use of geochemical and isotopic data for groundwater gives important information for developing and calibrating groundwater flow models for the eventual location of a possible nuclear waste disposal vault on the Canadian Shield.

References

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