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Chemical Geology 228 (2006) 209–232

CHEMICAL GEOLOGY
INCLUDING
ISOTOPE GEOSCIENCE

www.elsevier.com/locate/chemgeo

Helium, radon and radiocarbon studies on a regional aquifer system of the North Gujarat–Cambay region, India

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Received 22 July 2003; accepted 31 October 2005

Abstract

The study reports the age evolution of groundwater as it flows from the recharge area through a regional alluvial aquifer system in North Gujarat–Cambay region in western India. Radiocarbon (^{14}C), ^{4}He and $^{4}He/^{222}Rn$ dating methods have been employed. Sediments from a drill core in the Cambay Basin were also analysed for uranium (U) and thorium (Th) concentrations and the measured values have been used to estimate the ^{4}He and ^{222}Rn production rate for groundwater age calculations. Additionally, factors controlling the distribution of ^{222}Rn, ^{4}He and temperature anomalies in groundwater, vis-à-vis their relation to the tectonic framework and lithology of the study area, have also been examined.

The multi-isotope study indicated a reasonable correspondence in groundwater age estimates by the three methods employed. The groundwater ^{14}C ages increased, progressively, in the groundwater flow direction: from the foothills of Aravalli Mountains in the east, and reached a value of ~35 ka towards the region of lowest elevation, linking Little Rann of Kachchh (LRK)–Nalsarovar (NS)–Gulf of Khambhat (GK) in the western part of the study area. In this region, groundwater ages obtained for free flowing thermal wells and springs employing ^{4}He and $^{4}He/^{222}Rn$ systematics are in the order of million years. Such anomalous ages are possibly due to enhanced mobilisation and migration of 'excess helium' from hydrothermal circulation vents along deep-seated faults. Excluding such anomalous cases and considering all uncertainties, presently estimated ^{4}He and $^{4}He/^{222}Rn$ groundwater ages are in reasonable agreement with ^{14}C age estimates in the Cambay Basin for helium release factor (Λ_{He}) value of 0.4 ± 0.3. The ^{4}He method also indicated west-southwards progression of groundwater ages up to ~100 ka beyond the Cambay Basin.

Large 'excess helium' concentrations are also seen to be generally associated with anomalous groundwater temperatures (>35 °C) and found to overlie some of the basement faults in the study area, particularly along the east and the west flanks of the Cambay Basin. Groundwater ^{222}Rn activities in most of the study area are 800 ± 400 dpm/l. But, a thermal spring at Tuwa on the east flank of the Cambay Basin, having granitic basement at shallow depth, recorded the highest ^{222}Rn activity (~63,000 dpm/l).

Keywords: Helium; Radon; Radiocarbon; Groundwater age; Tectonics

1. Introduction

Determining the age evolution of groundwater as it moves in an aquifer from the recharge area to a distant discharge location is still a challenging task for hydrogeochemists. Sampling locations are often randomly scattered over an area where water from an aquifer is pumped from various depths or where springs bring

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0009-2541/$ - see front matter © 2005 Elsevier B.V. All rights reserved.
doi:10.1016/j.chemgeo.2005.10.007

water to the surface. Several environmental tracers (including radio nuclides) find important and wide applications in determining direction and flow of groundwater, hydro-geological parameters of the aquifer and age of groundwater (Andrews et al., 1989; Cserepes and Lenkey, 1999).

In regional aquifer systems, groundwater ages may range up to 10^3 ka and beyond. Radiocarbon, with a half-life ($t_{1/2}$) of 5.73 ka can be used for groundwater dating up to ~35 ka (Geyh, 1990). The other available radionuclides such as ^{36}Cl ($t_{1/2}=3.01\times10^2$ ka; Andrews and Fontes, 1992), ^{81}Kr ($t_{1/2}=2.1\times10^3$ ka; Lehmann et al., 1991) and ^{234}U ($t_{1/2}=2.45\times10^2$ ka; Fröhlich and Gellermann, 1987) provide groundwater ages well beyond the radiocarbon dating range. On the other hand, the range of groundwater age estimation by radiogenic ^4He is 10^0 to 10^2 ka (Torgersen, 1980, 1992; Mazor and Bosch, 1992; Clark et al., 1998; Castro et al., 2000). When combined with ^{222}Rn activity measurements, the $^4He/^{222}Rn$ systematics also provide groundwater age estimation from 10^0 to 10^3 ka (Torgersen, 1980; Gupta et al., 2002). Another advantage of both ^4He and $^4He/^{222}Rn$ methods is that measurements of ^4He and ^{222}Rn are relatively simple. However, some complications also exist. (i) Recent studies (Stute et al., 1992; Imbach, 1997; Minissale et al., 2000; Gupta and Deshpande, 2003a,b) indicate that ^4He in deep groundwater often exceeds the accumulated in situ production by several orders of magnitude, particularly in regions of active tectonism and/or deep hydrothermal circulation. (ii) The possibility of a steady state whole crustal helium degassing flux affecting the dissolved helium in groundwater has been suggested (Torgersen and Clarke, 1985; Torgensen and Ivey, 1985). (iii) The possibility of enhanced release of geologically stored radiogenic helium in relatively young fine grained sediments derived from old protoliths was shown by Solomon et al. (1996). (iv) Ground waters carry small excesses of helium and radon along with dissolved air acquired during the recharge process, both in solubility equilibrium and as a supersaturation component of atmospheric air (Heaton and Vogel, 1981; Aeschbach-Hertig et al., 2000, 2002). Thus from a practical point, He in groundwater comprises, in addition to in situ radiogenic production, a mixture of atmospheric and terrigenic He. Use of ^4He for dating requires that components other than radiogenic production be small and /or accountable.

As part of a larger study aimed at understanding the recharge and flow in regional alluvial aquifer systems in arid environments and under exploitation stress, the applicability of ^{14}C, ^4He and $^4He/^{222}Rn$ groundwater dating methods was investigated in the regional aquifer system of the North Gujarat–Cambay region. The region is characterised by well defined recharge and discharge areas, presence of a few thermal springs (GSI, 2000) and neo-tectonic activity along major basement faults (Merh, 1995; Maurya et al., 1997; Srivastava et al., 2001).

The objectives of this investigation were to study (i) groundwater age progression from the recharge area towards the discharge area employing ^{14}C, ^4He and $^4He/^{222}Rn$ dating methods, and (ii) factors controlling the distribution of ^4He, ^{222}Rn and temperature in groundwater vis-à-vis their relation to the tectonic framework and hydrothermal venting in the North Gujarat–Cambay region.

2. Hydro-geological setting of the study area

The study area in the North Gujarat Cambay region (71.5–74°E and 22–24.5°N) has been divided into three main geographical units (i) the Cambay Basin (ii) West Flank, i.e., the region to the west of the West Cambay Basin Boundary Fault (WCBBF), and (iii) East Flank, i.e., the region to the east of the East Cambay Basin Boundary Fault (ECBBF); (Fig. 1).

The Cambay Basin, is a ‘Graben’ characterised by a NNW–SSE trending major fault system and successive down faulting along sympathetic faults that run parallel to the major trend line and many orthogonal faults cutting across (Merh, 1995). Geomorphologic studies have indicated recent movements along many faults in this region (Maurya et al., 1997; Srivastava et al., 2001). Several thermal springs also lie along some faults and fissures in this region (GSI, 2000) suggesting active hydrothermal circulation. The Deccan basalt of Late Cretaceous age forms the basement in most of the study area excepting the East Flank where Proterozoic granitic rocks are also exposed on the surface. Within the Cambay Basin, the Quaternary alluvial deposits are underlain by a succession of Tertiary sedimentary formations with productive oil and gas reservoirs. The thickness of the sedimentary cover varies from a few metres on the east and west flanks to >3 km towards the centre of Cambay Basin. Quaternary alluvial sediments with alternating sand and silty-clay layers constitute the regional aquifer system having its recharge area in the foothills of Aravalli Mountains and discharge area in the Little Rann of Kachchh–Nalsarovar–Gulf of Khambhat region (LRK–NS–GK). Deccan traps and Mesozoic sediments are exposed on the West Flank (Fig. 1). Parts of the East Flank lying along the foothills of Aravalli Mountains are mainly granitic.