Potential slow circulation of water through granite bedrock

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Hot springs of high temperature in non-volcanic areas are derived through deep circulation of meteoric water in bedrock such as granite. Chugoku district, western Japan, is divided into two regions, San'in and San'yo, by Chugoku Mountains having the altitude of about 1000 meters. Granite outcrops can be seen everywhere in both the regions. In San'in region, hot springs of high temperature are in alignment in the ENE-WSW direction extending over several hundred kilometers. The location of the hot spring band coincides clearly with the seismic zone in the area. Two dormant volcanoes, Mt. Daisen and Mt. Sanbe, are also located on the extension of the band. On the other hand, in contrast, there are no hot springs of high temperature, very few seismicity and no volcanoes in the San'yo area. The occurrence of hot springs of high temperature in the San'in region must result from deep circulations of meteoric water through fractured systems in the bedrock from the Chugoku Mountains to the spa in low lands. The deep circulation of water may be in a scale of several ten kilometers in horizontal and several kilometers in vertical. Stable isotopic study of deuterium and oxygen-18 in hot spring water has been made to confirm a deep circulation of meteoric water. As the evidence, the isotopic ratios in hot spring waters from San'in are low relative to those in shallow meteoric waters such as cold spring at the same altitude to the hot springs and are similar to those in meteoric waters of stream and cold spring at high elevations. Therefore, the hot spring water can be considered to originate from meteoric water in mountain areas at high elevations, suggesting the occurrence of active deep circulation of meteoric water.

On the other hand, isotopic ratios of waters from bore holes of 1000 to 1500 meters deep in granite bedrock in the San'yo region have been determined. Large part of the isotopic ratios fall into levels lower on the further side than the lower limit of isotopic ratios in meteoric water even at mountain regions at high elevations. Such the low isotopic ratios in waters from deep bore holes can be found in many areas from the coastal areas of Seto Inland Sea to the foothill areas of Chugoku Mountains in the San'yo region. The water of low isotopic ratio could not derived obviously from any modern meteoric waters including waters at high elevations but might indicate to be fossil water. The isotopic records of oxygen-18 in ice core bored in Greenland ice sheet have shown clearly that the low isotopic ratio of ice can be corresponded to be from the glacial epoch of more then ten thousand years old at least. The low isotopic ratios in deep water from San'yo region might be therefore very old at least several ten thousand ago.

A possibility of very slow circulation of water will be examined from the hydrologic point of view. If the travel time of water is assumed to be fifty thousand years to pass through the bedrock with porosity of 0.001 in the horizontal distance of 50 km from Chugoku mountains to the coastal area, the calculated specific seepage of E-9 cm/s can be corresponded to the hydraulic conductivity (permeability) of E-7 cm/s in order under the condition of hydraulic gradient of 0.01 for the distance. For the vertical direction, if seepage time is assumed to be several ten thousand years to travel from shallow zone to 2 km deep in the bedrock with porosity of 0.001 similarly, the specific seepage of E-10 cm/s is calculated to be corresponded to the hydraulic conductivity of E-9 cm/s under the vertical hydraulic gradient of 0.01. The rough estimation of hydraulic conductivity to be from E-9 cm/s to E-7 cm/s is not always to be unreasonable as the value of hard granite bedrock. Thus, a large-scale water circulation over several ten kilometers in the horizontal (and several kilometers in the vertical) with time scale of several ten thousand years could occur through the granite bedrock in the Chugoku region.