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GEOCHEMICAL INDICATORS FOR GEOTHERMAL EXPLORATION

B. K. Handa

Ground Water Board, NH IV, Faridabad, Haryana, India

Abstract

Of the various chemical parameters that can be applied to investigate potential geothermal areas, the most important are:

(*i*) elements associated with some late phase of magmatic or volcanic activity, *e.g.*, cesium.

(*ii*) Atomic ratio Na/K and the Na-K-Ca relationship.

(*iii*) Silica content of thermal spring water, and

(*iv*) the absence or near absence of some elements, *e.g.*, Mg, which are affected by temperature dependent reactions.

The appllication of these parameters in the case of thermal spring water from Puga (Ladakh) area, shows that the underground reservoir temperature, feeding the thermal springs, are likely to be around 200° C or even a little higher, indicating the strong potential of this area for exploitation of geothermal energy.

Introduction

GEOCHEMICAL methods are now being increasingly employed to evaluate the various physicochemical parameters, which are important in the planning and operation of geothermal development programme. It has been shown that the silica content and the atomic ratio Na/K of the thermal spring water can be used to calculate reservoir temperatures (Fournier and Rowe, 1966; Mahon, 1966, White, 1965, 1967; Ellis, 1970). Recently Fournier and Truesdell (1972) have advocated the use of an empirical Na-K-Ca geothermometer for computation of reservoir temperatures. The use of other temperature dependent equilibria (*e.g.*, CO_2, H_2, CH_4, H_2O) in the gases discharged from the thermal springs and the associated carbon and sulphur isotopic ratios may also be used for estimating underground reservoir temperatures (Mahon, 1970).

Qualitative appraisal of reservoir temperatures can be made on the basis of presence or virtual absence of some elements like As, Hg, F, B, Cs; Mg, etc.

Gupta, M. L. and Sukhija (1974) and Gupta, Rao and Narain (1974) have recently applied the silica and the Na/K atomic ratio techniques to evaluate underground temperatures in Puga area. In the present paper apart from these two parameters, the Na-K-Ca method has also been used along with some qualitative parameters to estimate underground reservoir temperatures in Puga area.

Description of the Area

The Puga valley is located in the Ladakh District (Kashmir) and falls in the Survey of India Toposheet No. 52 K/8. It is situated at an altitude of 4400 m above m.s.l. and lies between the Zanskar and Ladakh ranges. The east-west trending Puga valley is about 15 km long and 1 km wide at its maximum and is surrounded by hills rising to a maximum elevation of 6033 m above m.s.l.

The climate is of the dry Arctic type, *i.e.*, hot days with very cold nights. Rainfall is scanty, but the higher peaks have some snowfall.

Geology

The country rock is quartz-mica-gneiss and quartz-mica-schist the latter often containing garnet (Sinha, 1971). The country rock contains micaceous quartzite sands and has been intruded by basic rocks occurring as sills and dykes. It is also traversed by a number of quartz veins.

The valley portion is covered by scree morraine and glaciofluvial and aeolian sands, which in turn are superficially encrusted upon by borax and sulphur. Borax surface encrustations occur in the central and eastern parts of the valley, the central portion having richer deposits than the eastern portion. Sulphur occurs as encrustations along fractures, joints and foliation planes in the quartzsericite schists (which are locally gypsiferous). At the foot of the northern mountain, there is a very conspicuous thick sulphur and borax deposit, which at places is associated with gypsum, the latter apparently having been formed by the oxidation of sulphur.

The thermal waters issue out from over 100 springs, distributed all along the valley. In addition, 40–60 minor hot water seepages are also noticed. The majority of the hot springs fall in the temperature range 50° C to 70° C. The discharges of the thermal springs vary from a mere trickle to about 5 litres/sec. Some springs emanate small amounts of H_2S, CO_2, etc.

EXPERIMENTAL

About two and a half litres of water samples collected in polyethylene bottles were analysed for pH, HCO_3, CO_3, B, F, Cl, SO_4, NO_3, Ca, Mg, Na, K; sp. conductivity, SiO_2, total dissolved solids Fe, Mn, Br, I, Li, Rb and Cs by standard methods described in literature (Handa, 1974). Due to the possible presence of polymeric forms of silica, the samples were pre-treated with sodium hydroxide before applying the molybdate method.

RESULTS

While the actual chemical composition of the various thermal spring waters from the Puga area varies considerably, the salient features may be judged from the following data :

T° C	80		Cl	390	mg/l
pH	7·3		HCO_3	887	,,
Cond.	2690 micro-mhos/cm		SO_4	390	,,
			NO_3	tr	,,
TDS	2154	mg/l	B	116	,,
SiO_2	251	,,	F	12	,,
Ca	·8	,,	Fe	1·6	,,
Mg	2·7	,,	Br	1·2	,,
Na	596	,,	I	4·4	,,
Li	5·8	,,	Cs	11·3	,,
K	80	,,	Rb	·9	,,

Atomic Ratio	
Na/K	12·65
Na/Rb	2593
Na/Li	29·8
Cl/B	1·05

DISCUSSION OF RESULTS

(A) *Qualitative Indicators* :

(*i*) *High cesium content.*—Because of its large ionic radius (1·67 Å), Cs^+ has a tendency to concentrate in the volatile phase during magmatic crystallization and may be strongly enriched in some pegmatites and pegmatite minerals, where its concentrations may even be high enough to form the mineral pollucite (Cs, Na) $AlSi_2O_6H_2O_1$. The relatively high cesium content of Puga thermal spring water (11·3 mg/l) seems to indicate its association with some late phase of magmatic or volcanic activity.

(*ii*) *Low magnesium content.*—The interaction of magnesium with clay is a temperature dependent reaction and magnesium is preferentially incorporated in the clay minerals which are stable at high temperatures. Consequently waters which have been in contact with rock minerals at 200° C (or more) should normally be highly depleted in magnesium, as is found to be the case with the Puga thermal spring water.

(B) *Quantitative Indicators*

(*i*) *The silica geothermometer.*—Assuming that at depth, the silica content in water is governed by the solubilty of quartz, Fournier (1970) has given two curves (Fig. 1) for estimating underground reservoir temperatures, depending upon whether the upward moving thermal spring waters are cooled entirely by adiabatic expansion at constant enthalpy (*i.e.*, steam losses occur due to decrease in hydrostatic pressure head) or whether heat losses occur by conduction into the wall rocks. The first curve is used for vigorously boiling springs with discharge rates in excess of 15–20 litres/sec., while the second curve is to be used for thermal spring having low rates of discharge (1–2 lit./sec.) and/or at below boiling temperatures.

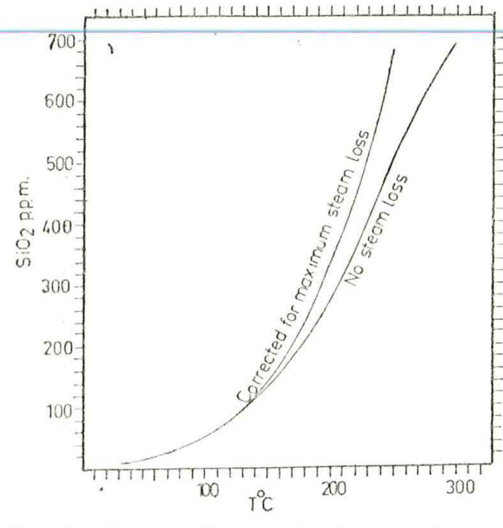

FIG. 1. Curves for estimating underground temperatures from the silica contents of waters discharged from hot springs.

Since the silica content of Puga thermal spring water is 251 mg/l, the use of these curves gives 183° C to 194° C, as the temperature range for the underground reservoir. This temperature range is likely to be the minimum, as some silica may be precipitated enroute and/or the silica content may be lowered through admixture with shallow aquifer waters.

(*ii*) *The Na/K geothermometer.*—The equilibrium constant K for the reaction : $K^+ +$ Na-feldspar $\rightleftharpoons$ K-feldspar $+ Na^+$ is given by the equation ;

$$K = \frac{(\text{K-feldspar})(\text{Na}^+)}{(\text{Na-feldspar})(\text{K}^+)} = \text{molar Na}^+/\text{K}^+$$

neglecting the effect of pressure and assuming that the activities of the solid species are unity and that the activity coefficients of Na^+ and K^+ cancel out each other, the variation of the equilibrium constant with temperature is given by the Van's Hoff equation, *viz.*,

$$\frac{d \log K}{d\,(1/T)} = -\frac{\triangle H^\circ (T)}{4 \cdot 578}$$

where T is the absolute temperature, $\triangle H^\circ$ (T) is the standard heat of reaction at a given temperature. Since $\triangle H^\circ$ (T) varies only slightly with temperature, a plot of log K, *i.e.*, log Na^+/K^+ (molar) *vs* 1/T can be used to determine the underground temperature. Ellis (1970) has drawn a curve (Fig. 2) showing the relationship between reservoir temperature and Na/K molar ratio. Since the Na/K molar ratio for Puga thermal spring water has a value of about 12·6, a reservoir temperature of 220° C is indicated. Recently Helgeson (1969) has given equilibrium constant values for the exchange reaction involving K-feldspar/albite and the use of these values gives a reservoir temperature of 204° C for the Puga thermal spring area.

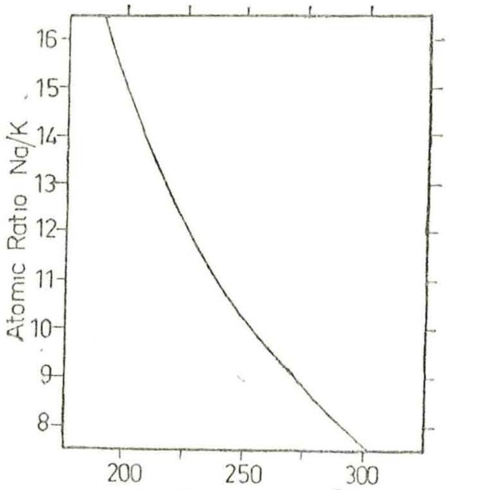

FIG. 2. The variation with temperature of the atomic ratio Na/K in waters in equilibrium with albite and feldspar.

(*iii*) *Na-K-Ca geothermometer.*—Since the exchange reaction between K-feldspar/albite may be affected by other cations, Fournier and Truesdell (1972) give the following equation for equlibrium constant involving Na, K and Ca, *viz.*,

$$\log K_{,} = \log \frac{Na^+}{K^+} + \beta \log \frac{\sqrt{Ca^{++}}}{Na^+}$$
$$= \frac{1647}{T^\circ (K)} - 2 \cdot 24$$

where T°(K) is the absolute temperature and β depends upon the sto:ch:ometry of the reactio For reactions above 100° C, a value of 1/3 for β has been suggested, while for reactions belo 100° C a value of 4/3 for β has been empiricall deduced by Fournier and Truesdell (1972).

From Fig. 3 and assuming a value of 1/3 for the reservoir temperature for Puga area comes ou to be 240° C.

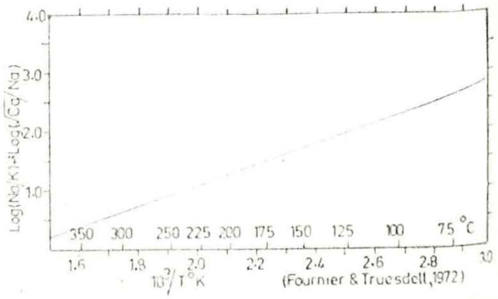

FIG. 3. Curves for geothermometry of thermal spring waters based on the Na-K-Ca relationships.

CONCLUSIONS

All the three quantitative geothermal indicators, *viz.*, the silica geothermometer the Na/K atomic ratio and the Na-K-Ca geothermal indicators give temperatures around 200° C for the underground reservoir in Puga area. The low content of Mg and relatively high cesium content also qualitatively support the above findings, indicating high potential of this area for geothermal exploitation.

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