Proceedings World Geothermal Congress 2010
Bali, Indonesia, 25-29 April 2010

Preliminary Evaluation of Geothermal Reservoir in Central Nepal Using Geochemical Data

Mahendra Ranjit

Research Centre for Applied Science and Technology, Tribhuvan University, Kathmandu, Nepal

mranjit11@yahoo.com

Keywords geothermal reservoir, geochemical tool, reservoir estimation, central Nepal

ABSTRACT

The oxygen-18/16 and deuterium ratios of water samples collected from 36 hot springs have been determined in the central region. The tritium activity of 14 of them shows that the thermal waters where outflow temperatures are up to 71°C are characterized by two features, results of stable isotope measurements fit the so-called world meteoric line and all the springs tested have tritium activity between 7 and 68 T.U. The author has combined the results of other geochemical data of the thermal water in the area with the results of the above isotope study to undertake preliminary estimation of the reservoir size.

It the tritium content is appreciable and variable with time, it means that an appreciable amount of water younger than 40 years is present and the variations imply a short circulation time of the order of a few years. Another possibility is that waters from two different sources are present: a mixture of old tritium-free water and a young water containing tritium. If the tritium content is appreciable and constant in time, the younger water is well mixed in the aquifer with old water and the size of the reservoir masks any fluctuations in recharge.

However, it has been found that the waters at Sadhu Khola, Tatopani-Mustang and Mayangdi lying in this region have relatively high chloride content suggesting that the waters are fairly mature. Variation in oxygen and hydrogen isotopes show the high possibility that waters from two different sources are mixed. Since tritium is present in appreciable quantity, younger water is well mixed in the aquifer with old water and the size of the reservoir masked any fluctuations in recharge. Hence there is possibly a large geothermal reservoir in the Sadhu Khola – Jomsom area in the central region of Nepal.

1. BRIEF GEOLOGICAL BACKGROUND

The Himalayan arc extends about 2400 km from Nanga Parbat (8,138 m) in the west to Namche Barwa (7,756 m) in the east (Le Fort, 1996). This region includes Nepal, Bhutan and as well as parts of Pakistan, India, and China. Since 55 Ma, the Himalayan orogen which began with the collision of India and Eurasia at the Paleocene/Eocence epoch (Rowley, 1996), has thickened the Indian crust to its present thickness of 70 km (Le Fort, 1975).

The rocks of the Himalaya are divided into four tectonostratigraphic zones that are characterized by Himalayan, Greater Himalayan, and Tibetan Himalayan zones.

2. GEOCHEMICAL DATA AND RESERVOIR ESTIMATION

The central region of Nepal possesses great potentiality for the utilization of geothermal energy. The region has been a centre of attraction to a number of visiting national and foreign scientists, encouraging them to collect and analyze geothermal water samples at different localities on a sporadic basis. One of such studies has determined the oxygen-18/16 and deuterium ratios of water samples collected from 36 hot springs in the region (Fig. 1).

2.1 Isotopic Composition of Water

The usual way of measuring isotopic composition of samples waters in routine is comparison of the samples with a reference standard sample R_{std} of known isotopic composition. This approach is used because the determination of the true isotopic composition of a sample is extremely difficult, whereas measurements of differences in composition are relatively easy. The isotopic ratio is conveniently expressed as deviation per mil.

$$d = (R_{sample} - R_{std}) * 10^3 / R_{std}$$

The standard adopted for $\delta^{18}O$ and δD in waters is SMOW (Standard Mean Ocean Water), whose isotopic composition represents a good average of the ocean water (Craig, 1961a). This standard was so chosen because the oceans represent initial and final points of any important hydrological circuit. In addition, the ocean has a fairly uniform isotopic composition. By definition, SMOW has $\delta^{18}O = 0$ and $\delta D = 0$.

Local meteoric waters in different geothermal areas can have different isotopic compositions. In fact, the mean annual isotopic composition of precipitation is, by and large, related to the local mean annual temperature, the lower the temperature, the lower the content of heavy isotopes; in other words, $\delta^{18}O$ and δD are more negative in colder regions. An altitude effect, a latitude effect and a continental effect will in turn be observed. Due to preferential removal of heavier isotopes from the precipitating clouds that are moving towards higher altitudes, the δ-values decrease (become more negative) with increasing latitude. For the same reason, one would expect the δ-values to decrease towards higher altitudes and with distance from the coast (Arnason, 1976).

The relation between δD and $\delta^{18}O$ is a linear correlation

$$\delta D = 8\delta^{18}O + B$$

where the constant B is in most cases 10, which means that, independently of their absolute concentrations, in a δD - $\delta^{18}O$ plot, the isotopic compositions of waters recharging the geothermal systems will fall on a straight line called the meteoric line (Craig, 1961b).

The deuterium concentration is constant for each system and equal to that of the local meteoric water of the area, but the oxygen-18 concentration may show characteristics enrichment which is known as an “oxygen shift”, meaning the shift of the isotopic composition towards an $^{18}O/^{16}O$

ratio higher than that of the local meteoric water (Trusdell and Hulston, 1980). This shift is a consequence of oxygen isotope exchange between the water and rocks constituting the geothermal reservoir and is most pronounced at high temperatures and low water-rock ratios, i.e. when a relatively large amount of water is in contact with the rock and this may mean poor permeability. The meteoric waters infiltrating at depth to form a geothermal reservoir are in isotopic disequilibrium with the rocks and exchange their oxygen with the surrounding rocks, much richer in heavy isotopes than the waters themselves, in order to approach the equilibrium corresponding to the temperature of the geothermal waters. The oxygen isotopic composition of the water is shifted toward that of the rocks because of the high temperatures at which the exchange takes place. Such modification in oxygen isotopes is most characteristic for deep high temperature waters usually with negligible tritium concentration.

Tritium, T, the radioactive isotope of hydrogen, with mass 3, is a commonly adopted isotope in geothermal investigations. It is formed in the atmosphere by the interaction of cosmic radiation-produced neutrons with nitrogen

$$^{14}N + n \rightarrow {}^{3}T + {}^{12}C$$

The tritium content in natural waters is expressed in T.U. (tritium unit); 1 T.U. corresponds to a concentration of 1 tritium atom per 1018 hydrogen atoms. The basis for tritium analysis is the tritium released during the H-bomb in the fifties increasing the tritium contents of surface and ocean waters.

The tritium activity of 14 of them shows that the thermal waters where outflow temperatures are up to 71°C are characterized by two features, results of stable isotope measurements fit the so-called world meteoric line and all the springs tested have tritium activity between 7 and 68 T.U. (Fig. 2).

The isotope data leads to the following conclusion (Nuti, 1991):

If the tritium content is appreciable and variable with time, it means that an appreciable amount of water younger than 40 years is present and the variations imply a short circulation time of the order of a few years. Another possibility is that waters from two different sources are present: a mixture of old tritium-free water and a young water containing tritium.

If the tritium content is appreciable and constant in time, the younger water is well mixed in the aquifer with old water and the size of the reservoir masks any fluctuations in recharge.

2.2 Mixing Characteristics of Thermal Waters

The following characteristics of mixing are described by Arnonsson (1985):

i. A huge mass flow rate of spring;
ii. Low pH of water relative to the water salinity (water containing chloride concentration less than 100 ppm should have pH between 6 and 7);
iii. Variation in oxygen and hydrogen isotopes;
iv. Calcite unsaturation
v. A high concentration of silica relative to discharge temperature.

2.3 Estimation of Reservoir

Even though the above table suggests that none of the springs have a huge mass flow rate, a number of springs emerging in the vicinity could have lowered the flow rate. Water containing chloride concentration less than 100 ppm in case of Jomsom and Singha Tatopani (only two springs applicable here) does not meet the mixing characteristics since their pH values do not lie between 6 and 7; calcite is either supersaturated or almost saturated in Jomsom, Mayangdi and Sadhukhola, suggesting that there is no mixing. No high concentration of silica is observed relative to discharge temperature in all the five spring waters. However, there is a variation in oxygen isotopes ranging between -7.6 and -15.7 and variation in hydrogen isotopes between -52 and -118. It leads to conclude that the waters are mixed.

The waters at Sadhu Khola, Tatopani-Mustang and Mayangdi lying in this region have relatively high chloride, suggesting that the waters are fairly mature as indicated by the Giggenbach's diagram of concentrations of the major anions, Cl^-, SO_4^{2-} and HCO_3^-. Appreciable tritium content shows that the younger water is well mixed in the aquifer with old water and the size of the reservoir masked any fluctuations in recharge.

3. CONCLUSION

Hence there is possibly a large geothermal reservoir in the Sadhu Khola – Jomsom area in the central region of Nepal.

The study result provides a qualitative estimation of reservoir. However, support from geophysical investigations is appreciated before the methodology can be applied to other locations.

REFERENCES

Arnason, B.: Groundwater systems in Iceland traced by deuterium. Societas Scientiarum Islandica, XLII, Reykjavik, (1976).

Arnorsson, S.: Application of silica geothermometer in low-temperature hydrothermal area in Iceland. Am. J. Sci.,275, (1975), 763-784

Craig, H.: Standards for reporting concentrations of deuterium and oxygen-18 in natural waters. Science 133, (1961a), 1833-1834.

Craig, H.: Isotopic variations in meteoric waters. Science, 133, (1961b), 1702-1703.

Grabczak, J., and Kotarba, M.: Isotopic composition of the thermal waters in the central part of the Nepal Himalayas, Geothermics, 14, (1985), 567-575

Le Fort, P.: Himalaya, the collided range, Present knowledge of the continental arc. Am. J. Sci., 275A, (1975), 1-44.

Le Fort, P.: Evolution of the Himalaya. In Yin, A., and Harrison, T.M., (Eds.), The Tectonic Evolution of Asia. Cambridge University Press, (1996), 95-109

Nuti, S.: Isotope techniques in geothermal studies. In: D'Amore (co-ordinator), Applications of geochemistry in geothermal reservoir development. UNITAR/UNDP Publication, Rome, (1991), 215-251.

Ranjit, M.: Geochemical studies of some thermal springs in Nepal, Reports 1994, 11, The United Nations University Geothermal Training Programme, Reykjavik (1994), 267-290.

Ranjit, M.: Geothermal Energy Update of Nepal, Proceedings of World Geothermal Congress, Turkey (2005)

Rowley, D.B.: Age of collision between India and Asia: A review of the stratigraphic data. Earth Planet. Sci. Lett., 145, (1996), 1-13.

Schärer, U.:The effect of initial 230Th disequilibrium on young U-Pb ages: the Makalu case, Himalaya. Earth Planet. Sci. Lett., 67, (1984), 191-204.

Trusdell, A.H., and Hulston, J,R.: Isotopic evidence of environments of geothermal systems, In: Fritz, P., and Fontes, J.C., (editors), Handbook of Environmental Isotope Chemistry, Elsevier, New York, (1980), 179-226.

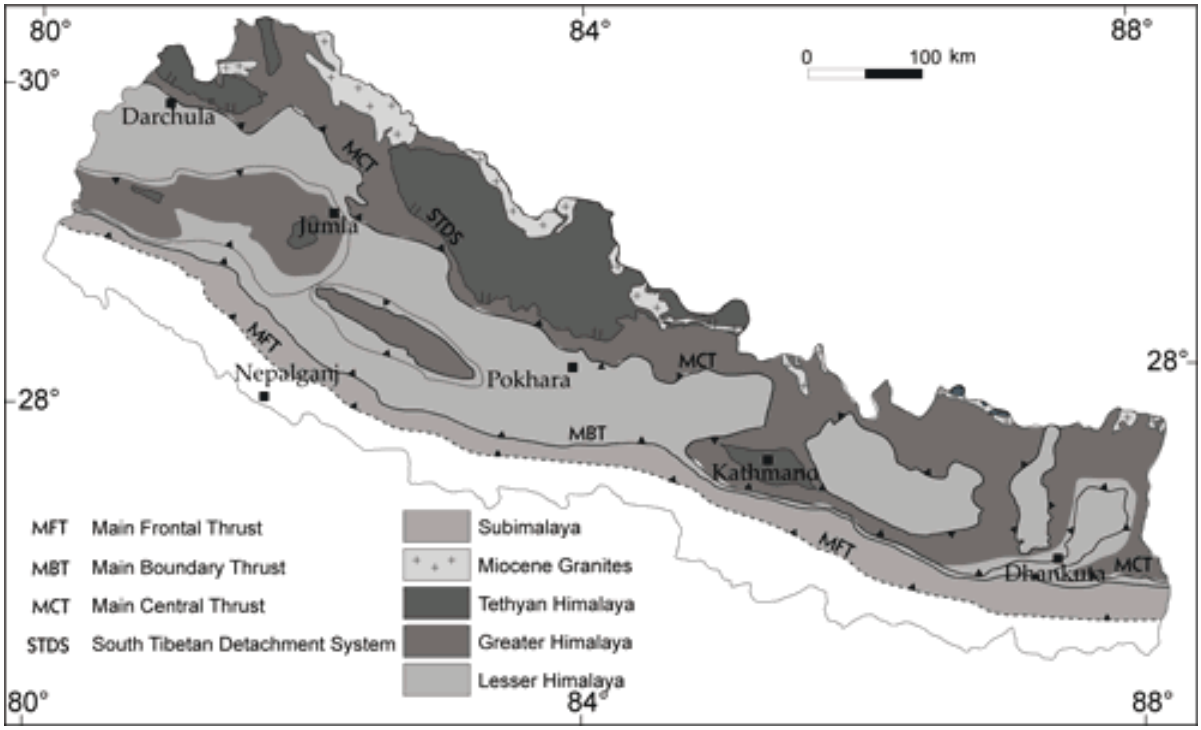

Figure 1: Geological map of Nepal.

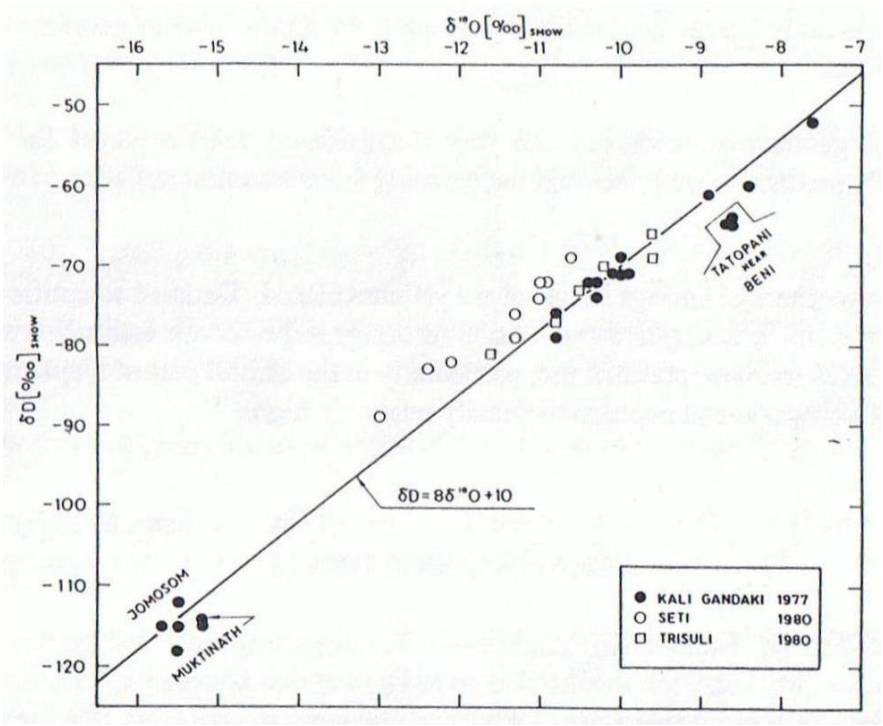

Figure 2: δ18O - δ D correlation of analyzed waters (Grabczak and Kotarba, 1985).

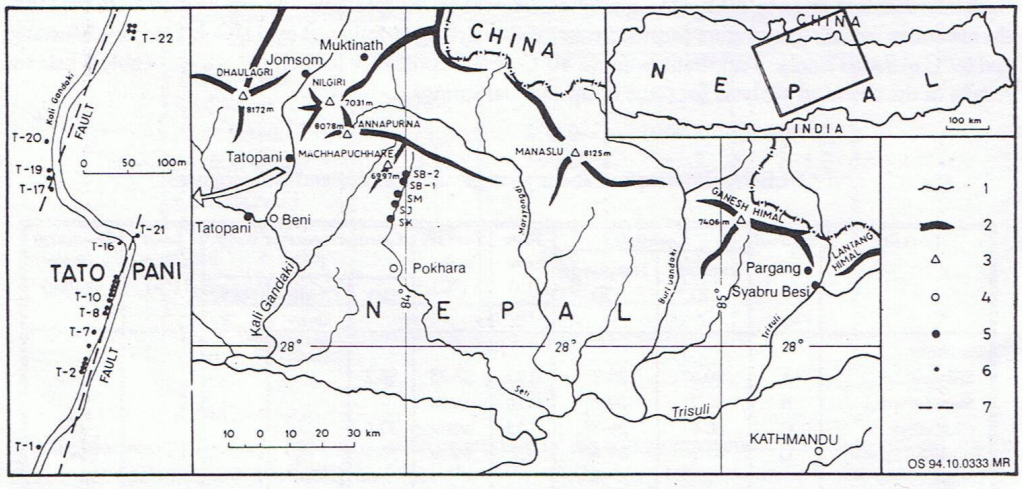

Figure 3: Location of hot springs investigated in the central parts of the Nepal Himalayas; 1) river, 2) massif, 3) peak, 4) locality or village, 5) springs region, 6) hot spring, and 7) wrench fault (Grabczak and Kotarba, 1985).

Table 1: Isotopic composition of waters from central Nepal (modified after Grabczak and Kotarba, 1985).

Region - altitude	Spring no.	Temp. (°C)	Discharge (l/s)	TDS (g/L)	$\delta^{18}O$ (0/00)	δD (0/00)	Tritium (T.U.)
Tatopani – Beni - 900	B-1	35.8	1	0.46	-8.6	-65	45±2
	B-2	34.4	0.4	-	-8.6	-64	-8.6
	B-3b	52.3	-	1.68	-8.7	-65	13±1.5
Tatopani - 1250	T-1	44	0.3	1.14	-8.9	-61	33±2
	T-2c	63	0.1	-	-10	-69	-
	T-7B	61	0.2	-	-10	-71	-
	T-8	71	1.8	1.84	-10.3	-72	7±1.5
	T-10a	70	0.7	-	-10.4	-72	-
	T-10b	55	0.1	-	-10.3	-74	-
	T-16	35	0.05	-	-10.8	-76	-
	T-17b	66	0.5	-	-9.9	-71	-
	T-19c	64	1.1	-	-10.1	-71	-
	T-20	21.4	-	-	-7.6	-52	-
	T-21	25.4	3	0.98	-8.4	-60	55±2
	T-22	63.5	0.7	4.69	-10.8	-79	10±1.5
Jomsom – 2850	J-1a	20.8	4.5	-	-15.7	-115	-
	J-1b	20.7	0.2	0.89	-15.5	-112	63±3
	J1-c	20.6	3.1	0.96	-15.5	-115	68±3
	J-2	19	5	-	-15.2	-115	-
	J-3	13.8	3.5	-	-15.5	-118	-
Muktinath - 3800	M-1	6.5	0.07	0.38	-15.2	-114	67±3
Mirsa – Seti Khola Area – 1200	SK-1b	44	0.3	3.32	-10.9	-72	14±1.5
	SK-2	35.4	0.6	-	-11	-74	-
Jamaile -1500	SJ-1	30.6	0.05	-	-11.3	-79	-
Machhapuchhre base camp - 800	SM-1a	64	2.2	1.02	-13	-89	8±1.5
	SM-2	22.4	0.1	-	-11.3	-76	-
	SM-3	43	0.01	-	-12.1	-82	-
	SM-4	9.8	-	-	-10.6	-69	-
Down Batese -1900	SB-1b	44.3	0.1	0.42	-12.4	-83	-
Up Batese - 2000	SB-2	21.5	0.2	-	-11	-72	-
Syabru Besi – Trisuli area	TS-1	38	0.2	0.63	-10.2	-70	24±1.5
	TS-2	51	0.02	1.98	-9.6	-66	7±1.5
	TS-3	35.5	0.3	-	-10.8	-77	-
	TS-4	30	0.01	-	-9.6	-69	-
	TS-5	23.5	0.05	-	-10.5	-73	-
Pargang - 2600	TP-1	49	3.8	0.39	-11.6	-81	20±1.5

Table 2: Characteristic data for the springs of Nepal.

Location	Flow rate (l/s)	Discharge temp. (°C)	Geothermometer Temp. (SiO_2) (°C)	pH	Cl (ppm)	Log Q/K (Calcite)	SiO_2 (ppm)
Jomsom	3	22	50.3	7.7	96	s.s.	14
Bhurung Tatopani	1.8	72	115.4	7.1	583	n.a.	71
Singha Tatopani	6	54	91	7.2	51	n.a.	68
Mayangdi	2	40	89.8	8.2	351	s.s.	43
Sadhu Khola	1.5	68	109.8	7.1	286	a.s.	60