ISOTOPE COMPOSITION OF GEOTHERMAL WATERS IN EAST ASIA AND THE PACIFIC REGION: HYDROLOGICAL AND GEOTHERMAL ENERGY IMPLICATIONS

Zhonghe Pang[1*1], Kavallappa Shivanna[2], Zainal Abidin[3], Azimudin, Tafif [4], Kim Geon Young[5], Yongkwon Koh[5], Saim Suratman[6], Fredolin Javino[6], Ummi Daeimah Hussin[7], Manzoor Ahmad Choudhry[8], Malik Abdul Hafeez[9], Manual Ogena[10], Noel D. Salonga[10], Pongpor Asnachinda[11] and Surachai Praserdvigai[12]

[1]Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing 100029, China
[2]Department of Atomic Energy (DAE), Bhabha Atomic Research Centre (BARC), Isotope Applications Division, Trombay, Mumbai 400085, India
[3]National Nuclear Energy Agency (BATAN), Centre for the Application of Isotopes and Radiation, Pasar Jumat, Jl. Cinere P.O. Box 7002 JKSKL, Jakarta 12070, Indonesia
[4]Pertamina Geothermal Energy, M.H. Tharmin No. 9, Jakarta 10340, Indonesia
[5]Korea Atomic Energy Research Institute (KAERI), 150 Deokjin-dong, P.O. Box 105, Daejon 305-600, Yuseong, Korea, Republic of
[6]Minerals and Geoscience Department Malaysia, Jalan Penampang, P.O. Box Locked Bag 2040, 88999 Kota Kinabalu, Sabah, Malaysia
[7]Ministry of Primary Industry, Minerals and Geoscience Department Malaysia, Jalan Tun Razak, P.O. Box 11110, 50736 Kuala Lumpur, Malaysia
[8]Pakistan Atomic Energy Commission, Pakistan Institute of Nuclear Science and Technology (PINSTECH), Division of Radiation and Isotope Applications, P.O. Nilore, Islamabad 45650, Pakistan
[9]Geological Survey of Pakistan, Sariab Road, Quetta, Pakistan
[10]Philippine National Oil Co., Energy Development Corp., Merritt Road, Fort Bonifacio, Makati City 1201, Metro Manila, Philippines
[11]Chiang Mai University, Department of Geological Sciences, 239 Huey Kaew Road, Chiang Mai 50200, Thailand
[12]Electricity Generating Authority of Thailand, 11130 Nonthaburi, Thailand

ABSTRACT

A survey of isotopic composition of geothermal waters and local groundwater in more than 30 geothermal areas in eight countries in East Asia and the Pacific region identified four types of geothermal waters:

1. A mixture of meteoric and andesitic magmatic waters. The isotopic trends of these waters converge towards the isotopic composition of andesitic waters, as shown by waters from the geothermal systems in the Philippines.
2. A mixture of meteoric and sea water such as Busan, Korea, Zhangzhou, China.
3. Meteoric water heated by a deep circulation:
   1) Without significant oxygen-18 shift such as Thailand, Peninsular Malaysia, Tattapani, India and Kotly, Pakistan, Yangbajain of Tibet, China, Sybayak of Indonesia.
   2) With high oxygen-18 shift such as in Chakwal and Chagai areas of Pakistan, Xi'an of China.
4. A mixture of cold component and a hot component of meteoric water during accent.

The δD values of geothermal waters are different from those of local groundwater in most cases. Significant Oxygen-18 shift in low temperature geothermal waters (estimated reservoir temperature < 200 ℃) is a distinctive phenomena revealed in this survey. The fact that geothermal waters circulate in different paths and flow fields as compared to groundwater implies different recharge sources and the fact that extensive water-rock interactions have taken place suggest elongated time scale of water cycle in the geothermal systems, imposing strong concerns of sustainable production of geothermal power.

Key words: geothermal water, isotopes, oxygen shift, groundwater, geothermal energy

[1] Formerly (-2005) at the International Atomic Energy Agency

1. INTRODUCTION

Existing understanding on the origin of geothermal waters tends to emphasize the close correlation or similarity of geothermal waters to local groundwater ever since the oxygen-18 shift model was proposed by Craig (1961). After the theory of "Andesitic water" was proposed by Giggenbach (1992), magmatic and other sources have been paid more attention to by the geothermal community. In fact, for geothermal waters in the circum Pacific geothermal zone, magmatic contributions are significant and could reach up to 25% of total discharge in some of the systems as recently reported by Pang (2006).

East Asia and the Pacific (referred to as AP in the following) is a region of dynamic tectonics and rich in geothermal resources. The origin and circulation of geothermal water carry strong implications on sustainable production of the concerned geothermal fields. It is helpful to synthesize all possible types of origins to planning and management of geothermal development programs.

A few geothermal projects at the regional and cross regional level sponsored by the International Atomic Energy Agency (IAEA) and completed recently involving 9 countries in the region offered a unique opportunity to conduct a systematic survey of isotope composition of geothermal fluids in various geothermal systems concerned.

In this contribution, we intend to present the major types of origins of geothermal waters based on their isotope compositions and discuss their implications on the hydrology and sustainability of power production with a comparison to local groundwater.

2. SAMPLE ANALYSES AND DATA ACQUISITION

Geothermal and groundwater samples were collected for isotope measurements in a total of more than 30 geothermal areas with more than 130 individual hot springs in 8 countries in AP region (Figure 1). The water samples were taken from geothermal and local groundwater wells and springs in other cases. Chemical constituents and isotopic composition of the samples were analyzed in selected laboratories.

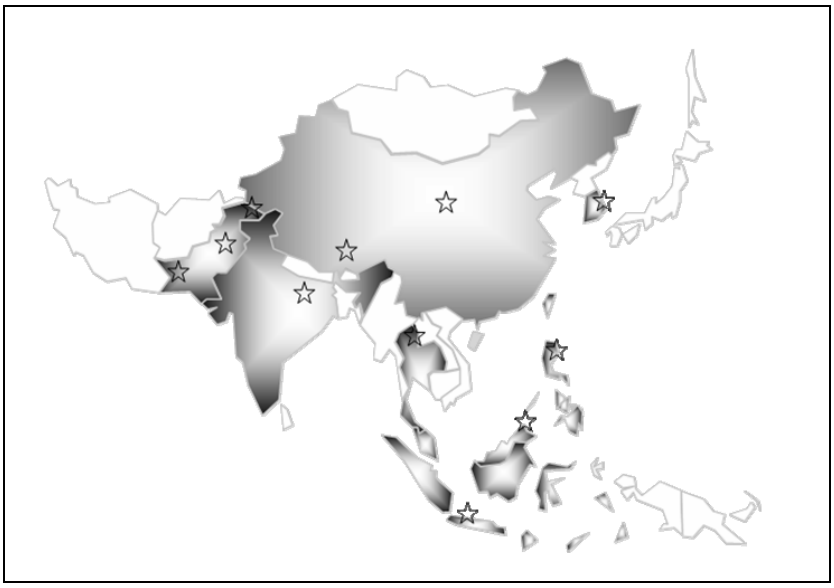

Figure 1 A schematic map showing geothermal fields included in the survey of isotope composition of geothermal waters

Involved in this survey are 12 geothermal research institutions or nuclear research institutions as well as geothermal power companies. Sampling procedures are standardized with IAEA published guidebooks. Isotope measurements were carried out either at the Isotope Hydrology Laboratory of IAEA in Vienna or at the laboratories receiving IAEA Quality Assurance and quality control (QAQC) assistances. In addition to these, during implementation of the projects, several rounds of inter-laboratory comparison exercises (Pang et al, 2006) were conducted to ensure compatibility of chemical analyses of the participating laboratories from the respective research and industrial institutions.

Table 1 lists the geothermal systems surveyed and their main characteristics. The following discussions will be largely based on the information.

Table 1 Isotope composition of geothermal water and local groundwater in the selected geothermal fields in East Asia and the Pacific region.

Country	Area	No. of springs	$T_{surface}$	Chemical type	Isotopes measured	$T_{chem.}$	$T_{isotope}$	SI (hot)		SI (cold)		Grad ^2H / ^{18}O per 100m
China	Xi'an	na	na	Cl-HCO_3-Na	^2H, ^{18}O, ^3H, $^{13}C_{DIC}$, $^{14}C_{DIC}$,	135	na	-3	-80	-10	-60	na
	Yangbajain	na	na	Na-Cl	^2H, ^{18}O, ^3H, $^{13}C_{DIC}$, $^{14}C_{DIC}$, $^{34}S_{SO4}$, $^{87}Sr/^{86}Sr$, noble gases	290	na	-18	-150	-20	-160	na
	Zhangzhou	na	na	Na-Cl	^2H, ^{18}O, ^3H, $^{13}C_{DIC}$, $^{14}C_{DIC}$, $^{18}O_{SO4}$, $^{34}S_{SO4}$	145	145	-5.53	-37.6	-6.5	-42	na
India	Tatta pani	6	98	Na-HCO_3-Cl-SO_4	^2H, ^{18}O, ^3H	177-193		-5	-36	-5.5	-38	3.75
Indonesia	Sibayak	7	86	Na-Cl	^2H, ^{18}O, ^{34}S	255	265	-5.4	-42	-8.8	-59	
	Tompaso	6	95	Na-Cl	^{18}O,^2H&^3H	285	275	-4.6	-39.7			
	Lahendong	12	92	Na-Cl	^2H, ^{18}O, ^{34}S	290	315	-5.7	-40.9			
	Dongrae	9	46.2-68.1	Na-Cl	^2H, ^{18}O, ^3H, $^{13}C_{DIC}$, $^{14}C_{DIC}$, $^{34}S_{SO4}$, $^{87}Sr/^{86}Sr$, noble gases	150	na.	-8.15	-58.4	-7.53	-50.6	8
Korea	Haeundae	10	44.0-59.9	Na-Cl	^2H, ^{18}O, ^3H, $^{13}C_{DIC}$, $^{14}C_{DIC}$, $^{34}S_{SO4}$, $^{87}Sr/^{86}Sr$, noble gases	100-120		-7.97	-53.5	-7.4	-50.8	
Malaysia	Apas Kiri	8	41.1-77.6	Na-Cl	^2H, ^{18}O, ^3H, $^{13}C_{DIC}$, $^{14}C_{DIC}$, $^{18}O_{SO4}$, $^{34}S_{SO4}$	205	152-196	-4.69	-38.7	-6.13	-38.9	
	Jepun River	2	63.9-64.9	SO4	^2H, ^{18}O, ^3H, $^{13}C_{DIC}$, $^{14}C_{DIC}$, $^{18}O_{SO4}$, $^{34}S_{SO4}$	185	124-156					
	Tawau Town	1	48.8	Na	^2H, ^{18}O, ^3H, $^{13}C_{DIC}$, $^{14}C_{DIC}$, $^{18}O_{SO4}$, $^{34}S_{SO4}$	200	112					
	Murtazabad	11	47.3-92.0	Na-HCO_3	^2H, ^{18}O, ^3H, $^{13}C_{DIC}$, $^{18}O_{SO4}$, $^{34}S_{SO4}$	160-245	130-185	-12.8	-98	-11.9	-78	
Pakistan	Tatta Pani	14	53.8-87.5	Na-HCO_3	^2H, ^{18}O, ^3H, $^{13}C_{DIC}$, $^{18}O_{SO4}$, $^{34}S_{SO4}$	100-185	130-160	-10.7	-76	-9.8	-83	
	Tato	3	88.3-92.0	Na-HCO_3	^2H, ^{18}O, ^3H, $^{13}C_{DIC}$, $^{18}O_{SO4}$, $^{34}S_{SO4}$	150-200	170	-10.6	-79			
	Kotly	5	54.3-63.1	Na-HCO_3	^2H, ^{18}O, ^3H, $^{13}C_{DIC}$, $^{18}O_{SO4}$, $^{34}S_{SO4}$	122-213		-6.5	-40	-2.1	-10	
	Chagai	7	25.6-34.8	Mg-SO_4 Na-Cl	^2H, ^{18}O, ^3H, $^{13}C_{DIC}$, $^{18}O_{SO4}$, $^{34}S_{SO4}$	87-148	100-200	3.4	-32.3	-6.8	-41	
	Chakwal	3 hot springs	52-65	Na-Cl	^2H, ^{18}O &^3H (H_2O), ^{13}C (DIC)	56-91	na	-4.2	-72	-3	-20	
		12 Oil wells		Na-Cl	^2H, ^{18}O (H_2O), ^{13}C (DIC)	70-145	na	8	-70			
	Karachi	2	39-53.3					-7.3	-55	-5.7	-44	
Philippines	Palinpinon	8	260-300	Na-Cl	^{18}O D S34	260-300	na	-4.7	-46	-8.1	-51	
	Tongonan	5	280-320	Na-Cl	^{18}O D	280-320	na	-1.7	-29	-6.4	-37	
	Mahanagdong	6	240-300	Na-Cl	^{18}O D S34	240-300	280	-2.7	-36	-6	-38	
	Manito Lowlands	7	220-240	Na-Cl	^{18}O D	220-240		4.2	-26.5	-4.5	-22	
	Bacon-Manito	12	270-320	Na-Cl	^{18}O D S34	270-320		-2	-26	-5.5	-32	
	Mindanao	10	240-320	Na-Cl	^{18}O D S34	240-320	300	-5.4	-63	-7.6	-54	
	North Negros	9	220-270	Na-Cl	^{18}O D	220-280		2	-31	-9.3	-59	
	Tha Pai	3	74	Na-HCO_3	^{18}O D ^3H	144	na.	-7.5	-49.9	-7.8	-51.8	8
Thailand	Muang Rae	2	38	Na-HCO_3	^{18}O D ^3H	142	na.	-6.6	-47.7	-7.3	-50.3	
	Muang Paeng	2	94	Na-HCO_3	^{18}O D ^3H	153	na.	-6.1	-44.9	-7.32	-51.7	
	Phu Klone Phu Nam Ron	2	68	Na-HCO_3	^{18}O D ^3H	129	na.	-6.3	-41	-7.1	-48	
	Pha Bong	2	62	Na-HCO_3	^{18}O D ^3H	127	na.	-6.1	-40.4	-6.7	-45.3	
	Nong Haeng	3	70	Na-HCO_3	^{18}O D ^3H	141	na.	-6.2	-42.7	-6.6	-43.3	
	Um Long Luang	2	77	Na-HCO_3	^{18}O D ^3H	152	na.	-5.9	-38	-6.3	-43.5	

3. ISOTOPE COMPOSITIONS AND ORIGINS OF GEOTHERMAL WATERS

Figure 2 is a plot of oxygen-18 versus deuterium values of geothermal and local groundwater in the investigated geothermal fields. According to this diagram, the following types of geothermal waters can be identified.

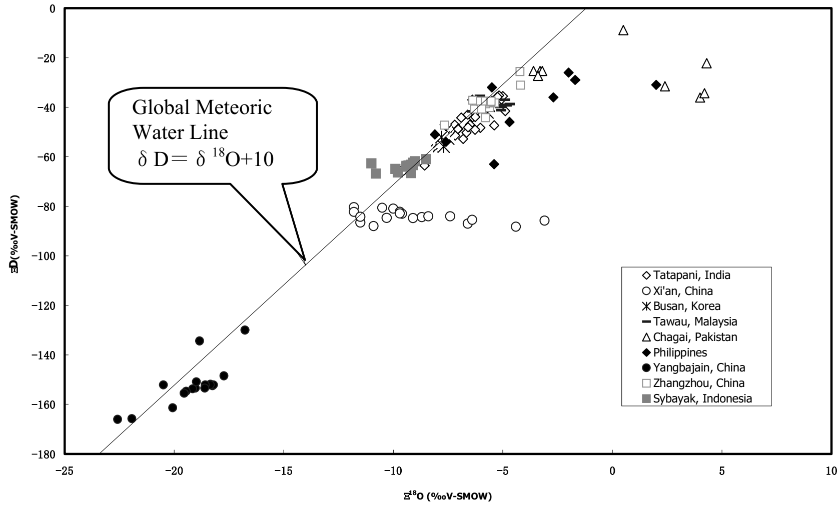

Figure 2 Isotope composition of geothermal water and related natural waters in selected geothermal areas of Asia

3.1 Mixing of Meteoric and Andesitic Magmatic Waters

The isotopic trends of these waters converge towards the isotopic composition of andesitic waters (Giggenbach, 1992). Examples are geothermal waters from the high temperature geothermal systems in the Philippines and probably in the Tawau geothermal field currently under investigation in Sabah, Malaysia. This origin is typical for arc-type geothermal systems along the circum-Pacifc ring of fire, including Japan. An IAEA research project completed recently provided new information on the origin of acidic waters in this type of geothermal systems (IAEA, 2005), in which pH was found to be inversely correlated to stable isotope composition of the geothermal waters and the estimated magmatic share could reach up to 25% of total water (Pang, 2006) in some cases.

3.2 Mixing of Meteoric Water with Sea Water

Many of the geothermal systems found along the coastal zones of the AP region are found to show isotope compositions between seawater and local precipitation. Examples are geothermal systems located in Busan of Korea and Zhangzhou of SE China (Pang, 2005). In Zhangzhou geothermal field, the seawater share in the total water balance was calculated to be around 35% (Pang, et al., 1995).

3.3 Meteoric Water Heated by Deep Circulation

This type of waters can be further divided into two groups based on whether there is a significant oxygen-18 shift in the geothermal water. Examples of waters without a significant oxygen-18 shift are found in many localities such as in Thailand, Peninsular Malaysia, Tatta pani of India and Kotly of Pakistan, Yangbajain of Tibet, China (Zhao, et al., 2000), Sybayak of Indonesia (Abidin et al, 2005). Among these examples are both high temperature and low temperature geothermal fields.

Examples of waters with a significant oxygen-18 shift are found in Chagai geothermal field of Pakistan, Xi'an geothermal field of China (Qin et al., 2005). In China and Pakistan, low temperature geothermal fields in sedimentary basins with estimated reservoir temperatures of lower than 200℃ exhibit oxygen-18 shift of up to around 10 per mil in deuterium.

3.4 Mixing of a Hotter and a Colder Component of Meteoric Water During Accent

It is a common process when hot water ascends towards the ground surface it mixes with a colder groundwater component. This type of water is often found in hot springs of un-drilled geothermal fields.

4. GEOTHERMAL WATER AS COMPARED TO LOCAL GROUNDWATER

Isotope composition of geothermal water is, in most cases, different from that of local groundwater. This is usually achieved by comparing their δD values, which are not influenced by water-rock interaction processes and therefore still represent the source water isotope composition. In Figure 3, both high temperature systems and low temperature systems show deviation of deuterium values of geothermal waters from those of groundwater.

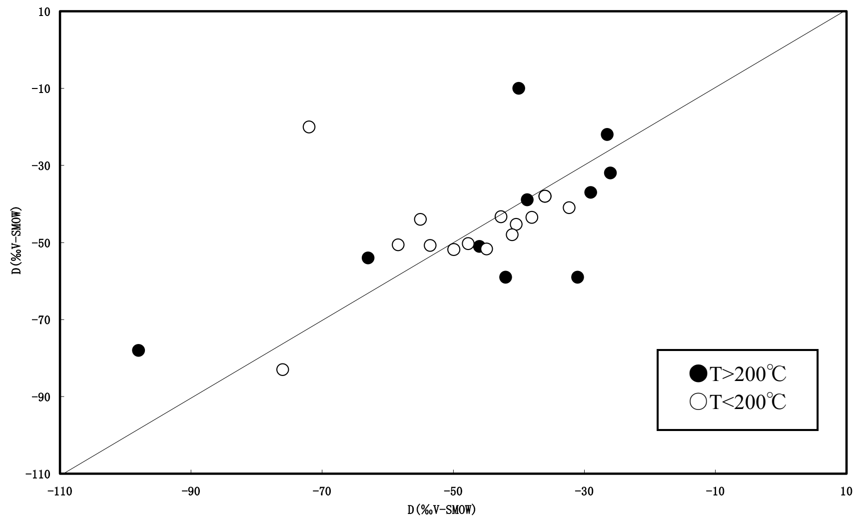

Figure 3 δD values as indication of recharge elevation of geothermal water as compared to local groundwater.

This difference in isotope composition shows that although waters are of meteoric origin the recharge area of the geothermal water can be different from that of the local groundwater. In case of Mae Hong Son area in Thailand, the recharge area of the geothermal water is estimated to be 200 m higher than that of the local groundwater. Geothermal waters are usually tritium-free waters, indicating water ages older than 50 years. It is remarkably different from young groundwater with present recharge.

5. HYDROLOGICAL AND GEOTHERMAL ENERGY IMPLICATIONS

Magmatic contributions can be assumed to be relatively stable with time in a short run. The higher the magmatic input the higher is the acid risk.

If the seawater involved in the geothermal circulation is not present day seawater, it can be expected that salinity of geothermal waters will decrease with production.

Significant oxygen-18 shifts mean extensive water rock interactions and low permeability of the geothermal systems. The geothermal water has not natural recharge and depletion will take place very soon after production starts. Re-injection production is usually very hard.

Different isotopic composition of geothermal water from groundwater means different sources of recharge and different paths of circulation and likely different flow fields.

6. CONCLUSIONS

1) Four main types of origins of geothermal waters are identified East Asia and the Pacific region according to their isotope composition
2) Significant oxygen-18 shift in low temperature geothermal systems in sedimentary basins in the AP region is not a single case, implying elongated time scale of water cycle.
3) Different deuterium values are observed in geothermal and local ground water, implying different recharge sources and circulation pathways.

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