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Discussion on Questions Related to Geothermal Research and Application

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ABSTRACT

Geothermal research and application has an important significance for recognizing and solving some questions in geotectonics, prospecting of mineral deposits, hydrogeology and engineering geology. It is known that the distribution of geothermic fields coincides clearly with the basement and the shape of folded structures in many basins; and the geotectonic situation and the relative movement between the lithospheric plates strictly control the distribution of hot springs. Besides, researching the genetic relationship between the formation of geothermic anomalies and geothermal water, oil, natural gas, coal, salt and several metal deposits can provide the important information of searching the favorable structural location of above-mentioned mineral resources, comprehensively assessment and economical rational development. At the same time, according to the temperature equilibrium between underground water and surrounding rock, geothermic parameters and forms of isotherms the flow rate and flow direction, and supplement, runoff and discharge conditions of artesian basins or confined water systems can be determined. By way of investigating the underground temperature, the high geotemperature at a depth can be predicted that may give the necessary geological reasons for compiling an engineering project and proposing the prevention and care measures of "thermal harm"; and "turn harm into benefit". The paper discusses above-mentioned questions related to the geothermal research and application.

1. INTRODUCTION

The Geothermics or Thermics of the Earth is an important branch of Geophysics and a new one of the Earth's Sciences which rose in the early 50s of 20th Century. With uninterrupted research in depth of the geothermic basic theory, increasingly broadening of the range of the geothermal research and the study of geothermal experimental methods being perfected, the Geothermics is progressively developed into Theoretical Geothermics, Applied Geothermics and Geothermic Methodology.

Theoritical Geothermics is a basic science concerning all the thermal phenomena and thermal history of the Earth. Its main task is to recognize and to control the manifestation forms of all the thermal phenomena, the sources of thermal energy, its spacial distribution and variation processes, and regularity of development and movement, etc. The questions, which should be studied in Theoretic Geothermics, are a heat source of the Earth's Interior, thermal state and thermal history of the Earth's Interior, the variation laws of the Earth's thermal fields with time and space and related with them questions such as an origin and evolution of the Earth, and crustal movement, etc. Many famous geologists, geophysicists and geochemists of the world, for example, Gutenbourg, Bulard, Lee, Goguel, Liubimova, and J.S.Lee, Fu Chengyi and others, have discussed and explained the most important questions of Geothermics and the questions related to its application. With the rising and the development of Plate Tectonics, Geomechanics and other Geotectonics with different points of view, a great progress has been made in research of Theoretical Geothermics and Applied Geothermics.

Applied Geothermics is a new applied science, which may be applied to recognize and to solute several questions in the geotectonics, prospecting of mineral deposits, hydrogeology and engineering geology (including the temperature measurement of underground engineering in mines and great tunnels). With strengthening the exploration of various mineral resources, especially, geothermal waters, oil, natural gas, and the development of the mining industry Applied Geothermics became gradually an important part of Geothermics. The paper discusses the questions related to geothermal research and application including: distribution of geothermic field and geostructures, distribution of hot springs and plate tectonics, geothermic anomaly and prospecting, geotemperature distribution and movement of underground water, and prediction of geotemperature at a depth and prevention of "thermal harm".

2. GEOTHERMIC FIELDS AND GEOSTRUCTURES

It is known that the distribution of geothermic fields coincides clearly with the basement rise and fall and the shape of folded structures in many basins. For example, in the Daqing Oil Field of our country, the measured temperature values at a depth of 900m between a top and the two flanks of an anticline structure have been taken to compare. It is indicated that the values of the former are obviously higher than that of the latter, the difference values between them reached to 3~7□. It can also be seen from an isotherm section, there is a rise tendency of isotherms in the uplifted parts of the structures. Another example being taken for Tianjin Region shows that the geothermal gradient of the rised part in Changzhou Uplifted Zone is of 4□/100m, its maximum is up to 7~8□/100m, but it is of only 2.0~2.5□/100m in Baitangkou Depressed Zone, which is greatly lower than that of the former. Thus it can be seen that according to the results of the geotemperature or heat flow measurement the structural forms of the basin basement and the various shape of the folded structures can be effectively outlined.

Besides, according to the characteristics of isotherms obtained by the geotemperature measurement at a shallow layer and modeling experience, the geothermal anomalous center and the position and dip of the fault in the hot spring area can be determined. According to the direction of a long axis of the horizontal isotherms of geothermal anomalous center and the concentrated or scattered degree of the isotherms in the two sides of this center, the fault strike may be inffered or determined and can provide the geological reasons for drilling the geothermal wells.

3. DISTRIBUTION OF HOT SPRINGS AND GLOBAL PLATE TECTONICS

Accumulated great deal of references in many countries indicate the hot springs are distributed regularly being controlled strictly by the geotectonic situation and the relative movement between the lithospheric plates. It is clear from a general regularity of global distribution of hot springs, the concentrated zones of high-temperature hot springs in the world——the high-temperature geothermal zones (≥150℃) are distributed in the relatively narrow and mobile locations of the Earth's Crust which have been generally accepted as the boundary of global plates. Because of the high-temperature geothermal zones of the world are distributed along the boundary of global plates, therefore, since the earlier time they've been called as a plate-boundary geothermal zones or intraplate ones. The concentrated zones of medium-lower-temperature hot springs in the world——the medium-lower-temperature geothermal zones (≤150℃) are widespread distributed in the interior of global plates at tectonically relatively stable locations of the Earth's Crust, namely, the interplate uplifted regions of the Earth's Crust (in folded mountain system) and the interplate depressed regions of the Earth's Crust (mainly in large-scale Meso-Cenozoic sedimentary basins).

There are strong heat sources of volcanic and magmatic types at a shallow layer in the intraplate geothermal zones, where the high-heat flow and the high-intensity geothermal anomalous areas can be observed, and the water temperatures at a spring mouth are generally higher than that of local boiling point, the reservoir temperatures are mostly of up to 200~300℃ or over 300℃ (see Table 1).In these regions the surface hydrothermal activities are very intense and their types are complete in all varieties including a number of hot springs, boiling springs, geysers, boiling mud pot, fumaroles, hydrothermal explosions, hydrothermal alteration, sulfur flowers, siliceous sinter, travertine and others. The chemical composition of geothermal fluids is mainly soldium-chloride. The high-temperature geothermal resources are rich in the intraplate geothermal zones. There are many geotheramal fields having very high economic values, among them the famous geothermal fields are the Larderello of Italy, the Wairaki of New-Zealand, the Geysers in USA, the Kawah-Kamojiang in Indonesia and others.

4. GEOTHERMAL ANOMALY AND PROSPECTING

It is generally known that in the processes prospecting and exploration of geothermal resources the geothermal anomalies should be firstly investigated. Under an effect of volcanic and magmatic activities the high-intense geothermal anomalous areas can be usually formed, their heat flow and geothermal gradient values are generally higher a few times and even several tens times than that of geothermal normal areas. Many famous geothermal fields in the world, such as Mont-Amiate in Italy, Wairaki in New-Zealand and Kamchatka in Russia, the values of their geothermal gradient are of 20~30℃/100m, 30~40℃/100m and 10~100℃/100m, respectively.

Besides, there are many geothermal anomalies formed by a deep circulation of underground waters. The geothermal anomalous areas of this type are distributed widely. To date, most of them are all the discharge areas and concentration zones of geothermal water and geothermal steam, and where the geothermal fields having the development significance come into being. The buried depth of geothermal anomalies is different and the surface manifestation scale is also various. It can be classified into two types of geothermal anomalies: shallower and deeper ones. The former usually occurred to the surface directly or at a shallower part with a thin cover layer, there the surface manifestations are very obvious. The geothermal anomaly of this type is not only discovered easier, but also it is an easy place to explore, develop and utilize the geothermal resources. The latter buried deeply with a thick cover layer in its upper part. The presence of the anomaly at a depth indicates there exist the buried geothermal reservoirs at a depth of sedimentary basins and mines, where the surface manifestations are weak and even can't be observed. Although prospecting and predicting the deeper anomalies are more difficult, but the temperature measurement at a shallow layer in many cases can also indicate the presence of the deeper geothermal anomalies.

Except above-mentioned genetically relationship between the formation of geothermic anomalies and geothermal water, the geothermal anomalies are also in close relation with oil, natural gas, coal, salt and several metal deposits. It is indicated that the study on the genetically relationship between the formation of geothermic anomalies and geothermal water and other mineral resources, can provide the important information of searching their favorable structural location, comprehensively assessment and economical rational development.

5.GEOTEMPERATURE DISTRIBUTION AND MOVEMENT OF UNDERGROUND WATER

A number of practical materials indicate that the movement of underground water is a most active facter having effecting the geotemperature distribution in the upper part of lithosphere. Therefore, in the different geostructural and hydrogeological conditions, it plays a cooling role in several cases or a heating role in another cases to the surrounding rocks. It is known that the underground waters have a greatest heat capacity and they are a huge heat transport fluid and an important media of transferring the geothermal energy from the depth to the surface.

After penetrating into a depth of the Earth's Crust and being heated by deep circulation and at the favourable geostructural conditions, and under the effect of hydrostatic pressure, the atmospheric precipitations can rise along the channels to the surface. Generally, the underground waters move in the slightly tilted or near-horizontal stratum and structural channels, the temperatures between water and rock are basically in an equilibrium state. When the underground waters move in the steeply tilted or near-vertical stratum and fracture channels, because the water has a rapid flow rate during the ascending processes to the surface there is not enough time to realize the complete heat equilibrium between water and surrounding rock. In these cases the geothermal anomalies are usually formed. In hot spring areas or artesian basins all the isotherms at the discharge areas have a rising character upward to the surface, indicating clearly the movement direction of underground water.

The temperature-depth curves measured in many areas of the basin indicate that the steepness of the curves has the different characters and from the supplement areas to the runoff and discharge areas the geothermal gradient value has a progressively varying tendency from lower to higher ones.

It can be seen that in the study on the relationship between the geotemperature distribution and the movement of underground waters it is necessary to analyze concretely and explain the various geotemperature curves and according to the temperature equilibrium conditions between underground water and surrounding rock, geothermic parameters and forms of isotherms the flow rate and flow direction, and supplement, runoff and discharge conditions of artesian basins or confined water systems can be determined.

6. PREDICTION OF TEMPERATURE AT A DEPTH AND PREVENTION OF "THERMAL HARM"

What is called the "thermal harms", generally, during the construction processes of underground engineering such as in the mines or the channels, the higher temperature conditions at a depth often harm the worker's health and seriously threat the production security. In many countries of the world, the thermal harmful events in the mines appeared early or late

With the broadening of production scale and the continuously deepening of the mines and these events happened frequently and became more and more serious. For example, the temperature of thermal water in one of the mines in Peru reached up to 69□, the temperature of rock is of 61□; in South Africa the most depth of the mines is of 3500m, the temperature of rock is of 55□; Japan is a country, where the thermal harmful events occurred with the largest frequency and the highest temperatures of rock in the mines can reach up to 60~130□, at the same time there exist the geothermal fluid (geothermal water and geothermal steam). In China, since the end of 50s in 20 Century the thermal harmful events happened in several mines of nuclear, coal, metallurgical and other industries. For example, in 1958 the serious "thermal harms" occurred by the confined thermal waters with a temperature of 43□ and a discharge of $83m^3/h$.

The practice indicates that the study on "thermal harms" has not only an important theoretical significance for developing Geothermics, but also has a directive function for the development and utilization of geothermal resources in mines. Besides, by way of investigating the underground temperature, the high geotemperature at a depth can be predicted that may give the necessary geological reasons for compiling an engineering project and proposing the prevention and care measures of "thermal harm"; and "turn the harm into a benefit". In these respects, several mines of China have certain experience.

7.CONCLUSION

This paper only discussed the questions related with geothermal research and application, the analysis and understanding of these questions are preliminary. The purpose is to indicate an important direction of Geothermics research in the present stage. With a deep study continuously on various questions, Geothermics, as a new field of the Earth's Science, will be certainly enriched and developed greatly.

It is known that the various geological processes such as volcanic explosion, magmatic intrusion, earthquake activity, orogenic movement and mineralization all related closely with the heat energy of the Earth's Interior. Therefore, Geothermics research has a broad field. To date, the basic theory and method of Geothermics obtained a wide application having an important significance for recognizing and solving some questions in Geotectonics, Prospecting of mineral deposits, Geothermo-geology, Hydrogeology and Engineering Geology, but the study contents are limited, the study ranges have yet to be extended.

The results obtained during a long time in many countries of the world related to basic geothermic research and practical application laid the foundation of the science of Geothermics. In China since realization of reforming and opening politics, the geothermal markets have been greatly broadened, the number of geothermal wells increased rapidly and the depths of them are more and more deepened, maximum depth of the well is of over 4000m. The great success has been obtained in the multipurpose utilization of geothermal resources and the social, economical and environmental effects are very obvious. In recent years, because the market economy plays a leading role in geothermal development, the geothermic basic research has been somewhat weakened. It is expected that the study on the questions related with geothermal basic theory, method and application should be strengthened in the future.

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TABLE 1 TEMPERATURE AND CHEMICAL COMPOSITION OF HIGH-TEMPERATURE HYDROTHERMAL SYSTEMS IN THE INTRAPLATE GEOTHERMAL ZONES

No.	Geothermal Field	Temperature □	pH	Salinity g/L	Chemical Type	Gas Compounds %	Minor Elements mg/L	References
1	Yanbajain China	329.8	8.57	1.83	Cl-HCO_3-Na	$CO_2$97H_2S0.11 $C_2H_6$0.37	F12 $HBO_2$240 $SiO_2$246 Li9.2 Rb1.71 Cs7.18 As2.81 Sb0.2	D. Grimaud, S. Huang, *et al.*,1985; S. Huang, K. Zheng, *et al*.,1985*
2	Puga India	135	6.9	2.67	HCO_3-Cl- Na		F15 $HBO_2$134 $SiO_2$160 Li6.3	Shanker *et al.* 1975
3	Kizilder Turkey	200	8.9	4.20	HCO_3-SO_4 -Na	CO_2	F21 $HBO_2$28.5 $SiO_2$330 $NH_4$3.0	A.Ten Dam, E.Dominco,1971
4	Larderello Italy	300		0.42	HCO_3-SO_4 -Na	$CO_2$92.8H_2S2.5 $H_2BO_2$0.45	$HBO_2$79.5	Kononov, 1983
5	Pauzhetsk Russia	195	8.2	3.10	Cl-Na	$CO_2$75.6$N_2$15.2 H_2S0.4	Br3.7 $H_2SiO_3$383 Li3.45 Rb0.23 Cs0.37 As7.5 Sb0.3	Kononov, 1977; 1983; Ivanov, 1960
6	Matsukawa , Japan	245	4.8	4.31	SO_4 -Na	$CO_2$81H_2S14.1 $N_2$4.1	$HBO_2$648 $SiO_2$882 Fe508	Ellis, Mahon, 1977
7	Matsao Taiwan, China	245	2.9	17.0	Cl-Na-Ca	$CO_2$92.0H_2S5.0 $N_2$1.5	$H_3BO_3$445.19 $H_4SiO_4$624.89 $NH_4$27 Fe148Mn28Cu0.035Pb0.5Zn8.8	Ellis, 1979
8	Kawah Kamojiang Indonesia	238		0.70	SO_4 -Na	CO_2		Kononov, 1983
9	Wairakei New-Zealand	260	8.4	4.98	Cl-Na		$H_3BO_3$164.7 $H_2SiO_3$896.3 Li14.2Rb2.8Cs2.5 F8.3Br6 As4.8Sb0.1Hg0.0001 I 0.3	Ellis, 1975 Ellis, Mahon, 1977
10	El Tatio Chile	265	1.85	15.60	Cl-Na	CO_2	$HBO_2$195 $SiO_2$450 Li43.0Rb8.3Cs17$NH_4$2.17	Lahsen, Trujillo, 1975
11	Ahuachapan, El Salvador	228	7.0	151.00	Cl-Na	$CO_2$50~80 $H_2$10~40, $N_2$2~10	$HB_3O_3$720.9$H_2SiO_3$570.3. As102Al0.2Br45 I 8.24 Li20.3Rb7.3Cs3.65	Sigvaldason, 1970
12	Cerro Prieto Mexico	388	6.7	27.60	Cl-Na	$CO_2$77.9~83.4H_2S2.3~3.7$N_2$0.1~8.$H_2$1.6~6.2	$HB_3O_3$70.9 H_2SiO_3 Li20.3Rb7.3Cs3.65	Ellis, Mahon, 1977; Marshall, 1975
13	Salton Sea United States	340	5.5	305.60	Cl-Na-Ca	$CO_2$90	$H_3BO_3$2232 $H_2SiO_3$520Li215 Rb135Cs14F15Br120I 18As12Sb0.4Hg0.006Fe2300Mn1400Cu8Pb102Zn540Ag1	Muffler, White, 1969; White *et al.*, 1971
14	Geysers United States	240	7.0	1.33	SO_4-Mg-NH_4	$CO_2$63.5H_2S1.73.5N_2 $H_2$14.7 $CH_6$15.3	$H_3BO_3$85.8 $H_2SiO_3$85.7	White *et al.*, 1971
15	Namafjall Iceland	289	7.0	1.27	HCO_3-SO_4 -Na	$CO_2$55.33H_2S44.53	$H_2SiO_3$8768.3	Sigvaldason, 1966
16	Dalloll Ethiopia	107.5	0.5	300.00	Cl-Na		$HBO_2$829.7Sr57Mn335 Cu18.5Pb1.0Zn5A Hg10g≤0.1 Au≤0.7As≤0.1	Tkachenko et al., 1978
17	Olkaria Kenya	286			Cl-HCO_3-Na	CH_4		Kononov, 1983
18	Thermal Brine Pool Red Sea	56.5	5.0	258	Cl-SO_4-Na-Ca		Si30Fe80Cu0.3Pb0.6Zn5Mn80Br130	Emeri, 1974