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贵德盆地热结构及地热成因机制

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贵德盆地位于青藏高原东北缘黄河谷地之中, 四周环山, 为新生代断陷盆地, 地貌单元位于青藏块体, 地处祁连、昆仑和秦岭三大褶皱系交汇地带; 新构造活动强烈, 发育一系列 NWW 向、NW 向及 NNW 向断裂, 为区内高温地热系统提供了较好的地热地质条件。区内地热显示类型多样, 水热活动剧烈, 尤其是盆地西部的扎仓寺热田, 水温高达 93℃, 蕴藏着丰富的地热资源。但是由于客观条件限制, 区内地热资源的开发利用及相关研究尚有不足之处。

(1)区内地热勘查工作及成果主要集中在浅部, 研究程度较低, 深部高温地热分布及成因机制仍不明确, 尤其是深部热结构至今还未进行过这方面的研究, 而某一地区的热结构能够反映区内热演化过程, 对区内地热资源的勘查具有重要意义。

(2)区内地热流体地球水化学方面的研究尽管前人也做过一些工作, 但是并未进行过系统的、专门的工作, 区内水文地球化学演化过程尚不明确, 尚未建立完善的地热成因概念模型来指导区内地热资源的勘查及开发利用。

这严重制约了该研究区内地热资源的开发利用。因此本文以贵德盆地两个典型地热区为研究对象, 采集研究区内地热流体进行水化学、稳定同位素等方面的测试分析, 结合区内地层、构造等地质条件, 从热源、地热流体补给来源、地热流体运移通道和热储特征等方面系统的研究了区内的地热系统成因; 同时采集研究区内不同深度的岩石样品进行岩石热物性参数测试, 分析区内岩石热导率、岩石生热率及热流在地层垂向上的分布特征。综合研究成果, 完善了区内地热成因概念模型并首次建立了区内地壳热结构概念模型, 主要认识如下:

贵德盆地内部三河平原地热区地下热水的水化学类型主要为 $Cl{\bullet}SO_4$-Na 和 $HCO_3{\bullet}SO_4$-Na, 盆地西部山区扎仓寺热田地下热水的水化学类型都为 $Cl{\bullet}SO_4$-Na, 沿着径流方向水化学类型不断演变。热水中富含 F、Li、SiO_2, 并且与 Cl^-呈现出良好的正相关性, 说明它们与 Cl^-具有相似或者相同的物质来源。利用地球化学温标估算的扎仓寺热田热储温度约为 133℃, 热循环深度约为 1 800 m; 利用硅-焓模型计算了扎仓寺热田地热流体中的冷水混入比例为 60%~68%, 冷水混入前的热储温度约为 222℃, 热循环深度约为 3 280 m。

在研究区内共取得 132 组水样进行测试, 氢氧同位素分析结果显示, 研究区内地下热水的主要补给来源均为大气降水, 地下热水径流方向由盆地周边山区向盆地中心呈聚辐状汇流; 地下水补给高程约为 3 300 m, 扎仓寺热田热水发生轻微氧-18 漂移。碳、硫同位素分析结果表明, 地下热水中的碳和硫主要来源于区内沉积层的风化淋滤作用, 地下热水年龄变化于((6.16±0.2)~(28.55±1.74)) ka 之间。

研究区内岩石样品热物性参数分析结果显示, 扎仓寺热田岩石的热导率值和生热率值都高于盆地内部三河平原地热区, 2 000 m 埋深以前地层中岩石放射性元素衰变产生的热能扎仓寺热田是盆地内部三河平原地热区的两倍。利用地震波速与岩石生热率之间的相关关系建立了研究区莫霍面埋深以前地层中的生热率模型, 并估算了研究区的壳、幔热流比为 1.2, 为“热壳冷幔”型热结构, 这与汪集旸等分析的中国西北部为“热壳冷幔”型热结构的结果一致。

利用相关资料计算了贵德盆地三个热流值, 其结果分别为 79.5 mW/m^2、74 mW/m^2、76 mW/m^2, 高于全球大陆地区平均热流值((65±1.6) mW/m^2)和中国大陆地区平均热流值((61±15.5) mW/m^2), 属于高

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热流区。从收集来的27个青海省大地热流值的空间展布上来看，青海省东北部地热条件优于西北部，其中贵德盆地具有较高的地热背景。

综合区内地热地质资料、深部物探资料及本文研究成果，完善了区内不同类型地热系统的地热成因概念模型:

(1)扎仓寺热田地热系统成因概念模型

扎仓寺热矿泉的形成严格受断裂构造复合部位控制，NNW向的深大断裂(热光断裂)与近EW向张扭性断裂为热泉水的溢出提供了有利的地质构造条件。热光断裂西部的近EW向张性断裂为地表水、大气降水的入渗通道，中三叠砂岩与花岗闪长岩接触变质带为径流储水含水带，地表水及大气降水入渗后在运移过程中不断接受来自地壳深部热能及地壳岩石放射性元素衰变产生的热量，水温升高，径流过程中受断层下盘新近系泥岩阻隔上涌，沿构造破碎带以上升泉的形式溢出地表，形成扎仓寺温泉。因此，扎仓寺温泉的形成主要依赖于热光断裂作为热源通道对地表渗入水进行加热受阻后出露地表。

(2)三河平原地热区地热系统成因概念模型

三河平原地热区地下热水的补给来源主要为大气降水。冷水沿着岩层中空隙及断裂入渗，接受来自地球深部热能(地幔热流)和花岗岩中放射性元素衰变产生的热能，温度升高。当温度升高到一定程度，伴随着气体成分的不断加入，地下热水开始对流向上运移，进入条带状分布的断裂形成基岩裂隙型热储；裂隙不发育的部位热能就会沿着含水层向侧向扩散形成层状热储，该过程中不断有围岩物质溶滤加入，以及近地表黄河水的混入，导致地热水的水化学类型发生变化。地下热水沿盆地边界断裂上升至近地表，进入具有良好孔隙渗透性的新近系的砂岩中，上面覆有第四纪的亚砂土和亚粘土层及新近系上新统是粉砂质泥岩、泥岩夹薄层细砂岩及粗砂岩组成盖层，从而形成新近系热储。综上所述，贵德盆地三河平原地热区热储兼有层状传导型热储及对流构造带状热储的特征。

从地热流体的水温以及地热在地表的显示形式可以看出，相比于盆地内部三河平原地热区，扎仓寺热田内的地热活动要剧烈的多。经分析认为造成这种现象差异的主要原因为：扎仓寺热田断裂非常发育，而且主要控热断裂都出露地表，具有良好的导热通道，利于深部热能向上传输；而三河平原地热区的主要控热断裂为隐伏断裂，埋藏较深，钻探时也难以到达断裂发育部位，这在一定程度上影响了地球深部热能由深部向浅部的传递。这一点可能是导致扎仓寺热田的地热状态，包括地热水温度、地热显示现象总体上优于盆地内部三河平原地热区的主要原因。

关键词: 贵德盆地；地热流体；热储温度；成因机制；地壳热结构
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The Thermal Structure and Geothermal Genesis Mechanism in Guide Basin

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Guide basin belongs to Cenozoic period fault basin, which is surrounded by hills that located in the Yellow River valley, northeastern margin of the Tibetan Plateau; from the perspective of geomorphicunits it is located the QingHai–Tibet block, which among the Qilian–Kunlun–Qinlingorogenic belts. The study area have a series of faults in the NWW, NW and NNW direction, the intense neotectonic activity provides good geothermal geological conditions for high temperature geothermal system. There are various types of geothermal manifestation in study area, and have intense hydrothermal activities, especially in the west of the basin - Zhacangsi thermal field, where the water temperature is as high as 93℃. However, limitedby the objective conditions, the development and utilization of geothermal resources in the area and the related research are not yet perfect:

(1)Geothermal exploration and achievements mainly concentrated in the shallow strata, high temperature geothermal distribution and genetic mechanism in deep strata is still not clear, especially the research of the deep thermal structure which can reflect the thermal evolution process in the area and has great significance to the geothermal resources of exploration, have not been carried out yet;

(2)It has done some study in geothermal fluid and hydrogeochemistry, but not for system, specialized work.The hydrogeochemical evolution process is

not clear in the study area, and it has not yet been established conceptual model of geothermal genesis mechanismto guide the exploration, development and utilization of geothermal resources in the area.

It seriously restricts the development and utilization of geothermal resources, so in this paper two typical geothermal areas are chosen in Guide basin as study object, according to collect and gather hydrochemistry, hydrogen and oxygen isotopes data, and its isotopes data in the study area to study the source of the geothermal fluid supply, the geothermal fluid migration pathways and the thermal reservoir characteristic; gather rock samples at different depths to test the heat rate and thermal conductivity and analyze the distribution characteristics of the parameter values in vertical direction. The concept model of geothermal genesis mechanism has been improved and the concept modes of crustal thermal structure in study area have been established for the first time based on the analytical results. Obtained the following understanding:

The geothermal groundwater hydrochemical types of Sanhe plain thermal field which located in the basin interior are mainly Cl•SO_4-Na and HCO_3•SO_4-Na, but the Zhacangsi thermal field which located in western of Guide basin are Cl•SO_4-Na, and the hydrochemical type of thermal water is changing along the flow direction. Hot water is rich in F, Li, SiO_2 and presents a good positive correlation with Cl^-, it shows that they have the similar or identical material source with Cl^-. With chemical geothermometer of thermal water, the geothermal reservoir temperature of zhacangsi thermal field is estimated about 133℃ and the depth of thermal cycle is about 1 800 m. There are 60% to 68% cold water mixed with thermal water estimated by silicon-enthalpy diagrams, and the geothermal reservoir temperature is about 222℃, the depth of thermal cycle is about 3280m before the cold water mixed.

132 groups of water samples are collected in the area for testing. Hhydrogen and oxygen isotope analysis results show that the thermal groundwater in the area is recharged by are atmospheric precipitation, the direction of thermal groundwater runoff is from the surrounding mountains to the center of the basin; The groundwater recharge elevation is about 3 300 m, and thermal water presents slight “Oxygen-18 drift” in Zhacangsi thermal field. Carbon and sulfur isotope analysis results show that carbon and sulfur in thermal groundwater mainly comes from the weathering leaching effectof sediments, and the age of thermal groundwater changes from (6.16±0.2) ka to (28.55±1.74) ka.

The analysis results of rock thermophysical parameters show that the rock thermal conductivity and heat generation rate of Zhacangsi thermal field are higher than Sanhe plain which located in the center of the basin. The thermal energy produced by the decay of radioactive elements in the strata of Zhacangsi thermal field is two times as much as Sanhe plain before 2 000 m. The heat generation rate model of stratum that above the moho discontinuity is established by the correlative relationship between the seismic wave velocity and heat production rate of rock, and the ratio of crust/mantle heat flow is 1.2, as “hot crust and cold mantle” type thermal structure, which are consistent with the study by Wang Jiyang etc, that the type thermal structure is “hot crust and cold mantle” in northwest of China.

Calculated by the relevant datas, heat flow values of Guide basin are respectively 74 mW/m^2、76 mW/m^2、79.5 mW/m^2, higher than the average heat flow value of global mainland ((65±1.6) mW/m^2) and the Chinese mainland area average heat flow value ((61±15.5) mW/m^2), which belongs to the high heat flow region.The spatial distribution of collected 27 terrestrial heat flow values in qinghai province shows that geothermal condition in northeast of qinghai provinceis superior tonorthwest, and Guide basin has better geothermal background.

Compound deep geothermal geological data, geophysical data and research results in this paper , it has improved thegeothermal genesis conceptual model of different types of geothermal systems:

(1) The geothermal genesis conceptual model of ZhaCangsi geothermal field

The formation of hot mineral springs in ZhaCangsi geothermal field are strictly controlled by fracture structure composite parts, deep fracture (Re Guangfracture) along NNW direction and tension-torsional fracture nearly along EW direction provide favorable geological structure conditions for the hot spring water overflow. The tensional fracture along nearly EW direction in west of the Reguang fracture provides the infiltration channel for surface water, atmospheric precipitation, contact metamorphic beltbetween middle-triassic sandstone and granodiorite is the runoff storage water bearing zone, during the migration process after atmospheric precipitation and surface water infiltration, constantly accept heat energy from the deep crust and radioactive element decay in rock, the water temperature increase and upwelling along the tectonic fracture zone when it is obstructed by neogene mudstone of footwall, finally overflow earth's surface in the form of rising springs, this is the formation process of ZhaCangsi hot spring. Therefore, the formation of ZhaCangsihot spring mainly depends on the Reguang fracture which as a heat source channel can heat the infiltrated water that when it obstructed it will expose to surface.

(2) The geothermal genesis conceptual model of Sanhe plain geothermal field

The mainly supply source of hot water in Sanhe plain geothermal field is atmospheric precipitation. Infiltrating along the pores and fracture of the rock, the temperature will increase when cold water is heated by the energy from deep earth (mantle heat flow) and decay of radioactive elements produced in the granite. When the temperature rises to a certain degree, with the increase of gas, the underground hot water begins to migrate upward, and enters the zonal distributed fracture to form the bedrock fissure type heat reservoir; with the process that lateral diffusion of heat energy along the aquifer in undeveloped parts of fissure to form layered heat storage, the surrounding rock matter leached into water as well as the near surface water from the Yellow River mixed, the hydrochemical type of geothermal water will be changed. The geothermal water rise to near surface into the sandstone with good porosity and permeability of the neogene along the basin boundary faults to form the neogene thermal storage, which the cap rock consists ofsilty mudstone, mudstone with thin layer of thin sandstone and coarse sandstone and covered by sub - sand and the sub - clay layer ofquaternary. To sum up, the geothermal reservoir of Sanhe plain in Guide basin has the dual characteristics of layered conduction and zonal convection.

From the geothermal fluid temperature and geothermal manifestation we can see that, the geothermal activity in the ZhaCangsi geothermal field is much more intense compared to Sanhe geothermal field of inner basin. After analysis in the paper, it is considered that the main reason for the difference of this kind of phenomenon is that the faults of ZhaCangsi geothermal field are very well developed, and the main geothermal water controlled faults are exposed to surface, which has good heat conduction channel and good for the deep heat transfer upwards, whereas the main geothermal water controlled faults of Sanhe plain geothermal field are concealed faults, and have the deep buried depth, so it is difficult to reach the fault development site when drilling, to a certain extent it affects the earth's deep heat energy transmission from the deep to the shallow part of earth. This may be the main reason that geothermal state of ZhaCangsi geothermal field is better than Sanhe plain including the temperature of geothermal water and geothermal phenomenon.

Key words: Guide basin; geothermal fluid; thermal storage temperature; genetic mechanism; thermal structure of the earth's crust

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