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Application of Heat and Flow Modeling to Study the Groundwater Circulation Patterns of the Ordos Plateau

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ABSTRACT

There are abundant mineral resources within the Ordos Plateau, such as coal, natural gas, petroleum and halite etc., which makes it to be one of the largest energy production zones in China. With the development of mineral resources, groundwater demand will increase dramatically. Due to limited understanding of the groundwater circulation patterns, groundwater development lacks solid basis. Cross-sectional simulations provide a tool for addressing some key issues of groundwater circulation and lay a solid basis for rational groundwater development programs. Based on the previous study, this paper carried out numerical modeling of head transport, aiming to study groundwater circulation patterns.

The No.2 cross section is located in the middle of the Ordos Plateau and is 240 km long. Simulation was performed using the HST3D of USGS and the model was calibrated to the observed data. The simulation shows that groundwater temperature protrudes downward in the Sishili Ridge, indicating cool water infiltration in the area. And in the Disitu River and Wusheng County, groundwater temperature protrudes upward, indicating groundwater with high temperature moves upward. This indication has a good agreement with the existing conclusions. The simulation shows that in the Dusidu River, groundwater temperature exceeds 30°C, which can be used to delineate zones with abundant geothermal resources.

1. INTRODUCTION

Groundwater is a valuable resource in many areas, and it commonly plays a key role in the economic development. The Ordos plateau is located in the eastern part of the north-western China. It overlaps three provinces and autonomous regions, i.e. the Shaanxi Province, the Inner Mogolian Autonomous Region and the Ninxing Hui Autonomous Region, and covers an area of about 81 000 km^2 (Fig. 1). Groundwater is the major water resource in the basin due to the undeveloped surface water drainage systems (Hou et al. 2006). Abundant mineral resources within the basin, such as coal, natural gas, petroleum and halite etc., make it one of the largest regions for energy and chemical production in China (Hou et al. 2006). Recently, water demand has increased rapidly, with the construction of energy and industrial chemical plants, the development of local industry and agriculture, urbanization, improvements in living standards and eco-environment construction. Therefore, groundwater circulation patterns study is a key issue for the groundwater development and management in the Ordos Plateau.

Many methods can be used to study groundwater circulation, including the potentmetric method, hydrogeological and isotopic method and numerical method. The Numerical method is a powerful method and is widely used to groundwater circulation (Toth, 1967; Winter, 1986). In this study, flow and heat modeling were used to study groundwater circulation patterns in the Ordos Plateau.

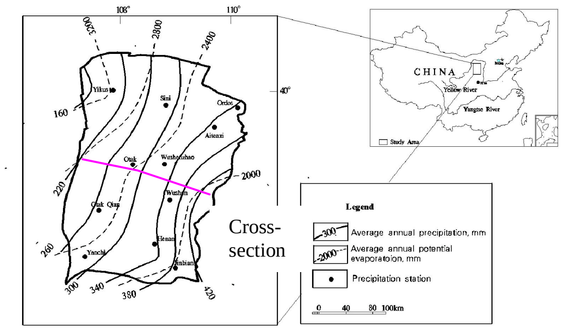

Figure 1: Location of the Ordos Plateau

2. CROSS-SECTION

The No.2 cross-section is simulated. The cross-section is 240 km long, starting from the Pingluo County, Ninxia, covering Etuoke County and Wushen County, Inner Mogolian and ending in the Yuling city, Shaanxi. The cross-section is aligned with the flow direction with 10 boreholes on it. The peak of the cross-section is 1448 m a.s.l., and the lowest points is 1200m a.s.l.. Precipitation decreases from 410mm/a in the east to 190mm/a in the west, while evaporation increases form 2500 mm/y to 2800 mm/y.

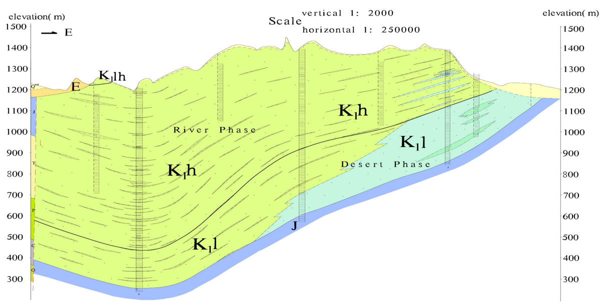

Figure 2: Geologicla profile of the section

3. NUMERICAL SIMULATION

The model consists of the groundwater flow model and the heat transport model. The groundwater flow model provides the head distribution used by the heat transport model. The development and calibration of the two models are described.

3.1 Boundary Conditions

The flow model is surrounded by no-flow boundaries at the bottom of the Cretaceous aquifer, contacting with the low permeability Jurassic-Carboniferous formation. The upper boundary is the water table. Ground water enters into the flow system across the upper boundary, or move out of the system across this boundary at natural ground-water discharge sites. On the west side and east side, the boundary is no-flow as the Cretaceous aquifers contact with impervious metamorphic rocks.

The Cretaceous aquifer consists of three hydrostratigraphic subunits, i.e., Luohandong Group (K_{1lh}), Huanghe Group (K_{1h}), and Luohe Group (K_{1l}). The Luohandong Group consists of mixed mudstone to sandstone and exists only in a localized area in the west. The Huanghe Group consists of primarily sandstone and consolidated gravel deposits. Except for an area near the eastern boundary where the Huanghe Group was eroded, the group ranges 400～600 in total thickness. The Luohe Group consists of fine to medium-grained sandstone in the eastern side, toward the west, it consists of fine-grained sandstone interbedded with mudstone. The total thickness of the Luohe Group is relatively uniform, around 200m. The top of cross section is covered by a layer of Cenozoic unconsolidate sediments ranging from 10 to 100 m in total thickness.

The upper boundary for groundwater flow is constant head boundary. The upper boundary for the heat transport modeling is the fixed temperature boundary where groundwater received recharge and others are variable temperature boundary. The west, east and bottom boundary are no-flow boundary. The west and east boundary for groundwater flow are no-heat boundary and the bottom boundary is fixed temperature boundary.

3.2 Parameters

The distribution of horizontal hydraulic conductivities for different hydrostratigraphic units was assigned on the basis of field pumping tests and sedimentary facies analysis as shown in Figure 3. The horizontal and vertical hydraulic conductivity were fixed at 1/1000.

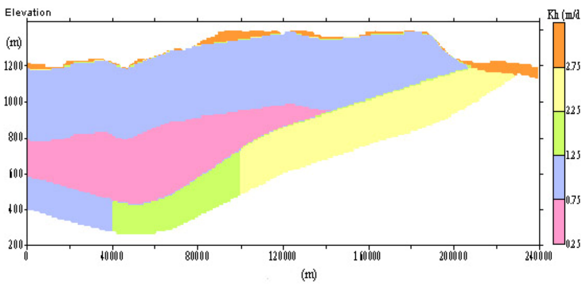

Figure 3: Distribution of hydraulic conductivities along Cross Section

The porosity used in the simulation is 0.22 that is the average of porosity of 260 rock samples taken in the Ordos Plateau. The longitudinal dispersivity is 10 m and the horizontal and vertical transverse dispersivities were fixed at 1/10th of the longitudinal dispersivity. The parameters for the heat transport are the default values of the HST3D.

3.3 Initial Conditions

The initial conditions for the groundwater flow simulation are the top elevations of cells. The initial conditions for the heat transport simulation are specified by Equation 1.

$$T_{i,j} = S + D_{i,j} \times K_{i,j} \quad (1)$$

S is the temperature at water table（℃）

$D_{i,j}$ is the burial depth of node i,j（℃）

$K_{i,j}$ is the thermal gradient of node I,j（2.5℃/100 m）

In the simulation, S is the average annual air temperature (10℃) and K is 2.5℃/100 m (Yin et al., 2008).

3.4 Results

A finite-difference grid consisting of 600 columns and 125 layers was used for the discretization . The grid spacing is 400 m in the horizontal direction and 10 m in the vertical direction. Due to the conditions that only limited groundwater heads are available along the section and out interest is in the understanding of the regional groundwater circulation patterns, the model was not calibrated fully. In the middle of the section, groundwater head varies from 1350m to 1400m, forming a 100km-wide groundwater dividing. Groundwater decreases eastward and westward. a discharge zone is located in the area bound by the Sishili Ridge and Wushen County. On the east side, due to uplifting of the impervious lower boundary, groundwater flow is dominated by horizontal flow. In general, groundwater flows are control by topography and forms a multi-level system.

The simulation shows that groundwater temperature protrudes downward in the Sishili Ridge, indicating cool water infiltration in the area. And in the Disitu River and Wusheng County, groundwater temperature protrudes upward, indicating groundwater with high temperature moves upward. This indication has a good agreement with the existing conclusions. The simulation shows that in the

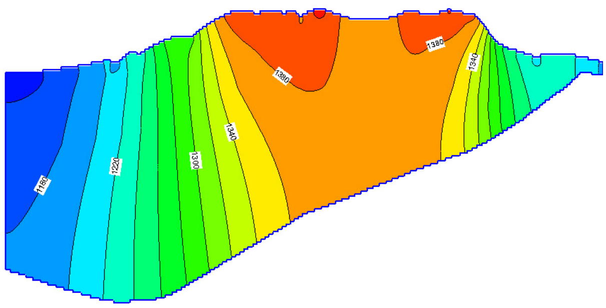

Figure 4: Simulated groundwater head distribution

Dusidu River, groundwater temperature exceeds 30℃, which can be used to delineate zones with abundant geothermal resources

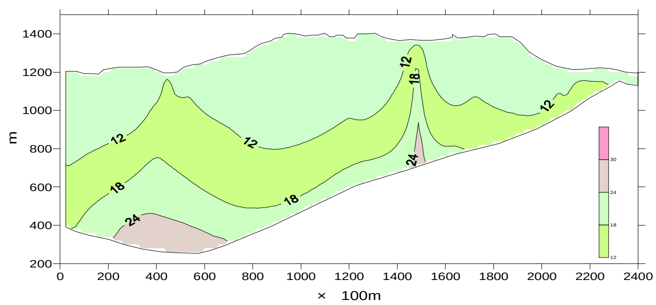

Figure 5: Simulated temperature distribution

Based on the simulation, three circulaton patterns are present in the Ordos Plateau, i.e. the shallow, intermediate and regional circulation patterns (Fig. 6).

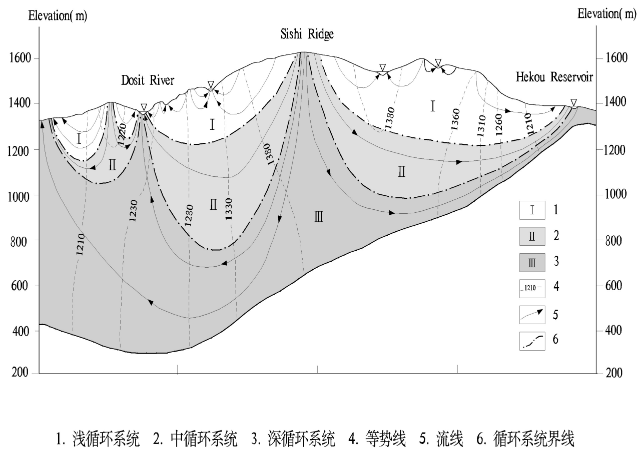

Figure 6: Groundwater circulation in the CAB

1. Shallow circulation system 2. Middle circulation system 3.deep circulation system
4. Equal potential line 5. flow line 6. boundary of system

Shallow circulation system (III): This system occurs between ridges and nearby rives or lakes with circulation depth of 100-150m. This system is characterized by fast circulation, high renewal capacity and good water quality. Generally, groundwater age is less than 12℃.

Intermediate circulation system (II): Compared with the shallow circulation system, intermediate circulation system is involved with more extent and deeper with the maximum circulation depth of up to 300m. The middle-scaled river and larger lakes are the main discharge zones. Groundwater temperature is less than 20℃.

Regional circulation system (I): In this system, groundwater flowing rate are extremely low and the circulation depth is between 500-1000m below land surface up to the lower bottom of Cretaceous aquifer. Groundwater temperature is higher than 20℃.

CONCLUSIONS

In this study, groundwater flow and heat transport for the No.2 cross-section were simulated in order to study the groundwater circulation patterns in the Ordos Plateau. The results show that there are three circulation patterns, i.e. the shallow, intermediate and regional circulation patterns. The results can be used to make effective groundwater development progames.

REFERENCES

Hou G.C., Zhao M.S., Wang Y.H et al. Groundwater Investigation in the Ordos Basin, (2006) China Geological Survey (in Chinese)

Toth, J.. A theoretical analysis of groundwater flow in small drainage basins, (2006) Journal of Geophysical Research, 68(16), 4795-4812

Winter, T.C., 1986. Effects of ground-water recharge on configuration of the water table beneath sand dunes and on seepage in lakes in the sandhiils of Nebraska, U.S.A. J. Hydrol., 86: 221-237.

Yin L.H., Hou G.C., Wang X.Y. Geothermal Gradient in the Ordos Basin , (2005) Proceedings World Geothermal Congress 2005, Antalya, Turkey, 24-29 April 2005