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A PRELIMINARY STUDY OF THE GEOTHERMAL RESOURCES OF THE FEN-WE1 RIFT, CHINA

Wang Liancheng

Taiyuan University of Technology

Zheng Keyan

Beijing Corporation of Hydrogeology and Engineering Geology

ABSTRACT

The Fen-Wei Rift, located in the west part of North China, is a Cenozoic asymmetric fault trough basin. The boundary of the rift, the distribution of subterranean uplifts and depressions beneath the basin, the rather thin crust, and the seismicity are all controlled by active rifting, The rift extend6 over a distance' of more than 800 km.

Geothermal resources are found along the boundary faults, i.e. along the margins of the depression, and along faults of median basement horsts. Higher temperature are usually found within fracture zones near to the deepest portion of the Graben. Apart from fracture zone systems there are also extensive sub-horizontal aquifers within the rift from which thermal fluids can be produced.

Although geothermal exploration and resources utilization are limited to a few prospects, the recognition and classification of the geothermal resources associated with the Fen-Wei Rift will be helpful for further development.

INTRODUCTION

Warm and hot springs in both Saanxi and Sanxi provinces bounded by the Yellow River have a certain distributional regularity and inner link. Warm springs in Saanxi province are distributed mainly in Guanzhong Basin of the Wei River Basin, and in Sanxi province are distributed mainly in Xinding, Jinzhong, Linfen and Yuncheng Basins of the Fen River Basin. They are all located in the area of the Fen-Wei Rift geologically.

By regional geological survey, geophysical survey and some explorations for coal, petroleum oil and geothermal, it has been confirmed that, as the result of the action of tensional stress within crust since Cenozoic era, recent tectonic movements are significant, i.e. upper mantle swell led crust to arching and then rifting, molten mass from crust and mantle intruding and erupting, and shallow-focus earthquakes have been widespread. These typical features are similar to those of other well-studied continental rifts like the Rhine Graben [2] and the Lake Baikal depression [3].

Anomalous heat flow in the rift valley was caused by the upper mantle swell. Estimated heat flow is about 1.2 - 1.3 times the normal heat flux. This anomalous flux heats up deeply infiltrating meteoric waters; some of the heat is transported to the surface by convective cells. Numerous warm and hot springs therefore occur along the boundary faults, i.e. along the margins of depression, and along faults of median basement horsts. some wells drilled in corresponding geological structures have found geothermal waters.

It is the purpose of this paper to expound the relationship between geothermal resources and the rift structure. It will guide further exploration and development for the potential geo-thermal resources in the region, and give full benefit to the resources utilization thereby.

GEOLOGY OF THE FEN-WE1 RIFT

Fen-Wei Rift consists of a series of Cenozoic oblique, graben - type basins. It strikes generally north-east with a flexuous median axis. The rift zone is over 800 km long and 20-80 km wide (Fig. 1).

The Fen-Wei Rift is located within the North China Platform. During very long geological history it had been relatively keeping in stable situation until the later stage of Mesozoic era, Then the swelling of upper mantle mass led upper crust to arching as an anteklise before the rifting. So the northern and

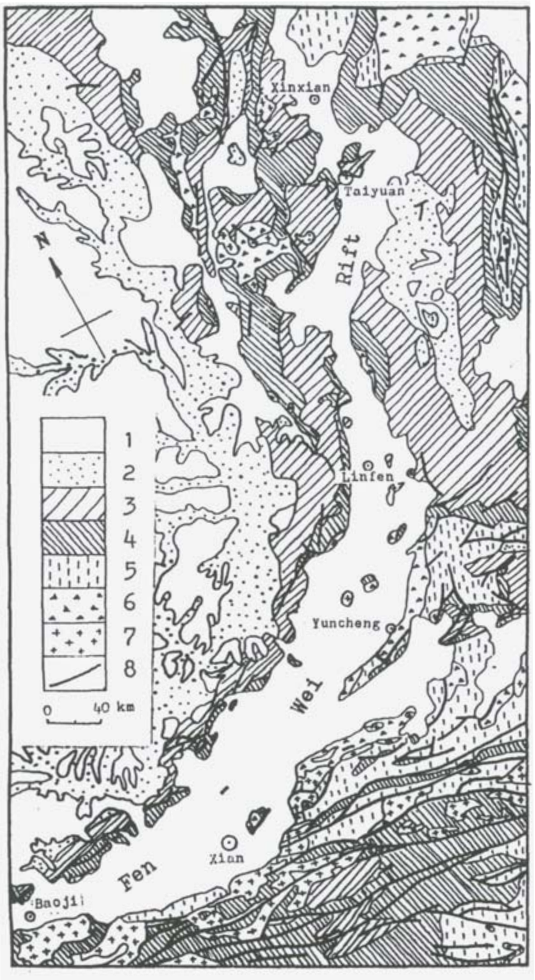
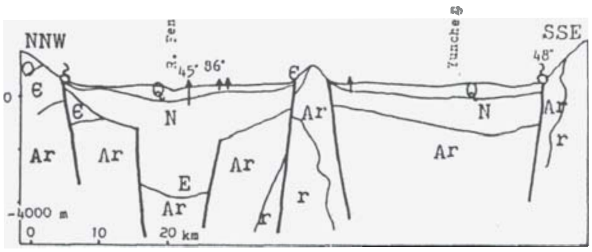


Fig.1 Geological map of the Fen–Wei Rift
LEGEND: 1.Cenozoic; 2.Mesozoic; 3.upper Palaeoxoic; 4.lower Palaeozoic; 5.Sinian system; 6.Archaean; 7.intrusive rock; 8.fault

mid sections of the Fen–Wei Rift consist of the axial line of the Sanxi Anteklise, i.e. Archaean gneiss forms an axial line of the anticlinorium, and Palaeozoic and Mesozoic groups form its flanks. The southern section consists of the southern flank of the Erduosi (Saanxi) Syneclise, that is, Archaean gneiss forms also the axial line of the southern anticlinorium (linking up with the southern Qinglin Fold Belt). Accompanying the crustal movement, some magmas of granite, diorite, syenite and quartz–porphyry etc. intruded partially in many places of the rift zone during Yanshanian stage (J-K).

Since the begining of Cenozoic era, the upper mantle had been further swelled, thus arching of the crust transferred into rifting. Along with the original compressive stress in the rift zone, transferred into recent tensile stress, the rift valley was formed progressively. The tensile stress in NW-SE direction made the mid–southern section of the rift with NE strike rift widely (–80 km), and the northern section with near south to north direction rifted narrowly (~20 km). The Cenozoic deposits in the series of five basins have a thickness of 1360, 2570, 2100, 4500 and 6000 m respectively. In the Datong Basin located at the northern end of the rift, tensile stress action combined with the effect of shearing stress reached greater depth, therefore it rifted the crust, basaltic magma of upper mantle extruded, and Quaternary alkaline basalt covered a large area.

The rift valley consists of some grabens intercalated with horsts, i.e. subterranean uplifts and depressions distributed beneath the rift valley (Fig. 2). Non–uniform rifting formed an asymmetric fault trough basin. There are thicker Cenozoic sediments deposited in the southeastern flanks of grabens. The cycle of sedimentation shows binary texture which is from coarse to fine for Tertiary and from fine to coarse €or Quaternary.



*above: A–A' cross section

*below: B-B' cross section

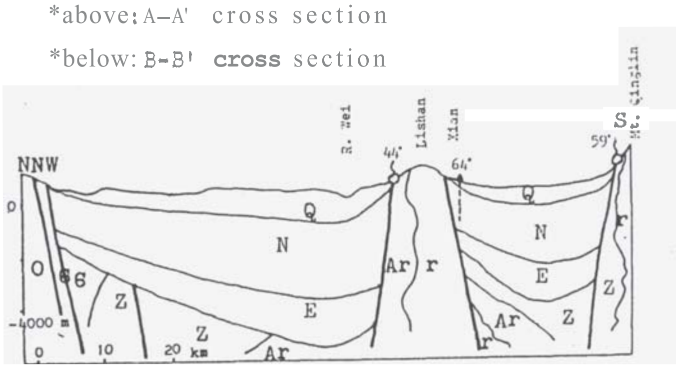


Fig.2 Geological cross section AA' & BB'
LEGEND: Q–Quaternary; N-Neogene; E–Eogene; 0–Ordovician; C–Cambrian; Z-Sinian; Ar–Archaean; r-granite. Springs, drillholes and fault6 are also shown.

Regional geophysical surveys demonstrated that: gravity field in the rift valley showed partial relative normal Bouguer anomalies overlapped upon the background of negative anomalies; magnetic survey found striped normal anomalies along the rift axis accompanied by negative anomalies at both flanks; the

Mohorovicic discontinuity, situated at 27-42 km depth at the southern part of the rift and at 37-39 km depth for the mid and northern parts, is shallower by several km than that beneath the flanks.

Seismicity is Illustrated in Fig.3. Three earthquakes with Richter magnitude 8, and some with Richter maqnitude 7 ani! 6 occurred along the Fen-Wei Rift valley historically (Fig. 3). They are shallow-focus earthquakes basically.

In general, the Fen-Wei Rift Zone represents the first stage of the rifting, i.e. the continental stage. It is similar to the Baikal rift but a little younger than the latter.

THERMAL ACTIVITY OVER THE FEN-WEI RIFT

Warm springs in both Saanxi and Sanxi province are concentrated in the Fen-Wei Rift, Their distribution is regular. Most warm springs occur along the margins of grabens, and along faults of median basement horsts. The geothermal water is also found in some drillholes drilled in corresponding geological structure. The warm springs occurring in southeastern boundary faults of the rift have higher temperature, For example, the Xitangyu and Dongtangyu springs are 63 ℃ and 59 ℃ respectively. But their flow rate is small usually, because they come from the deepest part of the graben and occur directly in fault zone of basement rocks, The energy discharged by individual spring areas is about 0.4 - 1.1 $\times 10^6$ J/s. After drilling exploration it may reach 3 - 4 $\times 10^6$ J/s. Temperature in thoae springs distributed in northwestern margin of the rift is lower. Those springs occur in a Quaternary alluvial layer, or in karst of basement rocks. Due to their large flow rate the heat discharge rate is about 2 - 6 $\times 10^6$ J/s for each, and some of them can reach to 26 - 56 $\times 10^6$ J/s.

The famous ancient Huaqing Warm Spring occurs on the median basement horst of the rift. It has a temperature of 41.7 - 44.1 °C. The flow rate was 113 m^3/h at the begining of 50s. It decreased to approximately 20 m^3/h in recent years. This indicates that the natural heat discharge rate has decreased from previous 3.9 $\times 10^6$ J/s to present 0.7 $\times 10^6$ J/s. It may be affected by the extraction from drillholes located in the recharge area of the thermal water, For example, from the geothermal wells drilled in eastern and southeastern suburban areas of Xian (about 15 - 25 km away to the Huaqing Spring) extracted total heat energy is about 2 - 3 $\times 10^6$ J/s. Individual spring area located in the median basement horsts discharge heat rate more than 1 - 10 $\times 10^6$ J/s usually, Some great springs, e.g. Yuanjiapo Spring with flow rate near 2 m^3/s and temperature' 29 ℃ has a natural heat discharge rate 133 $\times 10^6$ J/s, which is similar to a small geothermal field located in the Taupo Volcanic Zone of New Zealand [1].

The total natural heat discharge rate from the Fen-Wei Rift valley is larger than 400 $\times 10^6$ J/s. But there is no high heat flow existina in any partial points, The natural heat flow estimated for each warm spring or thermal well area is about 65 - 90 mW/m^2 mostly, It is 1.2 - 1.3 times the normal heat flow. The maximum value of heat flow in the rift

Fig.3 Map showing the seismicity and locality of warm springs and thermal wells over the Fen-Wei Rift. This map covers the same area as fig. 1.

valley is 118 mW/m^2. It is only 82.5 % and 67.0 % by comparison with the Baikal and the Rhine Rifts respectively, Thus the regional heating in the rift zone is caused not by the disturbance from adjacent surface but by the heat conductive transport concerned with the upper mantle swell [4].

CHEMISTRY OF THE THERMAL WATERS

The chemistry of some of the warm springs and thermal wells shown in fig.3 is summarized in table 1. The recent analytical data for a few springs have not been obtained yet,

Warm springs and wells discharge near neutral to weak alkaline $Na\text{-}SO_4$ water (including $Na\text{-}SO_4\text{-}Cl$ and $Na\text{-}Cl\text{-}SO_4$ waters) basically. In its surrounding thermal anomalous areas $Na\text{-}HCO_3$ water exists as a transitional belt. The total dissolved solids of warm spring waters are generally between 0.6 and 1 g/kg. For the thermal water in wells nearby the basement faulted fractures it can reach 2 - 3 g/kg. It is indicated that natural warm springs are all diluted by cold water to a certain extent, Some pore water stored in Tertiary continental deposits has a TDS over 8 g/kg. All constituents in these warm springs and wells are enriched in comparison with those found in non-thermal groundwater of the region.

According to Giggenbach's K-Na and K-Mg geothermometers [5] which are suitable for use in intermediate and low temperature geothermal fields, and conductive silica geothermometer, calculated temperatures for shallow reservoir are about 40 - 100 °C mostly, The maximum temperature represented by T_{kn} except in rare cases (e.g. Tertiary pore water) reaches over 170 °C usually. In a system associated with a fracture reservoir in metamophics, for instance Huaqing warm spring, the highest T_{kn} temp. (211°C) is indicated. It makes sense since the spring lies over a more active part of the Fen-Wei Rift,

GEOTHERMAL RESOURCES IN THE RIFT

The Fen-Wei Rift valley covers an area of 36 $\times 10^3$ km^2. Even considerinn only a quarter of the area with temperature of 150 °C in 3 - 5 km depth, using an average thermal capacity of 2 $\times 10^6$ J/m^3 °C, the total energy stored deep in the Fen-Wei Rift is of the order of 5 $\times 10^{21}$ J. Of course the energy at these depths is not economic to develop and use. But at least it indicates to a certain extent that the geothermal resources in the rift zone are significant.

The extractable geothermal energy reserve stored at 1 - 2 km depth in the rift zone can be approximately calculated. It is about 1.45 $\times 10^{18}$ J for the basement fracture reservoir, and about 2.04 $\times 10^{18}$ J for the extensive sub-horizontal aquifers within the rift, The sum of the two values corresponds to one third of the wellhead thermal energy of the Geysers Geothermal Field of the United States [6].

The recognition and classification of the geothermal resources associated with the Fen-Wei Rift will be helpful for further development. The direct use of geothermal water even low enthalpy can produce certain economical and social benefits. Warm water with low temperature and large flow rate can be used for agricultural irrigation, growing seedlings and fish

Table 1 Chemistry of some of warm springs and thermal wells located in the Fen-Wei Rift Zone (all contents in ppm)

Locality	T_{max}	pH cold	Na	K	Ca	Mg	Cl	SO_4	Alky	F	SiO_2	TDS	T_{km}	T_{kn}	T_{Qc}	T_{ch}
Huaqing Spring	44	7.6	228	17	39	3.7	137	234	191	6.6	42	852	93	211	94	63
Well X6	64	8.6	894	5	32	3.9	291	1352	263	4.5	56	2798	63	74	107	78
Xitangyu	63	8.8	154.4		9	.6	21	243	75	20	90	574			131	104
Dongtangyu	56	8.9	176.1		13	.6	23	319	45	14	70	638			118	90
Nanshandi	48	7.7	705	30	77	1.8	897	423	83	6.0	57.5	2196	116	169	108	79
Beichi	86	7.3	641	29	161	4.9	681	838	76	3.6	(32.5)	2431	104	177	(83)	(51)
Xima	45	8.1	1980	13	555	212	1500	3993	94	1.6	22.5	8346	(40)	79	68	(36)
Deximao	41		188	10	70	35	236	220	195		28.5	981	53	184	77	46
Gudui	23	7.7	114	6	108	40	113	300	250	1.5	17.5	931	42	186	58	26

farming. For basement fracture reservoir, geothermal drillholes can be selected in appropriate locations to get hot water with higher temperature, which might exceed 100°C at shallower depth.
However, this kind of hot water will produce wide-ranging benefits in space heating, greenhouse and medical treatment.

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