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Geologic Background of the Hangay Geothermal System, West-Central Mongolia

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ABSTRACT

Tectonically the territory of Mongolia occupies key position in the Central Asian Orogenic Supercollage or Altaids, located between the Siberian craton on the north and Katasia (Tarim and sino-Koreon cratons) on the south. The Hangay dome in west-central Mongolia is the western end of Hangay Daurian terrane of the Mongol-Okhotsk orogenic belt. The Hangay region consists of intensely deformed Devonian-Carboniferous and not wide distributed Permian-Triassic sedimentary rocks intruded by late Paleozoic and early Mesozoic granites and granodiorites huge bodies. Late Cenozoic numerous high potassium alkaline basaltic provinces are distributed throughout the Hangay area. According to existing data, mantle plume beneath the region resulted in developing of 4-5 stages of magmatic processes from late Paleozoic to Late Cenozoic (Holocene epoch) in this region. It shows still active long-living mantle plume manipulating geothermal gradient in the crust. Therefore, India-Asian collision stress from the southwest (Algay transpressional belt) and Baikal extensional structures from the north are playing an important role for neotectonic faulting and perhaps Tertiary magmatic activation in the Hangay dome. There are number of NE and NW-trending normal faults within the Hangay mount region. Most of hot springs controlled by intersections of such kind of fractures, faults and contact brecciated zones between Permian, Carboniferous and Devonian sedimentary rocks and Permian-Triassic granitic rocks. The regional heat flow in the Hangay dome reaches 60-70 mW/m^2 (Khutorskoi and Yarmoluk, 1989; Dorofeeva, 1992; 2003). The high heat flow of the Hangay dome is reflected in localization of over 30 hot and warm springs from 43 known in whole Mongolian territory with temperatures of 25-92°C. Uplift, alkaline magmatism, high heat flow, asthenosphere upwelling and neotectonic faulting are showing that characteristic signatures of geothermal ability in Hangay region.

1. INTRODUCTION

The Hangay dome in west-central Mongolia is mountainous region covering 200000 km^2 with numerous peaks over 3500 m. River system on the north and northeast side of Hangay dome are extensive, integrated and deeply incising, whereas on south and southwestern sides of the range rivers are shorter, have lower volumes, and have incised less deeply (Cunningham, 2001). The Hangay geothermal field covers 3 province centres and 44 soum (village) centres, with approximately 251,000 people. Hot springs are though used for bathing, health resorts (balneology) and to a small amount for greenhouse heating. Mongolia has a harsh winter climate, with large seasonal variation in temperature. Coal, wood and animal dung are used for heating. Ample and comprehensive studies on geothermal resources and their potential uses have not been carried out in Mongolia.

Geological exploration is considered to be the first step for any geothermal utilization process of an area and gives an idea about the behavior of the geothermal system and its evolution during geologic time. Main goal of this study was to carry out surface geological and geothermal mapping in the Hangay region by classifying the rock units depending on their petrological characters, mapping the main structural features in the area and outlining the locations of the geothermal activities and the tectonic setting of the study area.

2. REGIONAL GEOLOGY

The Hangay region has been discribed as ‘domed’ (e.g. Windley and Allen, 1993; Cunningham, 2001). The basement of dome is problematic issue for many geologists and consists of Precambrain block that contains tonalitic and trondhjemitic gneisses, potassic granitoids and various migmatites and high grade schists and gneisses (Kepezhinskas, 1986). According to Kovalenko (1996), geological interpretation of the isotopic data implies that blocks of the concolidated pre-Riphean crust were overthrusted, during the accretionary-collision formation of the foldbelts, onto younger crustal complexes of sea basins between these blocks.

The Hangay region consists of intensely deformed Carboniferous-Devonian and not wide distributed Permian-Triassic sedimentary rocks which were deposited on basement intruded by late Paleozoic and early Mesozoic granite and granodiorite huge bodies. Late Cenozoic numerous high potassium alkaline basaltic provinces are distributed throughout the Hangay area (Figure 1). They are covered by unconsolidated Quaternary sediments.

2.1 Stratigraphy

The series of Devonian-Carboniferous sandstone-aleurolite which occurred in Hangay region are called ‘Hangay series’ (e.g. Filifova, 1969, 1970). It has thickness of 10-12 km and consists of 4 formations: Early-middle Devonian Erdenetsogt, Carboniferous Tsetserleg, Jargalant and Baidrag (Geology of Mongolia I, 1973). In generally, Hangay series is divided into both siliceous terrigene turbidites lower part (layered sandstone, chert, siliceous claystone, lenticular body of limestone with fossils) and sandstone-aleurolites flychoid upper part (minor amount of chert) by their characters of formations and lithology (Filifova, 1969; Zonenshain, 1972; Ariunchimeg, 1995).

The series of Permian clastic sediments which distributed in central and south-eastern part of Hangay region are called Tamir gol series (figure 1). It consists of 4 series: sandstone, sandstone-aleurolites, sandstone-conglomerates and aleurolite-sandstone with thickness of 2000 m. Their lithological characteristics show that the origin of series is lagoon facies (the west margin of an ancient Permian sea in central Mongolia).

The local distribution of Triassic conglomerates with coarse grained sandstone lenses occurred in Hangay named 'Bugat' trough. It lays on devonian, carboniferous, permian sediments and Hangay granitoid complexes by washout.

The sediments have been regional metamorphosed to the greenschist facies and have been highly folded as well as fractured.

2.2 Magmatism

2.2.1 Granitoid magmatism

In central and southern Hangay region, late Paleozoic granitoids are Carbon to Permian and early Mesozoic granitoids are Triassic to Jurassic batholitic bodies widely exposed (Figure 1). The batholitic bodies are named Hangay complex, Sharus gol complex and Egiin davaa complex in usual geological map sheets (e.g., Geological map of Hangay highland, 1993; Geological map of Mongolia, 1999). The two main units of them in the study area have been ascribed to the Permian Hangay complex and the Triassic- Jurassic Egiin Davaa complex (Takahashi et al., 1999; Jahn et al., 2004). These units are predominantly granite and granodiorites associations (Figure 1). The granitoids are medium enriched in aliuminium, K-subalkaline and calk-alkaline series. The granitoids are slightly enriched in Pb, Th, Nd, Sm, Tb, but depleted in Nb, P, Ti, Ba (specially in granites). Its REE composition is relavily higher than HREE in granitoids but also large negative Eu anomaly in granite and slight or no Eu anomaly in granidiorites (Orolmaa, 2006; 2008). The geochemical characteristic suggests that the granitoids could have been formed by palingenic processes involving collision processes of Mongol-Okhotsk fold belt (Table 1).

2.2.2 Cenozoic volcanism

Late Cenozoic 5 stages of high potassium alkaline basaltic provinces are distributed throughout the Hangay region (Figure 1). The general characteristics of them are toleiite basalts of Oligocene (28.5 ± 1 Ma, Devyatkin, 1981), alkali trachybasalts, trachyandesite-basalts and trachyandesite of Miocene (15-11 Ma, Yarmolyuk, 1994) and Pleistocene (2.5-1.75 Ma, Devyatkin, 1981) and K-alkaline basalts of Holocene (110 ka, Enkhtuvshin, 1995). Tertiary lavas occur in sequences exceeding 200 m in thickness that constitute plateaus making up much of the high Hangay southeast of Chuluut gol. Quaternary lavas are found as isolated lava fields in topographic lows, confined by valleys carved into the pre-Tertiary bedrock. Several processes have been proposed for the tectonic origin of Cenozoic volcanism in central Mongolia (also Central Asia). Proposals include: a mantle plume (Windley and Allen, 1993); mantle plume processes combined with effects of the India-Asia collision (Khain, 1990); a shallow thermal anomaly heating metasomatized lithosphere (Barry et al., 2003); and a crustal weakness along cratonic boundaries resulting in a thin lithosphere (Yarmolyuk et al., 1991); a hot spot volcanism (Sengor et al., 1987); as well. In generally, geochemical analysis of Cenozoic basalts in Hangay shows that basalt fields were supplied from the enriched mantle (e.g. Zhukova, 2007; Barry, 2003; Genshaft, 2006). Younger volcanic necks occur also in this region, in close to proximity to active faults.

2.3 Geotectonic evolution of the Hangay region

Mongolia is an important link between the Siberian craton, essentially an amalgamation of lower Paleozoic terranes, and northern China, an area of complex middle Paleozoic-Tertiary suturing and tectonics. The rocks record successive episodes of terrane accretions and consequent deformation. It is western end of the Hangay Daurian terrane of the Mongol-Okhotsk orogenic belt.

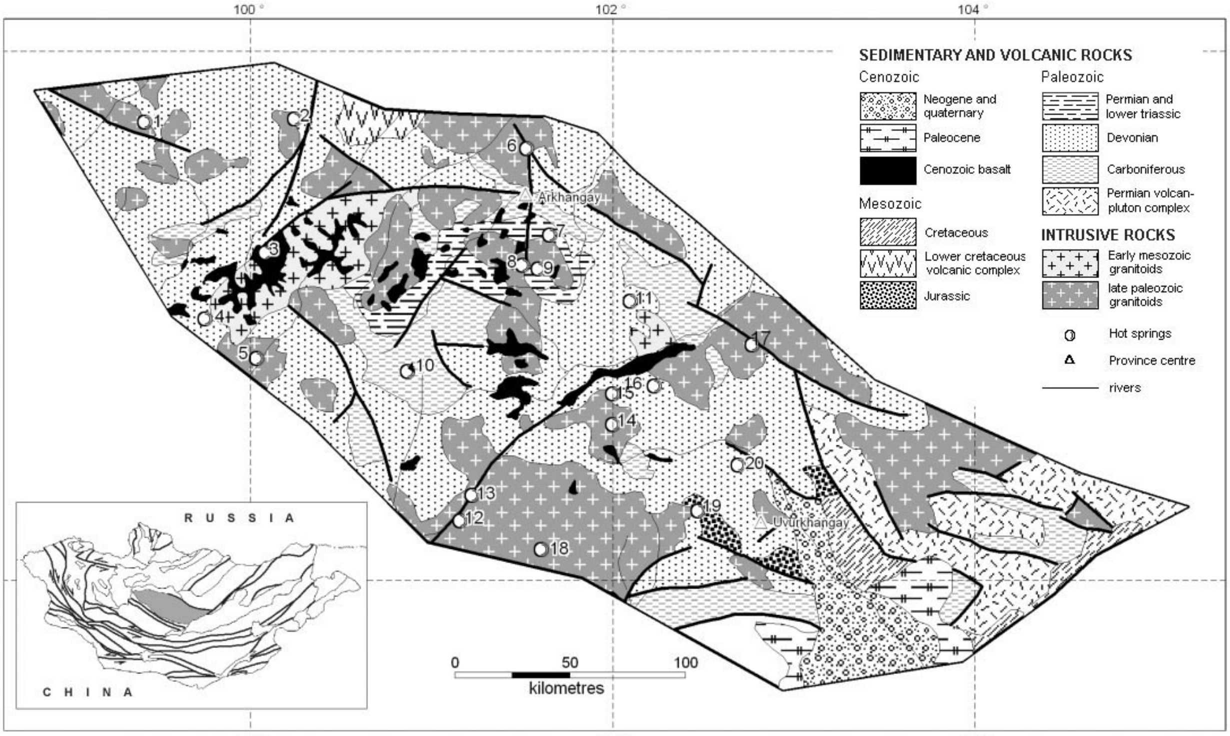

Figure 1. Geological map of Hangay region

It has been studied tectonically by many geologists: it was described as accretionary complex (including several terrane collages) by Tomurtogoo (2002) and as a Devonian-Carboniferous postamalgamated turbidite basin by Badarch (2002). According to reseachers, Hangay-Hentey fold belt tectonic evolution of continental regime started in late Permian. Table 1 shows that geotectonic evolution of the Hangay region.

2.3.1 Neotectonic

Hangay doming began in the middle Oligocene, and was contemporary with alkaline volcanism throughout the Hangay Mountains (Cunningham, 2000).

The total amount of surface uplift is about 3 km, with the most active phase of uplift between 3-4 Ma and the present day (Logatchev, 1984).

The young normal fault systems in the Hangay are perhaps a response to crustal uplift and doming in the range. In addition, the faults with the clearest evidence for Holocene activity within the Hangay occur at relatively high elevations suggesting that these areas are most actively extending (Cunningham, 2001). West-central Mongolia has been the site of 4 great (Ms>80 and many moderate sized (Ms 5.3-7.5) earthquakes in XX century. This activity related to the peculiar position of Mongolia, situated between the extensional structure of the Baikal rift system and the transpressional mountain belt of Central Asia (the collesion zone between India and Asia) (e.g. Baljinnyam, 1993; Bayasgalan 2001). The active faulting in western-westcentral Mongolia forms a pattern resembling a parallelogram of conjugate strike-slip faulting surrounding the Hangay dome. Right-laterial faulting on NW-SE or N-S occurs in the west (Mongolian Altay) and east (Mogod), while E-W left lateral faulting occurs to the north (Bulnay) and south (Gobi-Altay) (Figure 2). There are number of NE and NW-trending normal fault scarps within the Hangay area and probably many more that have not have been discovered yet. Northeast-striking Cenozoic normal faults at the high elevation are the most recently active. The southern Hangay dome region is dominated by Late Cenozoic normal faults that bound small half grabens (Cunningham, 2001). India-Asian collision stress from the southwest (Gobi-Altai) and Baikal extensional structures from the north and uplifting are playing an important role for neotectonic faulting and perhaps tertiary magmatic activation in the Hangay area.

2.4 Geophysical characteristics and crustal thickness

The geophysical survey on the crustal structure has established that accumulative thermal sources are located near the surface under Hangay dome. The lithospheric diapirism is the main cause of the uplifting of the westcentral Mongolia (Zorin, 1990). Compression from the Indian plate could induce some additional elevation of the ranges owing to crustal thickening. Such compression was also responsible for strike slip faulting (e.g. Molnar, 1975). Seismic data suggest that the thinnest lithosphere under Mongolia is located under the Hangay Mountains, where it may be less than 50 km (Zorin, 1990; Windley and Allen, 1993). The analysis of the crustal structure of the study region and the geophysical data available (including tomography, gravity anomalies) proved the presence of "hot" low-velocity upper mantle blocks (diapirs) under most of the areas of the Cenozoic volcanism in Hangay region.

Table 1. Geotectonic evolution scheme of the Hangay-Hentey fold belt (Orolmaa, and Erdenesaikhan, 2008).

Geological age		Tectonic condition	Depositional formation	Magmatism	Association of magma
Era	System				
Cenozoic	Q_2 Q_{1-2}	Within-plate activation	Continental	Volcanism	K-alkaline basalts, Subalkaline basaltes
	N				
	E_3				
Mesozoic	K_1	Continental rift	Lake and shallow water sediments (coal bearing)	Volcanism	Trachybasaltes, Trachyandesitebasaltes, (latite-shoshonite), trachyrhyolites and subvolcanic bodies
	J	?	?		
	T_3–J_1			Intrutions	Granites-leucogranites
	T_{2-3}		Continental molassa		
	P_3-T_2	Collision		Intrutions	Granites-granitodiorites, granites-granosyenites, monzogranites
Paleozoic	P_{1-2}	Mongolia-Okhotsk ocean	Molassa	Volcanism	Trachyrhyolites
	C_3		Sea molassa		
	C_2		Flyschoid		
	D_1-C_1		Terrigenous-silicastone or turbidites	Volcanism	Oceanic arc toleiitic basalts

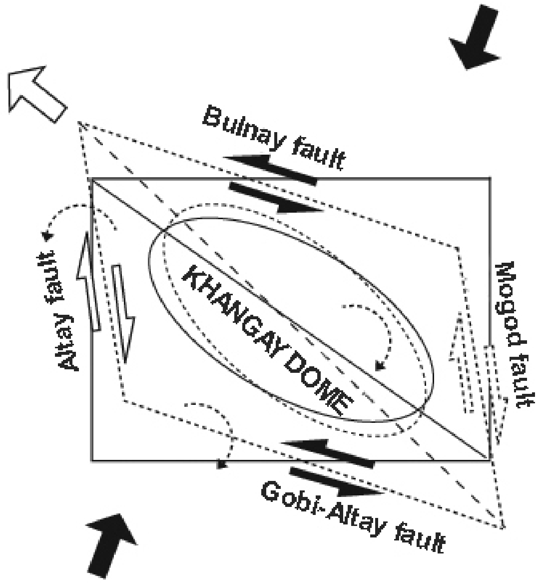

Figure 2. Deformation model of west-central Mongolia. (Bayasgalan, 2001).

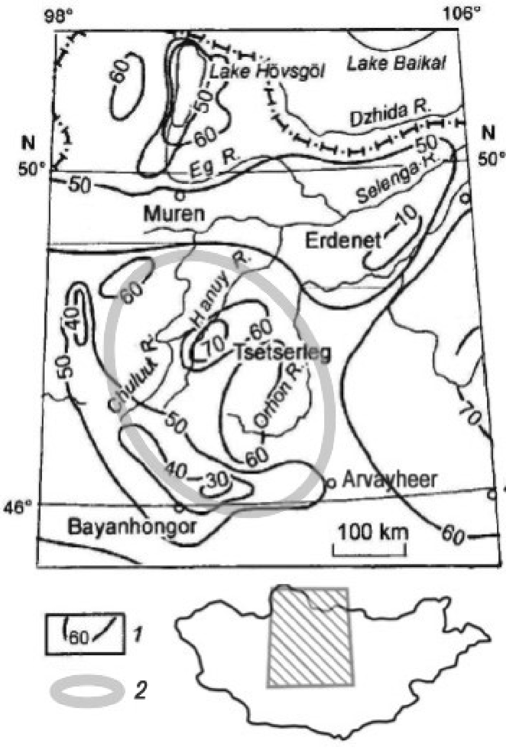

Figure 3. Heat flow map of Hangay (Lysak, et al., 2003). 1-counter lines, in mW/m2; 2-Hangay area.

GEOTHERMAL FEATURES IN HANGAY

There are more than 20 natural geothermal outcrops in Hangay uplifted and folded highland region from 43 known hot and warm springs in whole Mongolian territory with measured surface temperatures of 25-92°C (figure 1 and table 2). According to Dorjderem et al., the geothermal water in Hangay can be classified into 2 types: Open circulation system and closed or sealed systems. The regional heat flow in the Hangay dome reaches 60-70 mW/m^2 (Khutorskoy and Yarmoluk, 1989; Dorofeeva, 2003; Figure 3).

The waters in the Shivert hot spring are of sulfate-sodium, but other hot springs are of bicarbonate-sodium type (Gendenjamts, 2003) and have weak alkalinity with low mineralization, usually less than 250 mg/l. Thermal waters have more negative δ^2H values than cold waters. All the waters close to the local meteoric line, parallel to the world meteoric line, indicating that the hot and cold waters are of local meteoric origin, with no apparent $\delta^{18}O$ shift. This may indicate that hydrothermal alteration reactions have long ceased occurring, that aquifer temperatures are not high, or good permeability exists in the reservoir. The silica-enthalpy mixing model, predicts a subsurface reservoir temperature between 143°C and 245°C and most of the hot waters have probably mixed with cold water.

In order to better understand the geological background of geothermal outcrops of Hangay, geology-structural 2 weeks of fieldwork we were carried out in Chuluut, Shivert, Tsenkher, Bortal, Gyalgar, Tsagaamsum, Noyonkhangay Bagashargaljuut, Ikh Shargaljuut, , Khujirt, Khuremt and Emt hot springs areas in 2007. The locations of such hot springs are defined by GPS and their geological formations (figure1 and table 2) and structural studies were also included.

According to surface observation, the geothermal outcrops in Hangay region developed at not only an intersections of NW and NE trending faults and fractures but also contact brecciated zones between Permian, Carboniferous and Devonian sedimentary rocks and Permian-Triassic granitic rocks (different lithological units).

CONCLUSIONS

Uplift, basic alkaline magmatism, high heat flow, asthenosphere upwelling and neotectonic faulting are showing that characteristic signatures of geothermal ability in Hangay region.

In Hangay region, the geothermal outcrops developed at not only an intersections of NW and NE trending faults and fractures but also contact brecciated zones between Permian, Carboniferous and Devonian sedimentary rocks and Permian-Triassic granitic rocks (different lithological units).

Table 2. Geological formations of hot springs.

No. (Fig 1)	Spring names	Provinces	Latitude (N)	Longitude (E)	Total Flow (l/s)	Mineral. (mg/l)	Max. T (°C)	Geological formations
1	Noyonkhangay	Arkhangay	47°44'36"	99°24'53.6"	6	-	38	Middle permian porphyry granites.
2	Chuluut	-	47°45'20.4"	100°14'37.9"	1.2	250.5	45	Early and middle devonian siliceous aleurolite, aleuro-sandstone and brecciated quartzite.
6	Shivert	-	47°38'40.3"	101°31'34.0"	4	24.8	55	Middle and late devonian sandstone, schist and late permian granites.
7	Tsenkher	-	47°18'59.9"	101°39'08.7"	10	239.9	86	Permian aleurolite and brecciated quartzite.
8	Gyalger	-	47°12'07.1	101°30'16"	1	221.6	52	Late permian granite, leucogranites and neogene basaltic dykes.
9	Bor tal	-	47°11'19.5"	101°35'24.2"	4.5	258.9	46	Early carboniferous sandstone, schist and breccias.
11	Tsagaan Sum	-	47°04'01.8"	102°05'56.6"	8	-	69	Late triassic to early jurassic granites.
12	Baga Shargaljuut	Bayankhongor	46°14'02.4"	101°09'12"	10	37.3	58	Early to middle devonian alternating sandstone, argillite, schist and middle permian biotite-granites.
13	Shargaljuut	-	46°19'58.30"	101°13'30.10"	25	259	92	Early to middle devonian alternating sandstone, argillite, schist and middle permian leucogranites and quartzdiorites.
17	Khujirt	Uvurkhangay	46°54'04.8"	102°46'22.2"	16	-	55	Early and middle triassic granites, late carboniferous sandstone, aleurolite and breccias.
19	Khuremt	-	46°16'25.02"	102°28'20.68"	5	-	55	Early to middle devonian and jurassic sandstone, dark gray schist and early to middle triassic coarse and fine grained granite, granodiorite.
20	Emt	-	46°26'44.80"	102°41'36.12"	0.5	-	39	Early to middle devonian schist, sandstone and quaternary cover.

The open geothermal system of Khangai region is the most attractive site with regards to its location, social and economic situation where 3 of biggest provinces locates and 251000 people lives.

More detailed geological, geophysical and geothermal investigations are needed.

Finally, successful multi- and bi-lateral cooperation with international financial institutes and private sector investors will play a significant role in speeding up geothermal energy development in Mongolia.

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