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GEOTHERMAL FEATURES OF ARMENIA: A COUNTRY UPDATE

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ABSTRACT

Sixty heat flow values ranging from 38 to 157 mW/m^2 have been estimated for Armenia from geothermal gradient determinations in 90 locations and a limited number of thermal conductivity determinations. The highest values of heat flow (90-157 mW/m^2) occur in the central part of the country, which is characterized by vigorous Quaternary volcanic activity, manifestations of thermal springs, intensive aeromagnetic anomalies, and minimal negative values of Bouguer anomalies. To the northeast and southeast from this region, heat flow goes down to background values which is estimated to be 45-55 mW/m^2. It is found that a substantial part of the heat flow anomaly is caused by local shallow-depth heat sources, which must be cooling magmatic chambers related to recent volcanic activity. Based on magnetic investigations, depths, sizes, and current temperatures of magmatic chambers are estimated. An aeromagnetic data analysis shows that Curie point depth in Armenian territory varies from 5 (in volcanic region) to 12-13 km. Reservoir temperatures of mineral waters, estimated by silica geothermometry, generally range from 40^{o}C to 160^{o}C. The Eastern volcanic belt is thought to be the main area of geothermal potential in Armenia where both dry and hydrothermal resources are expected. The zones of deep faults almost everywhere in Armenian territory are promising for hydrothermal resources.

1. INTRODUCTION

Since Armenia does not have any considerable fuel resources, and is possessed of limited hydro-energy, it is very important to assess the geothermal resources of the country. The present update includes data and interpretation resulting from studies of regional heat flow, as well as from aeromagnetic, volcanological and water-chemistry investigations, which have direct application to geothermal resource assessment.

2. GEOLOGICAL SETTING

The territory of Armenia is generally drawn towards the axial zone of the Mediterranean orogeny. The regional complex of the territory, together with adjacent areas, curves to the north as an arcuated meganticlinorium of Minor Caucasus. In the structural plan of the Pre-Neogene stage, 6-7 tectonic zones have been distinguished. Their boundaries usually are deep faults (Aslanian, 1970). These zones have been grouped into 3 tectonic belts; the folds strike along a North West-South East direction (Fig. 1). Late orogenic (neotectonic) stage of the evolution of the area is characterized by several phases of arched-block differential uplifts accompanied by formation of new structural forms, activation of old structures, and vigorous volcanic eruptions (Aslanian, 1970; Karapetian and Adamian, 1973).

The most important volcanological features of Armenia are as follows: active Meso-Cenozoic granitoid and andesitic magmatism; Upper Cretaceous ultrabasic magmatism; Neogene-Anthropogene post-orogenic volcanism; various mineralizations of magmatic and postmagmatic origin; extensive accumulation of tuffs and lava (Aslanian, 1970).

3. GEOTHERMAL GRADIENT AND HEAT FLOW

At present, mean geothermal gradient values for 90 locations and heat flow values for 60 locations are determined. Temperature was measured using thermistors. Out of 60 heat flow values, 24 were obtained on the basis of temperature measurements in deep boreholes and measurements of thermal conductivity of samples of rocks (Avetisiants, 1975,1979; Mirijanian, 1972, 1974). For 31 other locations, heat flow values were determined on the basis of temperature measurements in shallow (80-250m) hydrological wells bored in basalts-andesitic basalts and dacites-andesitic dacites. For these locations, mean thermal conductivity of those groups of rocks was used for estimating heat flow values (Vartanian and Gordienko, 1984). Another five values of heat flow were determined by the method of temperature waves reduction (Vartanian and Gordienko, 1984). Geothermal gradients and heat flow maps drawn up on the basis of referred data are shown in Figures 2 and 3 respectively.

The highest values of both geothermal gradient and heat flow occur in the central part of the territory, which is characterized by vigorous recent volcanic activity, thermal spring manifestations, intensive aeromagnetic anomalies, and minimal negative values of Bouguer anomalies. Here, heat flow exceeds the mean value for Cenozoic volcanic regions and, in some local sites, reaches up to 130-157 mW/m^2. To the northeast and southwest from this region, heat flow goes down to background values, which are estimated to be 45-55 mW/m^2 (Vartanian, 1984).

Several attempts with different approaches have been made for interpreting the heat flow anomaly (Mirijanian, 1974, 1979; Avetisiants,1979; Vartanian and Yakobi, 1985; Badalyan 1976, 1986a; Badalyan et al., 1989). Calculations based on a non-stationary model of the heat flow anomaly show that it can be only partially (in regional plan) explained by deep heat-generating sources, particularly by sources related to the orogenic stage of development of the Minor Caucasus (Vartanian and Yakobi, 1985). A substantial part of the intensity of heat anomaly is likely to be caused by local shallow-depth heat sources (Badalyan et all, 1989), which must be cooling magmatic chambers detected by magnetic data (Badalyan, 1986a). This idea is supported by the results of magnetotelluric investigations, according to which, localized zones of high conductivity, possibly caused by partial melting, are revealed at depths of 9-15km and 20-40km (Cherniavsky et al, 1980).

4. RECENT VOLCANISM

The most recent (Late Pliocene-Holocene) volcanic activity is localized within two volcanic-structural zones (Fig. 1) named Western (or Trans-Caucasian) and Eastern volcanic belts (Karapetian and Adamyan, 1973; Shirinyan, 1975). The beginning of the Upper-Pliocene volcanic cycle (3.5 Ma) was characterized by fissure eruptions of mantle olivine basalts manifested mostly within the Western volcanic belt. The later development of volcanism was accompanied by transition from fissure to central eruptions. At the same time volcanic products evolved from basic to acidic.

In the Quaternary period, including Holocene, volcanism was mainly areal in character, especially within the Eastern belt (Karapetian and Adamian, 1973). More than 600 well-preserved monogenetic volcanic centers of this age are mapped on the comparatively small area of Armenia. The products of their eruptions are represented mainly by andesitic basalts and andesites, and less often by andesitic dacites. Centers of polygenetic activity are single.

A number of petrological and petrochemical peculiarities of the latest volcanics (Karapetian 1963, Shirinian 1975) and an analysis of geophysical data (Badalyan, 1986a) show that the Eastern volcanic belt is the surface indication of a larger volume of intrusives. On the basis of magnetic investigations and other geophysical and volcanological data, depths and sizes of the magmatic chambers were determined, and the ages of their crystallization was estimated. According to this analysis, the depth to their tops is found to be 2-3 km, and their sizes vary from 50-70 km^3 to 180 km^3 (Badalyan, 1986a). Cooling of the intrusions down to Curie point took place during the Brunhes magnetic epoch (not earlier than 0.7 Ma), most probably in Holocene (Badalyan, 1986b).

The parameters of these magmatic chambers are used to estimate what their current temperatures might be and the local heat flow anomalies they might sustain (Badalyan et al, 1989). It was found that near these intrusions the 150^0C isotherm might be reached at depths from 2 km to 3.5 km, depending on their sizes. Resulting heat-flow anomalies are estimated to be 25-80 mW/m^2, which is in good accordance with the results of heat flow data analysis (Badalyan et al, 1989).

A recent analysis of aeromagnetic data shows extremely shallow depths of the low boundaries of magnetic sources in the territory of Armenia: 5-8 km within the Eastern volcanic belt and up to 12-13 km in neighboring regions (Badalyan, Khourshudian, submitted). If these depths correspond to the Curie isotherm depth, as supposed (Fig. 4), then mean geothermal gradients in the central part of the territory may be much higher than previously measured. However, in general, a good correlation between maps of Curie point depths and geothermal gradients may be noticed (Fig. 2 and Fig. 4).

5. MINERAL AND THERMAL WATERS

In the Armenian territory over 700 mineral springs were investigated (Geology of Armenian SSR, 1972). They are mainly of infiltration origin. Total mineralization of waters ranges in general from 1 to 10 g/l. Based on chemical composition, 22 principal types of springs are distinguished. According to gaseous composition, the overwhelming majority of waters are carbonic acid with extremely abundant CO_2 (up to 97-99% of total volume), which is thought to be caused by its immediate release from hot magmatic chambers (Geology of Armenian SSR, 1972).

In spite of this, the majority of springs have low discharge temperatures: up to 20^{o}C. The main group of springs with discharge temperatures above 20^{o}C is shown on Fig. 1. All of them issue within the Eastern volcanic belt or near deep faults. The highest temperatures are measured in Jermuk (64^{o}C), Arzakan (44^{o}C), Hankavan (42^{o}C), Bjni (37^{o}C) and Sayat-Nova (36^{o}C) hydrothermal systems.

An attempt of applying chemical geothermometers (silica, Na-K-Ca and Na-K-Ca-Mg) was done to estimate deep reservoir temperatures of mineral waters (Badalyan, submitted). Data of chemical analysis of 186 springs were selected from a catalogue (Geology of Armenian SSR, 1972). The most reasonable results, shown on Fig. 5, were obtained by application of silica geothermometer (Fournier and Rowe, 1966). Estimated reservoir temperatures range from 40^{o}C to 160^{o}C; only in five cases do they exceed 160^{o}C.

The reservoirs with higher temperatures occur mainly within the Eastern volcanic belt or are associated with deep faults. Only a weak correlation between estimated reservoir temperatures and geothermal gradients (or Curie point depths) may be noticed (Figures 2, 4, and 5). This is probably caused by the fact that reservoir temperatures reflect not only geothermal gradients but also reservoir depths, which may vary over a wide range without any regularity.

6. CONCLUSION

The above results of regional heat flow studies, volcanological investigations, and chemical geothermometer applications are in good concordance, and lead to the conclusion that the main area of geothermal potential in Armenia is the Eastern volcanic belt. Both dry and fluid types of geothermal resources with high enthalpy are available in this area. Besides, the zones of deep faults almost everywhere in Armenian territory are promising for hydrothermal resources.

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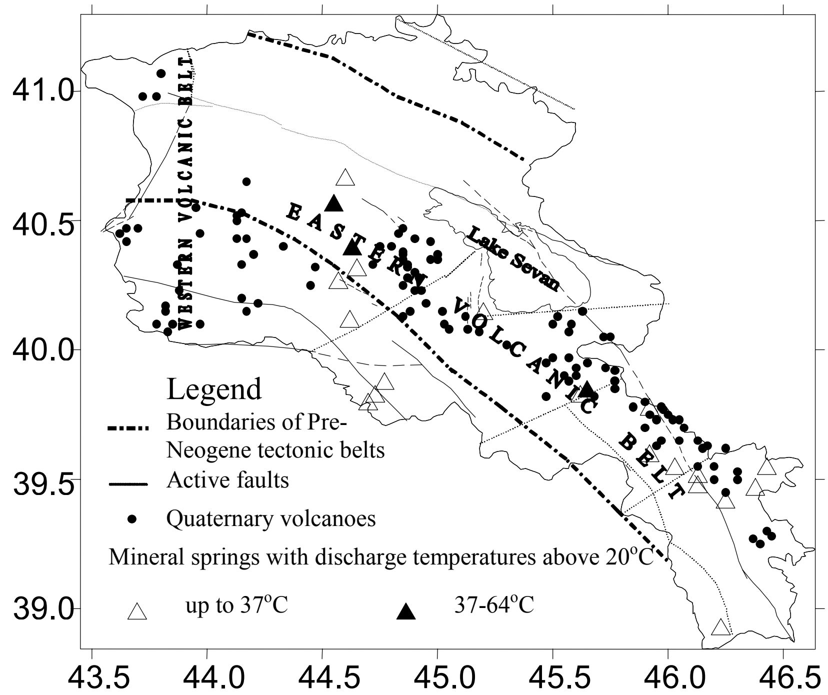

Figure 1. Simplified Tectonic Map of Armenia (After Aslanian, 1970; Balasanian et al, 1997)

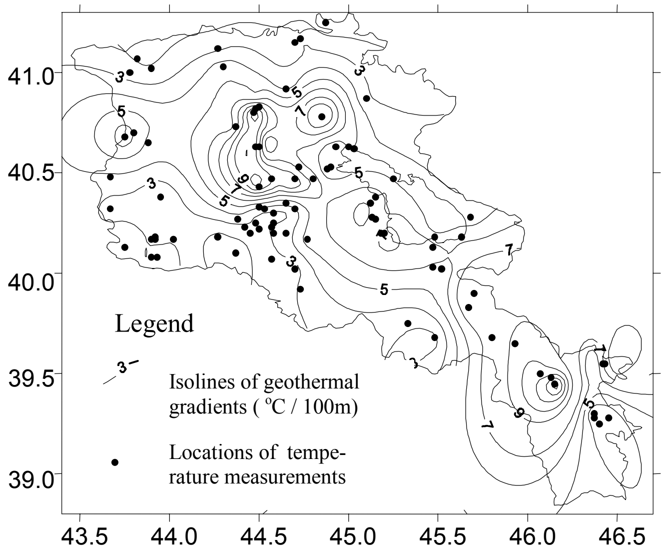

Figure 2. Map of geothermal gradients

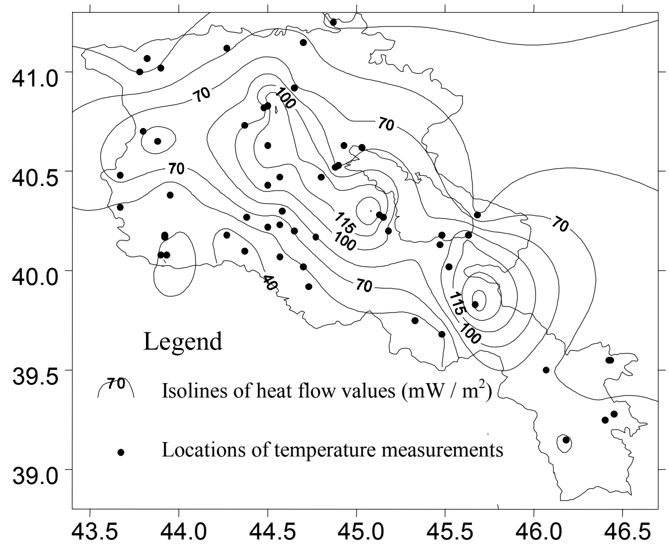

Figure 3. Map of heat flow

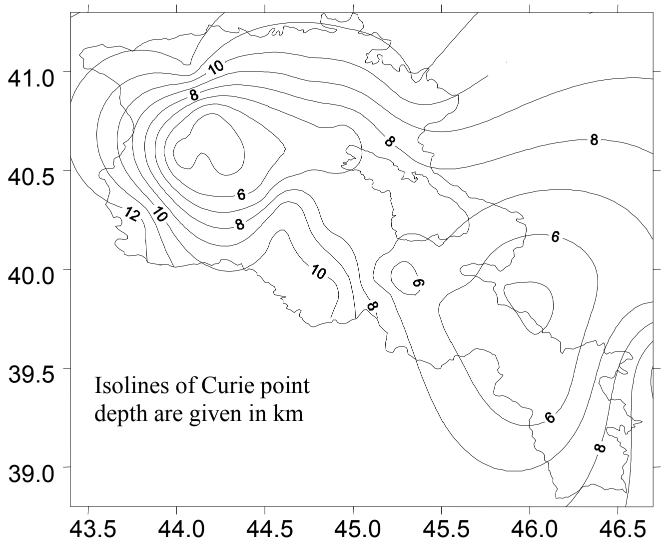

Figure 4. Map of Curie point depth

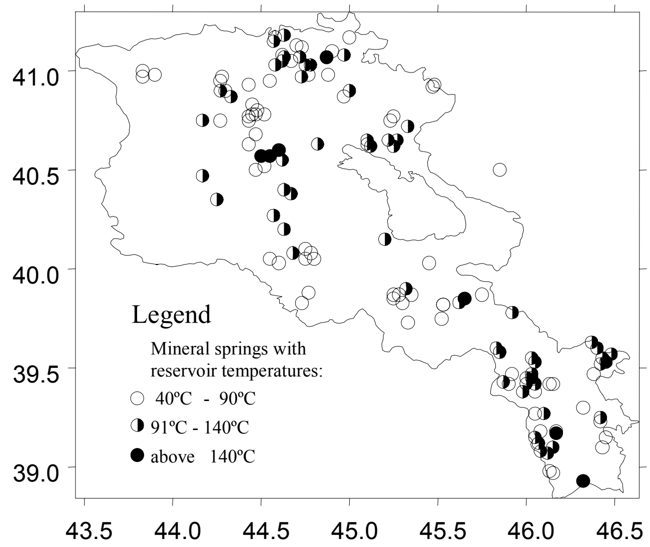

Figure 5. Reservoir temperatures of mineral springs estimated by application of silica geothermometer