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GEOTHERMAL RESOURCES OF ARMENIA

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ABSTRACT

Although no high-temperature geothermal resources have been identified in the Republic of Armenia, numerous low-temperature resource areas (cooler than 100°C) are present, mostly within a belt of Quaternary volcanism and elevated heat flow that trends northwest-southeast through the central part of the mountainous country. GeothermEx, Inc. has carried out a review and investigation of the geothermal resources of Armenia as part of an effort funded by the U.S. Agency for International Development to rehabilitate the country's energy sector. The location and extent of some resources should make them suitable for a variety of low-temperature applications such as space heating, greenhouse heating and other agricultural applications, and expanded recreational use. Three areas (Jermuk, Ankavan and the Vorotan River Valley) have been identified as having the greatest immediate potential for commercial geothermal applications; thermal areas at Arzakan, Gyumri and Martuni are also of potential commercial interest. Further exploration in the central volcanic zone of Armenia is warranted in an effort to expand the identified geothermal resource base. Zones of young volcanism in the Jermakhpur area, the Jermuk basin, the Gegam Mountains and the Vardenis Mountains are attractive targets for new exploration.

1. INTRODUCTION

The Republic of Armenia became independent in 1991 as the USSR broke up. The small, mountainous and landlocked country has few indigenous energy resources, and in recent years has relied heavily on imported fuels from surrounding states. In addition, a significant fraction of the supply of electric energy comes from an aging nuclear power plant at Medzamor, a short distance from the capital city of Yerevan.

During the early to mid 1990s Armenia experienced severe economic problems, including a significant energy shortage, provoked in part by a conflict with neighboring Azerbaijan. Economic conditions are improving, but offsetting energy imports by domestic production could have a significant positive effect on both domestic employment and the international trade balance.

The United States Agency for International Development (USAID) has for the past several years funded an effort to rehabilitate the energy sector of Armenia. Components of this initiative include studies for the refurbishment, restoration or upgrade of existing power plants, demand-side management studies, and investigation of indigenous energy resources. GeothermEx, Inc., in association with Burns and Roe Enterprises, carried out a detailed review of the geothermal resources of Armenia in 1998, as part of the USAID energy program. The principal objective of this review was to identify applications of geothermal energy (for power generation or direct use) that could be commercialized in the near future. As part of the study, potential resource areas were inventoried, then assessed and prioritized according to their attractiveness for development.

The use of geothermal energy in Armenia is quite limited at present, and mostly takes the form of small-scale and informal applications. However, significant investigations of the country's thermal areas have been undertaken, mostly during the Soviet era. As a result, the information available is more extensive than it might be in some other countries with similar levels of resource utilization. For example, thermal springs have been catalogued and described, and hundreds of shallow wells have been drilled, mostly for the purpose of investigating mineral water sources throughout the country (Mkrtchian, 1969). In addition to the investigations and reviews carried out by local specialists, several studies of the geothermal resources of Armenia have been funded and carried out by foreign entities (Lahmeyer International, 1994, 1996; Petroleum Geology Investigators, 1998).

2. GEOLOGIC SETTING AND HEAT FLOW

The Republic of Armenia is located in the Lesser Caucasus mountain chain, and geologic trends within the country parallel the general northwest-southeast trend of the chain. The geology of the region is complex, owing to accretion of exotic terranes through plate-tectonic processes, and to ongoing tectonic activity and volcanism. As a simplification, several different regions of distinct geologic characteristics can be identified.

The northeastern region of the country is dominated by rocks of Prepaleozoic to Lower Tertiary age, and a strong WNW-ESE structural grain is evident. Two ophiolite belts are present along the southern margin of this northeastern region.

A belt of Quaternary volcanic activity that is manifested in a series of volcanic highlands dominates the central part of Armenia (figure 1). Numerous Quaternary volcanic centers are present in the belt, and geologic mapping indicates that volcanism has taken place more or less continuously since Lower Pliocene or Upper Miocene time. There are four somewhat distinct zones of young volcanic activity within the belt: the Aragats Massif and related subsidiary volcanic centers at the northwestern end; the Gegam Mountains, which trend south-southeastward along the shore of Lake Sevan; the east-west trending Vardenis Mountains, located south of Lake Sevan; and the Karabagh Upland, which trends southeastward into the southernmost part of Armenia. The youngest dated eruptive deposits, about 4,000 years old, are in the Karabagh Upland in the Jermakhpur area.

Southwest of the southern part of the volcanic belt is a zone of rugged topography in which Prepaleozoic to Lower Tertiary formations predominate. Further northwest, along the Araks River and southwest of Yerevan, are two major sedimentary basins filled with as much as 6,000 to 8,000 m of sediments of Upper Mesozoic to Quaternary age, capped in some places by Pliocene and younger lavas from the volcanic belt. These basins have been the focus of exploration for hydrocarbons in Armenia.

Regional heat flow has been interpreted from measurements in numerous drillholes throughout the country, many drilled specifically for measurement of temperatures and rock thermal conductivities. Three heat flow zones have been distinguished on the basis of heat flow and temperature gradients (figure 2). The northeastern zone of Armenia (Zone I) is characterized by low heat flow (less than 60-75 mW/m^2) and low temperature gradients (less than 43°C/km). The central zone (Zone II), which coincides closely with the belt of Quaternary volcanoes, is one of high heat flow (75 to more than 90 mW/m^2) and elevated temperature gradients (generally greater than 50°C/km). The southwestern zone (Zone III) has low heat flow (less than 60-75 mW/m^2) and generally low temperature gradients (less than 33°C/km), but higher gradients occur locally.

3. OCCURRENCE OF GEOTHERMAL RESOURCES

To date no high-temperature geothermal resources have been identified in the Republic of Armenia. However, numerous low-temperature resource areas (cooler than 100°C) are present, and areas attractive for exploration for higher-temperature resources exist within the areas of younger volcanic activity. Figure 1 shows the locations of the more important identified thermal areas.

No thermal waters have been reported in either springs or wells within Zone I. This zone is therefore considered to have no significant potential for geothermal resources. In Zone III there are scattered occurrences of thermal water, despite the overall low heat flow in this region. These occurrences include several areas of low-temperature thermal springs, and waters produced from some of the deep wells drilled in the sedimentary basins.

The majority of known thermal areas, including all of the areas showing the greatest potential, occur within the central zone of high heat flow (Zone II). Some of the thermal areas in this zone are found in terranes of young volcanic rocks, but none show a clear association with a recently active volcano or a magmatic heat source, and some are distant from any centers of recent volcanism.

During the 1950s and 1960s hundreds of wells were drilled in the thermal areas, primarily for investigation and development of mineral water resources for therapeutic treatments and other uses, rather than for geothermal energy exploitation. Most of the wells were less than a few hundred meters in depth, but a few reached more than 1,000 m. Drilling was generally concentrated in the immediate area of thermal springs. Since the early to mid 1970s very few new wells have been drilled, and few original investigations of the thermal areas have been carried out.

Available data from the wells and warm springs were used to identify, characterize and compare the areas of geothermal potential. Using a cut-off temperature of 20°C to distinguish thermal from non-thermal waters, at least 17 thermal areas are known to exist in Armenia (figure 1). Of these, 6 were classified as major or important resource areas, based on their temperature, extent and/or degree of development. The characteristics of these areas are summarized in table 1.

All of the Armenian thermal and mineral waters studied have mixed-cation mixed-anion compositions. Total dissolved solids contents tend to be less than about 0.5 gm/l, but are occasionally higher. As is typically the case, the hotter and more saline samples tend to have higher ratios of (Na+K)/(Ca+Mg), and relatively high ratios of chloride to bicarbonate (Cl/HCO3) or sulfate to bicarbonate (SO4/HCO3). The cooler waters tend to be higher in Ca+Mg and bicarbonate.

Chemical geothermometers were calculated for waters where sufficiently complete data were available. For most areas, both silica and cation temperatures tend to be close to observed discharge temperatures, usually not exceeding them by more than 20-30°C. None of the thermal areas examined show geothermometer temperatures greater than 100°C. The two areas with the highest indicated temperatures are Jermuk (90-95°C) and Sisian, in the Vorotan River Valley (80°C).

3.1 Jermuk Area

At Jermuk, in the Karabagh Upland, springs and wells located alongside the Arpa River and on an adjacent lava plateau discharge water ranging in temperature up to 63°C. More than 30 wells of shallow to intermediate depth (maximum 642 m) have been drilled in and around the town of Jermuk for investigation and to serve long-established tourist facilities. A number of the wells, though not artesian, are capable of self-flow due to the gas content of the water. Flow rates are typically in the range of 2 to 8 l/sec, but may reach as high as 11 l/sec. According to local authorities, there are currently at least 4 wells at Jermuk in operating condition, capable of supplying a combined production rate of about 18 l/sec. Many other wells that have been temporarily abandoned could potentially be restored to service.

The wells and springs appear to be fed by a widespread aquifer of fractured rock located at or near the base of the Quaternary lavas that form the plateau and overlie much older basement rocks. The area is located along a structural high at the southwestern margin of an intermontane basin; the thermal waters likely rise there after circulating through the basin, which has young volcanoes located at its northern and northwestern margins.

A variety of resorts and health facilities were built in Jermuk beginning the 1950s to take advantage of the thermal and mineral waters, forming the basis for a once-important tourist industry. Most of these facilities are presently closed or operating at much-reduced capacity, and some are unfinished.

Water from one of the operating wells is bottled and sold as mineral water; the same well is used during the winter season to heat a nearby guest house. Other use of the thermal waters is very limited at present.

3.2 Vorotan River Valley

Thermal springs and wells are present at several locations adjacent to the Vorotan River, which flows through the southeastern part of Armenia. The distribution of springs suggests that a potentially large resource area may exist along a corridor of 50-60 km length. Wells have been drilled at Sisian, the principal city in the region, and near the villages of Uz, Vorotan and Shamb. The wells are characterized by relatively low temperatures (25° to 43°C), but have high artesian flow rates (from 10 l/sec up to a reported 102 l/sec). The hotter wells (40°C or greater) range from 700 m to 1,150 m in depth.

Geologic data indicate that the thermal waters are produced from various different Tertiary formations, rather than from a single widespread aquifer. No direct connection with centers of young volcanism is indicated. There is no use of the thermal waters in the Vorotan River Valley at present, except informal use for bathing.

3.3 Ankavan

Several warm springs and at least 11 wells are located along a several-hundred-meter stretch of the Marmarik River near the town of Ankavan, situated in the Tzaghkunyats Range about an hour's driving distance north of Yerevan. There are no nearby Quaternary volcanoes and the rocks of the area range from Prepaleozoic granite-gneisses to volcanic rocks of Lower Tertiary age.

Spring temperatures range only up to about 25°C, but several of the wells, drilled to depths of 50 to 410 m, have encountered temperatures as high as 42°C. Some wells are artesian, with flow rates reported to be as high as 25 l/sec, and 7 wells exceeding 10 l/sec. At least four wells exist today, and two are in active use, though not as energy sources. Both active wells are used as sources of CO_2 gas, one supplying a CO_2 bottling plant, the other a dry-ice factory. The latter well also supplies the Ankavan Sanatorium, a facility dedicated to the treatment of stomach ailments using the mineralized thermal water.

3.4 Other Areas

At Arzakan, located in the Tzaghkunyats Range about 30 km from Yerevan, several wells produce water as warm as 45°C at rates up to about 7 l/sec. One well supplies a commercial bathhouse in the agricultural village of Arzakan.

The Martuni thermal area is located along the southwestern shore of Lake Sevan in and near the city of Martuni. One or more thermal springs occur there, and several wells were drilled to depths of as much as 971 m, encountering temperatures up to at least 40°C. Interest has been shown in the Martuni resource as a possible source of heat for local buildings.

In the Gyumri area, near the northwestern border of the country, several wells with production temperatures up to 42°C have been reported near the city of Gyumri and the town of Kamo. Little information is available about the resource in this area, but there is potential demand from a large local population.

A number of other areas of thermal springs and shallow thermal wells occur in the central and southwestern zones of the country, with maximum observed temperatures mostly in the range of 25° to 35°C. Locations of these areas are shown in figure 1.

Deep wells drilled for hydrocarbon exploration in the sedimentary basins near and southwest of Yerevan have encountered temperatures up to at least 87°C, and an artesian flow from one well at 80°C was reported to have occurred for a brief period before the well scaled shut. Little or no hot water production from the deep wells is known to be available from any of the deep wells at present. Some interest has been shown in the possible exploitation of the sedimentary basins for geothermal energy production, especially in the vicinity of Yerevan where, if productive wells could be drilled, they could be used to supply the capital city's existing district heating system. However, the required depth (probably 2,000 m or more), relatively modest expected temperatures, and lack of demonstrated productivity of such wells limits the attractiveness of the basins for near-term commercial exploitation.

Exploration for higher-temperature resources, including various geophysical surveys, has been undertaken in the Jermakhpur area, located in the Karabagh Upland along Armenia's eastern border. This is the area of the youngest known volcanism in the country (Karakhanian et al., 1997), and warm springs (up to 32°C) are found in the area. A temperature of 99°C was measured in the deeper of two slim holes drilled to 600 and 1,000 m; however, no production of fluid was achieved from either hole.

4. POTENTIAL FOR DEVELOPMENT

At the present time there are no identified geothermal resources in Armenia that could be developed for commercial generation of electric power. Identified thermal water resources in the central zone of the country may be commercially usable in a variety of direct-use projects, including applications for agriculture, space heating and hot water supply, and tourism.

The Jermuk, Ankavan and Vorotan River Valley areas appear to have the greatest potential for commercial direct-use projects at this time. At Jermuk, projects compatible with the tourism-based economy, such as bathing and swimming pools, and space heating (including possible conversion of the district heating system), would be most suitable. Both resort-related and agricultural applications (such as greenhouse heating) may be possible at Ankavan, whereas the Vorotan River Valley is most attractive for greenhouse projects and, possibly, space heating.

Infrastructural and demand conditions appear to be favorable for the development of direct-use projects. However, given the present climate for investment, particularly in areas outside of Yerevan, projects that are feasible over the short term are almost certain to be small-scale and local in nature, and are likely to depend on local interest and on private or unconventional financing for their development. Transfer of expertise in project economics, finance and (particularly for tourism-related applications) marketing could play an important part in making such projects viable.

Further exploration within the zones of young volcanism is warranted in an effort to expand the identified geothermal resource base of Armenia. Expanded investigations around known thermal areas of higher temperature, as well as exploration in the areas of the most recent volcanism, are likely to be worthwhile in this effort. Review of geologic data and analysis of satellite imagery indicates that the Jermakhpur and Jermuk basin areas in the Karabagh Upland, the Gegam Mountains and the Vardenis Mountains are the most attractive areas of young volcanism for new exploration.

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REFERENCES

Aslanian, A. T., and Beguni, A. T. (1968). *Geologic Map of the Armenian SSR (1:600,000)*. Ministry of Geology of the USSR, Moscow.

Karakhanian, A. S., Trifonov, V. G., Azizbekian, O. G., and Hondkarian, D. G. (1997). Relationship of late Quaternary tectonics and volcanism in the Khanarassar active fault zone, the Armenian Upland. *Terra Nova*,Vol. 16, pp. 131-134.

Lahmeyer International GmbH (1994). *Development Planning in the Armenian Power Subsector*.

Lahmeyer International GmbH (1996). *Update of Least Cost Power Investment Program, Armenia*.

Mkrtchian, S. S. (1969). *Geology of the Armenian SSR (Vol. IX - Mineral Waters)*. Academy of Science of the Armenian SSR, Institute of Geological Sciences, Yerevan (in Russian).

Petroleum Geology Investigators ApS (1998). *Armenian Geothermal Project Reconnaissance Study - Final Report*. Report for International Bank for Reconstruction and Development.

Table 1. Characteristics of Principal Geothermal Resource Areas, Republic of Armenia

Area	Maximum Known Resource Temperature (°C)	No. of Wells Drilled	Typical Well Depth (m)	Maximum Well Depth (m)	Estimated Combined Production Rate (l/sec)
Jermuk	63	>30	150-500	642	>17
	Comments: Extensive area of thermal springs in Quaternary volcanics associated with nearby volcanic centers. Area is developed for tourism and bottling of mineral water.				
Vorotan River Valley	43	14+	150-250	1158	100-200
	Comments: Springs and wells produce 20-43°C water in at least 5 areas along a 25-30 km stretch of the Vorotan River. Some wells have very high reported flow rates. No known commercial use.				
Ankavan	42	11+	50-100	410	>40
	Comments: Springs and wells along Marmarik River. Two wells in use for CO_2 and dry ice production. Touristic area.				
Arzakan	45	2	?	800	7+?
	One well in use for commercial bathhouse. Resource is poorly documented. Agricultural area.				
Martuni	40+	3+	500-900	971	>6
	Comments: Production from aquifers in volcanics near lake Sevan. No presently active wells or commercial use. Feasibility study for geothermal heating of hospital has been performed.				
Jermukpur	99	2	600-1,000	1000	0
	Comments: Area of youngest (~4,000 yrs) volcanism in Armenia. Exploration by slim hole drilling and geophysics. Slim holes are dry. Local springs are 22-29°C. Isolated area.				

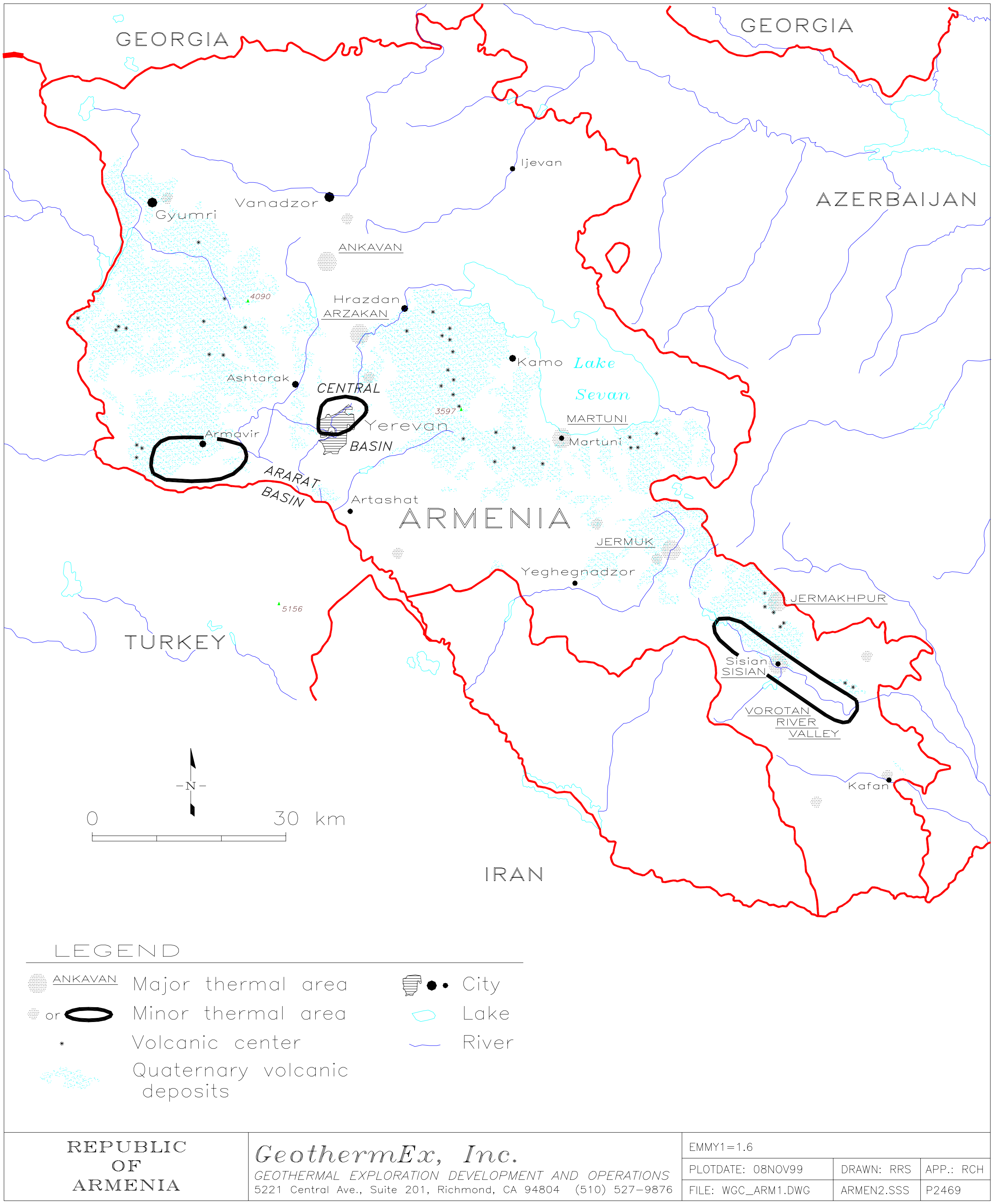

Figure 1: Distribution of Quaternary volcanic rocks and locations of thermal areas

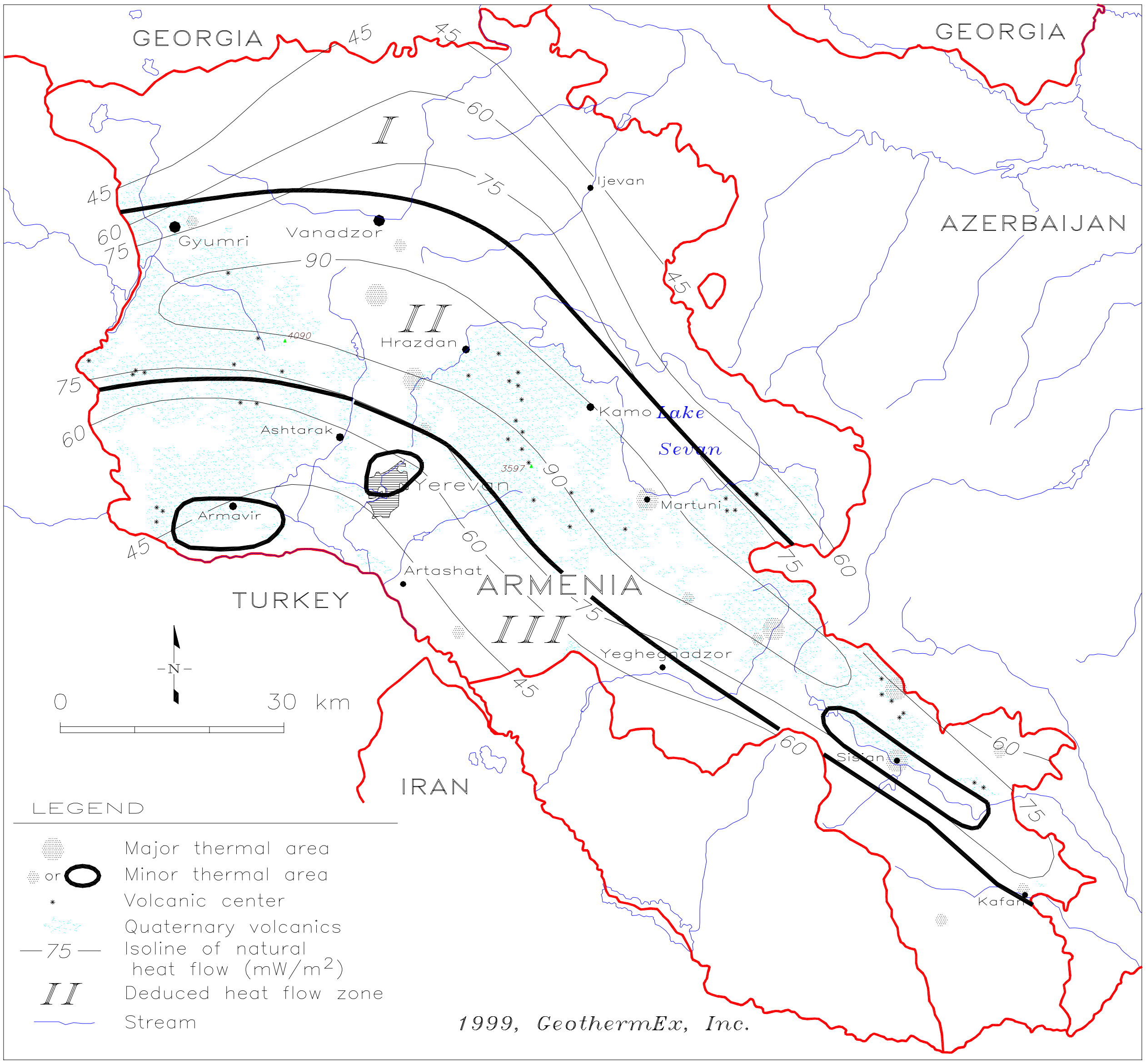

Figure 2: Contour of heat flow with deduced heat flow zones