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BURNS AND ROE ENTERPRISES, INC.

FINAL REPORT

ASSESSMENT OF THE GEOTHERMAL RESOURCES OF THE REPUBLIC OF ARMENIA

DELIVERY ORDER No. 28
Hydro/Thermal Power Rehabilitation Feasibility Reports

ARMENIA

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Prepared by	**GeothermEx, Inc**
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ASSESSMENT OF THE GEOTHERMAL RESOURCES OF THE REPUBLIC OF ARMENIA

for

BURNS AND ROE ENTERPRISES, INC.
Washington, D C.

by

GeothermEx, Inc.
Richmond, California
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SUMMARY

GeothermEx, Inc has carried out an assessment of the geothermal resources of the Republic of Armenia as part of the USAID Energy Efficiency and Market Reform Project The objectives of the assessment have been to characterize, compare and rank the different areas where geothermal resources are known, and to identify potentially feasible energy development projects that could utilize the known resources

The use of geothermal energy in Armenia is quite limited at present, but significant investigations of the country's thermal areas have been undertaken, including the drilling of numerous shallow to intermediate-depth wells Information for this assessment was obtained from direct observations made during site visits, from discussions with a number of government and academic specialists, from records and publications supplied by the government, and from other published sources

To date only low-temperature geothermal resources (cooler than 100°C) have been discovered in Armenia The most significant resources occur within a zone of high heat flow that trends roughly NW-SE through the central part of the country, this zone coincides closely with a belt of Quaternary volcanism, within which eruptive activity as young as 4,000 years has been identified In this central zone, production of water in the range of 40-63°C has been obtained from wells ranging in depth from less than 200 m to about 1,150 m, in the areas of Jermuk, the Vorotan River valley (including the towns of Sisian, Uz, Vorotan and Shamb), Ankavan, Arzakan, Gyumri, Martuni, and possibly Sayat Nova Wells presently capable of production are known to exist at Jermuk (with a combined capacity of at least 17 l/sec of 50-63°C water), Ankavan (perhaps 40 l/sec or more, 30-42°C), and Arzakan (probably less than 10 l/sec, to 45°C) In the Vorotan River valley there are several wells in different areas that might be capable of being rehabilitated, to produce water of 40-43°C at moderate

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to high rates Rehabilitation of one well at Martuni, to obtain production of up to 40-50 l/sec at 40°C or more, might be possible Development conditions at Gyumri and Sayat Nova are uncertain

Southwest of the central zone there are a few areas where water of 20-32°C has been produced from shallow wells In addition, temperatures up to 87°C have been encountered in deep (2,000 to 3,300 m) wells drilled in the Ararat Basin and the Central Basin Although production of water at 80°C or more has been reported in at least one deep well, it is uncertain whether any of the deep wells are currently capable of hot water production

The region to the northwest of the central zone is one of low heat flow, without any reported warm springs or wells This region appears to have no geothermal resource potential

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 may be commercially useable in a variety of direct-use applications, including agricultural applications, space heating and hot water supply, and applications related to tourism The use of heat pumps in combination with thermal waters should be considered as an option in heating applications, to allow for flexibility in working fluid temperatures Utilization of water from the deep zones of the Ararat and Central basins is unlikely to be economic if new wells are required to obtain production

Infrastructural and demand conditions appear to be favorable for the development of geothermal direct-use projects Projects that are feasible over the short term are almost certain to be small-scale and local in nature, and therefore are likely to depend on local interest and perhaps on private or unconventional financing for their development

The areas of known geothermal resources that are most attractive for near-term development of direct-use projects are

- **Jermuk** Bathing and swimming pools in conjunction with new or existing resort facilities, space heating and hot water supply for individual buildings, possible eventual conversion of the district heating system

- **Ankavan** Resort use (bathing and swimming pools), space heating and hot water supply for individual buildings, possible greenhouse heating

- **Vorotan River valley** Greenhouse heating or space heating, based on rehabilitation of existing wells

Other areas that may have near-term development potential include Martuni, Arzakan and the Gyumri area

Further exploration within the central zone is warranted in an effort to expand the identified geothermal resource base Both exploration around known thermal areas (to seek higher temperatures or more extensive resources) and investigation of the areas of youngest volcanism (to seek moderate to high-temperature resources) are recommended, these approaches could be followed individually or jointly Recommendations for activities to be undertaken within both types of exploration are included in this report Known areas that should be prioritized for further exploration are Jermuk, Ankavan, Arzakan, Gyumri, the

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Vorotan Rıver valley and Martunı Based on revıew of geologıc data and analysıs of satellıte ımagery, the Jermakhpur area, the Jermuk basın, the Gegam Mountaıns and the Vardenıs Mountaıns are the most attractıve areas of young volcanısm for new exploratıon

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1 INTRODUCTION

1 1 Background and Scope

GeothermEx, Inc has been contracted by Burns and Roe Enterprises, Inc to carry out an assessment of the geothermal resources of the Republic of Armenia, as part of the USAID Energy Efficiency and Market Reform Project (CCN-0002-Q-00-3154-00), Delivery Order No 28 Armenia Power Supply/Conservation Program The principal objective of the program is to identify potential energy supply or conservation projects that could be undertaken, using private or public financing, to reduce Armenia's present dependence on electric energy from the Armenia (Medzamor) Nuclear Power Plant Development of projects for the utilization of geothermal resources of Armenia is one means in which this objective could be partially met In addition, geothermal development would simultaneously reduce the country's demand for imported energy, diversify the energy resource base, expand the use of renewable energy sources, and help mitigate certain environmental problems on a local and global basis, particularly the emission of greenhouse gases

The use of geothermal energy in Armenia is quite limited at present, and mostly is in the form of small-scale and informal applications However, as described in section 2 1 of this report, significant investigations of the country's thermal areas have been undertaken, mostly during the Soviet era Therefore, the available information is more extensive than it might be in some other countries with similar levels of resource utilization, though much of it is in a form that is different than that commonly found in western countries

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 since the time of independence These include, most importantly, a study by Lahmeyer International (1994, 1996), and a "reconnaissance study" commissioned by the

World Bank and performed by Petroleum Geology Investigators (1998) The former study reviewed the occurrence and basic features of geothermal resources in Armenia, but focussed on the development planning aspects of resource utilization, particularly for electricity generation and district heating The latter study also summarized the resources of the country, but was largely devoted to an investigation of the potential use of geothermal water as an energy source for the Yerevan district heating system A more limited study, conducted by CFG (1993), assessed the feasibility of a geothermal pilot project for heating a hospital in the city of Martuni These studies have been reviewed as part of GeothermEx's work, comments are included within this report, and specific comments can be found in Appendixes A and B

In the present study, emphasis has been placed on developing a more complete description and assessment of the geothermal resources of Armenia, in order to allow the different areas of resource potential to be compared and prioritized on a consistent basis Chapter 2 presents this overall assessment Based on the occurrence and characteristics of the identified thermal areas, an overview of potentially feasible energy development projects is presented in Chapter 3 That chapter also includes a discussion and assessment of non-resource factors, including demand, legal, social and infrastructural factors that may influence the feasibility of commercial development

From the country-wide assessment of resources, several individual areas have been prioritized as having the greatest potential at this time for the development of commercial projects Chapters 4-6 describe in detail each of these areas, and the specific opportunities that exist there Chapter 7 briefly describes the potential of several other areas of lower priority

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In addition to the potential development of known resources, further exploration work is justified in Armenia for the identification of geothermal resources of greater temperature or extent than those currently identified Under present conditions it is unlikely that substantial privately funded exploration would be carried out in the near term, however, international assistance or other fund may become available for such activities Chapter 8 presents recommendations of areas and activities where new exploration work can appropriately be focussed, and gives general suggestions for reinforcing and broadening the geothermal energy establishment in the Republic of Armenia

1 2 Work Activities

This study is based mainly on the results of two visits made to Armenia by GeothermEx's Manager of Earth Sciences, in May-June 1998, and July-August 1998 During these visits, the following activities were undertaken

- Meetings with geothermal, earth science and engineering specialists from government agencies and organizations, including, most importantly, the Ministry of Mineral Resources (Ministry of Nature Protection), Ministry of Energy, and the Academy of Sciences Discussions of information sources, specific aspects of geothermal resource areas, current and planned utilization, and legal and infrastructural factors were carried out during these meetings

- Collection of pertinent information (maps, publications and unpublished data) from government and other sources

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- Visits to a number of geothermal resource areas, including Jermuk, the Sisian area, Ankavan, Arzakan and Martuni These visits included observation and description of existing wells and other facilities, collection of information on local infrastructure, and discussions with local authorities, where available Water samples were collected from several areas, for later analysis in the United States

- Preliminary review and assessment

Detailed descriptions of activities undertaken during these visits have been provided in separate trip reports The data obtained during the visits have been reviewed and analyzed along with other information obtained from published sources in the U S and elsewhere Analysis of data and preparation of the final report were undertaken in GeothermEx's home office

1 3 Data Base

Data used in the development of this assessment included

- Published descriptions and data from thermal areas This included, importantly, a comprehensive summary by Mkrtchian (1969)

- Various unpublished maps and data pertaining to the geothermal resources of Armenia, including data on wells and water chemistry

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- Published descriptions of the geological characteristics of Armenia in general and its geothermal resource areas in particular, these included geologic and tectonic maps, descriptions and results of geophysical surveys, and volcanologic studies

- Information obtained in the course of discussions with government and other specialists, relating to geothermal resources, geologic and volcanologic characteristics of the country, and non-resource factors influencing geothermal development

- Published data, including data from Internet sources, relating to the demographics, legal and social structure, infrastructural conditions, and energy demand conditions of Armenia

- The reports prepared by Lahmeyer (1994, 1996), Petroleum Geology Investigators (1998) and CFG (1993)

- Direct observations made during site visits to thermal areas, and the results of chemical analyses of samples collected during the site visits

The majority of available published and unpublished documents that contain information on the geothermal resources of Armenia are in Russian, and only partial translations were possible in the time available for this study In a number of cases, conflicts were found between different data sources, particularly as regards specific features of individual areas (for instance, discrepancies were often found in reported flow rates and temperatures of specific wells) In order to include as much information as possible that may be useful in promoting future development, some data are reported here for which such conflicts could not be completely resolved Where this is the case, conservative estimates of resource characteristics have been used

Aside from the discrepancies noted, the quality of the data obtained appears to be good overall, and the standard of the geologic and geophysical work undertaken on a regional and local basis is quite high In general, field observations indicated the data obtained from published and unpublished sources to be accurate It should be noted, though, that some types of information normally associated with the analysis and assessment of geothermal resources in western countries were not available For example, precise locations of wells with respect to physical and cultural features frequently could not be obtained, and descriptions of well completions (hole and casing diameters, casing depths, and wellhead equipment) were normally unavailable No downhole measurements from wells were obtained, such measurements, particularly of downhole temperature and pressure profiles, are a critical element of the assessment of developed geothermal areas Well testing data were often limited or absent It is not clear whether such data were not routinely collected, or were simply unavailable Chemical analyses of thermal waters, though apparently of good technical quality, most frequently either omit analysis of potassium or report sodium and potassium together as a single total, this restricts the calculation of chemical geothermometers

There has traditionally been an emphasis on using the thermal waters of Armenia for therapeutic, recreational and touristic purposes rather than as an energy source The types of information available reflect this emphasis

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2 OCCURRENCE OF GEOTHERMAL RESOURCES IN ARMENIA

2 1 History of Exploration

The thermal waters of Armenia have been described for at least several centuries Mkrtchian (1969) notes that the thermal waters of Jermuk were described in middle-age Armenian literature The first scientific studies of thermal and mineral waters were undertaken in the early 19th century by Armenian and Russian investigators, in conjunction with geologic and mineral resource surveys

Intensive study of thermal and mineral waters appears to have begun in the 1920s and 1930s, with investigation of water temperature and chemistry, and of the local geology of the thermal areas Some drilling or excavation of shallow wells may have taken place during this period, but no extensive drilling appears to have taken place

Significant drilling in the thermal areas began in the 1950s, and continued through at least the 1960s During this period hundreds of wells were drilled, mostly to depths of a few hundred meters or less, but some to more than 1,000 m In addition, regional heat flow studies were carried out during this period, with coreholes drilled to measure temperature gradients Other geophysical studies, including gravimetric, magnetic and electrical studies were also performed during this period (Mkrtchian, 1972) Most of these were of a regional nature, but local magnetic studies were carried out at the Jermuk area

The wells drilled during the 1950s and 1960s, along with concurrent geologic and geophysical investigations, provide substantial information about the temperature, chemical and hydrological characteristics of the known thermal areas of Armenia It should be noted, however, that for the most part these investigations were aimed at characterizing the thermal areas for their potential use as supplies of mineral water for therapeutic and other uses, rather than as an energy source Drilling was generally concentrated in the immediate area of thermal springs, and few attempts appear to have been made to seek higher-temperature water, either by step-out drilling or by hydrogeologic modeling of the thermal water systems

A number of deep wells (to depths of more than 3,000 m) were drilled in the Ararat Basin (along the Araks River) and the Central Basin (Yerevan area) during the 1960s and early 1970s These wells were drilled for petroleum exploration, but they provided useful data on deep temperature gradients and geology

Available data indicate that, since the early to mid 1970s, very few new wells have been drilled, and few specific studies of thermal areas have been carried out One exception is the Jermakhpur area in the Syunik region, where two slim exploration holes have been drilled within or near a young volcanic center, and complementary geophysical and volcanological studies have been carried out (Karakhanian et al , 1997)

2 2 Regional Geology

The Republic of Armenia is for the most part an area of rugged topography, located in the Lesser Caucasus mountain chain (figure 2 1) The predominant topographic and structural trend in Armenia coincides with the overall northwest-southeast trend of the Lesser Caucasus The geology of the region is complex, owing to accretion of exotic terranes through plate tectonic processes, and to ongoing tectonic activity and volcanism The regional geologic setting can be simplified somewhat by classifying the country into several different regions of distinct characteristics (figure 2 2)

In the northeastern region of the country, rocks of Prepaleozoic to Lower Tertiary age predominate, and a strong WNW-ESE structural grain is evident Along the southern margin of this region two ophiolite belts are present, reflecting the presence of a suture zone(s) between terranes

A belt of Quaternary volcanic activity that takes the form of a series of volcanic highlands dominates the central region of Armenia Figure 2 2 shows the distribution of Quaternary-age volcanic deposits Numerous Quaternary volcanic centers can be distinguished within the volcanic belt Geologic mapping indicates that volcanism has taken place more or less continuously since Lower Pliocene or Upper Miocene time

The distribution of volcanic centers and volcanic deposits indicates that there are 4 somewhat distinct zones of young volcanic activity The Aragats Massif dominates the northwestern end of the volcanic belt, with subsidiary volcanic centers extending to the western border of the country A gap in young activity separates the Aragats Massif from the Gegam Mountains, which extend along the southwestern shore of Lake Sevan as a series of distinct volcanic cones The east-west-trending Vardenis Mountains border Lake Sevan on its south side, and are relatively distinct from the Gegam range, but nearly contiguous with the Karabagh Upland, which trends southeastward into the southernmost portion of Armenia Analysis of topography and satellite imagery (see Chapter 8) indicates that the youngest volcanoes occur in the Karabagh Upland and the Gegam Mountains The youngest dated eruptive deposits, with an age of about 4,000 years, are in the Jermakhpur area of the Karabagh Upland (Karakhanian *et al*, 1997)

To the southwest of the southern part of the volcanic belt is a zone of rugged topography formed by the southern Gegam Mountains, the Vayk Mountains, and the Zangezur Range This region has a WNW to NW structural trend and an absence of young volcanic activity, Prepaleozoic to Lower Tertiary rocks predominate The extensions of these formations probably make up the basement rocks within the adjacent volcanic belt

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Along the Araks River and extending northeastward to the margin of the volcanic belt are two major sedimentary basins the Ararat Basin (along the river) and the Central Basin (northeast of the Ararat Basin, including the Yerevan area) These are divided structurally into a number of smaller sub-basins, and depths to basement vary considerably, from about 500 m to as much as 6,000-8,000 m (Petroleum Geology Investigators, 1998) The basin fill consists mostly of sediments of Upper Mesozoic to Quaternary age, but Pliocene and younger lavas, apparently erupted from centers within the present-day volcanic belt, cap the basin sediments in many areas The Ararat and Central basins have been the focus of petroleum exploration efforts in Armenia

2 3 Heat Flow Zones

Regional heat flow has been interpreted from measurements in numerous drillholes throughout Armenia, including more than 60 holes drilled specifically for the measurement of temperature gradients and rock thermal conductivities Figure 2 3 shows one interpretation of the distribution of natural heat flow, as reported by Lahmeyer (1994)

Investigators have used the distribution of heat flow and temperature gradients to distinguish several heat flow zones In most cases, a classification of three zones has been used The selection of the limits of the zones varies somewhat, figure 2 3 shows a generalized version of the zonation

The northeastern zone of Armenia (zone I) is characterized by low heat flow (less than 60-75 mW/m^2) and low temperature gradients (12 to about 43°C/km) No thermal waters have been reported in this zone in either springs or wells Zone I is considered to have no potential for geothermal resources, we concur with this assessment

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The central zone (zone II) is one of high heat flow (from about 75 to more than 90 mW/m^2) and elevated temperature gradients (generally greater than 50°C/km) As figure 2 3 indicates, this zone coincides closely with the belt of Quaternary volcanoes that trends through the central region of the country Zone II also includes all of the principal areas where thermal waters are found at relatively shallow depths The thermal areas do not coincide uniquely with areas of young volcanism, but they are relatively closely aligned along the axis of highest heat flow The central zone is generally considered to have the greatest potential for the discovery of new or higher-temperature resources, again, we agree with this conclusion

The southwestern zone (zone III) has low heat flow (less than 60-75 mW/m^2) and generally low temperature gradients (mostly less than 33°C/km), however, there are scattered occurrences of thermal waters in this zone These occurrences include water produced from deep wells drilled in the sedimentary basins, and several areas of low-temperature (32°C or less) springs There has been some interest in exploiting thermal waters in the sedimentary basins by deep drilling (to 2,000 m or more)

2 4 <u>Description of Thermal Areas</u>

The known natural discharges of thermal water in Armenia have been comprehensively catalogued and described, and one or more wells have been drilled in most thermal areas Therefore, it is possible to characterize and compare the different thermal areas to at least a preliminary degree This section presents brief descriptions of the various identified thermal areas, more complete descriptions of the areas considered to have the greatest potential for geothermal development are provided in chapters 4-6 Section 2 5 describes the chemical characteristics of the waters of some of the areas

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No production of thermal waters in excess of 65°C from wells or springs has yet been reported in Armenia, except for limited production of higher-temperature water (up to about 87°C) from some of the very deep wells drilled for petroleum exploration Therefore, all of the available geothermal resources of the country fall within the low-temperature classification (less than 100°C)

For the purposes of this study, an arbitrary cutoff temperature of 20°C was used to distinguish thermal from non-thermal waters This is a relatively low cutoff, but is appropriate given the overall low range of resource temperatures There are numerous reported occurrences of mineral springs with temperatures in the range of 10-20°C, applying the 20° cutoff restricts the areas examined to a reasonable number

The areas meeting the cutoff temperature criterion are shown in figure 2 4 The principal characteristics of the thermal areas are presented in table 2 1 Table 2 2 gives data for individual wells and springs in the different areas All wells and springs for which data were available are shown in table 2 2, but it is clear that, for at least some of the areas, some wells and springs are not included due to lack of information

We have classified 6 of the areas as major or important thermal areas, based on their temperature, extent, and/or degree of development These are Jermuk, the Vorotan River Valley (Sisian area), Ankavan, Arzakan, Martuni and Jermakhpur Other investigators have generally concurred in this classification, although there is no consensus as to the priority sequence Areas classified as minor in figure 2 4 are generally of lower temperature, have been little explored by drilling, or require very deep drilling to reach zones of thermal water

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Jermuk (Vayots Dzor region) is the area where the highest production temperatures (up to about 63°C) have been obtained, and which has been developed most extensively by drilling More than 30 wells reportedly have been drilled in and around the town of Jermuk, which occupies a lava plateau alongside the Arpa River, and which has long been developed as a touristic/health resort area One of the most popular brands of mineral water in Armenia is bottled here, the source of the water is one of the existing wells (30/62) Well depths are shallow to intermediate (maximum 642 m), and production appears to be obtained from an extensive aquifer or series of aquifers beneath thick young andesite/basalt flows Production rates for individual wells are typically in the range of 1 to 5 l/sec, and the combined production available from 4 currently active wells is said to be at least 17 l/sec, with an average temperature probably in excess of 55°C The temperature, size, and degree of development of the Jermuk resource gives it the highest priority as a candidate for possible geothermal energy utilization The characteristics of the Jermuk area are described in greater detail in Chapter 4

In the **Vorotan River valley** (Syunik region), thermal springs and wells are present at several locations adjacent to the river, notably at the principal city of Sisian and at the villages of Uz, Vorotan (formerly called Urut), and Shamb The distribution of springs suggests that a potentially large resource area may exist over a 50-60 km-long corridor along the river The wells that have been drilled in the area are characterized by relatively low temperatures (25 to 43°C), but high artesian flow rates (greater than 10 l/sec, up to a reported 102 l/sec) The wells that produce at the higher temperatures (greater than 40°C) are relatively deep (700 to 1,150 m), but the high production rates make the area attractive for low-temperature applications, particularly if one or more of the existing wells can be rehabilitated for use There is no current use of the thermal waters in this area, except informal use for bathing The Vorotan River valley thermal areas are discussed in Chapter 5

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At **Ankavan** (Kotayk region), several springs and at least 11 wells are located along a several-hundred-meter stretch of the Marmarik River Several of the wells appear to be in good condition, and two are in use at present for non-geothermal applications, supplying carbon dioxide to a bottling plant and dry ice factory, and mineral water to a local sanatorium Well depths are shallow (typically 50-100 m, maximum 410 m) and the maximum production temperature is 42°C Based on reported production rates, several wells could supply a large volume (in excess of 40 l/sec) of 30-40°C water The shallow resource depth and relatively extensive development give Ankavan priority as a resource area Chapter 6 describes the Ankavan area in greater detail

Arzakan is located a short distance up a river valley in the Tzaghkunyats Range, not far from the city of Charentsavan, and within about 30 km of Yerevan Little detailed information is available for this area, but at least two wells have been drilled, with production of water up to 45°C, and reported production rates up to about 7 l/sec One well currently supplies a commercial bathhouse located alongside the river The area is located within a zone of Mesozoic to Prepaleozoic sediments and intrusive rocks, overlapped by Upper Tertiary to Quaternary volcanics The thermal water probably originates from circulation within the older, basement rocks in the regime of high regional heat flow The potential extent of the resource is uncertain

The **Martuni** thermal area is located along the shore of Lake Sevan at its southwestern corner, within and near the city of Martuni One or more thermal springs occur in the area, this prompted the drilling of several wells to depths of 200-971 m Maximum temperatures of about 40°C have been reported for the deepest of the wells (3-T), the shallower wells have lower temperatures Investigations by CFG (1993), including geothermometry from chemical analyses of sampled water, concluded that higher temperatures (up to 60°C or greater) might be masked in well 3-T by influx of cooler water

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at shallower depths, however, there has been no direct measurement of such temperatures Two wells, including 3-T, can be seen in the area but they have no wellheads and damaged casings, these wells currently discharge cold mineralized water It is uncertain whether either of the wells could be rehabilitated for use Well 3-T had a high reported production rate of 40-50 l/sec

Production of thermal water at Martuni appears to come from one or more aquifers within the volcanic sequence filling the Lake Sevan basin Whether the water originates from heating by the regional gradient, or as outflow from a higher temperature system elsewhere, is unknown Interest has been shown in the Martuni area for possible use of the resource in heating local buildings (Appendix B), there is no use of the resource at present

The **Jermakhpur** area (Syunik region) is located along the crest of the Karabagh Upland, near the Armenian border Two springs in the area have reported temperatures of 22°C to 32°C In addition, the area is considered to be of interest because it is the center of the youngest volcanism in Armenia (Karakhanian et al , 1997) Detailed geologic mapping and various geophysical investigations, including magnetotelluric, seismic, magnetic and gravimetric surveys, have been carried out in the area The results of the geophysical surveys were not available for this study, however, a summary by Lahmeyer (1994) indicated that investigators have inferred the presence of a magma chamber at depths as shallow as 2 km beneath part of the area In addition, small caldera structures, and a north-south-trending graben structure formed by extensional tectonics, have been inferred

Two slim holes have been drilled in the Jermakhpur area, to depths of 1,000 m and 600 m Neither hole produced any fluid Temperatures measured in the southern, shallower hole were low (36°C maximum), but the northern hole reached 99°C at its total depth The temperature gradient in the deeper part of the northern hole is reportedly 80 to

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100°C/km, suggesting the possibility that temperatures as high as 200°C might be encountered at drillable depths However, based on existing information, there is no certainty that a high-temperature resource exists, and so far no commercial resource of any kind has been demonstrated, due to the lack of production The isolated location of the area presents a further obstacle to potential commercial development Chapter 8 discusses recommendations for further exploration in this area

The **Sayat Nova** area (Vayots Dzor region) is located a short distance (5 km or less) southwest of Jermuk, in a setting that is physiographically and geologically similar Little information is available for this area, but the similarity of its setting to that of Jermuk suggests that the thermal waters at Sayat Nova likely originate from a comparable system Several springs and shallow (less than 80 m) wells discharge water reported by Mkrtchian (1969) to be up to 36°C, though Lahmeyer (1994) reports temperatures as high as 44°C There is a reasonable possibility that deeper drilling might reveal a higher temperature resource, as at Jermuk, however, the lack of existing deeper wells, coupled with the lack of local demand, make commercial exploitation unlikely in the near term

In the **Gyumri area** (Shirak region) wells with production temperatures up to 42°C have been reported near the city of Gyumri and the town of Kamo This area is located at the margin of the Quaternary volcanics in northwestern Armenia, where they lap onto Lower Tertiary to Mesozoic units Little information regarding the wells in this area is available, however, the large population of the area would provide potential demand, should a significant resource be present

In the **Ararat area** (Ararat region), a number of springs and shallow wells (up to 478 m deep) are present near the margin of the Quaternary sediments of the Araks River valley, where they overlie rocks of Upper Paleozoic to Lower Tertiary age along the base of

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the foothills of the mountains to the northeast Maximum reported temperatures are 28°C, but reported production rates of some wells are high (in excess of 20 l/sec) The lack of variation in temperature with well depth in the area suggests that the maximum resource temperature is probably not significantly higher than the temperatures already observed

The **Ararat Basin** is the term for the major sedimentary basin that extends along the Araks valley through the Armavir and Ararat regions and includes, principally, the Oktemberian and Artashat sub-basins Deep wells (to more than 3,500 m) have been drilled in this basin for petroleum exploration, temperatures at least as high as 87°C have been measured in these wells Artesian flow of water in excess of 80°C at a high flow rate (20-25 l/sec) has been reported for one well (Oktemberian 11), this well is said to have scaled shut in a short period of time Reported water production rates for other wells are mostly small, and comprehensive temperature data do not seem to be available (Petroleum Geology Investigators, 1998) It can be concluded that, while production of water in the range of 50 to 100°C is possible in the Ararat basin, obtaining such production requires drilling wells of roughly 1,500 to 3,000 m, this implies very high drilling expense for a resource of these temperatures In addition, no production is known to be available now from existing wells, and new drilling would carry the risk of obtaining low production rates or even dry holes

Deep wells in the **Yerevan area** (Yerevan and Kotayk regions) have been drilled within the Central Basin for petroleum exploration The geologic and thermal characteristics of this basin appear to be similar to those of the Ararat Basin Temperatures ranging up to 80°C or more have been reported at depths of 1,500 m to more than 2,000 m The maximum reported production of hot water from a single well is about 1 4 l/sec, from Razdan-20 An interpretation of basin conditions by Petroleum Geology Investigators (1998) indicates that, in general, temperatures of 50°C are likely to be encountered near a depth of 1,800 m, and 110°C near 3,400 m As with the Ararat Basin, high drilling costs, dry hole

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risk, and the lack of existing production limit the attractiveness of this area for near-term commercial exploitation The main interest in the area is motivated by its proximity to the large population of Yerevan

At **Kajaran** (Syunik region) one well has been drilled to a depth of 100 m, with a reported temperature of 32°C Unlike most of the other known thermal areas, the Kajaran area is within or at the margin of an extensive terrane of Lower Tertiary-age intrusive rocks No other significant information was available for this area

In the **Yeghegis River area** (Vayots Dzor region) a single spring of temperature 30°C has been reported No wells appear to have been drilled in the area, and little information is available The warm spring occurs along the trend of the major thermal areas (figure 2 4), near the southern margin of the Quaternary volcanics of the Vardenis Mountains

The **Maymekh** area (Lori region) is located to the south of the city of Vanadzor, in the Pambak Mountains A single spring, of temperature 27°C, has been reported there Detailed information is not available for this area, but the geologic setting is somewhat similar to that of Ankavan, which is located about 10-15 km to the south

At **Kafan** (Syunik region), one well drilled to a depth of 337 m has a reported temperature of 23°C The area is within a terrane of Jurassic-age volcanogenic rocks, but a small exposure of Quaternary volcanics is present nearby

The **Arzni** area (Kotayk region) is located about 10 km NNE of Yerevan, in a zone where Quaternary volcanics cover Upper Tertiary volcanogenic units Numerous shallow wells have been drilled in the area, at least 6 of the wells encountered temperatures of 20-

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22°C These wells range in depth up to 170 m, and a flow rate of 9 2 l/sec has been reported for one well There is no indication of a resource of significantly higher temperature in the area, though it is possible that deeper drilling could yield slightly hotter water Several km to the northeast, a well drilled at Jraber had a reported temperature of 23 5°C

In the **Goris-Karashen** area (Syunik region), several springs with temperatures up to 21°C are reported It is uncertain whether any wells have been drilled in this area The springs are located in a terrane of Upper Tertiary-age volcanogenic units, along the trend of the Quaternary volcanic belt

2 5 Chemistry of Thermal Waters

2 5 1 Introduction

Chemical analyses of mineral and thermal groundwaters in Armenia were available from Mkrtchian (1969), and from a number of analyses that were provided by Armenian authorities In addition, four water samples were collected during field work in August 1998 (one at Ankavan, two at Jermuk, one at Sisian) and one water sample was collected during field work in May 1998 (at Jermuk) These were analyzed at a laboratory in the United States, and the results are included herein (Appendix C, plus tables and graphs discussed below)

The available analyses from six thermal areas or regions have been compiled into table 2 3, which lists only the major cations and anions plus silica (SiO_2), because most of the analyses do not include minor and trace species The six regions are Ankavan, Jermuk, Sisian (Vorotan River valley), Kamo-Martuni, Arzakan-Bjni and Arzni, and each is subdivided by name of local geographic area

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Many of the analyses (table 2 3) do not include potassium (K) In such cases, we have assumed that the reported value of sodium (Na) actually includes potassium, because Na probably has been determined by the analyst as equivalent to the excess of anions over the sum of calcium (Ca) plus magnesium (Mg)

In addition to the chemical data, table 2 3 lists the flow rates and measured temperatures of wells and springs, where available The temperature data are incomplete, so it is not certain that the samples fully represent the hottest thermal waters in each area The best-represented area is Jermuk, which is also the hottest

The highest temperature tabulated for a Jermuk sample is 63 C, but there is a report of 67°C at an unknown location there The highest temperature tabulated for the Sayat-Nova area of Jermuk is 34 to 36°C, but there is a report of 44°C in that area The deepest wells at Sisian are reported to reach 42 C but the highest temperature listed with a sample is 31°C, and there is one report of 40°C at Martuni, but sample data only to 19°C

2 5 2 Chemical Composition of the Thermal and Mineral Waters

The compositions of thermal and cold groundwater compositions are determined by various combinations of host rock chemistry, age of residence, presence of gases (primarily CO_2) that promote mineral alteration and dissolution, temperature, and mixing between waters of different origin As a very general rule, the highest temperature geothermal systems (above 200°C) tend to have waters dominated by sodium (Na) and chloride (Cl), whereas lower temperature systems (100 - 200 C, especially in volcanic rocks)

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tend to have waters dominated by Na and sulfate (SO_4), and cooler mineral waters (<100°C) tend to be dominated by calcium (Ca), magnesium (Mg) and bicarbonate (HCO_3)

However, even cool groundwaters can be dominated by Na and Cl, if they occur in rocks that contain halite (NaCl), and Na with Ca and SO_4 can dominate cool waters that reside in altered volcanic rocks Moderately thermal waters can show mixed anion compositions, though Ca and Mg tend to be low relative to Na as a result of temperature Potassium (K) usually substitutes for Na as an effect of increasing temperature, being relatively lowest at low temperature and higher at high temperature Magnesium is almost always very low if the water temperature exceeds 150°C

All of the Armenian thermal and mineral waters have mixed-cation mixed-anion compositions that correspond to temperatures not likely to exceed 100 C (see below) There are differences between regions, and some show broad internal variations Total dissolved solids (TDS) reach about 0 5 gm/l, sometimes higher As is common world-wide, the hotter and more saline examples tend to have a higher ratio (Na+K)/(Ca+Mg), and relatively higher chlorides to bicarbonate (Cl/HCO3) or sulfate to bicarbonate (SO_4/HCO3), and the cooler waters tend to be higher in Ca+Mg (especially Ca) and bicarbonate (HCO_3) These are the aforementioned effects of temperature, rock composition and mixing

Figures 2 5 - 2 10 illustrate the compositions of selected samples from local areas within each of the six regions The graphs are "Piper" diagrams, which represent the major cation and anion ratios, plus TDS Each triangular portion of the graph shows the relative percentage of each ion or ion sum, by weight, among three components The diamond-shaped portion of the graph shows points from the triangles projected into the diamond Ideally, data points that represent unaltered mixtures of two chemical compositions will fall into straight lines on both triangles and on the diamond In reality, mixing often involves

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more than two components, and other chemical alterations often contribute to a scatter of points Samples on figures 2 5 - 2 10 were selected to include areas where there are waters at about 30°C and hotter, plus cooler waters from immediately adjacent sources that are likely to be mixing with the hotter waters Accordingly, many of the samples from table 2 3 are not included

Figures 2 11 - 2 13 show TDS vs temperature in the Ankavan, Jermuk and Sisian areas The other areas could not be represented due to lack of temperature data that directly correlate with individual samples Summary comments by area follow in section 2 5 4

2 5 3 Chemical Geothermometers

Chemical geothermometry is a method of estimating aquifer temperature from fluids chemistry This is possible because temperature controls the chemical reactions between water and rock minerals, and the water composition does not shift during travel to the ground surface up a well or rapidly discharging spring, unless there is mixing with shallower water or deposition of mineral scale The available methods of geothermometry can be quite accurate and unambiguous when applied to waters that have aquifer temperatures above roughly 150°C, but they become increasingly uncertain at low temperatures Still, valid inferences can be drawn from lower-temperature data, down to well below 100°C

The most reliable methods depend upon the concentration of silica (SiO_2) and the ratios between cations, including Na, K, Ca and Mg Table 2 4 lists these geothermometers applied to the analyses of table 2 3, where possible

Silica solubility temperatures are listed for the minerals quartz, chalcedony and amorphous silica (which includes volcanic glass) The solubility of all three solids increases with temperature At the low temperatures of the Armenian geothermal systems, any of these three forms may, but do not necessarily, control the level of dissolved SiO_2 Silica temperatures that are substantially higher than measured temperatures are suspect unless there is good corroborating evidence that the deep hydrothermal system is substantially hotter than measured at the surface Many samples have less SiO_2 than would dissolve from amorphous silica at 0°C, but incomplete dissolution of the amorphous solid can produce a falsely high estimate if it is assumed that solubility is controlled by chalcedony or quartz In addition, any of the silica temperatures can be lowered by mixing between hotter (higher SiO_2) and colder (lower SiO_2) water prior to surface discharge In spite of these complications, there is general agreement between the silica temperatures and measured temperatures, as is expected

Cation temperatures also tend to be inaccurate at low temperatures, where the most reliable indications should be given by the forms that represent Na-K-Ca-Mg and KMg Na-K-Ca without Mg can be reliable but tends to overestimate, as does Na/K, which is reliable only when the aquifer temperature exceeds 150° to 200°C Table 2 4 KMg temperatures tend to be higher than Na-K-Ca-Mg temperatures, but the difference is within the range of uncertainty under these conditions, so there is general agreement between cation temperatures and measured temperatures in all of the areas

The results of chemical geothermometry are summarized as table 2 5, which shows the most reliable estimates for each area In some areas the uppermost cation temperatures are higher than reported temperatures and silica temperatures, by as much as 50°C This can be due to lagging re-equilibration, as cation temperatures do tend to represent deeper, hotter conditions where there is cooling Cation temperatures are usually less affected by

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mixing than silica temperatures, but this may not be the case where the cool component is highly mineralized, as is the case here

Table 2 5 Summary of chemical geothermometers

Area	Reported Maximum	Silica Temperature	Cation Temperature
Ankavan	42°C	30 - 60°C (amorphous)	50 - 65°C (Na-K-Ca-Mg and KMg)
Jermuk	64 - 67(?)°C	60 - 90+°C (chalcedony, quartz)	50 - 95 C (Na-K-Ca-Mg and KMg)
Sisian	to 42°C	60 - 80°C (chalcedony)	low (Na-K-Ca-Mg) 80°C (K-Mg)
Kamo - Martuni	40°C?	55 - 80°C (chalced) (data from Martuni only)	no data
Arzakan-Bjni	45°C	50+°C? (chalcedony)	<16 - 30 C (Na-K-Ca-Mg) 90 - 100°C (K-Mg)
Arzni	22°C	25°C (amorphous)	27 C (Na-K-Ca-Mg) 70 - 90°C (K-Mg)

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2 5 4 Summary by Area

Ankavan (figures 2 5 and 2 11) The waters have a (Na+K-Ca) - (HCO_3-Cl) composition with 0 52 to 0 65 gm/l TDS There is quite reasonable evidence that mixing occurs between a hotter water with lower salinity but higher relative Na+K and Cl, and a cooler water with higher salinity but lower relative Na+K and Cl Measured temperatures reach 42°C The chemical geothermometers suggest, tentatively and roughly, that temperatures to about 50° or 60°C may be present at depth, and this possibility is encouraged by the evidence of mixing

Jermuk (figures 2 6 and 2 12) is the best-represented area Here, mixing occurs between three components 1) a hotter Na - SO_4 water with about 0 4 gm/l TDS at 65°C or higher, 2) cool (Ca-Mg) - HCO_3 water with an average of about 0 2 gm/l TDS (maximum 0 4 gm/l) and, 3) cool dilute groundwater (probably shallow meteoric water), which reduces TDS but does not affect ion ratios

Jermuk provides the most confident chemical estimate of temperature higher than observed, and it is cautiously reasonable to expect 80 - 90 C somewhere at depth close to the range already drilled, given the existing evidence for mixing in the system

Sayat-Nova, adjacent to Jermuk, has a distinctive chemistry that is higher in TDS and chlorides, but at somewhat lower temperature

Sisian (Vorotan River) (figures 2 7 and 2 12) Cool to warm waters at Sisian and cool waters a few miles to the south have scattered cation compositions with roughly equal amounts of (Na+K) and (Ca+Mg), but they show a systematic range of anions from HCO_3 to HCO_3-SO_4 There probably are several mixing components, including a warmer water

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with about 0 2 gm/l TDS and equal amounts of SO_4 and HCO_3, and cooler waters with higher relative HCO_3 but TDS that ranges from less than 0 1 to 0 4 mg/l The highest geothermometers are 60 - 80°C, compared to a measured 42°C, but the evidence for temperatures above 40° - 45°C should be considered quite tentative, particularly because the mixing is relatively ill-defined

Martuni and Kamo (figure 2 8) This area is of interest because it could have outflow from deep geothermal system(s) that could (hypothetically) be located beneath the chain of relatively young volcanic centers that lies to the west The waters of Kamo and Martuni both (excluding other sources in the area) show mixing between mixed cation - HCO_3-Cl water (almost 50% anion fraction Cl) and more dilute bicarbonate water The higher-Cl component is probably also warmer, and it could be a much altered, cooled and mixed deep geothermal outflow, but there is no way to uniquely identify it as such

There are no temperature data associated with the water samples, and the cation analyses do not include K, so cation temperatures cannot be calculated It is reported that measured temperatures reach 40 C Silica temperatures (data from Martuni only) allow 50 - 80 C, but these should be considered unlikely in the absence of confirming information

Arzakan - Bjni (figure 2 9) There is loose evidence of mixing between mixed cation waters with greater and lesser fractions of HCO_3 relative to SO_4 and Cl Measured temperatures reportedly reach 45°C and the silica and Na-K-Ca-Mg geothermometers are in accordance KMg temperatures to 100 C are unlikely to be present at or close to the depths already drilled

Arzni (figure 2 10) There is well-defined mixing between a high Cl water with about 2 gm/l TDS and dilute HCO_3 water Measured temperatures reach only 22°C and the

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silica and Na-K-Ca-Mg temperatures are in accordance with the cold conditions Higher KMg temperatures (to 90°C) are doubtful

2 5 5 Mineral Scaling Potential

Low-temperature, bicarbonate-enriched thermal and mineral waters commonly deposit calcium carbonate in response to the degassing and loss of dissolved carbon dioxide (CO_2) that occurs upon discharge at the surface No attempt has been made to compile comprehensive information about carbonate scaling, but field observations indicate that it is fairly common Scaling can further be enhanced in wells if mixing between waters from different aquifers produces water that is more highly oversaturated with carbonate than is either component If wellbore or pipeline scaling does occur, it can be removed by mechanical means or acidization, or prevented using chemical scale inhibitors or by pumping the water to maintain pressure and avoid degassing

2 6 Summary

All of the geothermal resources identified to date in the Republic of Armenia can be classified as low-temperature resources (less than 100°C) Virtually all of the shallow resources (at depths less than 1,000 m) whose temperatures exceed 30°C occur within the zone of high heat flow that trends northwest-southeast through the central part of the country, which coincides closely with a belt of young volcanic activity Within this zone, production of water in the range of 40-63°C has been obtained at Jermuk, the Vorotan River Valley (Sisian, Uz, Vorotan, Shamb), Ankavan, Arzakan, Gyumri, probably Martuni, and possibly Sayat Nova Chemical geothermometry of waters does not indicate the presence of waters above 100°C in these areas

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The temperatures and chemistry of the waters in the central zone are generally consistent with an origin by heating resulting from circulation to moderate depths, given the regional heat flow and temperature gradient regime There is no strong indication that any of the systems are directly related to volcanic or subvolcanic heat sources (shallow intrusions or magma chambers) This does not, however, rule out the possible existence of moderate to high-temperature systems within the volcanic belt of Armenia, and additional exploration work is warranted to determine whether such systems may exist Chapter 8 provides some recommendations for such exploration Exploration in the Jermakhpur area has provided some indication that higher temperatures may be found within or near the youngest volcanic centers, but so far no production, or temperatures in excess of 100°C, have been encountered there

At present, substantial production (probably in excess of 17 l/sec) of water with temperatures in the range of 50-63°C is available at Jermuk It is probable that more production could easily be obtained there by rehabilitating existing wells At Ankavan, high volumes (perhaps in excess of 40 l/sec) of water at 30 to 42°C can be obtained from 2 to 4 existing wells Some production (probably less than 10 l/sec) can be obtained from one or more existing wells at Arzakan, with temperatures up to 45°C In the Vorotan River valley there are several wells in different areas that might be capable of being rehabilitated, for production of 40-43°C water at moderate to high rates Rehabilitation of one well at Martuni, to obtain production of up to 40-50 l/sec at up to 40°C or greater, might be possible It could not be determined whether any wells capable of production currently exist in the Gyumri-Kamo area Conditions are also uncertain in the Sayat Nova area

Deep wells drilled in the sedimentary basins southwest of the volcanic belt (Ararat Basin and Central Basin) have encountered water at temperatures consistent with the gradients of 15 to 33°C/km reported for this region, with a maximum temperature of 87°C

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reported in a well of 3,100 m depth Drilling for hot water in these basins would be both expensive (due to required well depths) and risky It is likely that no water production is available from any of the deep wells at present

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3 POTENTIAL FOR GEOTHERMAL DEVELOPMENT

3 1 Technical Considerations

At the present time there are no identified geothermal resources in Armenia that could be developed for commercial generation of electric power Although it is possible that such resources exist, additional exploration would be needed to discover and develop them At least the initial stages of such exploration work would likely have to be publicly funded, either internally or through foreign assistance, given the current information on prospective areas

It has previously been recommended that geothermal power generation of 5 to 55 MW be prioritized for development and inclusion in Armenia's energy mix within roughly a 5 year period (Lahmeyer, 1994) This is unrealistic given known resources conditions For electric power generation by binary cycle units, substantial production of thermal fluid at a minimum temperature of 100-150°C would be required At these relatively low resource temperatures, well depths would have to be quite shallow (probably no more than 1,000-1,500 m) and production rates high in order for a project to be economic Because, to date, no production of water hotter than 63°C is known, except from wells deeper than 2,000 m, and no temperatures above 100°C have been observed at depths shallower than 1,000 m, it should not be anticipated that discoveries of resources suitable for power generation will be made quickly or easily

In the course of investigations for this study, the possibility of exploitation of relatively hot but impermeable rock masses (such as has been identified at Jermakhpur) by hot dry rock (HDR) technology was mentioned by several government specialists HDR exploitation has not yet been proven to be economic anywhere in the world, even in areas

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where higher rock temperatures occur at similar depths Therefore, it is unrealistic to expect any commercial HDR projects to be implemented in Armenia anytime in the near future

Ideally, exploration for higher-temperature resources should continue as a longer-term activity, while at the same time promoting appropriate commercial development of the known low-temperature resources of Armenia Exploration recommendations are presented in Chapter 8

The identified thermal water resources of Armenia, though they are generally of quite low temperature, may be commercially useable in a variety of direct-use applications Table 3 1 shows a commonly accepted classification of potential applications according to resource temperature The likely uses of the Armenian resources include, primarily

- **Agricultural applications**, such as greenhouse heating, soil warming, fish farming, mushroom growing, and other uses

- **Space heating and hot water supply**, for individual buildings or in district heating systems

- **Tourism**, using thermal water primarily for bathing for recreational or therapeutic purposes

Because of the overall low resource temperatures, the use of heat pumps in combination with thermal waters is an option that should be considered for heating applications such as greenhouse or space heating Though the use of heat pumps would add to the capital cost, complexity and fuel requirements of potential projects, it would greatly

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improve design flexibility by allowing working fluid temperatures to be elevated to desired levels Heat pump-based applications would be particularly attractive in areas where temperatures are somewhat low but available fluid production is large (e g the Vorotan River valley, Ankavan)

Promotion and financing of initial or demonstration projects would be most feasible in areas where active wells exist in good condition, and where there is at least some development and infrastructure related to the thermal wells Jermuk is the most attractive area in this regard, because of its extensive development and existing use of thermal waters Ankavan is also attractive, to a lesser degree Of next greatest interest are areas where adequate temperatures and substantial production have been demonstrated, but wells would require some rehabilitation or even replacement The Vorotan River valley, Arzakan, Martuni and probably Gyumri fall into this category Areas where temperatures are uniformly less than 30°C, or where no significant drilling has taken place, are unattractive for development until the feasibility of projects has been demonstrated elsewhere

Based on available information, it appears unlikely that any significant hot water production capacity presently exists from the deep wells that have been drilled in the Ararat and Central basins As discussed in Chapter 2, the cost and dry hole risk involved in drilling wells of this type to obtain water at temperatures less than 100°C makes it unlikely that any project based on this resource would be economic if new wells are required

3 2 Demand Considerations

Direct use of geothermal waters normally requires that the demand for the energy use exist close to the source of the water (ideally less than a few km), due to transport and heat loss considerations The known thermal water resources of Armenia occur in a variety of settings, some close to population centers, others more isolated Figure 2 4 shows the regions and principal cities and towns of Armenia, in comparison with the locations of the identified thermal areas Table 3 2 shows the population distribution of the different regions of the country

Because of the high latitude and generally high elevations of Armenia, virtually all populated areas of the country have significant demand for heating during at least the winter months, for either residential, industrial or agricultural activities Therefore, except in very remote areas (e g Jermakhpur), there is potential demand for geothermal direct use applications if such projects are economically feasible and of local interest Certain areas of the country are developed for tourism or have potential for such development, in these areas, there is a potential for integrating thermal water use into tourist activities

Significant thermal water resources occur near towns large enough to have district heating systems at Jermuk, Sisian, Martuni, and possibly Gyumri In these areas, as well as at Ankavan, and possibly Arzakan and the villages of the Vorotan River valley, there could also be demand for space heating or hot water heating for individual buildings

Areas where the demand for agricultural heating is likely to be greatest are the Vorotan River valley and Arzakan, but at least limited agricultural applications are possible in virtually all of the areas where thermal waters have been produced Greenhouses are used in many parts of Armenia to extend the growing season In some cases crops are raised entirely in the greenhouses, in others seedlings are started in greenhouses and then transplanted There is a potentially lucrative market for vegetables (tomatoes, cucumbers, onions, etc) and cut flowers during the winter season, which would favor the development or improvement of greenhouse operations

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3 3 Legal, Social and Infrastructural Considerations

Detailed investigation of the laws and regulations affecting the development and use of geothermal resources was not conducted as part of this study However, based on informal discussions, it appears probable that there is no law that specifically addresses geothermal resources in Armenia This could be an impediment to development in some instances, as it is in many countries that have not passed geothermal resource laws

Geothermal resources in Armenia are considered to be owned by the State, and therefore an agreement or contract with the government is a necessary condition for the commercial utilization of produced thermal fluids Without a comprehensive geothermal law, it is probable that each agreement must be reached by negotiation on a case-by-case basis It is unclear how, for instance, the use of an existing (State-owned) well would differ from the production of a new well drilled by a developer Geothermal development could be more easily promoted if there existed a clear legal framework that defined potential developers' rights and procedures for establishing exploration leases and concessions, and standardized the procedures and costs of resource utilization

Based on the characteristics of the geothermal resources presently identified, any commercial projects developed over the short term are almost certain to be small-scale and local in nature It is unlikely that such projects will attract the attention of the national government, or of conventional international public financing Therefore, successful project development is likely to depend on interest at the local level or by smaller, more entrepreneurial outside entities Projects that represent a clear expansion of the local economy and provide new employment opportunities will likely be easier to promote than projects based on energy cost savings alone (such as conversion of district heating systems)

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There do not appear to be any significant infrastructural obstacles to the development of geothermal projects, as materials, equipment, transportation and technical expertise are generally available However, we did not verify the local availability of drilling equipment and expertise, which would be an essential component in any projects requiring new wells

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4 DEVELOPMENT OPPORTUNITIES IN THE JERMUK AREA

4 1 Setting

Jermuk is located along the Arpa River, one of the major tributaries of the Araks River, in southern Armenia The Arpa drains a highland of moderate to steep relief where the northwestern end of the Karabagh Upland meets the northern end of the Zangezur Range The resort town of Jermuk lies above the Arpa on a plateau at an elevation of 2,060 to 2,070 m The Arpa has cut a steep gorge into the plateau

The countryside around Jermuk is relatively heavily wooded for this part of Armenia, with oak forest predominating The climate is cool in the summer, and cold in winter, it reportedly is common for 2 m of snow to be on the ground in the winter There are abundant small streams in the area that drain into the Arpa

Jermuk is situated in the northeastern part of the Vayots Dzor region in south-central Armenia A paved highway in fairly good condition connects the town with the main highway running south from Yerevan, the driving distance from Yerevan to Jermuk is 250 km There is an airport between Jermuk and the village of Kechut, this airport is not currently in use, but appears to be in good condition, suitable for use without major repairs, at least by small aircraft

The population of the Jermuk area, including the town of Jermuk and the village of Kechut, several km downstream, is said to be about 10,000 Electric power, gas and water supplies for the area appear to be adequate and in good condition

In the general region of Jermuk, widespread lower Tertiary (Paleogene) sedimentary and volcanic rocks are locally overlain by lava flows and other volcanics of

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Quaternary age (Aslanian and Begumi, 1968) Mkrtchian (1969) describes the Tertiary rocks in the immediate area of Jermuk as Eocence to Oligocene-age volcanogenic and sedimentary units In addition, there are scattered exposures of intrusive rocks, described mostly as granodiorites and monzonites, within and near the Jermuk area The age of these intrusives is uncertain, but mapped relationships suggest that they intrude the Tertiary volcanics and sediments

The Quaternary volcanics at Jermuk consist mainly of thick, columnar-jointed lava flows of andesitic to basaltic composition North of Jermuk they are widespread, but at Jermuk and to the south and west they are narrow, and can clearly be seen to fill the pre-existing Arpa River gorge The present gorge in some places has been cut within the lavas, in other places it is cut along the contact of the lavas with the older rocks Mkrtchian (1969) describes several episodes of gorge formation and filling by lava flows The presence of alluvial layers between flows, as seen in some of the local wells, shows that the position of the gorge has changed in successive episodes

Several Quaternary volcanic centers have been mapped a few km to the north and west of Jermuk These are likely the source of the lava flows that fill the river valley and form the plateau on which the town is situated

Few geologic structures have been mapped in the vicinity of Jermuk Mkrtchian (1969) shows a single northwest-trending fault passing northeast of the town and the thermal area He also mentions the possibility that the contact of the intrusive rocks with the Quaternary lavas is faulted, but also concedes that it could be an erosional contact Examination of satellite images of the area confirms a lack of strong recent faulting within the volcanic upland

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4 2 Resource Characteristics

The basic characteristics of the geothermal resource at Jermuk, and of the wells for which data are available, are summarized in tables 2 1 and 2 2 Figure 4 1 shows the locations of some of the thermal springs and wells, in relation to other physical and cultural features of the town Chemical characteristics of the thermal waters are reviewed in section 2 5

Warm springs occur in several areas along the banks of the Arpa River, and on the lava plateau where the town is located Study of these springs beginning in the 1920s led to the drilling of at least 30 wells during the 1950s and 1960s, to depths of up to 642 m Production temperatures vary, but the hotter wells cluster in the range of 54-64°C, temperatures in this range are observed in wells as shallow as 17 m in addition to the deeper wells In at least some cases, the wells are not artesian, but are capable of self-flow at wellhead pressures less than one bar, after stimulation by injection of air or gas, this is presumably due to lifting by exsolving gases once flow is initiated Reported well production rates are typically 2 to 8 l/sec, but may range up to 11 l/sec Available data indicate that many, if not most, wells produce from intrusives or other pre-Quaternary rocks that underlie the plateau lavas and young sediments

The distribution of production temperatures and production zones in the wells, along with the occurrence of the springs, suggest that the thermal waters are produced from a fairly widespread aquifer or reservoir consisting of fractured rock, located below or near the contact of the Quaternary lavas and sediments with the underlying units The thermal area occurs along the margin of a structural high at the southwestern edge of what has been interpreted to be an intermontane basin The thermal waters may originate from circulation to deep levels within the basin, or may represent outflow from a higher temperature system

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related to the young volcanoes that occur in the northern and northwestern parts of the basin The thermal water probably rises along the structural uplift, emerging at river level in the Jermuk area

According to local authorities, 4 wells at Jermuk are currently in operating condition, and these are capable of supplying a combined production rate of about 18 l/sec, presumably in the 54-64°C range Numerous wells that are not in use have been covered or temporarily abandoned, but could potentially be restored to use In all there may be as many as 30 wells that could be put into service, without the need for any new drilling The wells that were observed in the area appear to have relative small-diameter completions with wellhead assemblies no more than about 10 cm in diameter

4 3 Infrastructure and Existing Resource Use

The town of Jermuk was developed for resort use during this century, mostly from the late 1950s through the end of the Soviet period Numerous resort facilities have been developed, including a number of health resorts or treatment centers (sanatoria), hotels, restaurants, parks and a drinking gallery (water temple) However, many of these facilities are not currently in use because of a decline in tourism, and there are several hotel or resort facilities whose construction was stopped before completion Several resort facilities have also been built along the shore of the Kechut reservoir, but these are not presently in use Overall, the unused buildings and other facilities appear to be in good condition The location of the major buildings and facilities in the main town area are shown in figure 4 1

During the Soviet period, tourist visitation of Jermuk was heavy, with the majority (reportedly about 75%) coming from Russia, the remainder mostly from Armenia There is little industry in the area other than tourism Agriculture is light, and within and around the

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town of Jermuk it appears to be mainly of a supplementary nature As a result of the decline in tourism, unemployment in the area is extremely high, in the vicinity of 70% In addition, a number of residents have reportedly left the area due to lack of employment

Traditionally, the thermal waters of Jermuk have been used as mineral water for drinking and for therapeutic treatments A network of steel and PVC piping was used in the past to deliver thermal water from one or wells to the health clinic and several of the sanatoria in the town, this system is not in operation now due to lack of demand

The thermal water is bottled and sold domestically and abroad as mineral water under the Jermuk label The bottling operation has been privatized as a Joint-Stock Company and is being upgraded, however, demand for the water is only about 10% of what it was at its peak At present, well 30/62 supplies all of the water for the bottling plant, via PVC piping

The 30/62 well is located at one of the sanatoria (rest houses) Within the last several years, the operators of the sanatorium (one of the few in town presently in operation) installed a heat exchanger system at the well to provide hot water and, if needed, space heating to the building The heat exchanger is said to be a standard Russian design, with a steel exterior and internal brass tubing The output of well 30/62 is diverted to the heat exchanger as needed, the fluid is kept under pressure within the exchanger to prevent calcium carbonate scaling due to gas exsolution According to the operators, this system is sufficient to supply all of the hot water requirements of the sanatorium, as well as the space heating requirement As far as can be determined, this is the only use of thermal water for heating in Jermuk, or anywhere in the country, at the present time

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The town has a district heating system, operated by the municipal government, that supplies most or all of the larger buildings in the central town area, including residential apartment buildings and town office buildings The system is supplied by a central boiler complex fueled by natural gas The water is heated to an initial temperature of 60-70°C, with a return temperature of 40-45°C According to the local authorities, there is no interest in converting the system to a geothermal heat source, because they are satisfied with the existing natural gas supply

4 4 Potential Projects

A variety of direct-use geothermal applications would likely be feasible at Jermuk, given the high quality of the resource at relatively shallow depth, the existence of a number of productive wells, and the presence of substantial infrastructure, local familiarity and expertise However, the local authorities place strong emphasis on restoration of the now-declined tourist industry as the preferred means of improving local economic conditions, the cost of energy supply does not appear to be an important concern Therefore, it is important that any geothermal applications to be promoted and developed should be in harmony with touristic activities, and in particular should not interfere with or degrade the existing resort operations, the mineral water bottling operations, or the general environment and ambience

Based on this background, the most attractive projects for the Jermuk area include

Bathing and swimming pools, in conjunction with existing or new resort facilities These could be supplied directly by thermal water, or by water heated using a heat exchanger system In the former case, some type of scale control or management might be

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required Traditionally the resort developments at Jermuk have been based on the therapeutic properties of the thermal waters While some demand for spa-type treatments by overseas visitors might be generated with proper marketing, purely recreational use by hot-spring enthusiasts would likely be as easy, or easier, to promote

Heating of individual buildings The existing use of a heat-exchanger system for one of the sanatoria demonstrates that it is possible to develop relatively simple systems that are adequate to meet the space heating and hot water requirements of a typical building in the town The most likely scenario for implementing of such systems is the privatization of an existing but unused facility by a private or semi-private developer The capital cost of installing such a system would depend in part on whether an existing well is available for a thermal water supply (rather than having to drill a new well), and if so, at what distance from the building Because existing buildings typically have heating systems already in place, capital costs from the wellhead onward would be limited to the cost of heat exchanger installation, limited piping, and ancillary equipment

Conversion of the district heating system As noted above, there does not appear to be significant local support for this option at present However, it might be more attractive in the future if smaller-scale projects prove successful The relatively low operating temperature of the existing system makes the feasibility of conversion to a geothermal source more likely Because the characteristics of the resource are relatively well known, a feasibility study for converting the system could be conducted at relatively small expense, once local interest in the project develops

In addition to offsetting existing or new consumption of natural gas or other fuels, implementation of one or more of the above projects could be used as a promotional tool to increase interest among potential visitors Integrated development and promotion of

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geothermal resources in concert with the other attributes of the town would constitute a form of eco-tourism which offers the potential for improving local economic conditions and increasing foreign exchange

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5 DEVELOPMENT OPPORTUNITIES IN THE VOROTAN RIVER VALLEY

5 1 Setting

The Vorotan River flows southeastward through the northern part of the Syunik region of Armenia for a distance of more than 60 km before turning eastward and crossing the national frontier Based on information from springs and wells, the zone of geothermal interest may include a corridor several km or more in width, extending along the entire SE-trending portion of the river, however, only the 15 km stretch from the city of Sisian to the village of Shamb has been explored by drilling to a significant degree

In this region the Vorotan flows through a broad valley, bounded on the southwest by the rugged mountains of the Zanzegur Range, and on the northeast by the gentler slopes of the Karabagh Upland The slope of the Karabagh Upland flattens to a broad volcanic plain or shelf located mainly along the left bank of the river Beginning a short distance above Sisian, the river enters a gorge cut into the shelf, the gorge is narrow in most places, but occasionally widens to form small valleys at river level The main highway continues along the shelf as it approaches Goris to the southeast, but the larger settlements, including Sisian, are located along the river on secondary roads The volcanic shelf and the ranges bounding the valley are almost entirely unforested, and even along the river vegetation is somewhat sparse The elevation of the area ranges from about 1,500 m at the SE end to a bit less than 2,000 m in the NW, maximum elevations in the adjacent ranges exceed 3,200 m

Northeast of the river, Quaternary basalts and andesitic basalts cover the Karabagh Upland and form the volcanic shelf Where the river canyon cuts these deposits, thick, columnar-jointed lava flows can be seen Numerous volcanic centers have been mapped in the Karabagh Upland, some within about 10 km of the river

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Over most of its course the Vorotan River is close to the contact of the Quaternary volcanics with older rocks to the southwest, these include sediments and volcanic rocks of Eocene to Pliocene age, and Tertiary-age intrusive rocks which are exposed mainly in the Shamb area. Extensive Pliocene deposits of clayey, diatomaceous sediments are exposed in the area of Sisian, these presumably are of lacustrine origin

5 2 Resource Characteristics

Tables 2 1 and 2 2 summarize the main characteristics of the geothermal resources of the Vorotan River valley, and of the wells for which data are available Figure 5 1 shows the approximate locations of some of the thermal springs and wells, in relation to other features Chemical characteristics of the thermal waters are reviewed in section 2 5

Numerous mineral springs have been described along much of the length of the Vorotan River However, thermal waters (hotter than 20°C) are only found at and downstream of the city of Sisian At Sisian, at least 6 shallow wells (57 to 193 m) have been drilled, these discharge moderate to high volumes of water at 20 to 27°C One deeper well (11-T) was drilled at Sisian airport to a depth of 1,158 m, this well is reported to discharge more than 9 l/sec of 42°C water During our visit one well at the east end of Sisian was observed flowing freely, with a cyclical discharge behavior and a water temperature of 31°C It is not clear whether this well is one of those listed in table 2 2 It is also unknown whether any of the other wells now exist in a usable condition

A short distance south of Sisian, at the village of Uz (Uts), at least two wells have been drilled The deeper of these (41-T) was drilled to 730 m, and reportedly discharged 52 l/sec at 43°C It is not known whether the wells at Uz now exist

At the village of Vorotan (Urut) one thermal spring, two shallow wells and one deeper well (47-T, 916 m) are described Well 47-T had a very large reported flow rate of 102 l/sec at 43°C One free-flowing well, with a temperature of 35°C, was observed and sampled at Vorotan, the temperature suggests that this is probably well 47-T, but the flow rate appeared to be less than 10 l/sec Two wells are described at the village of Shamb One of these wells had a reported flow rate of 10-12 l/sec at 42°C, but no depth data or other documentation were available

Several other thermal springs are reported along the Vorotan River downstream from Shamb (figure 5 1) No wells are reported in these areas

Geologic data from the wells indicate that the thermal waters are produced from various different Tertiary formations, there does not appear to be a unique aquifer The broad distribution of productive wells suggests that an extensive area of potential for production of water up to 45°C may exist, possibly along much of the river valley The temperature of the thermal waters is roughly what would be expected at the observed depths, given the regional heat flow regime, therefore the water does not necessarily originate from a deep or distant source

5 3 Infrastructure and Existing Resource Use

As noted, the population of the area is concentrated along the Vorotan River The city of Sisian is a commercial center with a population that probably exceeds 20,000, there is also agriculture in the area The villages in the area all have populations smaller than about 1,000, and do not appear to have any significant industry other than agriculture Although the region is distant from the main population centers in the northern part of the country, there is substantial commercial traffic along the main highway that connects Armenia with Iran

No commercial use of the thermal waters is known to exist at present, nor is there evidence of past commercial use The flowing wells at Sisian and Vorotan are used informally for bathing and recreation At Vorotan, construction of a rest house near the flowing well was begun a number of years ago (probably in the 1980s), however, the construction was halted, reportedly due to the Spitak earthquake in 1988, and was never completed

5 4 Potential Projects

The thermal wells in the area produce water of relatively low temperature (less than 45°C) but have potentially large flow rates Data available so far indicate that relatively deep wells (800 to 1,200 m) are required to obtain water in the upper end of this temperature range Wells of this depth, even if drilled with small diameters, would typically cost several hundred thousand dollars, however, drilling costs may be somewhat lower in Armenia, depending on the availability of equipment and materials For initial projects, it would be preferable to minimize development costs by rehabilitating one or more of the existing wells, if this is possible Wells that might be capable of rehabilitiation exist at Sisian, Uz, Vorotan and Shamb

The geothermal applications likely to be of interest include

Greenhouse heatıng, eıther dırectly usıng thermal water, or ın combınatıon wıth heat pumps Any of the 4 sıtes mentıoned above would be suıtable for greenhouse operatıons, though at the sıtes vısıted (Sısıan and Vorotan) there are no exıstıng greenhouses

Space heatıng Thıs would be most attractıve at Sısıan, where there ıs a substantıal local populatıon There ıs probably a dıstrıct heatıng system ın Sısıan, gıven the sıze of the cıty, but detaıls are unknown

The resources and ınfrastructural settıng of the Vorotan Rıver valley are best suıted to the development of small-scale projects that could be undertaken by entrepreneurs, ındıvıdual farmers or small companıes The ımplementatıon of one or more demonstratıon projects, utılızıng exıstıng wells, would lıkely spur ınterest ın the further development of what may be an extensıve low-temperature resource

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6 DEVELOPMENT OPPORTUNITIES AT ANKAVAN

6 1 Setting

Ankavan (Hankavan) is located along the Marmarik River, which flows southeastward through a moderately steep mountain valley between the Pambak Range to the north, and the Tzaghkunyats Range to the southwest The area is connected by paved road to Hrazdan, about 30 km to the southeast, and is slightly less than 100 km by road from Yerevan The mountain slopes and the area around the river are lightly forested

The village of Ankavan (also called Miskhana) is located at the western end of the thermal area, and has less than 1,000 inhabitants There are several schools, camps and resort-type facilities in the area, although it appears that not all are in full-time operation The area is used by many visitors for informal recreation (camping and picnicking) The elevation at Ankavan is just under 2,000 m, and the peaks on either side of the valley reach about 3,000 m Accordingly, the area has a mountain climate, with cool summers and cold winters

Although it is situated within Armenia's central zone of high heat flow, there are no Quaternary volcanoes or volcanic deposits in the area of Ankavan The rocks exposed in the area range from Prepaleozoic granite-gneisses to Lower Tertiary volcanics Leucocratic granite and metamorphosed shales are most common in the thermal area Alluvium covers much of the river valley, including most of the area of springs and wells

6 2 Resource Characteristics

Warm springs occur along the river, beginning at Ankavan village and extending slightly more than 1 km downstream All of the springs are within a few tens of meters of

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the river or its larger tributaries At least 12 wells have been drilled throughout the area of warm springs, to depths of as much as 410 m At least 4 of the wells still exist today, and 2 are in use It is not known whether any other wells still exist, but examination of the area indicates that a number of wells have been abandoned Figure 6 1 shows the locations of reported springs and wells in the area

Spring temperatures range up to about 25°C, but several of the wells have encountered temperatures up to 42°C The hottest production comes from the deepest wells, but temperatures near 35°C were found in several wells less than 100 m deep At least some of the wells are artesian, and reported flow rates range as high as 25 l/sec, with 7 wells having reported production rates of 10 l/sec or greater The two active wells probably have a combined output of at least 25 l/sec Chemical characteristics of the thermal water are summarized in section 2 5

Well logs indicate that production zones occur in several different rock units, including the metashales, the granite, and the overlying alluvial sediments The springs and wells are probably fed by fractures that allow upflow from deeper levels Several faults paralleling the river have been mapped in the area, but it is unlikely that individual springs or wells can be linked to specific faults, due to the alluvial cover in the area The water temperatures and the absence of nearby volcanism suggest that the thermal waters originate from moderate to deep circulation within the zone of high heat flow

6 3 Infrastructure and Existing Resource Use

Commerce and industry in the area are limited In addition to the resorts and schools noted above, a sanatorium and several light industrial operations are located along

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the river Aside from these, agriculture appears to be the main economic activity in the area

Several facilities make use of the 2 active thermal wells, though not as a source of energy Well 14 is produced as a source of CO_2, which is reportedly used by a soft drink bottling company The gas is separated in a gas separator of standard design, and sent by PVC pipe to the plant Separated water is discharged to an open tank, which is used informally for bathing, the water then discharges to the river

A second well supplies CO_2 to a small dry-ice factory, and provides water to the Ankavan Sanatorium This well is either well 18 or well 3/63, based on its observed characteristics it is more likely the latter A wellhead valve allows water to be diverted and transmitted through several hundred meters of PVC pipe to the Sanatorium, a separator like the one at well 14 is used to provide CO_2 to the factory Unused water is discharged on the ground

The Ankavan Sanatorium is a medium-sized facility of several stories, dedicated to the treatment of stomach ailments using the local thermal water Since 1988 it has operated very little, due to poor economic conditions and lack of demand Its use increased somewhat beginning in 1996, but still it operates only about 1 month per year, because the cost of treatment (though low by European or American standards) is too great for most Armenians

6 4 Potential Projects

The demand for energy projects in the area is limited by the small local population and limited overall development However, the resource potential of the area is favorable, with up to 4 potentially usable wells in existence, and relatively shallow drilling depths if new wells are required In addition, the area is well suited for tourism, with some facilities already in place Potential projects using geothermal energy therefore include

Resort use, in bathhouses or swimming pools These could use the thermal water directly, or with heat exchangers As at Jermuk, the presence of warm springs and wells would constitute a point of attraction that could be used in promoting tourism

Space heating and hot water supply At present the village of Ankavan is not well suited to implementing geothermal heating, and most of the larger local buildings probably are unused in winter However, if local activity expands, existing or new buildings could incorporate geothermal heating systems, similar to those described for Jermuk (section 4 4)

Greenhouse heating This is probably unlikely in the short term, given local demand and economic conditions, but could be considered in the future

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7 OTHER AREAS OF INTEREST

7 1 Martuni

A feasibility study of a proposed geothermal heating system for the local hospital at Martuni was made in 1993 (CFG, 1993) Comments on this study are presented as Appendix A Space heating applications, if feasible, are probably the most appropriate use of the geothermal resource in this area, though agricultural applications could be possible as well

It has been postulated that the true resource temperature at the depths reached by the deepest Martuni wells (about 900 m) may be greater than the approximately 40°C observed in produced fluids Temperatures of 60°C or greater would make the Martuni resource much more attractive than it currently appears, therefore it would be worthwhile to carry out limited investigations, such as downhole temperature logging, to determine if higher temperatures may in fact be obtained without drilling deeper

7 2 Arzakan

The thermal water at Arzakan is presently used in a commercial bathhouse (supplied by well 16-T), but greenhouse heating may be feasible as well, particularly if there are other existing wells that can be rehabilitated for use A number of active greenhouses exist in the area, one across the road from well 16-T was visited, but the owners indicated that attempts to use the thermal water for heating were abandoned due to calcium carbonate scaling of the pipes It should be possible to design a piping system that controls such scaling by keeping the fluid under pressure, preventing exsolution of CO_2 Alternatively, a simple heat exchanger could be employed

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7 3 Gyumrı Area

Informatıon about the Gyumrı-Kamo area ıs lımıted, so the potentıal for project development there ıs uncertaın, however, there appears to be some prospect of usable resources ın the area Further ınvestıgatıon would be worthwhıle to determıne the number, locatıon, current condıtıon, and productıon rate of wells drılled ın the area

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8 RECOMMENDATIONS FOR FUTURE EXPLORATION

Although no high-temperature geothermal resources have been discovered in Armenia to date, continued exploration is warranted to determine if such resources, or more extensive low-temperature resources, exist Privately financed exploration is unlikely to take place until at least one high-temperature resource has been identified, therefore, any exploration undertaken with government or foreign assistance funds should be aimed at facilitating a possible commercial discovery

Exploration efforts should be concentrated within the central belt of young volcanoes and high heat flow, as the probability of finding economic resources elsewhere in the country is low Deep drilling in the Ararat and Central basins could yield some production of hot water, but the cost of drilling new wells to such depths is so high that it is unlikely to be economic

We recommend two general approaches to new exploration, which could be followed individually or simultaneously

- Exploration around known thermal areas, to seek higher temperatures or more extensive resources, and

- Investigation of the areas of youngest volcanism, to seek resources that may have no surface expression in the form of hot springs or fumaroles

The subsequent sections discuss these two approaches, with some recommendations

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8 1 Additional Exploration of Known Thermal Areas

While substantial investigations of many areas of warm springs have been carried out, including the drilling of many wells, the understanding of the extent and nature of these areas could be improved by conducted detailed studies of them, based on the standard procedures for hydrogeologic modeling (conceptual modeling) that are practiced in the geothermal industry The activities required for such a study of any given area would include

- Compilation of all available technical data from the area, particularly well data (including details of well completion, downhole geologic data, downhole temperature/pressure measurements, well testing data, and chemical data) Much information is likely to be available in government archives, as investigations and drilling were generally carried out by the government, and detailed records were probably kept However, many original records could be difficult to locate

- Conducting measurements in wells to complement existing data These would likely include production tests to determine well output characteristics and reservoir characteristics, collection and analysis of water samples, and measurement of downhole temperature and pressure profiles

- Development of an accurate map, with verified locations for springs, wells and other features

- Completion of local and regional geologic studies, if adequate maps and studies do not already exist

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- Conducting selected geophysical surveys The most appropriate geophysical exploration techniques for a given area will depend on its geologic characteristics, so the surveys to be conducted would be selected after preliminary analysis of other data

- Analysis and integration of existing and new data to develop a model of subsurface geology, subsurface temperature and pressure distribution, fluid chemical characteristics, origin of fluids, and the pattern of fluid movement

- Drilling additional wells, stepping out from explored areas to areas of potentially higher temperatures based on the results of the conceptual modeling work The field model would then be updated based on the results of the new drilling

Based on the review conducted here, the areas that should be prioritized for such studies are Jermuk, Ankavan, Arzakan, Gyumri, the Vorotan River valley, and Martuni Investigation of areas in the volcanic belt where thermal springs exist but little or no drilling has been carried out would also be worthwhile, in these areas, new drilling might be needed early in the investigation to gather sufficient data for a reliable conceptual model

This type of investigation and modeling of identified geothermal resources not only would provide a basis for planning their further development, but also would help attract investment or financing for potential development projects by providing a characterization of the resources in an accepted format

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8 2 Analysis of Satellite Imagery

The areas of youngest volcanic activity provide the best prospects for the discovery of high-temperature geothermal resources in Armenia Field inspections and review of geologic mapping indicate that the zones of youngest volcanism are the Gegam Mountains, the Karabagh Upland, and possibly the Vardenis Mountains The Aragats Massif is a large, young volcanic edifice, but the degree to which it has been eroded suggests that it has not been a site of continual, recent volcanism, we therefore consider it of lower priority for exploration

In order to better define areas that are attractive for new exploration, a study of satellite imagery in the region of the youngest volcanoes was carried out The purpose of the study was to confirm the relative ages of the volcanoes, and to seek features that might be indicative of hydrothermal activity, including hydrothermal alteration and unusual structural features

The basis of the study was a single image of the Lake Sevan region acquired by the Landsat 5 Thematic Mapper (TM) (figure 8 1) The data from the TM sensor contain 7 wavebands three in the visible range, three in the near-infrared, and one thermal infrared (table 8 1) The spatial resolution of the data (pixel width) is 28 5 meters Data have been corrected radiometrically, to calibrate and balance sensor sensitivities among the wavebands, and geometrically, to account for satellite orbit and geoid shape, and angle of view along scan lines In addition, they have been aligned to the UTM map projection system (zone 38) The image data utilized here were obtained by the satellite on September 28, 1987 (1987-09-28), the catalog number is LT5169032008727110

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The ER Mapper 5 5 software package was used to process the data This software provides many powerful tools to construct processing algorithms, including standard transforms that allow the data to be rescaled for optimal display, filters to enhance linear features (edges) and for other purposes, and statistical tools such as principal component (PC) analysis In addition, the software allows one to construct a wide variety of formulas for use in algorithms

Two basic types of false-color images were produced for analysis RGB (red, green, blue) displays of bands 7-4-2(1) (i e , red=7, green=4, blue=2 or 1), and RGB displays of Crosta calculations, which employ PC analysis Transforms used were mostly linear (95% clipping), but Gaussian transform was also used For all the 7-4-2(1) displays, edge sharpening (rgb) has been included

The RGB display of bands 7-4-2(1) is generally considered optimal for depiction and analysis of geology We feel that band 2 is superior to band 1 because it is less subject to less atmospheric scattering Figure 8 1 is an image of this type Crosta displays are generally considered useful for highlighting iron-oxide alteration (red) and clay alteration (blue), the combined alterations often yield a nearly white color

Cloud cover is minimal in the data set used (figure 8 1, white patches with shadows) There is some snow cover (light blue areas), but for the most part the image provides nearly optimal conditions for analysis

In figure 8 1, a prevailing northwest-southeast topographic trend can be observed northeast of Lake Sevan, southwest of the volcanic belt (lower left corner of the image), and, to a lesser degree, northeast of the Karabagh Upland (right-hand side) This trend is consistent with the known trend of geologic structure Visibility of the trend is enhanced in

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an image prepared with a vertical edge filter and 95% transform (figure 8 2) This image also reveals a weak northeast-trending structural pattern in the Karabagh Upland as well as the non-volcanic areas Other than this, the volcanic areas do not exhibit much structural expression

More detailed images were prepared and analyzed to examine the characteristics of specific volcanic areas Figure 8 3 shows an image of bands 7-4-2 for the Gegam Mountains area, with Lake Sevan at the northeastern edge Numerous small volcanic cones can be seen, particularly at the northern and southern ends of the range There are few lineations indicative of tectonic features, one exception is a N-S linear feature just west of the Lake, which is probably a young fault Most other linear features appear to reflect dissection of the volcanic highland by erosion, without a significant structural pattern Some clustering of volcanic centers in the central and south-central part of the range (confirmed by geologic mapping) suggests that this part of the areas might be of slightly greater interest for exploration, but, overall, the satellite imagery in the Gegam Mountains does not yield any strong exploration guidelines

Figure 8 4 is an image of bands 7-4-2 that includes most of the Vardenis Mountains (upper left) and the Karabagh Upland (central part, trending SE) Very young lava flows can be seen in several places, appearing as dark purple zones with distinct outlines Most prominent are a bifurcated flow in the Vardenis Mountains (next to the medium-sized Lake Greater Al), and a single flow in the central Karabagh Upland, which occurs in the Jermakhpur area These and several smaller flows are confirmed by geologic mapping (Aslanian *et al*, 1968, Karakhanian et al, 1997) Based on figure 8 4, the entire zone of highlands extending from the Jermakhpur area northwestward to the eastern Vardenis Mountains is of interest for exploration because of its well-developed young volcanism

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The Jermakhpur area was examined in greater detail by preparing an image of bands 7-4-2 (figure 8 5) and a Crosta image (figure 8 6) of this part of the Karabagh Upland, both at a scale of 1 200,000 Areas covered by snow were excluded from the Crosta data processing (slot-shaped area at top) in order not to degrade the calculations with extraneous information Figure 8 5 shows the volcanic features of the areas with clarity, including not only the extensive young lava flow (dated to be roughly 4,000 years old), but a collapse or blast feature within the peak to the southeast (white ring) The collapse crater contains a small younger cone, and eruptive deposits (likely pyroclastic flows and/or debris flows) extend northeastward from the collapsed side In the Crosta image, much of the peak shows a white color that could be associated with rock alteration Overall, the characteristics of this peak, located along the national frontier, resemble those of long-lived volcanoes that often are associated with high-temperature hydrothermal systems It therefore is an attractive area for exploration, and continued investigation in this area is worthwhile

Figure 8 7 is an image of another subset of the area of figure 8 4 This image includes the Jermuk area (along the river, approximately in the center of the image) and the volcanic upland to the north and east The broad area of gentle relief north of Jermuk has been interpreted as a basin (structurally low area), bounded by uplift on the south and west, this can readily be visualized from the image Young lavas appear to be exposed at the northwestern margin of the basin, reflecting recent volcanic activity Near the upper right corner of the image, a sub-circular feature surrounding a small lake appears to be a relatively large volcanic center Considering the occurrence of thermal water at Jermuk, these volcanoes, and the adjacent Jermuk basin, are attractive exploration sites

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8 3 Exploration for New Resources

Based on the preceding analysis and other available data, we recommend that exploration for as-yet unidentified geothermal resources be directed toward the following areas (in order of priority)

- **Jermakhpur** (southern Karabagh Upland), with particular emphasis on detailed investigation of the volcanic complex observed in figure 8 5 As noted elsewhere, substantial exploration activity has taken place in this area, though the precise locations of surveys and wells are uncertain

- **The Jermuk Basin**, including the volcanoes located along its northern margin Exploration in this area could usefully be integrated with continued investigation of the Jermuk thermal area

- **The Gegam Mountains**, particularly the south-central part of the range

- **The Vardenis Mountains**, particularly the eastern portion near Lake Greater Al

Exploration activities recommended in these areas include

- Careful review and integration of existing geologic, volcanologic, geophysical and geochemical data

- Verification of surface geology, either by review of existing data or (if necessary) new mapping More detailed analysis of satellite imagery, and other remote

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sensing data if available, is likely to be useful Any occurrences of hydrothermal alteration should be noted and investigated

- Dating of young volcanic deposits, where dates are not already available

- Thorough sampling and chemical analysis of spring waters and gas emissions Analytical results should be interpreted to determine possible origins of waters, and geothermometers should be calculated

- Selected geophysical surveys In the volcanic areas mentioned, electrical resistivity surveys (preferably using magnetotelluric or controlled-source audio magnetotelluric methods) would probably be the most useful, gravity surveys conducted within the same areas may also be helpful Drilling shallow temperature gradient observation holes may be valuable, depending on local geologic and hydrologic conditions

- Integration of data collected in the above activities into a conceptual hydrogeologic model of the prospect area

- Drilling of one or more exploratory wells, at sites selected based on the conceptual model

8 4 Development of Local Expertise

There are many highly trained scientists and engineers in Armenia However, they have been substantially isolated from most of the world geothermal community, and so have limited familiarity with commercial project development and with some types of exploration and investigation techniques Independence has generally not improved this condition, due to a lack of funds for government and academic research Therefore, assistance provided for the purpose of improving local geothermal expertise would be most usefully directed toward improving and expanding the interchange of information and ideas with geothermal practitioners in other countries, with emphasis on economic resource utilization

Local specialists should be encouraged to establish contact with geothermal industry organizations (such as the International Geothermal Organization), sponsorship of memberships would help facilitate this Attendance at regional or international conferences could also be sponsored If foreign training of specialists is to be subsidized, it ideally should take place in a country or countries where a variety of commercial projects of different types and scales (including direct use projects) are in operation, so that direct practical experience can be obtained The United Nations has sponsored such training in the western U S , with excellent results

Funding of training courses within Armenia is another approach that may be useful Similar courses conducted in several regions, particularly Latin America, have proven to be very well received, and create an excellent venue for promoting interest in the host country and for allowing potential developers, suppliers and financiers to establish local knowledge and relationships

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TABLES

Table 2 1 Summary of Identified Thermal Areas, Republic of Armenia

Area	Region	Maximum Known Resource Temperature (°C)	No of Wells Drilled	Typical Well Depth (m)	Maximum Well Depth (m)	Estimated Combined Production Rate (l/sec)	Comments
Jermuk	Vayots Dzor	63	>30	150-500	642	>17	Extensive area of thermal springs in Quaternary volcanics associated with nearby centers Area is well developed for tourism and bottling of mineral water
Vorotan River Valley	Syunik	43	14+	150-250	1158	100-200	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 of thermal waters
Ankavan	Kotayk	42	11+	50-100	410	>40	Springs and wells along Marmarik River Two wells in use for CO_2 and dry ice production, medical treatments Touristic area
Arzakan	Kotayk	45	2	?	800	7+?	One well in use for commercial bathhouse Resource is poorly documented Agricultural area

Table 2 1 Summary of Identified Thermal Areas, Republic of Armenia

Area	Region	Maximum Known Resource Temperature (°C)	No of Wells Drilled	Typical Well Depth (m)	Maximum Well Depth (m)	Estimated Combined Production Rate (l/sec)	Comments
Martuni	Gegharkunik	40+	3+	500-900	971	>6	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	Syunik	99	2	600-1 000	1000	0	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
Sayat-Nova	Vayots Dzor	44?	3	<80	<80		Near Jermuk Springs and wells in Tertiary units Little documentation
Gyumri Area	Shirak	42	2?	400-500	540	?	Wells in Gyumri and Kamo areas with temperatures of 32-42°C Little documentation available Area of large population
Ararat Area	Ararat	28	7+	200-400	478	>20	Springs and shallow wells near range-front No indication of higher-temperature resource

Table 2 1 Summary of Identified Thermal Areas, Republic of Armenia

Area	Region	Maximum Known Resource Temperature (°C)	No of Wells Drilled	Typical Well Depth (m)	Maximum Well Depth (m)	Estimated Combined Production Rate (l/sec)	Comments
Ararat Basin (including Oktemberian and Artashat basins)	Armavir, Ararat	87	6+	1,000+	>3,500	-	Deep wells drilled mostly for petroleum exploration Temporary production of 80°C+ water reported for at least one well Well locations uncertain
Yerevan Area (Central Basin)	Yerevan, Kotayk	76	6+	1,000+	2270	?	Production up to ~2 l/sec reported for one or more wells Wells penetrate Eocene-Oligocene sediments Feasibility study of geothermal district heating for Yerevan has been performed
Kajaran	Syunik	32	1		100		In southernmost Armenia Little documentation
Yeghegis River Area	Vayots Dzor	30	0			0 7	One spring only, no wells reported
Maimekh	Lori	27	0			1 4	In Pambak Mts south of Vanadzor One spring, no wells reported
Kafan	Syunik	23	1		337		Little documentation

Table 2 1   Summary of Identified Thermal Areas, Republic of Armenia

Area	Region	Maximum Known Resource Temperature (°C)	No of Wells Drilled	Typical Well Depth (m)	Maximum Well Depth (m)	Estimated Combined Production Rate (l/sec)	Comments
Arzni	Kotayk	23	6+	100	170	>10	No evidence of higher temperature resources Near Yerevan
Goris-Karashen	Syunik	21					Several springs, uncertain if wells have been drilled

Table 2 2 Summary of Thermal Wells and Sprmgs, Republic of Armenia

Area/Well or Spring	Year Drilled	Depth (m)	Reported Flow Rate (l/sec)	Flowing or Maximum Temp (°C)	Deepest Production Zone (m)	Comments
Jermuk						
Sprmg 19	-	-		30 6		
Sprmg 24	-	-	0 6	47 4		
Sprmg 25	-	-	0 9	50		
Sprmg 26	-	-	0 01	38		
Sprmg 27	-	-	0 1	38		
Sprmg 28	-	-	0 1	31 2		
Sprmg 29	-	-		30		
Sprmg 36	-	-	0 3	31 5		
Sprmg 37	-	-		23		
Sprmg 41	-	-		24		
Well 1		17	6 1	54	14	
Well 4		47	3 2	54	46 2	
Well 7		36		61	21	
Well 9		32 4	6 4	64		
Well 18/62	1962	150 1	8	52	125	
Well 20/62	1962	150 0	6	58	133	
Well 21/62	1962	126 1	10 9	56	99	
Well 24/62	1962	130 7	2 5	54	117 5	
Well 7/58	1958?	<200	1 2	52		
Well 2/61	1961?	<200	5 6	54 2		
Well II-OK		<200	0 7	54 7		
Well 1 N				24	100	No flow reported
Well 2 N	1958			35 8	100	No flow reported
Well 10 N				34	100	No flow reported
Well 3 N				34	100	No flow reported
Well 4 N				32	100	No flow reported

Table 2 2 Summary of Thermal Wells and Springs, Republic of Armenia

Area/Well or Spring	Year Drilled	Depth (m)	Reported Flow Rate (l/sec)	Flowing or Maximum Temp (°C)	Deepest Production Zone (m)	Comments
Well 6 N	1958			30 1	200	No flow reported
Well 11 N	1960	502		58 1	502	No flow reported
Well 12 N	1961	642		62 9	642	No flow reported
Well 1-K			2 0	63		Supplies drinking gallery
Well 30/62	1962	199	4 6	54 7		Supplies bottling plant
Well 33/62	1962			40		
Vorotan River Valley						
Sisian 12		57	12	22	56 5	
Well 119 (Sisian)		125	0 3	20		
Well 129 (Sisian)		174	15	27		
Well 185 (Sisian)		160	30	27		
Well 192 (Sisian)		193	0 2	27		
Sisian 11-T (Sisian airport)		1158	9 6	42	1158	PI=57 6 m3/hr/bar
Well 155	1964	150		25 8		Completed in "sediments"
Spring Urut 1-I	-	-	0 08	23 1	-	
Urut 15		63 0	8 4	23 5	21 5	
Urut 834	1960	116 7	15	27		
Well 47-T (Urut)		916	102	43		PI=166 9 m3/hr/bar
Shamb 16		74 5	3 0	26	74 5	
Well at Shamb (name not given)			10-12	42		
Well 114 (Uz)		151 5	0 4	20		
Well 41-T (Uz)		730	52	43		PI=40 7 m3/hr/bar

Table 2 2 Summary of Thermal Wells and Sprıngs, Republıc of Armenıa

Area/Well or Sprıng	Year Drılled	Depth (m)	Reported Flow Rate (l/sec)	Flowıng or Maxımum Temp (°C)	Deepest Productıon Zone (m)	Comments
Sprıng Tatev 1	-	-	4 8	24		
Sprıng Tatev 2	-	-	4 1	23 5		
Sprıng Tatev 3	-	-	1 4	21		
Sprıng Tatev 4	-	-	1 1	21		
Shakhverdlyar Sprıng	-	-	1 5	22 5		
Ankavan						
Sprıng "3"	-	-	0 6	23 3		Ankavan vıllage, near well 10
Ankavan 7	1952	97 8	5 0	22	30	Rıght bank of Marmarık R just below Ankavan vıllage, not seen
Ankavan 8	1952	54 6	12	25 7	25 2	Left bank Marmarık R at Ankavan vıllage, not seen
Ankavan 10	1952	50 1	10	22 2	25	In Ankavan vıllage, not found
Ankavan 14	1953	70 9	15	34 5	57	Rıght bank of Marmarık, supplıes CO2 to bottlıng plant
Ankavan 18	1953	50 0		27		Left bank, ınactıve
Ankavan 1/63	1963	101	25	32 6	70	Rıght bank Marmarık, may have been recently actıve
Ankavan 3/63	1963	409 7	25	42	409 7	Near well 18, supplıes sanatorıum and dry ıce plant (?)
Sprıng "14"	-	-	0 2	20 9	-	Left bank of Marmarık
Sprıng "16"	-	-	0 2	22 7	-	Rıght bank of Marmarık near Sanatorıum
Sprıng "9"	-	-	2 3	24 6	-	Left bank Marmarık, below Sanatorıum
Sprıng "5"	-	-	0 2	21	-	Left bank near sprıng 9
Ankavan 3		103 3	14	21 5	51	Left bank below Sanatorıum, probably abandoned
Ankavan 4		50 9	7 0	27	26	Rıght bank near old water bottlıng plant
Ankavan 17		121 8	20 0	32	85	Left bank above sanıtorıum not seen
Ankavan 21/64	1964			42?		Rıght bank near old water bottlıng plant, probably abandoned
Ankavan 22	1964	230	21 0			No flow reported
Ankavan 23	1964	120	22 0			No flow reported

Table 2 2 Summary of Thermal Wells and Springs, Republic of Armenia

Area/Well or Spring	Year Drilled	Depth (m)	Reported Flow Rate (l/sec)	Flowing or Maximum Temp (°C)	Deepest Production Zone (m)	Comments
Arzakan						
Well 16-T		799	7 0	45	799	Bathhouse well - in use
Martuni						
Spring Lichk 1-I	-	-	2	25	-	
Well 3-T		971	40-50	40		Hospital heating study based on this well
Well 40-c	1958	210		21 2		
Well 405	1964	590		35 2		
Jermakhpur						
Spring Bugur 1-I			2 0	29		Lahmeyer (1994) says 32-33°C
Spring Bugur 2-I			0 4	22		
Jermukpur - north slim hole		1000	0	99		No production - deep gradient 8-10°C/100 m
Jermukpur - south slim hole		600	0	36		No production - deep gradient 7°C/100 m
Sayat-Nova						
Spring 1-I	-	-		23	-	Lahmeyer (1994) says 44°c
Spring 2-I	-	-		23	-	
Well 1		<80 m		34-36		Well not described individually
Well 2		<80 m		34-36		Well not described individually
Well 3		<80 m		34-36		Well not described individually

Table 2 2 Summary of Thermal Wells and Springs, Republic of Armenia

Area/Well or Spring	Year Drilled	Depth (m)	Reported Flow Rate (l/sec)	Flowing or Maximum Temp (°C)	Deepest Production Zone (m)	Comments
Gyumri Area						
Well 726 (Gyumri)	1960	388		32 3		Completed in "sediments"
Well 150c (Kamo)	1959	540		42 0		Completed in "volcanics"
Ararat Area						
"Kotkirigel" (Lake 1)	-	-	23-33	28 4		
"Jagatsneri" springs			0 1-6 8	24 2		
"Group 3" springs	-	-	0 1-7 4	22 5		
"Ilijik" (Lake 4)	-	-	14 6	25 5		
"Akhgel" (Lake 5)	-	-	16-42	25 5		
"Kyagriz 1"	-	-	6 7	24 0		
"Kyagriz 2"	-	-	1 5	23		
Well 1	1950	201 5	27	25		
Well 6		239 8	1 1	23 5	52	
Well 21a		478 4		25		
Well 22		357	5	25 2	49 5	
Well 56		401 2	2 2	24 5		
New well 1	1966			22		
New well 2			1 5	23		
Ararat Basin						
Sevapert well		3100		87		Well produced but reportedly scaled up
Oktemberian 1		1000		41		Completed in "sediments"
Mkhchyan 11		3303	1 5	42	2638	

Table 2 2 Summary of Thermal Wells and Springs, Republic of Armenia

Area/Well or Spring	Year Drilled	Depth (m)	Reported Flow Rate (l/sec)	Flowing or Maximum Temp (°C)	Deepest Production Zone (m)	Comments
Yerevan Area (Central Basin)						
Abovyan 85	1964	430		21 0		Completed in "volcanics and sediments"
Yerevan 6-P	1964	1000		40		Completed in "sediments"
Yerevan 6-P	1961	1000		42		Completed in "sediments"
Hrazdan 4		2270		76		Discharged 40°C water
Hrazdan 15		1670		60		
Hrazdan 20	1963	1920		58		
Kajaran						
Well (name not given)		100		32		"Production from granite pluton"
Yeghegis River Area						
Getikvank Spring	-	-	0 7	30		
Maimekh						
Maimekh (Takakhpur) Spring	-	-	1 4	27		In Pambak Mts SSE of Vanadzor
Kafan						
Well 674	1964	337		23 0		

Table 2 2 Summary of Thermal Wells and Springs, Republic of Armenia

Area/Well or Spring	Year Drilled	Depth (m)	Reported Flow Rate (l/sec)	Flowing or Maximum Temp (°C)	Deepest Production Zone (m)	Comments
Arzni						
Arzni 19		70		20 1		
Arzni 15		107 5	9 2	21 5	80	
Arzni 42		72		22 5		
Arzni 43		170		22		
Arzni 44		75		20		
Arzni 1/62			5 3	20 4		
Jraber	1964	400		23 5		NE of Arzni, no flow reported
Goris-Karashen						
Spring Karashen 1-l	-	-	0 9	20	-	
Spring Karashen 1-l	-	-	0 09	21	-	
Spring Karashen 9-l	-	-	2 0	20	-	

Table 2 3 Major Element Chemistry of Groundwaters in Selected Geothermal Areas of Armenia

Num	Area	Type	Name	l/s Total Flow	°C Meas Temp [1]	pH	mg/l Ca	Mg	Na[2]	K	SO4	Cl	Alk as HCO3	SiO2	TDS (sum)	%(Cat An)/(Cat+An) Ion Balance	Comment[3]
Ankavan																	
1	Ankavan	well	Well 14 (139)	15	**34 5**	7 2	355 2	98 6	1571 4		177 8	1647 2	2684 0	130 0	5300	0 02	
2	Ankavan	well	Well 3/63 (141)			7 4	384 0	87 0	1839 3		223 0	1973 8	2806 0	130 0	6017	0 01	
3	Ankavan	well	Well 3/63		**37 2**	6 9	355 0	125 1	1504 6	122 2	227 0	1953 0	2371 0	83 2	5586	-0 37	Sampled Aug 1,1998
4	Ankavan	well	Well 1/63(14Oa)	25	**32 6**	7 2	435 2	41 5	1746 8		208 8	1724 0	2952 4	206 0	5814	-0 13	
5	Ankavan	well	Well 17 (153)	10	**32**		628 0	57 5	1803 2	19 5	230 0	1930 8	3513 6	73 9	6505	-0 19	
6	Ankavan	well	Well 4 (152)	8	27		637 4	106 4	1730 9	13 7	220 3	1960 9	3525 8		6430	-0 17	
7	Ankavan	well	Well 21/64(154)		**42**		355 2	75 4	1595 0		174 5	1547 8	2806 0	130 0	5258	0 01	
Jermuk																	
8	Elegis	well	Well 4 (346)	3 5	15		364 3	37 0	2654 3		450 0	2811 0	2928 0		7756	0 01	
9	Elegis	well	Well 5 (347)	0 8	14		19 0	23 2	1408 7		329 1	1246 0	1342 0	69 5	3772	-0 03	
10	Elegis	well	Well 58 (349)				485 7	129 1	4184 5		70 0	4473 0	451 4		9564	23 26	
11	Elegis	well	Well 59 (350)	13 5	18		120 0	60 0	3791 7	120 0	627 0	3862 4	3538 0		10330	-0 23	
12	Elegis	well	Well 61 (352)	12	14		370 5	40 6	3682 8		806 3	3390 7	4209 0	25 6	10451	-0 03	
13	Elegis	well	Well 67 (354)	14	17		700 0	60 0	3912 3	100 0	740 0	5047 4	4636 0		12851	-4 66	
14	Elegis	well	Well 72 (355)				425 0	104 5	3357 0		750 0	3221 0	3904 0		9777	1 55	
15	Elegis	well	Well 89 (357)	0 6	16		200 0	63 5	2681 8	100 0	542 0	2417 5	3355 0		7658		
16	Elegis	spring	Spr 339				388 0	43 7	266 3	10 0	40 0	284 0	1597 0	14 6	1838	-0 01	
17	Elegis	spring	Spr 340				270 0	46 8	400 2	10 0	45 0	276 9	1611 6	15 4	1862	0 01	
18	Elegis	spring	Spr 341				278 4	49 3	129 0	4 5	95 0	149 1	1074 2	28 5	1266	-0 02	
19	Elegis	spring	Spr 359	0 07			55 2	5 3	73 4	3 4	27 0	85 0	217 8	16 2	375	0 09	
20	Elegis	spring	Spr 360	0 05			247 2	49 4	511 7	15 0	135 0	518 3	1437 2	51 5	2278	-0 08	
21	Elegis	spring	Spr 361	1	14 5		302 0	68 2	485 8	10 6	420 0	337 3	1537 0	30 8	2436	0 02	
22	SW of Jerm	spring	Spr 362	0 1	13 5		234 0	84 2	944 8	26 6	370 0	1004 7	1537 2	11 5	3444	0 02	
23	SW of Jerm	spring	Spr 364	0 7	19 1		180 0	54 2	772 1	27 0	290 0	532 5	1683 6	11 5	2704	-0 01	
24	SW of Jerm	spring	Spr 365	0 3	18 9		296 8	56 2	794 2		290 0	710 4	1709 2	0 4	2991		
25	SW of Jerm	well	Well 10 (458)	1	18 5	6 2	280 0	72 1	1215 0		368 0	422 4	3172 0		3925	1 01	
26	SW of Jerm	well	Well 8 (461)		17	6 7	570 0	134 2	608 4		200 0	168 2	3267 4		3303	3 15	
27	SW of Jerm	well	Well 9 (462)	3 5	17 5	6 8	377 8	115 6	583 0		400 0	364 0	2147 2		2914	0 53	
28	SW of Jerm	well	Well (466)				16 7	116 0	1620 1	40 0	580 0	401 1	4026 0		4755	-4 34	
29	SW of Jerm	spring	Spr (463)	0 02	12		256 8	71 4	339 0	7 9	350 0	110 0	1451 8	23 5	1880	0 05	

[redacted]

Table 2 3 Major Element Chemistry of Groundwaters in Selected Geothermal Areas of Armenia

				l/s	°C		mg/l									%(Cat An)/(Cat+An)	
Num	Area	Type	Name	Total Flow	Meas Temp [1]	pH	Ca	Mg	Na[2]	K	SO4	Cl	Alk as HCO3	SiO2	TDS (sum)	Ion Balance	Comment[3]
30	SW of Jerm	spring	Spr (467)	1 8	15	6 5	396 2	68 3	82 9	3 6	10 5	28 4	1718 0	35 1	1473	0 03	
31	SW of Jerm	spring	Spr (468)					164 0	127 0	39 0	74 0	16 0	914 0		871	8 41	
32	SW of Jerm	spring	Spr (469)					174 0	87 5	39 0	68 0	16 0	854 0		808	9 68	
33	SW of Jerm	spring	Spr (470)					186 0	33 3	37 0	75 0	25 0	708 0		708	12 53	
34	NE of Jerm	spring	Spr 369	0 12	8		20 0	3 6	19 8		250 0			19 2	377	-0 04	
35	Jermuk	well	Well 1 (414)	6 1	**54**		182 0	74 9	1015 2		830 0	301 8	2060 8	30 1	3450	-0 06	
36	Jermuk	well	Well 4 (415)	3 2	**54**	7 1	188 8	74 9	1015 4	90 0	900 0	301 8	2148 4	40 8	3678	0 22	
37	Jermuk	well	Well 7 (416)		**61**	5 9	82 4	12 0	358 8	16 0	260 0	127 8	740 5	60 4	1284	0 39	
38	Jermuk	well	Well 9 (419)	6 4	**64**	7 6	148 0	74 4	1213 9	89 0	900 0	475 7	2243 0	107 7	4120	0 22	
39	Jermuk	well	Well 18/62(420)				144 3	37 6	759 1		426 0	206 0	1671 0		2395	1 46	
40	*Jermuk*	*well*	*Well 20/62(431)*	6	**58**		198 2	73 6	1036 1		720 7	346 8	2208 0		3461	0 03	
41	Jermuk	well	Well 21/62(432)	10 9	**56**		177 1	70 8	997 9		707 6	314 9	2098 0		3300	0 05	
42	Jermuk	well	Well 22/62(433)	4			181 3	65 5	1147 3		768 0	364 1	2269 1		3642	0 69	
43	Jermuk	well	Well 24/62(434)	2 5	**54**		185 5	75 1	1146 0		718 3	418 9	2351 0		3700	-0 02	
44	Jermuk	well	Well 1-K (439)	1 6	**63**	6 8	75 0	76 0	959 1		600 0	340 8	1799 5		2936	0 11	
45	Jermuk	well	Well 1-K				168 3	53 5	979 8		644 0	326 6	2000 8		3156		
46	Jermuk	well	Well 1-K		**51**	7 0	*161 3*	*46 0*	*890 1*	*70 0*	*544 0*	*308 0*	*1925 0*	10 3	3000	1 25	Sampled Aug 5,1998
47	Jermuk	well	Well 1Y-K				184 4	62 0	819 5		621 0	248 5	1830 0		2835	0 01	
48	Jermuk	well	Well 30/62(436)	4 6	**54 7**	6 7	100 0	79 0	1106 3		706 0	355 0	2135 0		3396	-0 08	
49	Jermuk	well	Well 30/62				164 3	55 9	1036 6		685 2	340 8	2074 0		3303	0 02	
50	Jermuk	well	Well 30/62		**56**	7 0	149 5	54 1	973 0	83 8	649 0	316 0	2004 0	15 0	3244	1 39	Sampled Aug 5 1998
51	Jermuk	well	Well 7/58 (420)	4 8	**52**	6 5	240 0	97 3	828 5		666 6	220 1	2196 0		3132	-0 06	
52	Jermuk	well	Well 2/61 (422)	4	**54 2**	6 6	175 0	76 0	1007 4		857 0	241 4	2074 0		3377	0 13	
53	Jermuk	well	Well II-OK(440)	0 65	**54 7**	6 4	125 0	69 9	1073 4		757 0	287 6	2135 0		3363	-0 16	
54	Jermuk	well?[4]	Well? along river		**53**	6 8	182 9	69 7	756 1	73 0	339 0	229 0	2201 0	17 2	2764	0 02	Sampled May 30 1998
55	Jermuk	well	Well 33/62(438)		**40**	6 2	*200 0*	*91 2*	*803 0*		*706 0*	*276 9*	*1830 0*		*2977*	*-0 09*	
56	Jermuk	well	Well 7 (444)	12	11	6 4	74 6	166 8	602 1		260 0	203 1	1805 6		2197	3 56	
57	Jermuk	well	Well 12 (445)	0 25	13		178 2	14 0	148 0		220 0	31 2	671 0		921	0 07	
58	Jermuk	well	Well 13 (446)	2	13		414 2	23 0	462 9		600 0	70 3	1720 2		2416	0 03	

Table 2 3 Major Element Chemistry of Groundwaters in Selected Geothermal Areas of Armenia

				l/s	°C		mg/l									%(Cat An)/(Cat+An)	
Num	Area	Type	Name	Total Flow	Meas Temp [1]	pH	Ca	Mg	Na[2]	K	SO4	Cl	Alk as HCO3	SiO2	TDS (sum)	Ion Balance	Comment[3]
59	Jermuk	well	Well 19 (451)	2 5	13 5	6 3	154 2	60 0	234 1		160 0	62 5	1085 8		1205	-0 17	
60	Jermuk	well	Well 20 (452)	2 5	13 5	6 0	232 5	99 7	393 4	56 3	224 0	142 0	1830 0		2058	0 07	
61	Jermuk	well	Well 855 (453)	0 6	15 5		243 4	129 8	977 0		1331 2	149 1	2110 0		3868	-0 90	
62	Jermuk	well	Well 856 (454)	0 5			130 2	78 9	377 7		175 0	123 5	1342 0		1545	0 50	
63	Jermuk	well	Well 857 (455)	4	12 5		272 2	95 5	454 2		247 5	140 0	1756 8		2073	4 17	
64	Sayat Nova	spring	Spr 1 (471)		23	7 0	493 9	117 7	2191 7	200 0	1332 9	2099 5	2928 0	141 6	8037	-0 07	
65	Sayat Nova	well	Well 2 (475)		**34-36**		168 0	51 1	2069 1	86 0	460 6	1771 5	2897 5	66 9	6137	-0 26	
66	Sayat Nova	well	Well 3 (476)		**34-36**		186 8	30 6	1994 6	80 0	500 0	1675 6	2745 8	69 2	5911	-0 43	
Sisian (Vorotan River area)																	
67	Bazarchai	well	Well 4 (479)	1 5	16		230 9	138 0	293 8		250 0	117 8	1659 2		1849	0 05	
68	Bazarchai	well	Well 8 (480)	3 5	16	5 8	124 0	106 7	326 7		243 0	73 8	1134 0		1432	6 28	
69	Balak	well	Spr (481)	0 2	10		98 5	45 9	5 0				542 9		417	0 11	
70	Balak	well	Spr (482)	0 05	13	5 8	80 0	48 0	32 4			7 1	561 2	51 6	496	-0 13	
71	Beechanag	well	Spr (483)	0 1	13	5 8	116 0	58 8	11 7			14 2	658 8	48 0	573	-0 14	
72	Beechanag	well	Spr (484)	0 2	10	6 0	124 0	80 4	8 0			14 2	780 8	63 2	674	-0 14	
73	Angrehakot	well	Well 9 (486)	10 3	24	6 4	137 2	60 0	142 1		94 0	35 1	915 0		918	0 06	
74	Sisian	well	Well 6 (487)	0 5	18		140 0	99 6	207 0		170 0	38 0	1195 6		1243		
75	Sisian	well	Well 12 (488)	1 5	22		104 0	117 6	128 3	56 3	163 2	35 5	1098 0	58 8	1209	-0 74	
76	Sisian	well	Well 838 (489)	0 4	14	6 2	118 0	33 6	179 6		319 2	66 7	488 0		957	-0 19	
77	Sisian	well	Well 188 (489a)	10		6 9	318 8	242 1	876 2	60 0	706 0	408 9	2879 2		4028	1 38	
78	Sisian	well	Well		**31**	6 2	182 5	120 2	325 9	33 6	585 0	103 0	1192 0	39 2	1991	-0 32	Sampled Aug 5, 1998
79	Vorotan	well	Well 15 (505)	15	23 5		240 0	194 4	823 6		450 0	585 4	2318 0		3433	-0 06	
80	Vorotan	well	Well 834 (506)	15	27	6 6	175 2	228 3	649 2		45 7	588 7	2342 4		2839	-0 16	
81	Vorotan	well	Well 16 (508)	3	26		330 0	222 0	639 8		450 0	554 5	2293 6		3327	0 04	
82	Brnakot	spring	Spr (490)				132 0	31 0	75 5		233 0	38 0	396 5		704	-0 01	
83	Uz	spring	Spr (491)	0 2	16	6 6	136 0	225 6	369 3	30 0	460 7	255 6	1592 8	53 6	2315	-0 79	
84	Uz	spring	Spr (492)	0 6	16		240 0	168 0	345 7		300 0	129 2	1891 0		2114	0 01	
85	Tolors	well	Well (497)	1 5	14		200 0	60 0	91 0		90 0	38 0	976 0		960	-0 04	
86	Ahlatyan	spring	Spr (500)	0 2	12	6 8	84 0	225 6	292 1		279 8	120 7	1610 4	44 4	1840	-0 13	
87	Ahlatyan	spring	Spr (501)	0 3	12	6 6	20 0	240 0	339 3	30 0	329 0	120 7	1586 0	44 4	1905	0 13	
88	Ahlatyan	spring	Spr (502)	0 2	13	6 8	36 0	43 2	36 1	15 0	82 3	14 2	317 2	44 4	427	-0 06	

Table 2 3 Major Element Chemistry of Groundwaters in Selected Geothermal Areas of Armenia

				l/s	°C		mg/l									%(Cat-An)/(Cat+An)	
Num	Area	Type	Name	Total Flow	Meas Temp [1]	pH	Ca	Mg	Na[2]	K	SO4	Cl	Alk as HCO3	SiO2	TDS (sum)	Ion Balance	Comment[3]
89	Bugur	spring	Spr (509)	2	29	5 8	380 8	68 1	92 0		225 0	14 2	1470 0	72 4	1585	-0 37	
90	Bugur	spring	Spr (510)	0 4	22	6 4	284 6	109 0	54 5		140 0	14 2	1390 2	83 6	1379	-0 39	
Kamo-Martuni																	
91	Kamo	well	Well 1 (193)	0 3	17	6 3	354 8	125 0	433 6		60 0	729 2	1537 2		2458	-0 17	
92	Kamo	well	Well 2 (194)	5 4		6 7	349 0	140 0	502 5		80 0	813 0	1610 4		2678	-0 13	
93	Kamo	well	Well 3 (194a)	10	18		242 5	144 7	662 2		48 8	1031 2	1390 8		2824	-0 09	
94	Greedzor	spring	Spr (195)	1	14		132 0	682 4	619 8		1500 0	398 3	1805 6		4220	10 90	
95	Greedzor	spring	Spr (197)	0 1	4		192 0	17 5	103 5		491 0	8 0	311 0		965	-0 09	
96	Bardeneek	spring	Spr (199)	1 5	6		10 0	1 2	15 2			16 3	48 8	30 0	97	0 54	
97	Atash	spring	Spr (200)	6 5	11 1		55 0	25 0	52 6		7 0	12 0	317 0		308	11 09	
98	Atash	spring	Spr (201)		10		519 0	62 0	116 0		10 0	59 0	20 8		776	88 43	
99	Martuni	well	Well 47c (206)	10			24 0	6 1	25 1		20 0	14 1	122 0	33 7	183	-0 40	
100	Martuni	well	Well 146c (207)	2 5	14		36 2	17 3	90 1			7 2	427 0	38 0	399	-0 36	
101	Martuni	well	Well 45c (208)	11			32 1	15 8	36 0		4 8	14 2	244 1	38 6	262	-0 37	
102	Martuni	well	Well 46c (209)	25			80 2	34 0	87 4		8 0	42 4	573 4	45 0	579	-0 71	
103	Martuni	well	Well 11c (210)	20			144 0	105 6	386 8		8 0	440 2	1171 2	48 4	1709	1 46	
104	Martuni	well	Well 12c (211)	19			232 0	158 4	480 6		25 0	426 0	2025 2	48 4	2369	-0 14	
105	Martuni	well	Well 38c (212)	25			363 6	184 9	687 7		16 0	852 0	2403 4	58 5	3344	-0 38	
106	Martuni	well	Well 152c (213)	10	19		260 8	177 9	556 9		35 0	615 6	2061 8		2660	-0 01	
107	N of Martu	well	Well 148c (214)	12 5	17		87 6	48 5	368 6		2 0	72 4	1342 0		1239	0 65	
108	N of Kamo	well	Well 64c (216)				255 1	116 6	100 9		1114 4	78 1	85 4	6 0	1713	-0 17	
109	N of Kamo	well	Well 65c (217)				54 1	44 1	185 6		40 0	418 4	109 8	15 0	811	-0 08	
Arzakan - Bjni																	
110	Arzakan	spring	Spr (176)				80 3	16 2	185 8		100 0	56 1	610 0	28 5	774	0 01	
111	Arzakan	well	Well (Arzakan)				118 0	71 7	1198 8	100 0	269 0	445 2	2928 0	76 9	3727	0 63	
112	Bjni	spring	Spr (177)	0 9	15		186 8	88 0	426 0		234 0	451 0	1075 0		1916	-0 10	
113	Bjni	spring	Spr (178)	0 26	14 2	8 0	84 8	21 5	162 1	1 2	37 5	74 2	622 2	45 0	732	0 03	
114	Bjni	well	Well (BJNI)				230 9	115 8	1217 2	78 0	218 0	556 6	3416 0	76 9	4181	0 11	
115	Djageedzor	spring	Spr (180)		15	7 0	77 2	3 6	10 1			7 1	268 4	10 0	240	-0 13	
116	Kasax	spring	Spr (181)	0 1	10 1	7 0	54 0	5 0	25 3			14 2	231 8	10 0	222	0 08	
117	Tudshur	spring	Spr (182)	0 75	8 6		16 0		5 1			10 7	43 9	10 0	63	-0 05	

Table 2 3 Major Element Chemistry of Groundwaters in Selected Geothermal Areas of Armenia

Num	Area	Type	Name	l/s Total Flow	°C Meas Temp [1]	pH	mg/l Ca	Mg	Na[2]	K	SO4	Cl	Alk as HCO3	SiO2	TDS (sum)	%(Cat-An)/(Cat+An) Ion Balance	Comment[3]
Arzni																	
118	Arzni	well	Well 15 (264)		21 5	6 5	300 0	198 2	2612 2		512 2	3420 1	2322 9	69 2	8268	-0 04	
119	Arzni	well	Well 23 (268)	0 5	18 5	6 6	137 0	45 0	1149 6		225 2	1363 2	1027 9	51 5	3483	0 57	
120	Arzni	well	Well 25 (270)		17 5		138 0	55 1	1034 3		249 6	1235 4	1000 4	52 3	3257	-0 03	
121	Arzni	well	Well 35 (275)	2 8	18 9		396 2	340 6	3013 4	54 0	652 8	4328 8	2730 9	115 6	10272	0 03	
122	Arzni	well	Well 42 (279)		22 5		55 7	34 2	541 2	41 0	100 5	620 0	644 7	99 1	1812	0 19	
123	Arzni	well	Well 54 (284)			6 4	159 9	144 0	1170 4		203 7	1664 4	1188 9		3927	0 04	
124	Arzni	well	Well 16/2 (285)				371 5	321 3	3012 5		630 6	4188 5	2730 6		9867	-0 01	
125	Arzni	well	Well 3/62 (286)			6 7	230 7	224 7	1847 8		368 9	2595 1	1800 0		6152	-0 01	
126	Arzni	well	Well X/64 (287)			6 2	474 7	568 7	7010 8		785 8	10230 6	4301 9		21186	0 00	

Note 1 Boldface type is used to indicate measured temperatures >= 30°C
Note 2 If K is not reported, then Na represents Na + K expressed as mg/l of Na
Note 3 Samples dated 1998 were collected by GeothermEx (R C Henneberger) and analysed at Western Analysis, Inc , Salt Lake City, Utah, U S A (Western Analysis ID# 66928,66930,66932,66934,66936, dated 08-24-98)
Note 4 Ultimate source of water is not clear, may be a developed spring rather than a well

Blank cell indicates no data available

Table 2 4 Chemical Geothermometers Applied to Groundwaters in Selected Geothermal Areas of Armenia

					l/s	°C		mg/l		Silica Temp °C[2]			Cation Temp °C[2]			
Num	Area	Port	Name	Date	Total Flow	Meas Temp[1]	pH	Cl	TDS (sum)	Quartz	Chalcedony	Amorphous	Na-K-Ca	Na-K-Ca-Mg[3]	Na/K	KMg
Ankavan																
1	Ankavan	well	Well 14 (139)		15	**34 5**	7 2	1647 2	5300	153	127	31				
2	Ankavan	well	Well 3/63 (141)				7 4	1973 8	6017	153	127	31				
3	Ankavan	well	Well 3/63	01 Aug 98		**37 2**	6 9	1953 0	5586	127	99	8	183	47	200	98
4	Ankavan	well	Well 1/63(14Oa)		25	**32 6**	7 2	1724 0	5814	183	161	58				
5	Ankavan	well	Well 17 (153)		10	**32**		1930 8	6505	121	93	3	77	<77	<150	63
6	Ankavan	well	Well 4 (152)		8	27		1960 9	6430				65	<65	<150	49
7	Ankavan	well	Well 21/64(154)			**42**		1547 8	5258	153	127	31				
Jermuk																
8	Elegis	well	Well 4 (346)		3 5	15		2811 0	7756							
9	Elegis	well	Well 5 (347)		0 8	14		1246 0	3772	118	89	<0				
10	Elegis	well	Well 58 (349)					4473 0	9564							
11	Elegis	well	Well 59 (350)		13 5	18		3862 4	10330				159	41	<150	108
12	Elegis	well	Well 61 (352)		12	14		3390 7	10451	73	41	<0				
13	Elegis	well	Well 67 (354)		14	17		5047 4	12851				136	114	<150	103
14	Elegis	well	Well 72 (355)					3221 0	9777							
15	Elegis	well	Well 89 (357)		0 6	16		2417 5	7658				157	55	<150	102
16	Elegis	spring	Spr 339					284 0	1838	52	20	<0	48	<48	<150	51
17	Elegis	spring	Spr 340					276 9	1862	54	21	<0	58	<58	<150	51
18	Elegis	spring	Spr 341					149 1	1266	78	46	<0	27	<27	<150	34
19	Elegis	spring	Spr 359		0 07			85 0	375	56	23	<0	42	<42	159	51
20	Elegis	spring	Spr 360		0 05			518 3	2278	104	73	<0	75	<75	<150	59
21	Elegis	spring	Spr 361		1	14 5		337 3	2436	81	49	<0	60	<60	<150	48
22	SW of Jer	spring	Spr 362		0 1	13 5		1004 7	3444	43	11	<0	127	43	<150	65
23	SW of Jer	spring	Spr 364		0 7	19 1		532 5	2704	43	11	<0	136	51	<150	71
24	SW of Jer	spring	Spr 365		0 3	18 9		710 4	2991	v low	v low	<0				
25	SW of Jer	well	Well 10 (458)		1	18 5	6 2	422 4	3925							
26	SW of Jer	well	Well 8 (461)			17	6 7	168 2	3303							
27	SW of Jer	well	Well 9 (462)		3 5	17 5	6 8	364 0	2914							
28	SW of Jer	well	Well (466)					401 1	4755				149	v low	<150	71
29	SW of Jer	spring	Spr (463)		0 02	12		110 0	1880	70	38	<0	51	<51	<150	42

Table 2 4 Chemical Geothermometers Applied to Groundwaters in Selected Geothermal Areas of Armenia

					l/s	°C		mg/l		Silica Temp °C[2]			Cation Temp °C[2]			
Num	Area	Port	Name	Date	Total Flow	Meas Temp [1]	pH	Cl	TDS (sum)	Quartz	Chalcedony	Amorphous	Na-K-Ca	Na-K-Ca-Mg[3]	Na/K	KMg
30	SW of Jer	spring	Spr (467)		1 8	15	6 5	28 4	1473	87	55	<0	13	<13	155	27
31	SW of Jer	spring	Spr (468)					16 0	871				-1	-1	337	67
32	SW of Jer	spring	Spr (469)					16 0	808				-1	-1	390	66
33	SW of Jer	spring	Spr (470)					25 0	708				-1	-1	574	64
34	NE of Jerm	spring	Spr 369		0 12	8			377	62	30	<0				
35	Jermuk	well	Well 1 (414)		6 1	**54**		301 8	3450	80	48	<0				
36	Jermuk	well	Well 4 (415)		3 2	**54**	7 1	301 8	3678	93	62	<0	186	44	207	97
37	Jermuk	well	Well 7 (416)			**61**	5 9	127 8	1284	111	82	<0	98	92	156	76
38	Jermuk	well	Well 9 (419)		6 4	**64**	7 6	475 7	4120	142	115	21	181	34	192	97
39	Jermuk	well	Well 18/62(420)					206 0	2395							
40	Jermuk	well	Well 20/62(431)		6	**58**		346 8	3461							
41	Jermuk	well	Well 21/62(432)		10 9	**56**		314 9	3300							
42	Jermuk	well	Well 22/62(433)		4			364 1	3642							
43	Jermuk	well	Well 24/62(434)		2 5	**54**		418 9	3700							
44	Jermuk	well	Well 1-K (439)		1 6	**63**	6 8	340 8	2936							
45	Jermuk	well	Well 1-K					326 6	3156							
46	Jermuk	well	Well 1-K	05 Aug 98		**51**	7 0	308 0	3000	37	8	<0	178	61	197	97
47	Jermuk	well	Well 1Y-K					248 5	2835							
48	Jermuk	well	Well 30/62(436)		4 6	**54 7**	6 7	355 0	3396							
49	Jermuk	well	Well 30/62					340 8	3303							
50	Jermuk	well	Well 30/62	05 Aug 98		**56**	7 0	316 0	3244	53	21	<0	186	51	205	99
51	Jermuk	well	Well 7/58 (420)		4 8	**52**	6 5	220 1	3132							
52	Jermuk	well	Well 2/61 (422)		4	**54 2**	6 6	241 4	3377							
53	Jermuk	well	Well II-OK(440)		0 65	**54 7**	6 4	287 6	3363							
54	Jermuk	well?	Well?on river	30 May 98		**53**	6 8	229 0	2764	58	26	<0	186	44	214	92
55	Jermuk	well	Well 33/62(438)			**40**	6 2	276 9	2977							
56	Jermuk	well	Well 7 (444)		12	11	6 4	203 1	2197							
57	Jermuk	well	Well 12 (445)		0 25	13		31 2	921							
58	Jermuk	well	Well 13 (446)		2	13		70 3	2416							

Table 2 4 Chemical Geothermometers Applied to Groundwaters in Selected Geothermal Areas of Armenia

Num	Area	Port	Name	Date	l/s Total Flow	°C Meas Temp [1]	pH	mg/l Cl	mg/l TDS (sum)	Silica Temp °C[2] Quartz	Silica Temp °C[2] Chalcedony	Silica Temp °C[2] Amorphous	Cation Temp °C[2] Na-K-Ca	Cation Temp °C[2] Na-K-Ca-Mg[3]	Cation Temp °C[2] Na/K	Cation Temp °C[2] KMg
59	Jermuk	well	Well 19 (451)		2 5	13 5	6 3	62 5	1205							
60	Jermuk	well	Well 20 (452)		2 5	13 5	6	142 0	2058				193	35	250	81
61	Jermuk	well	Well 855 (453)		0 6	15 5		149 1	3868							
62	Jermuk	well	Well 856 (454)		0 5			123 5	1545							
63	Jermuk	well	Well 857 (455)		4	12 5		140 0	2073							
64	Sayat Nova	spring	Spr 1 (471)			23	7	2099 5	8037	158	133	35	193	74	209	113
65	Sayat Nova	well	Well 2 (475)			**34-36**		1771 5	6137	116	87	<0	160	58	152	101
66	Sayat Nova	well	Well 3 (476)			**34-36**		1675 6	5911	118	89	<0	157	92	<150	106
Sisian (Vorotan River area)																
67	Bazarchai	well	Well 4 (479)		1 5	16		117 8	1849							
68	Bazarchai	well	Well 8 (480)		3 5	16	5 8	73 8	1432							
69	Balak	well	Spr (481)		0 2	10			417							
70	Balak	well	Spr (482)		0 05	13	5 8	7 1	496	104	73	<0				
71	Beechanag	well	Spr (483)		0 1	13	5 8	14 2	573	100	70	<0				
72	Beechanag	well	Spr (484)		0 2	10	6	14 2	674	113	84	<0				
73	Angrehakot	well	Well 9 (486)		10 3	24	6 4	35 1	918							
74	Sisian	well	Well 6 (487)		0 5	18		38 0	1243							
75	Sisian	well	Well 12 (488)		1 5	22		35 5	1209	110	80	<0	250	v low	388	79
76	Sisian	well	Well 838 (489)		0 4	14	6 2	66 7	957							
77	Sisian	well	Well 188 (489a)		10		6 9	408 9	4028				165	v low	187	72
78	Sisian	well	Well	05 Aug 98		**31**	6 2	103 0	1991	91	60	<0	174	17	219	67
79	Vorotan	well	Well 15 (505)	-	15	23 5		585 4	3433							
80	Vorotan	well	Well 834 (506)	-	15	27	6 6	588 7	2839							
81	Vorotan	well	Well 16 (508)	-	3	26		554 5	3327							
82	Brnakot	spring	Spr (490)					38 0	704							
83	Uz	spring	Spr (491)		0 2	16	6 6	255 6	2315	105	75	<0	166	v low	200	57
84	Uz	spring	Spr (492)		0 6	16		129 2	2114							
85	Tolors	well	Well (497)		1 5	14		38 0	960							
86	Ahlatyan	spring	Spr (500)		0 2	12	6 8	120 7	1840	97	66	<0				
87	Ahlatyan	spring	Spr (501)		0 3	12	6 6	120 7	1905	97	66	<0	186	v low	207	57
88	Ahlatyan	spring	Spr (502)		0 2	13	6 8	14 2	427	97	66	<0	88	<88	380	60

Table 2 4 Chemical Geothermometers Applied to Groundwaters in Selected Geothermal Areas of Armenia

					l/s	°C		mg/l		Silica Temp °C[2]			Cation Temp °C[2]			
Num	Area	Port	Name	Date	Total Flow	Meas Temp [1]	pH	Cl	TDS (sum)	Quartz	Chalcedony	Amorphous	Na-K-Ca	Na-K-Ca-Mg[3]	Na/K	KMg
89	Bugur	spring	Spr (509)		2	29	5 8	14 2	1585	120	91	2				
90	Bugur	spring	Spr (510)		0 4	22	6 4	14 2	1379	128	100	8				
Kamo-Martuni																
91	Kamo	well	Well 1 (193)		0 3	17	6 3	729 2	2458							
92	Kamo	well	Well 2 (194)		5 4		6 7	813 0	2678							
93	Kamo	well	Well 3 (194a)		10	18		1031 2	2824							
94	Greedzor	spring	Spr (195)		1	14		398 3	4220							
95	Greedzor	spring	Spr (197)		0 1	4		8 0	965							
96	Bardeneek	spring	Spr (199)		1 5	6		16 3	97	80	48	<0				
97	Atash	spring	Spr (200)		6 5	11 1		12 0	308							
98	Atash	spring	Spr (201)			10		59 0	776							
99	Martuni	well	Well 47c (206)		10			14 1	183	85	53	<0				
100	Martuni	well	Well 146c (207)		2 5	14		7 2	399	90	59	<0				
101	Martuni	well	Well 45c (208)		11			14 2	262	91	59	<0				
102	Martuni	well	Well 46c (209)		25			42 4	579	97	67	<0				
103	Martuni	well	Well 11c (210)		20			440 2	1709	101	70	<0				
104	Martuni	well	Well 12c (211)		19			426 0	2369	101	70	<0				
105	Martuni	well	Well 38c (212)		25			852 0	3344	110	80	<0				
106	Martuni	well	Well 152c (213)		10	19		615 6	2660							
107	N of Martu	well	Well 148c (214)		12 5	17		72 4	1239							
108	N of Kamo	well	Well 64c (216)					78 1	1713							
109	N of Kamo	well	Well 65c (217)					418 4	811	53	21	<0				
Arzakan - Bjni																
110	Arzakan	spring	Spr (176)					56 1	774	78	46	<0				
111	Arzakan	well	Well (Arzakan)					445 2	3727	123	95	4	190	30	202	100
112	Bjni	spring	Spr (177)		0 9	15		451 0	1916							
113	Bjni	spring	Spr (178)		0 26	14 2	8	74 2	732	97	67	<0	16	<16	<150	18
114	Bjni	well	Well (BJNI)					556 6	4181	123	95	4	170	29	182	87
115	Djageedzor	spring	Spr (180)			15	7	7 1	240	38	7	<0				
116	Kasax	spring	Spr (181)		0 1	10 1	7	14 2	222	38	7	<0				
117	Tudshur	spring	Spr (182)		0 75	8 6		10 7	63	38	7	<0				

Table 2 4 Chemical Geothermometers Applied to Groundwaters in Selected Geothermal Areas of Armenia

					l/s	°C		mg/l		Silica Temp °C[2]			Cation Temp °C[2]			
Num	Area	Port	Name	Date	Total Flow	Meas Temp[1]	pH	Cl	TDS (sum)	Quartz	Chalcedony	Amorphous	Na-K-Ca	Na-K-Ca-Mg[3]	Na/K	KMg
Arzni																
118	Arzni	well	Well 15 (264)			21 5	6 5	3420 1	8268	118	89	<0				
119	Arzni	well	Well 23 (268)		0 5	18 5	6 6	1363 2	3483	104	73	<0				
120	Arzni	well	Well 25 (270)			17 5		1235 4	3257	104	74	<0				
121	Arzni	well	Well 35 (275)		2 8	18 9		4328 8	10272	146	120	24	121	v low	<150	66
122	Arzni	well	Well 42 (279)			22 5		620 0	1812	137	110	16	177	27	194	87
123	Arzni	well	Well 54 (284)				6 4	1664 4	3927							
124	Arzni	well	Well 16/2 (285)					4188 5	9867							
125	Arzni	well	Well 3/62 (286)				6 7	2595 1	6152							
126	Arzni	well	Well X/64 (287)				6 2	10230 6	21186							

Note Blank indicates insufficient data to calculate

Note 1 Bold typeface indicates measured temperatures >=30°C

Note 2

Quartz temperature	*Fournier R O and Potter II R W 1982 A revised and expanded silica (quartz) geothermometer Geothermal Resources Council Bulletin November vol 11 no 10 pp 3-12 with correction for ommission in appendix vol 12 no 1 jan 1983 p 32 Range 0° - 330°C*
Chalcedony temperature	*Fournier R O 1981 Application of water chemistry to geothermal exploration and reservoir engineering Chapter 4 in Geothermal Systems Principles and Case Histories L Ryback and L J P Muffler Eds Wiley New York p 109-143 Range 0 - 250°C*
Amorphous Silica temp	*Fournier R O 1981 Loc Cit Range 0° - 250°C*
Na-K-Ca temperature	*Fournier R O 1981 Loc Cit Range 4 - 340°C*
Na-K-Ca-Mg temp	*Fournier R O 1981 Loc Cit Range lower limit is variable some results imply low to very low temperature even when out-of-range of quantitative method Upper limit is 340°C*
Na/K temperature	*Fournier R O 1981 Loc Cit Range >150°C*
KMg temperature	*Giggenbach W F 1986 Graphical techniques for the evaluation of water/rock equilibrium conditions by use of Na K Mg and Ca contents of discharge waters Proceedings 8th New Zealand Geothermal Workshop Range 0 - 350 C*

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Table 3 1 Classification of Geothermal Direct-Use Applications by Temperature
after Lindal, 1973

Minimum Temperature (°C)	Potential Applications
180	Evaporation of highly concentrated solutions Refrigeration by ammonia absorption Pulp and paper manufacture
170	Drying of diatomaceous earth Heavy water via hydrogen sulfide process
160	Drying of fish meal Drying of timber
150	Alumina via Bayer's process
140	Drying farm products at high rates Canning of food
130	Evaporation in sugar refining Extraction of salts by evaporation and crystallization Fresh water by distillation
120	Most multi-effect evaporation concentration of saline solution
110	Drying and curing of light aggregate cement slabs
100	Drying and curing of organic materials, seaweeds, grass, vegetables Washing and drying of wool
90	Drying of stock fish Intense de-icing operations
80	Space-heating (buildings and greenhouses)
70	Refrigeration (lower temperature limit)
60	Animal husbandry Greenhouses by combined space and hotbed heating
50	Mushroom growing Balneaology
40	Soil warming
30	Swimming pools biodegradation fermentations Warm water for year-round mining in cold climates De-icing
20	Hatching of fish, fish farming

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Table 3 2 Population of the Administrative Regions of Armenia

Region	Center	Population	Number of Rural Settlements	Number of Towns
Aragatsotn	Ashtarak	162,500	111	3
Ararat	Artashat	305,000	93	4
Armavir	Armavir	315,500	94	3
Gegharkunik	Gavar	272 400	87	5
Lori	Vanadzor	392,400	105	8
Kotayk	Hrazdan	325,900	60	7
Shirak	Gyumri	358,300	116	3
Syunik	Kafan	161,900	106	7
Vayots Dzor	Yeghegnadzor	68,300	41	3
Tavush	Ijevan	154,800	58	4
Yerevan	Yerevan	1 249,400	-	-
Total		3,766,400	871	47

Source Avagian, 1997

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Table 8 1 Wavebands of the Landsat 5 Thematic Mapper Satellite Image Data

Band	Wavelength (μm)	Properties
1	0 45 - 0 82	Visible blue-green Can distinguish soil from vegetation
2	0 52 - 0 60	Visible green Matches green reflectance peak of vegetation
3	0 63 - 0 69	Visible red Matches important chlorophyll absorption band
4	0 76 - 0 90	Photo IR Strong reflectance by all vegetation
5	1 55 - 1 75	Near IR Reflectance depends on water content of soil/vegetation
6*	10 4 - 12 5	Thermal IR Useful at night to detect temperature variation
7	2 08 - 2 35	Shortwave IR Falls in absorption band of hydroxyl ions

*Band 6 is not used in any of the images described in this report

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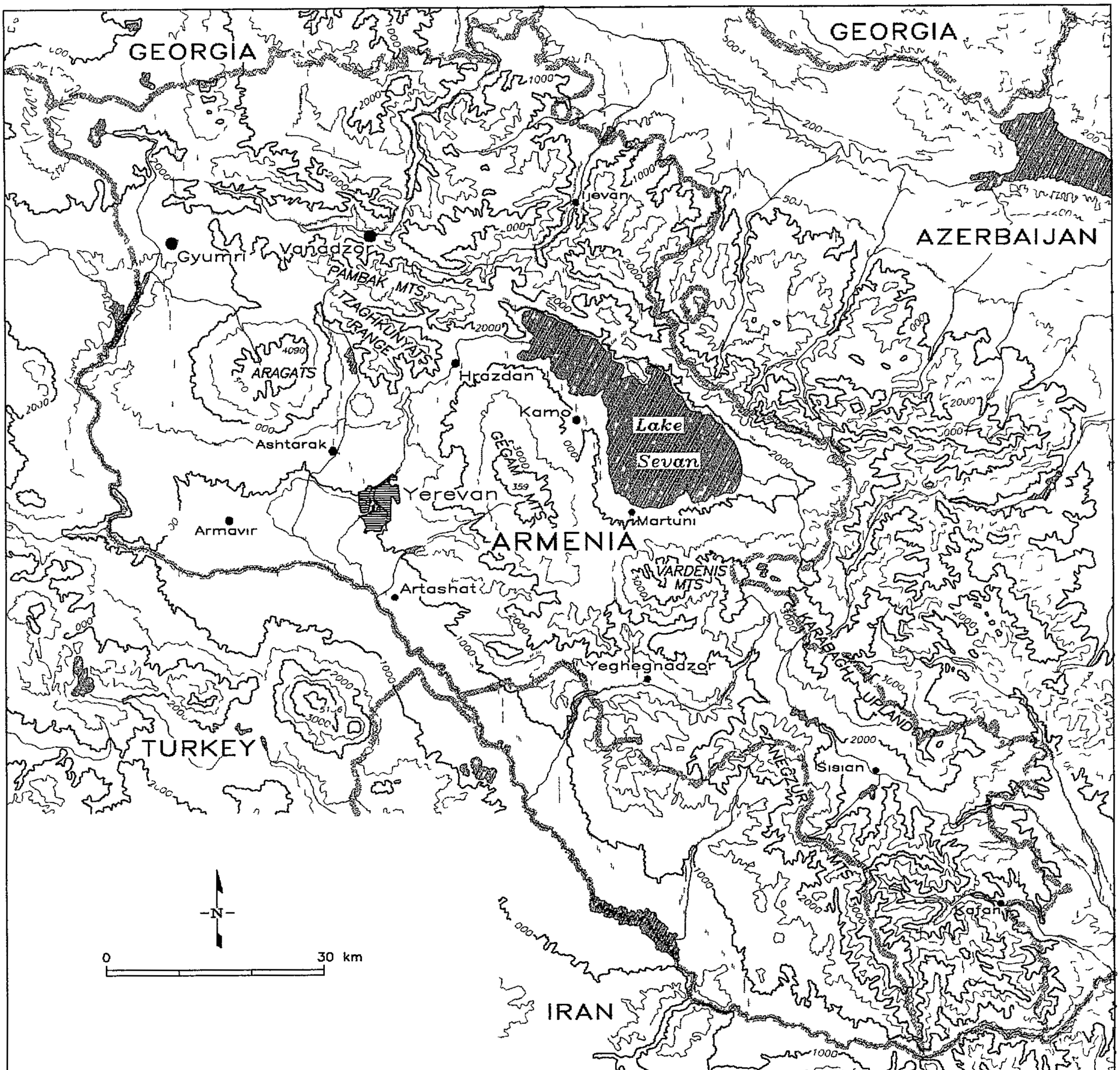
FIGURES



LEGEND

- Road
- Stream
- Principal city
- Elevation contour m

Figure 2 1 Topographic map of the Republic of Armenia

REPUBLIC OF ARMENIA

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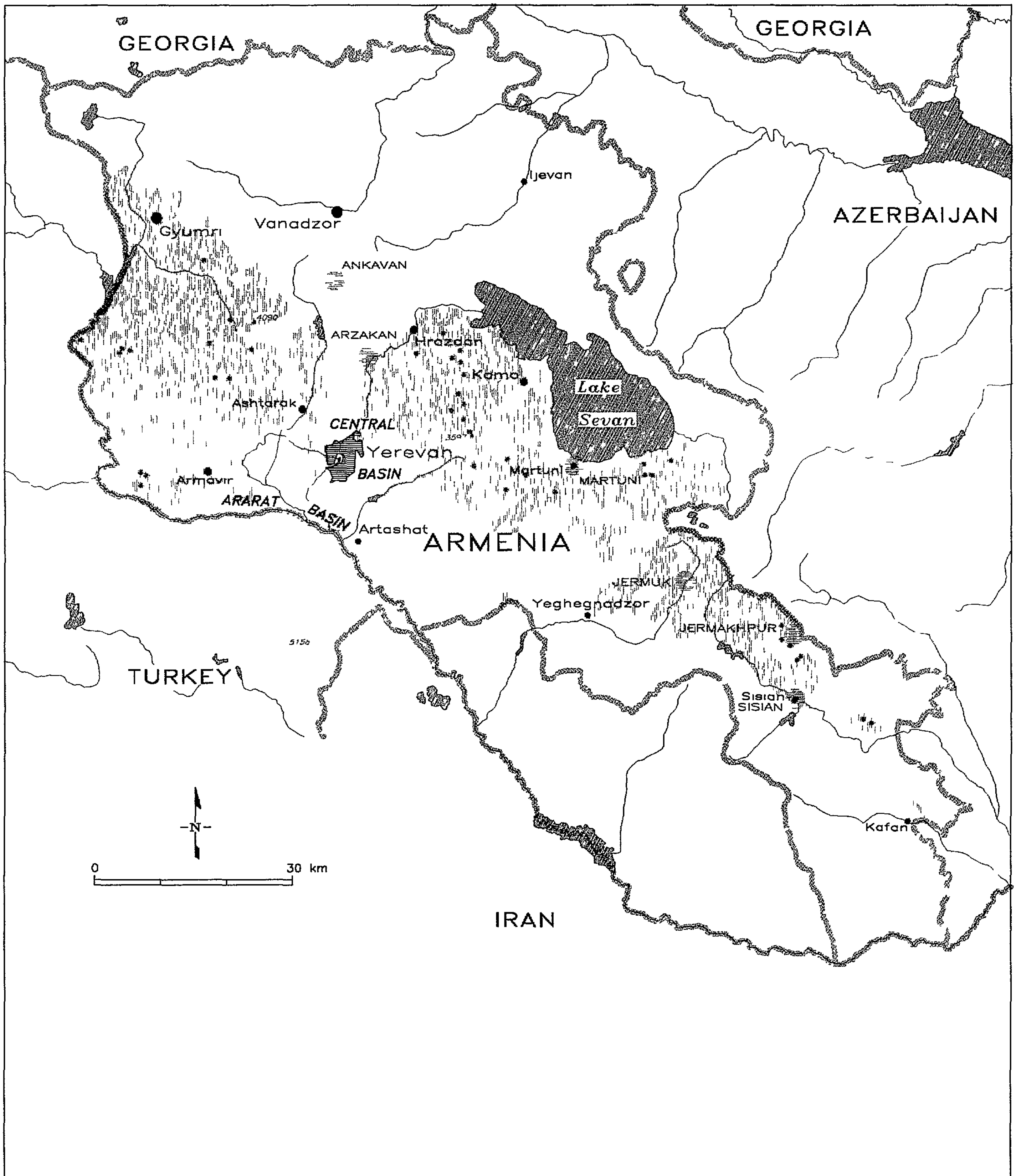

LEGEND

- Stream
- Major thermal area
- Volcanic center
- Quaternary volcanic deposits

Figure 2 2 Map showing distribution of Quaternary volcanic rocks

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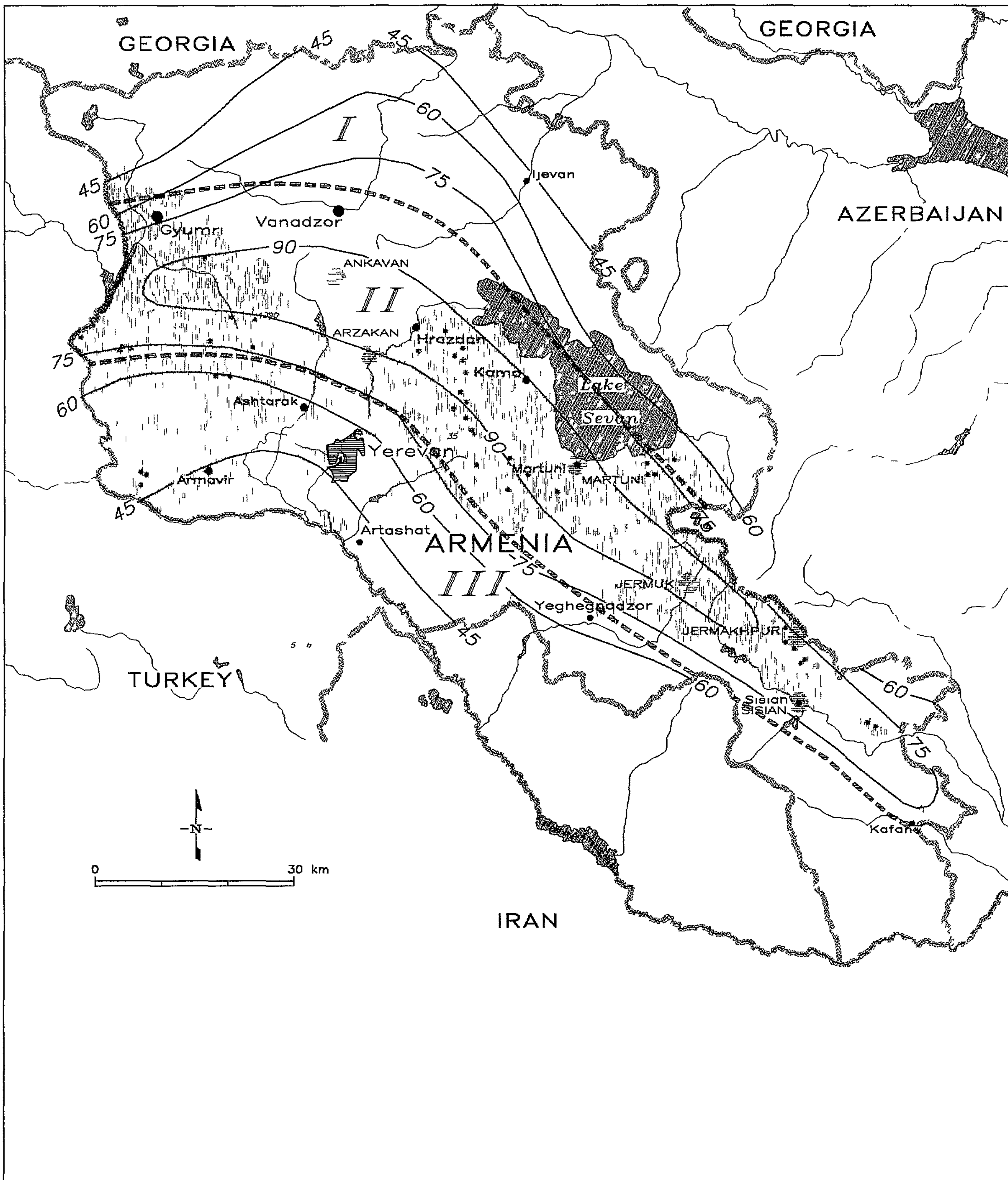

LEGEND

- Stream
- Major thermal area
- Volcanic center
- Quaternary volcanics
- —75— Isoline of natural heat flow (mW/m^2)
- *II* Deduced heat flow zone

Figure 2.3 Contour of heat flow with deduced heat flow zones

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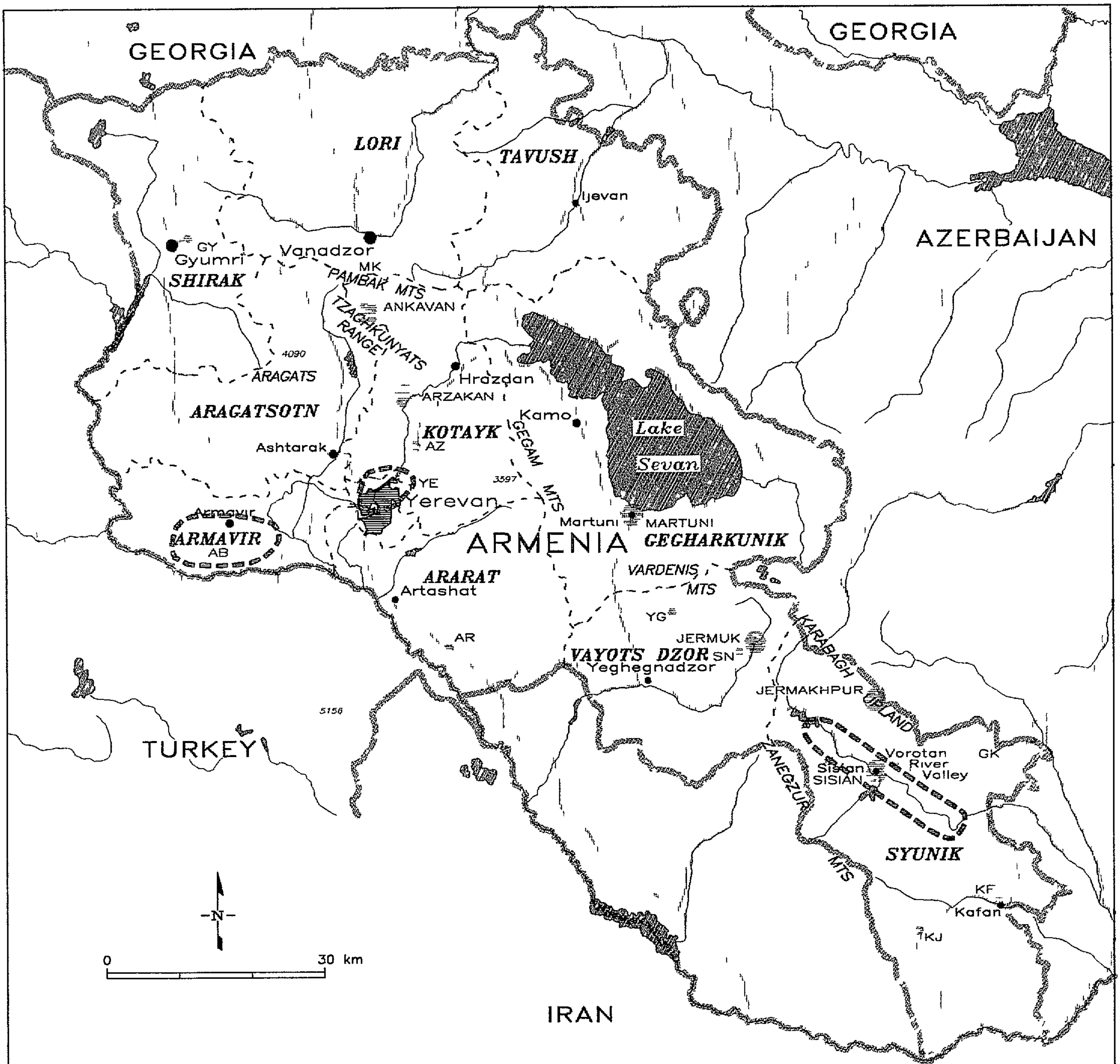

Key to Minor Thermal Areas

AB	Ararat Basin	MK	Maimekh
AR	Ararat	SN	Sayat Nova
AZ	Arzni–Jraber	YE	Yerevan area
GK	Goris–Kajaran	YG	Yeghegis River area
GY	Gyumri–Kamo		
KF	Kafan		
KJ	Kajaran		

LEGEND

- Road
- Stream
- Major thermal area
- KJ Minor thermal area

Figure 2 4
Location map of thermal areas

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FILE ARM_NT DWG	ARMEN2 SS	P 085

Figure 2 5

Piper diagram showing major element composition of groundwaters in the area of Ankavan

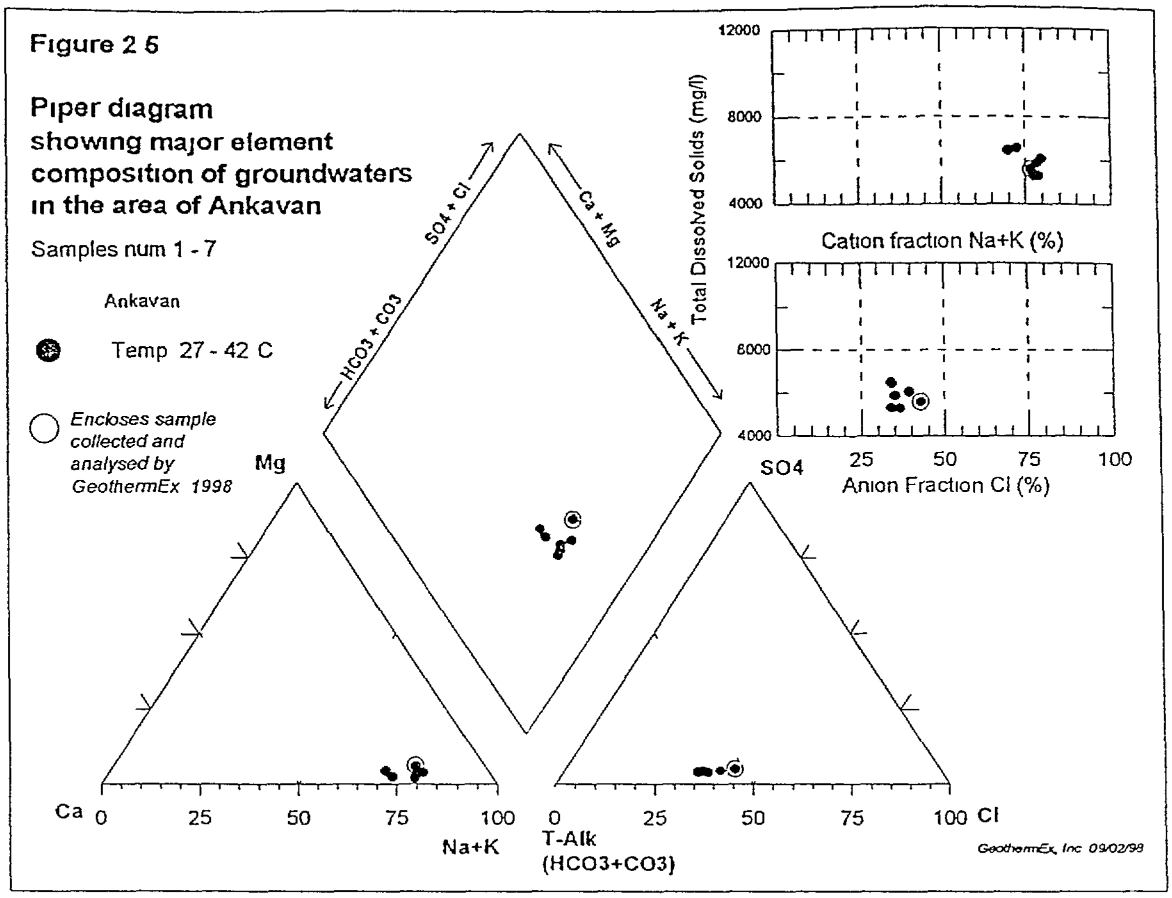
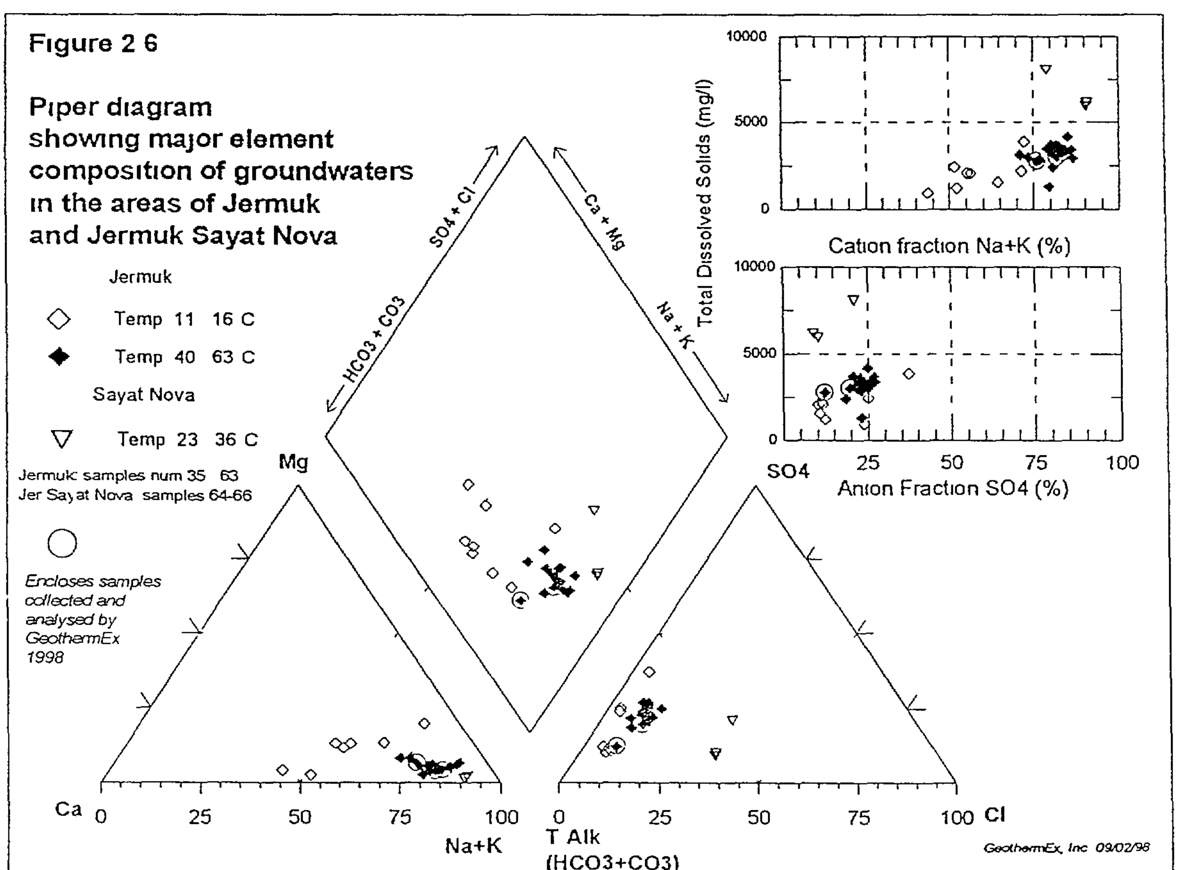


Figure 2 6

Piper diagram showing major element composition of groundwaters in the areas of Jermuk and Jermuk Sayat Nova



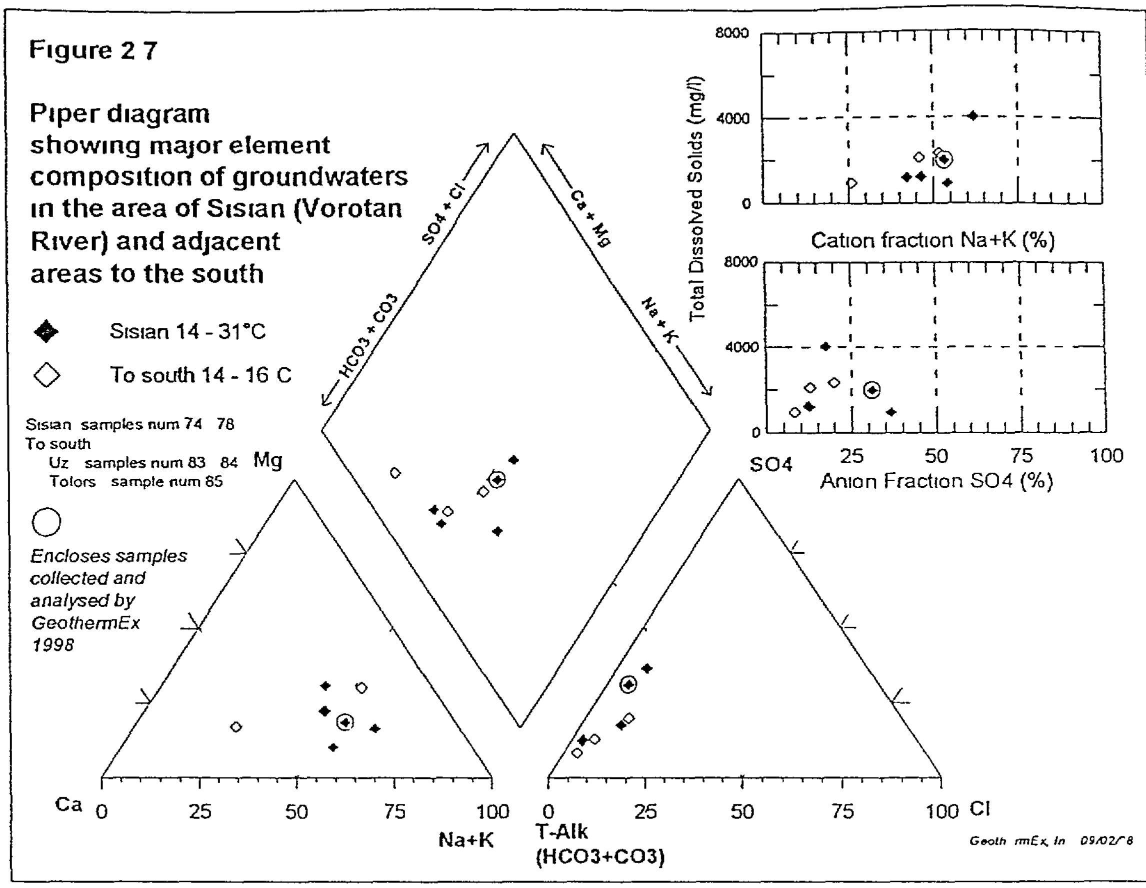


Figure 2 7

Piper diagram showing major element composition of groundwaters in the area of Sisian (Vorotan River) and adjacent areas to the south

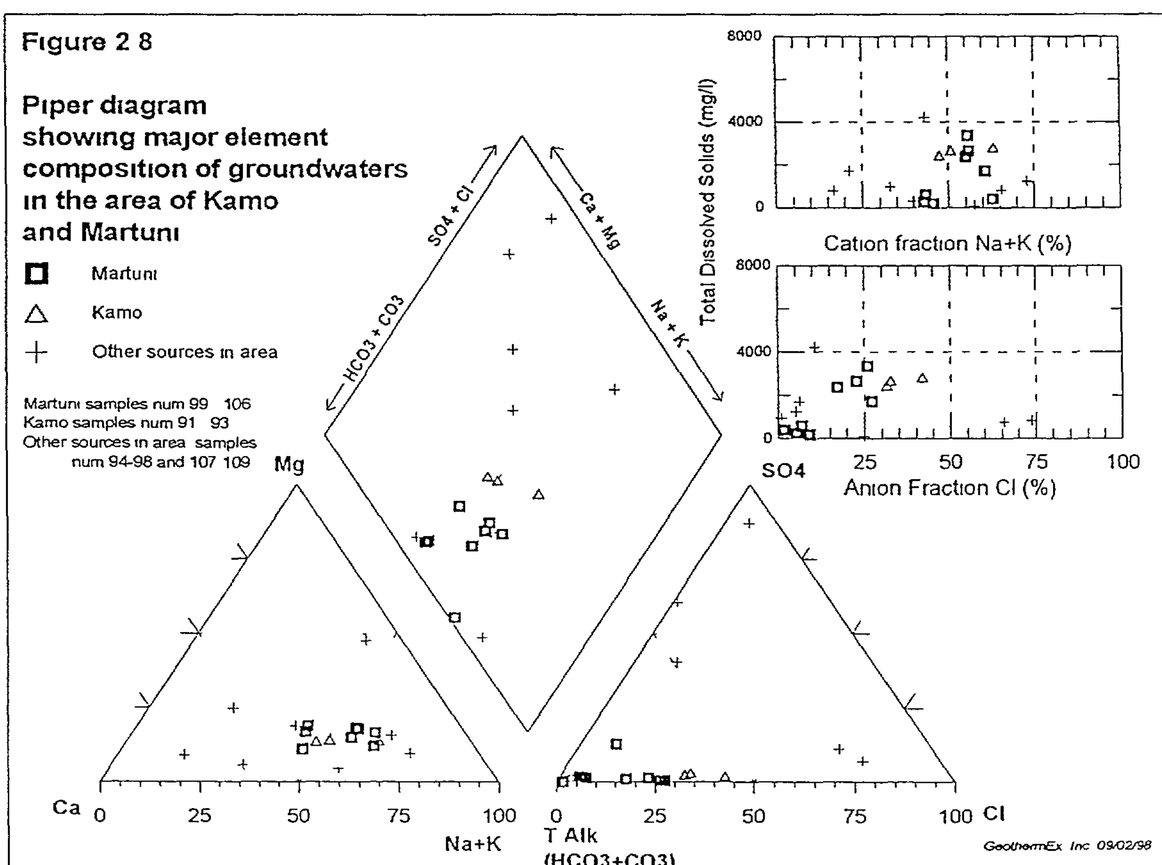


Figure 2 8

Piper diagram showing major element composition of groundwaters in the area of Kamo and Martuni

Figure 2 9

Piper diagram showing major element composition of groundwaters in the area of Arzakan - Bjni

Arzakan Bjni samples num 110 114

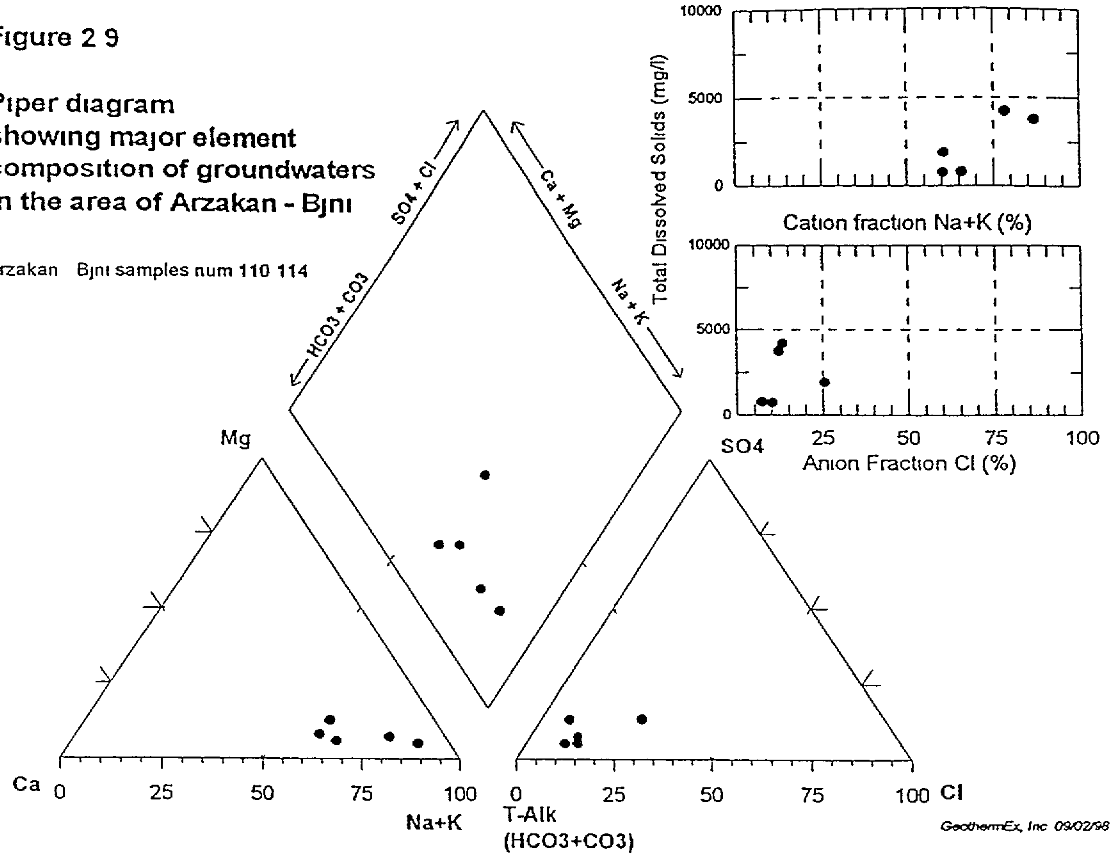
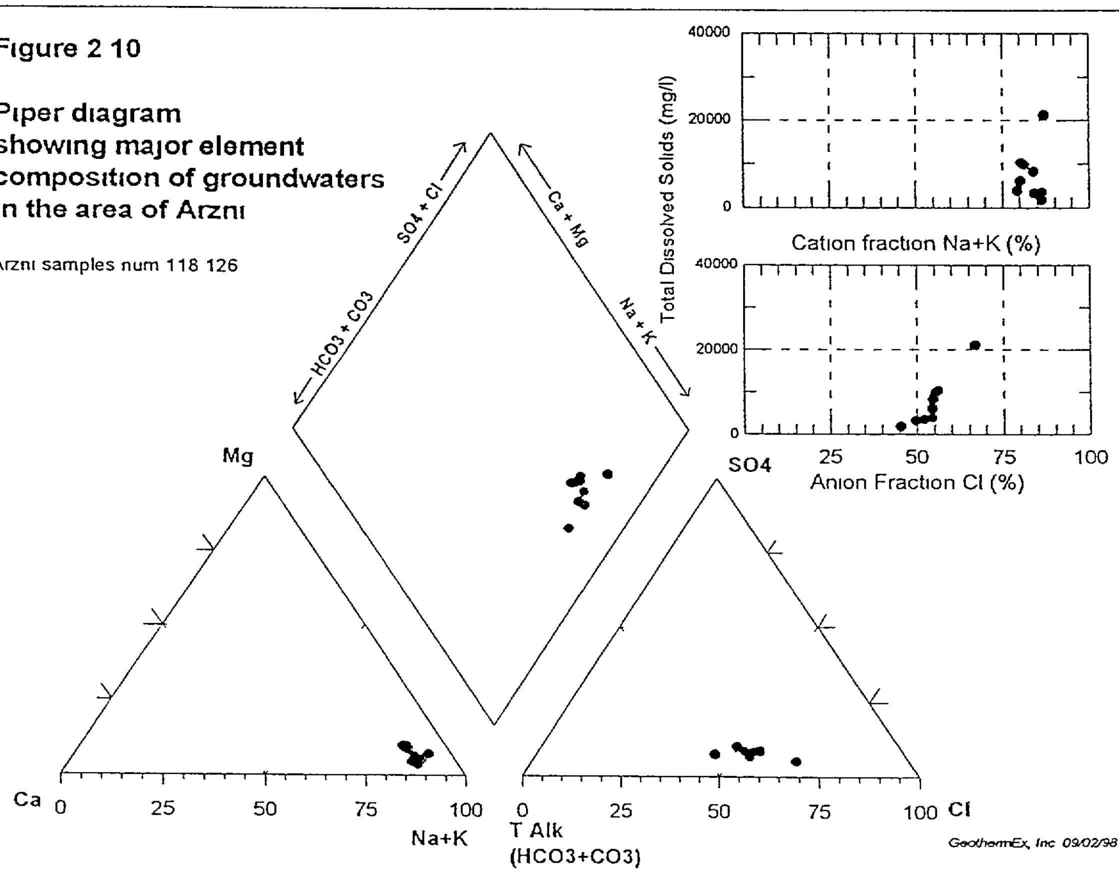


Figure 2 10

Piper diagram showing major element composition of groundwaters in the area of Arzni

Arzni samples num 118 126



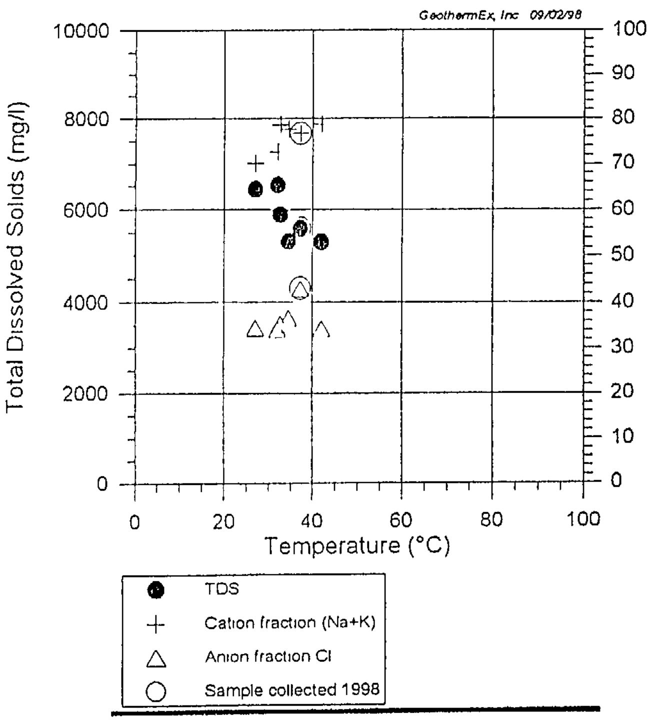


Figure 2 11

Salinity and composition vs temperature of groundwaters in the area of Ankavan

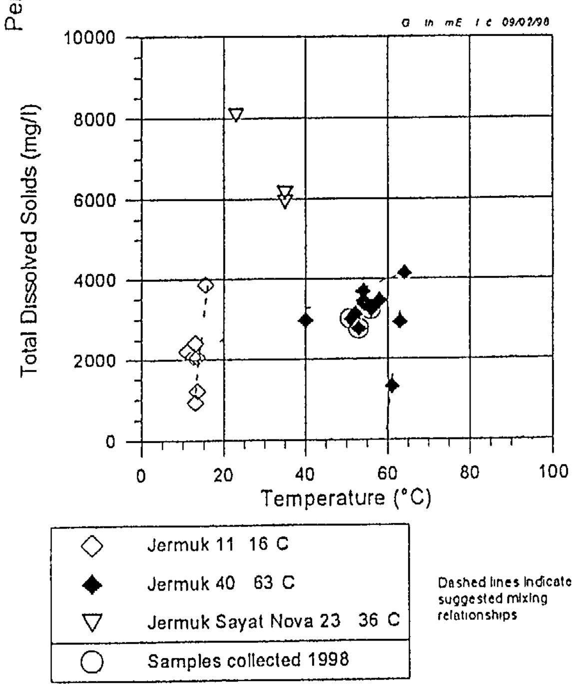


Figure 2 12

Salinity vs temperature of groundwaters in the areas of Jermuk and Jermuk Sayat Nova

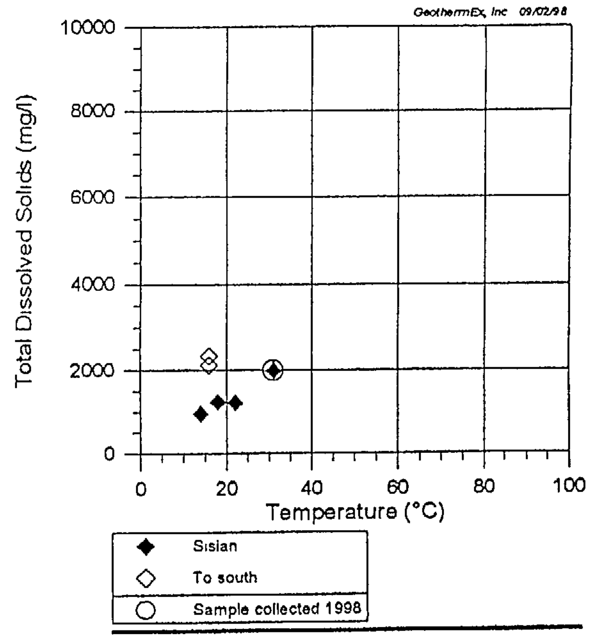


Figure 2 13

Salinity vs temperature of groundwaters in the area of Sisian and adjacent areas to the south

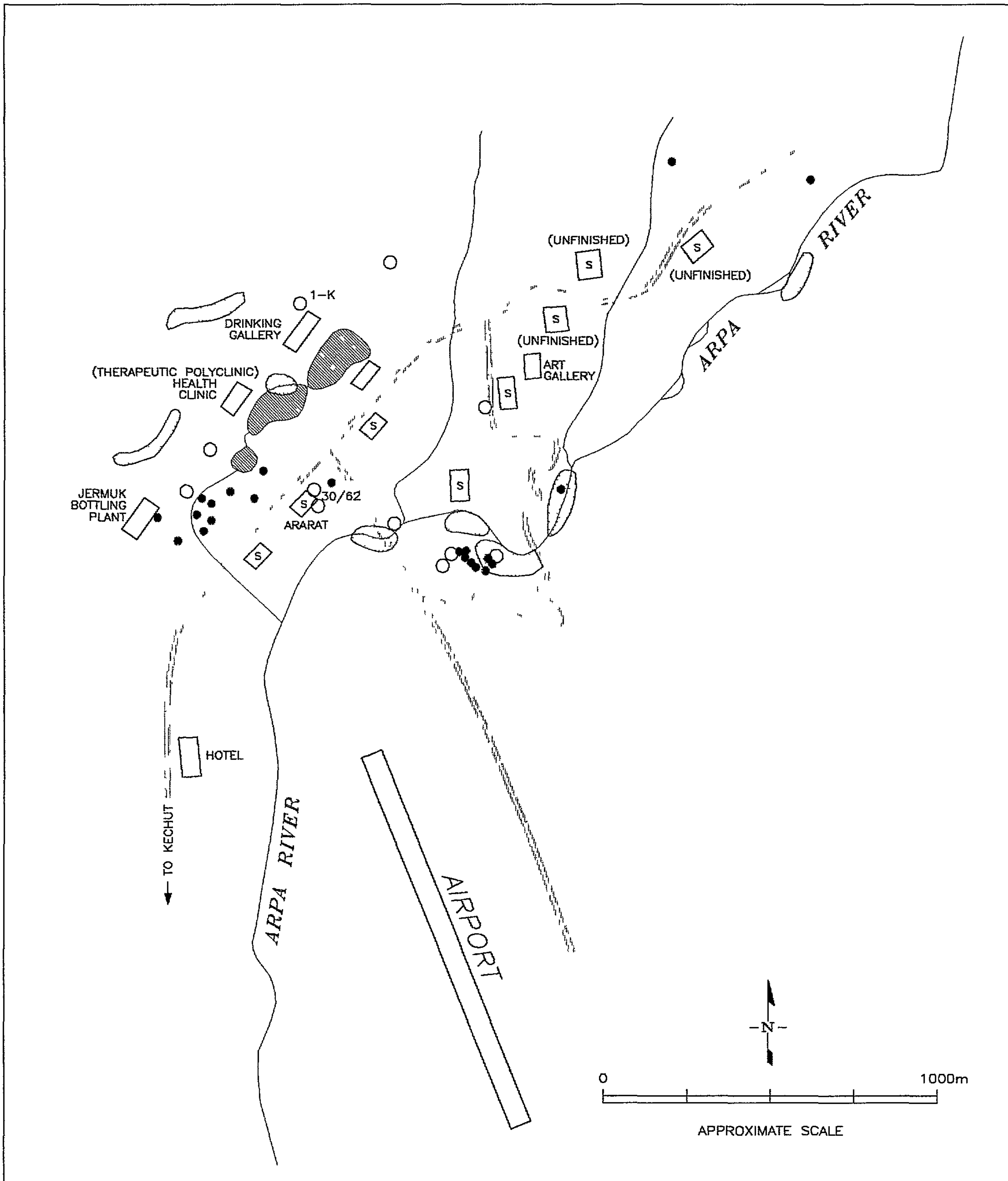


Figure 4 1 Schematic map of town of Jermuk

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PLOTDATE 04SEP98	DRAWN RRS	APP RCH
FILE. JERMUK DWG	ARMENIA.SS	P2085

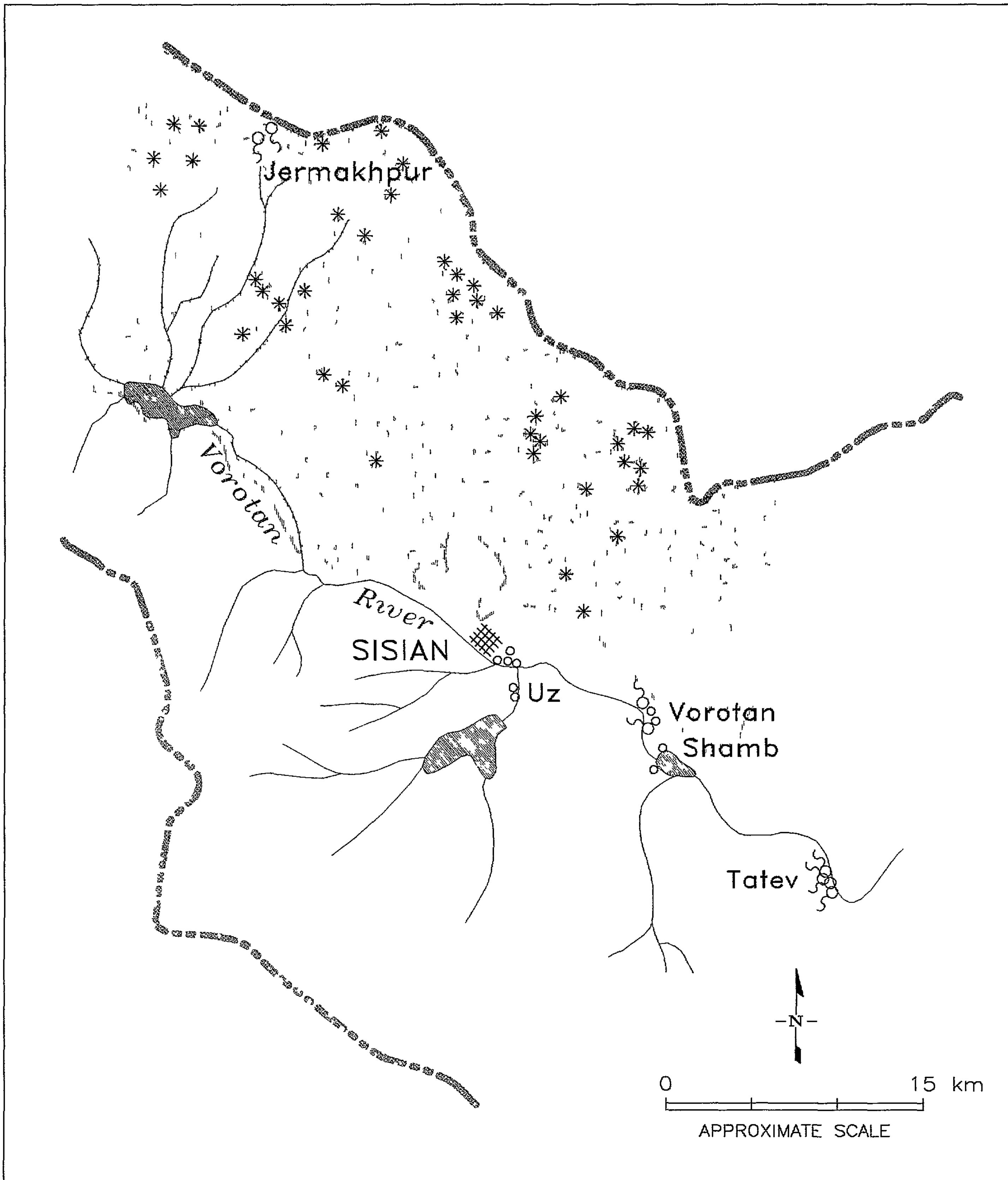

Figure 5 1 Map of thermal and volcanic features in the Vorotan River Valley

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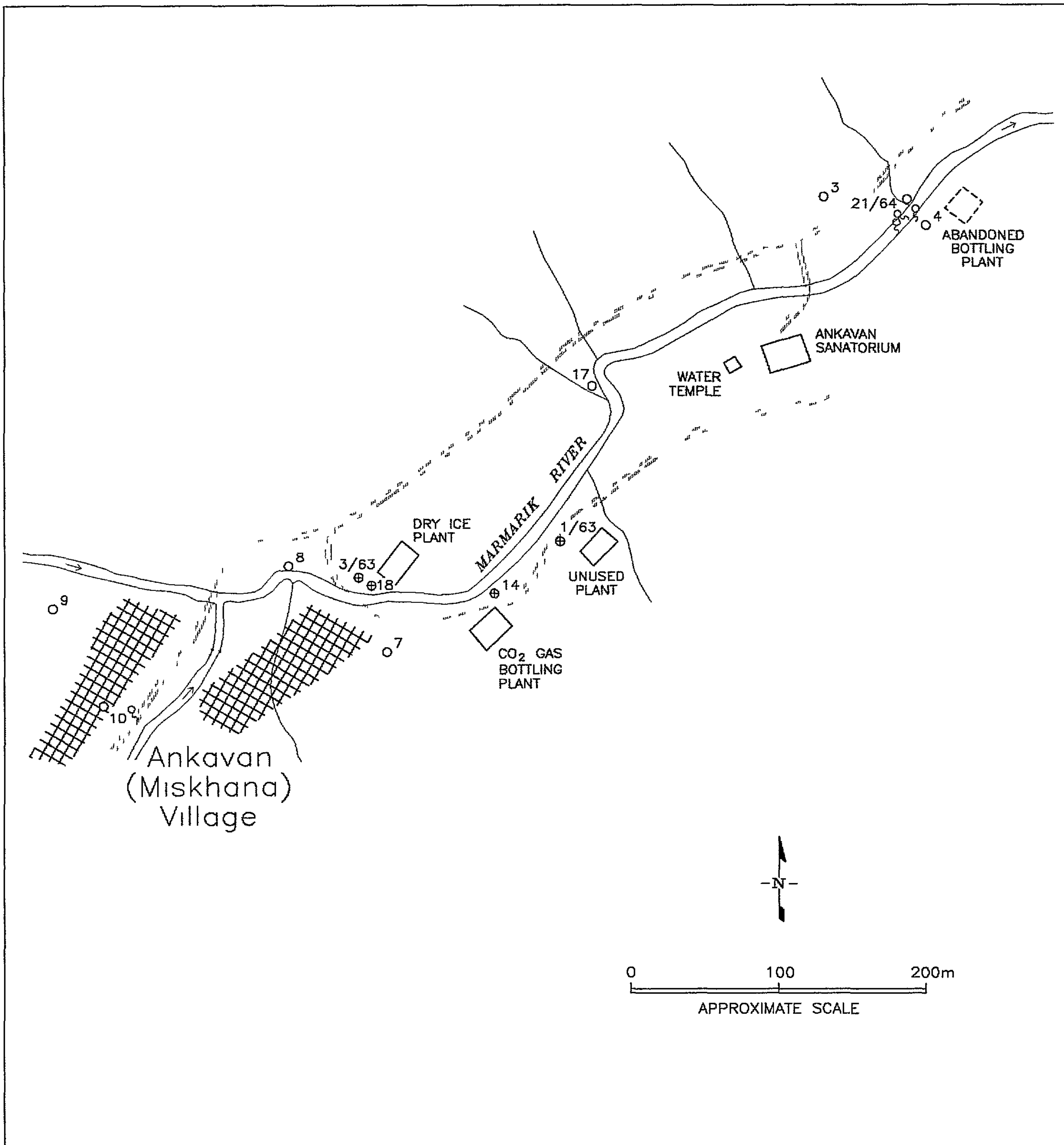
EMMYFIT		
PLOTDATE 25 EP98	DRAWN RRS	APP RCH
FILE VOROTAN2 DWG	ARMEN2 SS	P20P5



LEGEND

⊕ Existing well

○ Well not found in field investigations

Thermal spring (>20 C)

Highways and principal streets

River or stream

Figure 6 1 Schematic map of Ankavan area (after Mkrtchian 1969)

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EMMYFIT		
PLOTDATE 15SEP98	DRAWN RRS	APP RCH
FILE ANKAVAN DWG	ARMENIA SS	P2085

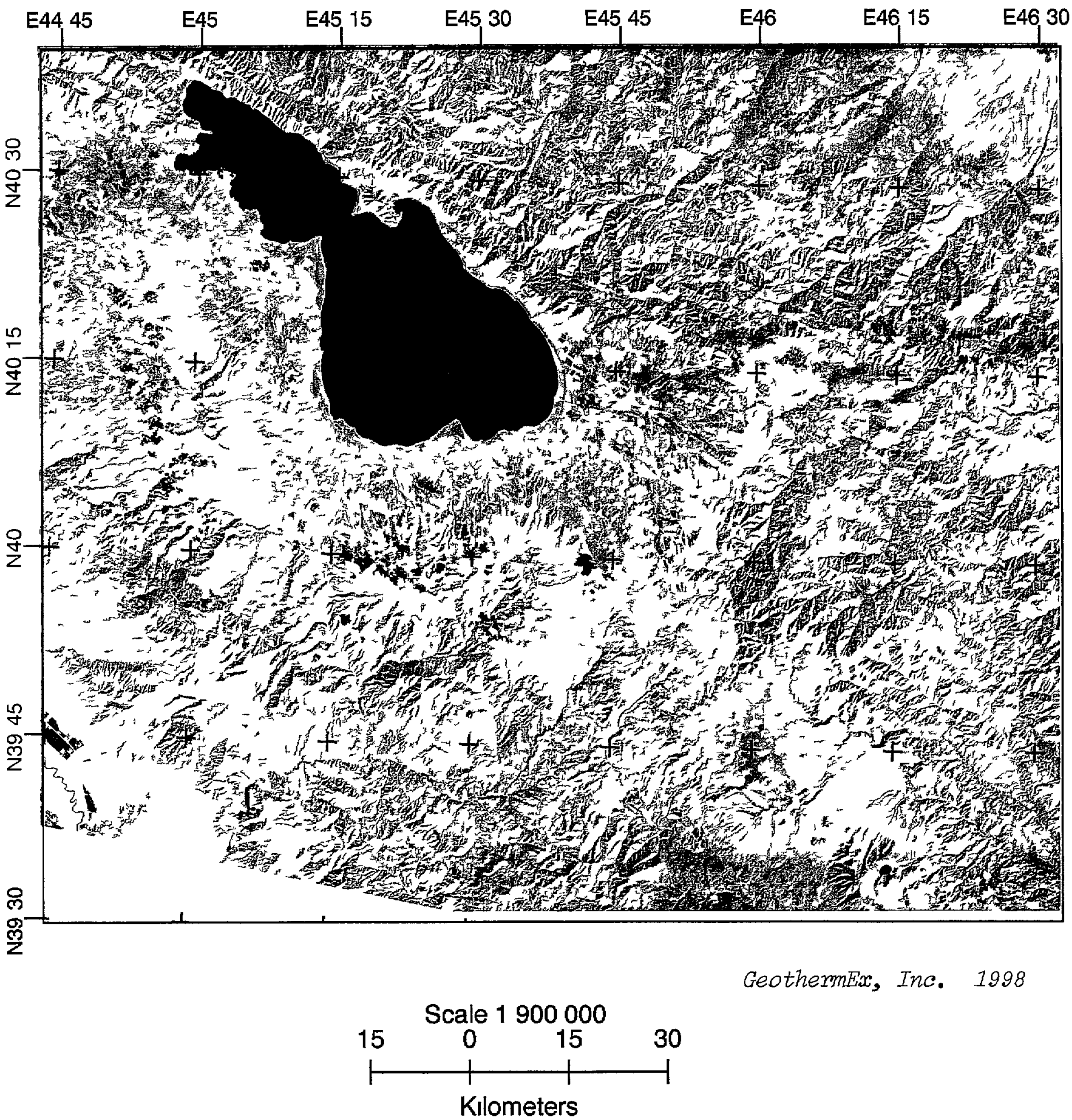
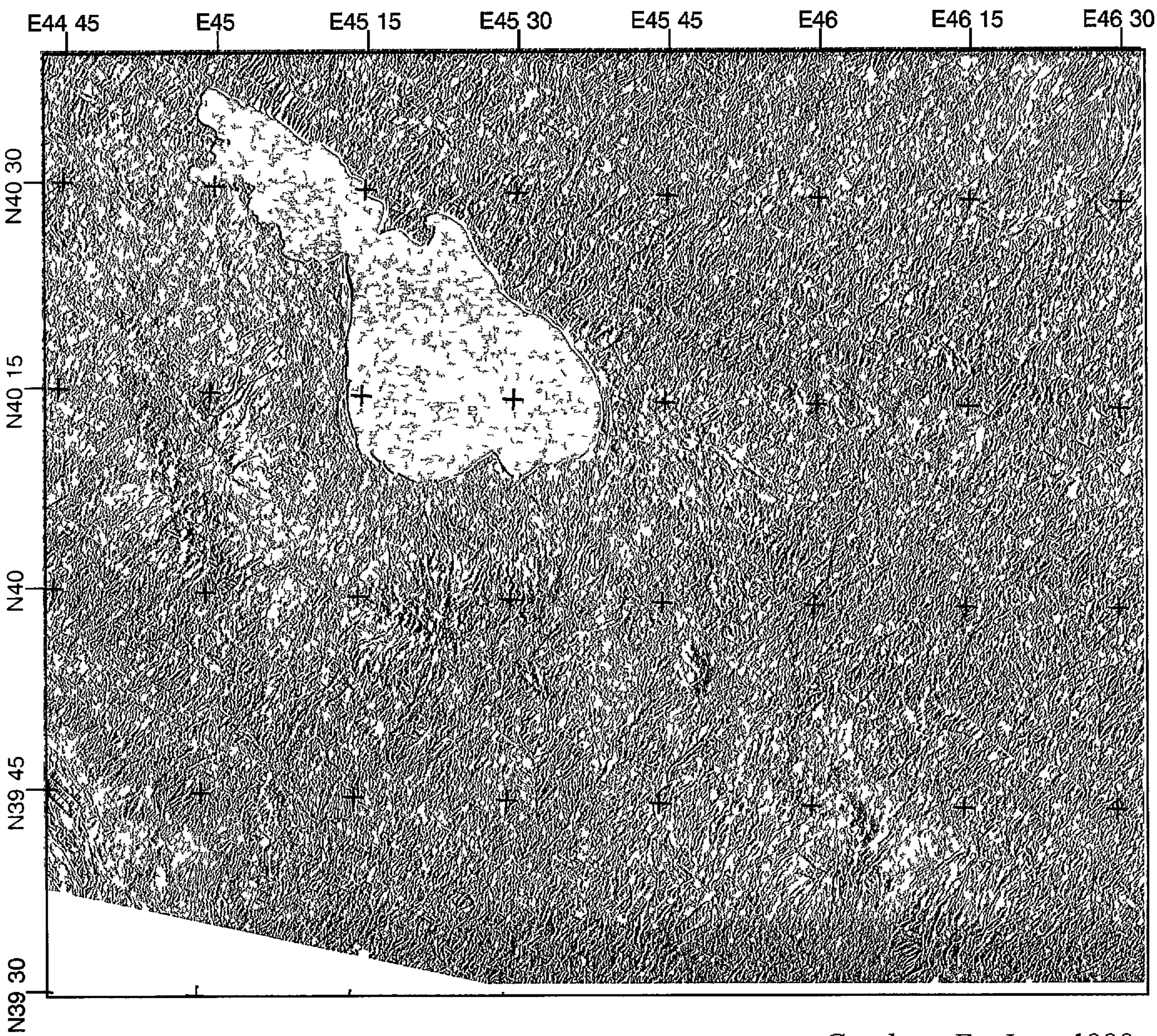


Figure 8 1 Landsat Image (Bands 7-4-2) of Central Volcanic Region

Gaussian Transform and rgb sharpening

1987-09-28

Image LT5169032008727110



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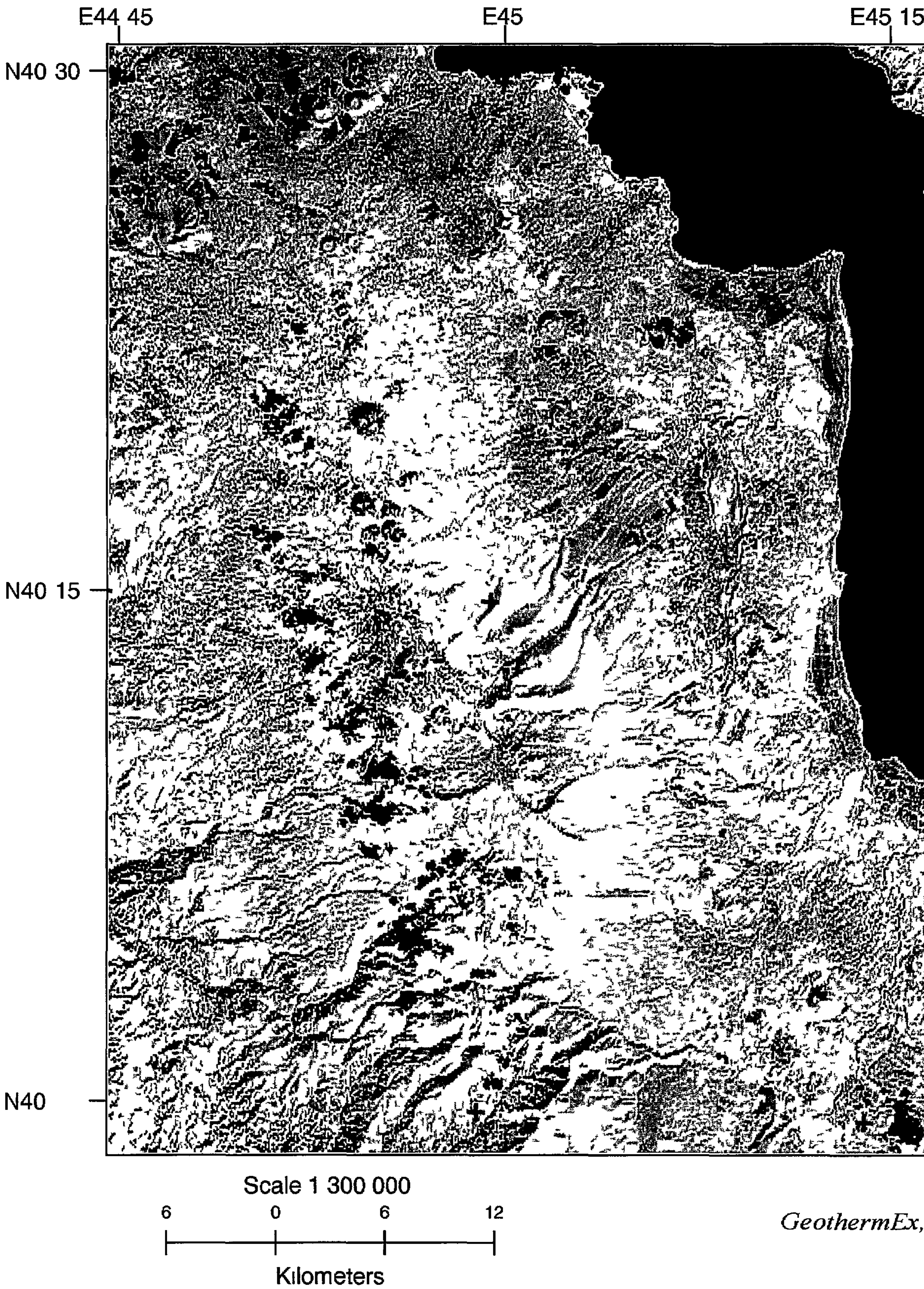
Scale 1 900 000
15 0 15 30
Kilometers

Figure 8 2 Landsat Image of Central Volcanic Region with Vertical Edge Filter

95% transform
1987-09-28
Image LT5169032008727110



GeothermEx, Inc 1998

Figure 8 3 Landsat Image (Bands 7-4-2) of Gegam Mountains Region

with edge sharpening and 95% transform

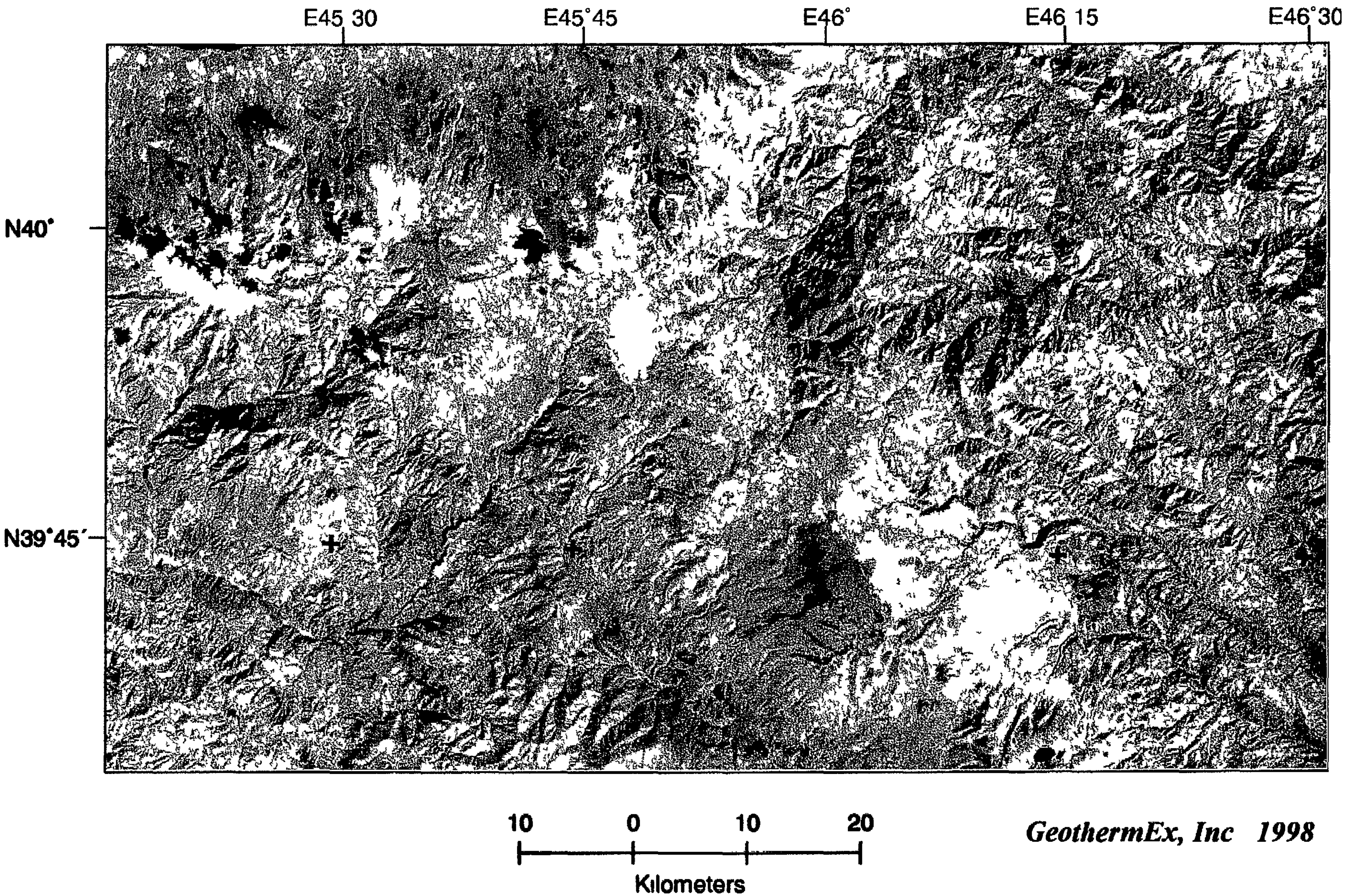


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Figure 8.4. Landsat Image (Bands 7-4-2) of Karabagh Upland Region

with PC1 intensity modulation,
edge sharpening and 95% transform

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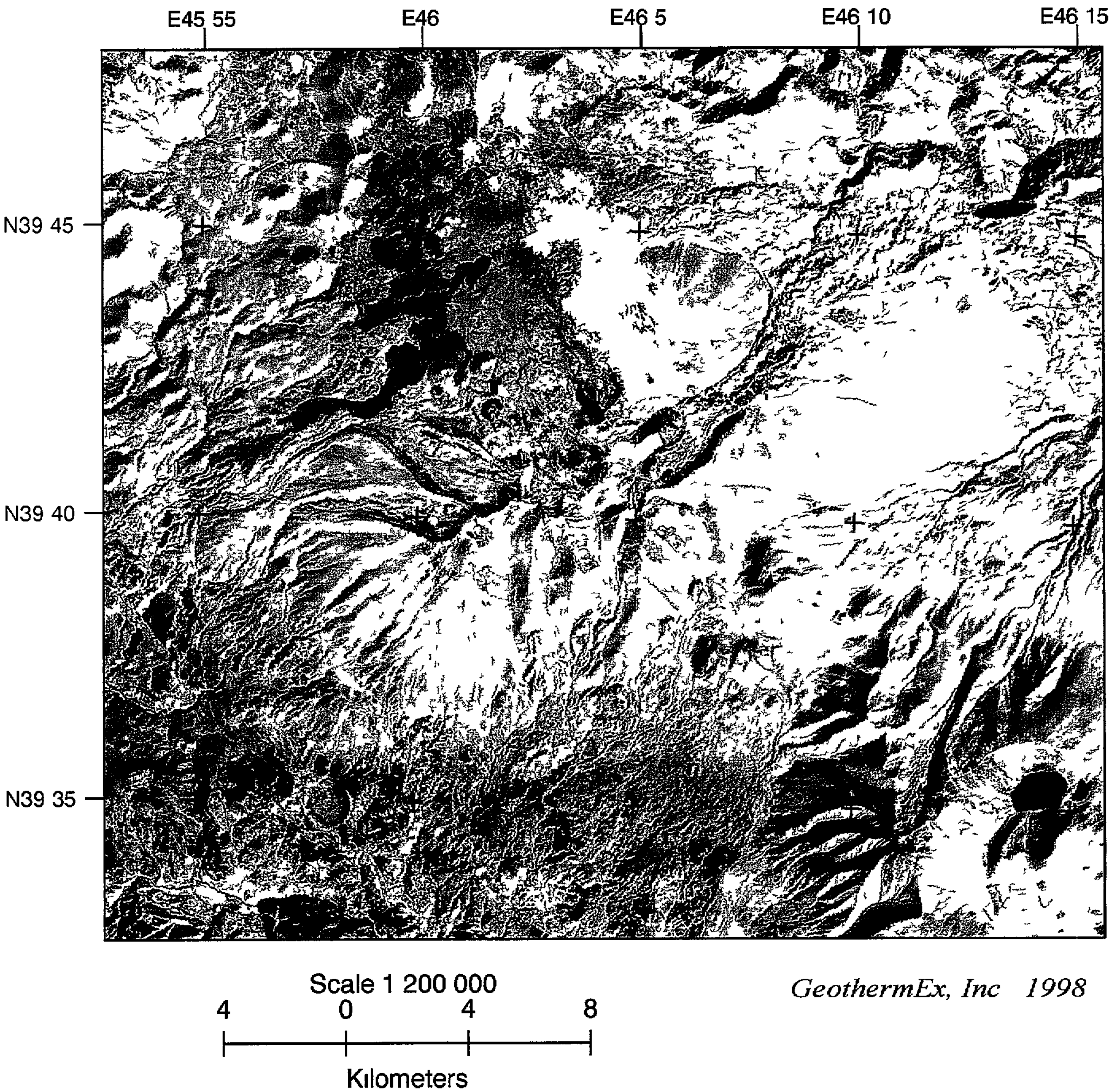

Figure 8 5 Landsat Image (Bands 7-4-2) of Jermakhpur Area

95% transform and rgb sharpening
Image LT5169032008727110

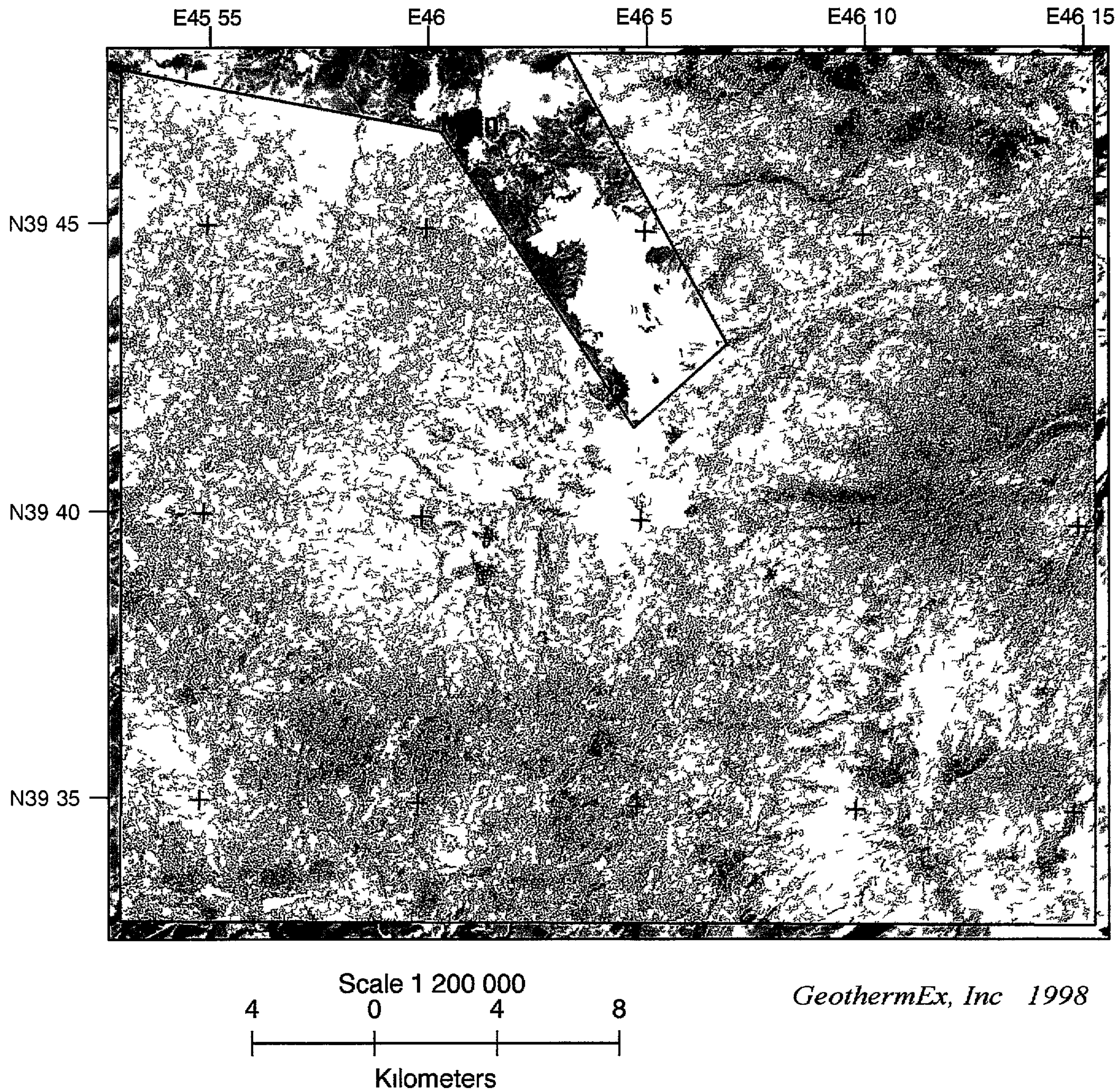

Figure 8 6. Landsat Crosta Image of Jermakhpur Area

Landsat TM5 Imagery, Crosta, bands 7-5-4-3-2-1
95% transform and rgb sharpening
Image LT5169032008727110

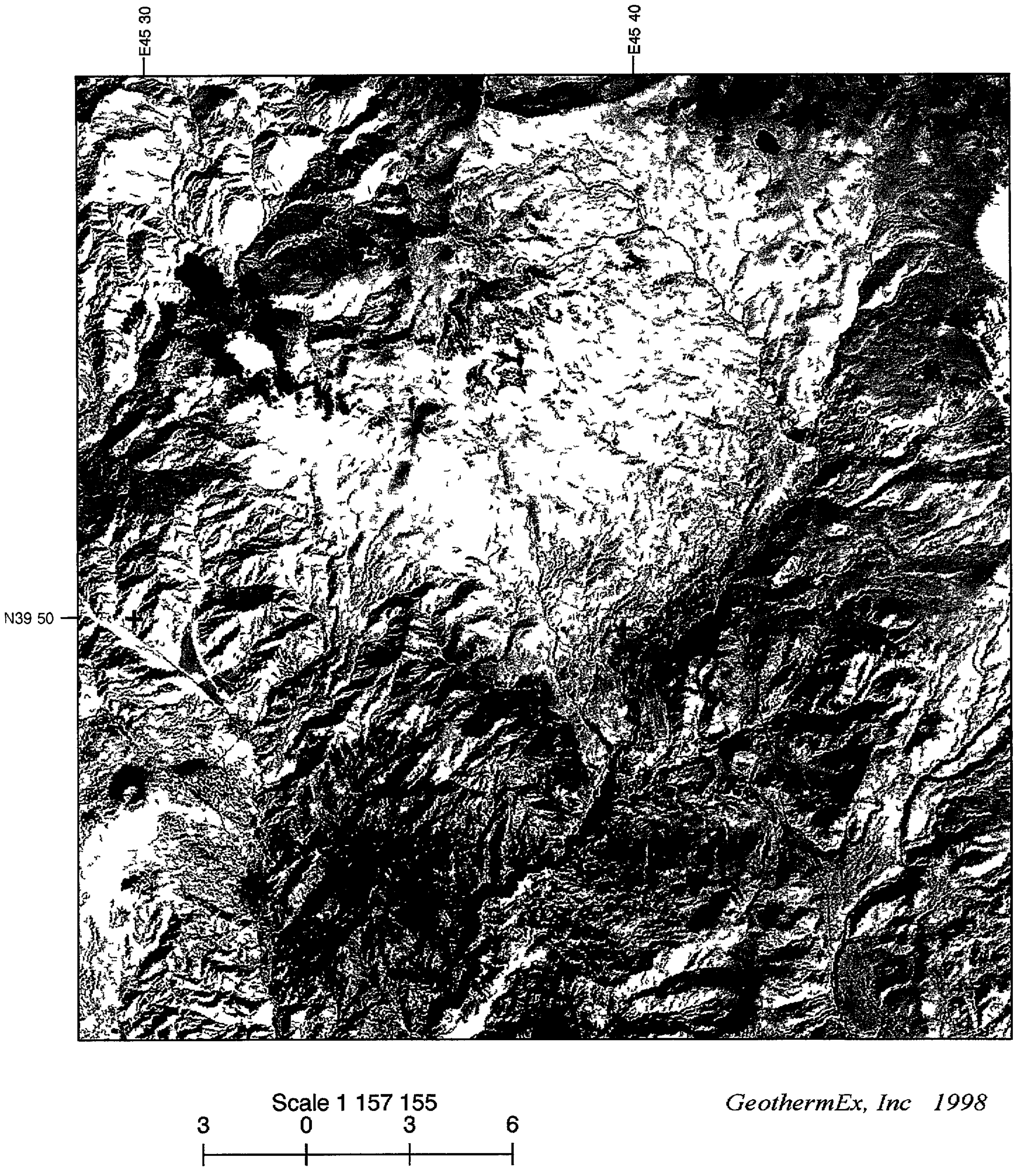

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Figure 8.7 Landsat Image (Bands 7-4-2) of Jermuk Basin Area

PC1, edge sharp

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APPENDIX A

Comments on Report

Geothermal Pilot Project in Martuni -

Synthesis Report of Feasibility Study

(CFG, 1993)

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GeothermEx, as part of its assessment of the geothermal resources of Armenia, reviewed the report prepared by CFG (1993), which investigated the feasibility of a proposed geothermal pilot project at Martuni The following comments on the report were developed from this review

The Martuni geothermal pilot project is an innovative approach to test the viability of a low-temperature geothermal resource for space heating and possible heating of domestic hot water The 40°C expected resource temperature is below what generally would be required for space heating, unless the facility to be heated was at an extremely high level of energy efficiency

From the report, it appears that the hospital heating system is designed for boiler-supplied hot water of approximately 90°C, therefore, the entire heat distribution system would have to be replaced if adequate heat were to be supplied from the geothermal source The report also states that indoor temperature is expected to be held at a maximum of 18°C, which is a very low temperature for a critical care facility such as a hospital

It is suggested, based on geothermometry of water sampled from well 3-T, that a higher temperature resource (up to 100°C) may be available at reasonable drilling depths (less than 1,000 m) However, the chemical data on which this inference is based are not supplied in the report, and the well was not in a condition to be sampled during our field investigations, therefore we cannot verify the likelihood of higher temperatures being present If geothermal water in the 60-90°C range could be obtained, it would provide a much more attractive resource than 40°C for heating of the hospital, as well as for providing domestic hot water

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It also appears that, because of the potential for outages of the municipal electrical supply, a back-up generator would have to be included in the design

In order to ensure the adequacy of the system to meet the hospital's requirements, several actions would be advisable The first task would be to re-complete the geothermal well so that the system design can be finalized Second, consideration should be given to treating the geothermal resource (if less than 60°C) as a baseload resource that would be peaked using other means For this purpose, several alternatives are possible One is to use a conventional fossil fuel boiler (it is possible that the existing boiler could be used for this purpose, depending upon condition) This would allow for peaking of the geothermal resource, and provide back-up should the geothermal system fail for some reason A second alternative would be to incorporate a fossil fuel-driven heat pump into the design The major advantage of the heat pump, based on either diesel or gas, is that it can be designed in to provide peaking capabilities, back-up to the heating system, and back-up electrical generation By dual shafting the combustion engine, or by installing both the heat pump compressor drive and the generator drive on a single shaft, the system can serve as the prime mover for both the heat pump and/or generation In addition, two streams of waste heat are available heat from the engine jacket cooling system and from the flue gas Both can be economically captured and used Peaking of the domestic hot water could be accomplished through the same design, or a smaller fossil fuel or electrical boiler system could be used for this purpose

These options would help ensure the reliability of the system and help meet minimum outside design temperatures that can fall below the temperature for which the system appears to be designed However, even if temperatures of 60°C or above are obtained, provisions for peaking and electrical back-up are critical to ensuring that the hospital's needs are met

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APPENDIX B

Comments on Report

Armenian Geothermal Project Reconnaissance Study - Final Report

(Petroleum Geology Investigators, 1998)

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The report entitled Armenian Geothermal Project Reconnaissance Study - Final Report, issued by Petroleum Geology Investigator ApS of Copenhagen, Denmark, examines the overall geothermal resource potential of the Republic of Armenia, and studies a potential pilot project to utilize geothermal water for the Yerevan district heating system The Yerevan study is based in large part on an assessment of the district heating system by Kattner/FVB District Energy, Inc , of Edmonton, Canada, the Kattner assessment is included within the report The following comments address the district heating system study

The Yerevan district heating system is designed to serve approximately 5,000 individual buildings or primary subscribers, with an energy demand equivalent to some 5,000 GWh/yr The system is designed for a maximum send-out temperature of 150°C on the primary transmission side and 95°C in the secondary loop The system is comprised of a CHP plant and ten hot water boiler stations (HWBS) The CHP plant and one HWBS serves one area and nine other are served by individual HWBSs An interesting aspect of the system is that, at least from the information presented, there is no interconnection between the various areas This is a serious impediment to taking maximum advantage of the existing equipment as well as incorporating geothermal into the system In effect, each area would need to have one or more geothermal doublets if the system was to take maximum advantage of the geothermal resource

The study considers two alternatives for utilizing the geothermal resource The first is to drill wells to a depth of approximately 3,500 m, where the temperature is anticipated to be 115°C, with production from an aquifer of Eocene rocks The second is to drill into an Oligocene aquifer at approximately 2,000 meters depth, where it is anticipated that the resource temperature would be approximately 65°C The second alternative would, according to the Kattner assessment, necessitate the use of an absorption heat pump and, based on the diagrams provided, also a boiler

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Well drilling costs are assumed in the study to be US$4 5 to $5 5 million for 3,500 m wells, and $2 5 to $3 5 million for 2,000 m wells, these are reasonable estimates However, they imply large expenditures for drilling to obtain water of relatively low temperature This is reflected in what appear to be marginal project economics, even after environmental benefits are taken into account In addition, the study states that resource risk (the risk of drilling unproductive wells) was not taken into account in the economic analysis Available data do not indicate that any productive wells of the types considered in the study have been drilled in the Yerevan area, therefore the resource risk must be considered to be significant

Before considering the geothermal options, Kattner/FVB evaluated alternative methods of cost-effectively reducing the temperature required in the district system and, secondarily, of reducing energy consumption

Prior to the breakup of the former Soviet Union, the Yerevan district system had an installed capacity of 2,300 MW and provided 5,000 GWh to the 5,000 subscribers At present only 1,000 subscribers are being served, and in 1997-98 it was estimated that only 500 GWh would be provided It is unclear from the report whether all 1,000 subscribers are in a limited number of the ten service areas, or scattered through all ten The transmission and distribution system is in a deteriorated condition, with losses of 400 to 500 m^3/hr Domestic hot water is supplied through a second set of mains, but due to cost and fuel availability constraints, no domestic hot water has been supplied since 1989

The entire system faces multiple challenges to repair or replace the 1,577 linear kilometers of piping in over 470 kilometers of trenches, to regain the 4,000 customers who no longer are supplied by the system, to reduce energy consumption and improve customer comfort, and to reduce the temperature requirements of the district system, if the geothermal resource is to be used as a source of heat

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From the report it appears that the municipal energy company is in the process of repairing approximately 40 km of trench length per year It was not, however, apparent from the report what repairs were actually being made and whether or not it would be more advantageous to replace the system as opposed to repairing it Considering that the system is only operated 3-4 months per year, it is likely to continue to deteriorate when not in use By replacing the system with state-of-the-art, insulated piping, thermal as well as losses through leaks should be dramatically reduced Elimination of the system designed to supply domestic hot water should be seriously considered, and instead a domestic water heat exchanger should be installed as part of each customer's connection This would eliminate one piping network and, although not mentioned in the report, what is probably a major on-going maintenance problem

The report discusses why 80 percent of the former customers no longer receive service, but it appears that is more a matter of lack of money to pay for service than a major dissatisfaction with the system Although reducing the cost of service would, in all likelihood, encourage previous customers to once again become system customers, there is very little that the municipal energy company can do to reduce the cost of service or improve the financial situation of potential customers

Several of the alternatives suggested by Kattner/FVB would result in reduced energy consumption and increased customer comfort, these include installation of triple pane windows, increased levels of wall insulation, radiator valves, and meters However, a quick evaluation of the costs of implementing these measures indicates that they are economically infeasible Although Kattner/FVB has calculated a payback time of 1 6 to 8 5 years for the various measures, it would appear that if all the measures were to be implemented, it would cost the average customer about $3 00 per month (a significant fraction of the average monthly wage) over 10 years to pay for the improvements based on approximately 5,000 connections or 170,000

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individual housing units being served Thus, implementing such improvements would appear to be an unrealistic approach Also, it appears in the report that the payback on each individual measure is calculated independently of the others However, once one measure is implemented, energy consumption and thus revenue would fall, making the payback time longer for each subsequent measure

The reduction in required send-out temperature is extremely important if geothermal is to be capable of meeting the needs of system customers Meeting system needs with only minor modifications could be achieved if the system uses fossil fuel for peaking, this would minimize the need for large numbers of geothermal wells Another possible way to reduce overall cost would be to interconnect the independent district heating areas so as to take maximum advantage of the waste heat from the CHP plant and use of the most efficient boiler plants A further measure that could prove to be economically attractive would be to reduce the thermal supply temperature requirement from the CHP plant, thus allowing for additional electrical production

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APPENDIX C

Chemical analyses of water samples collected during field work in 1998

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****

GEOTHERMEX INC   CHRIS KLEIN   ID # A 66928 GTA
[illegible] 980801   DATE 06-2[illegible]-98

****

SPECIES	CONCENTRATION (ppm)	ANALYTICAL METHOD	DETECTION LIMITS		CONCENTRATION (MOL/L)
Na	1559 000	1	95[illegible]		[illegible]E-0[illegible]
K	122 2[illegible]	1	[illegible]50		3 13E-02
Cl	2655 00		1[illegible]		[illegible]E-0[illegible]
Mg	123 [illegible]	1	[illegible]		[illegible]E-0[illegible]
Fe	6 220	1	010		1[illegible]E-0[illegible]
Al	[illegible]		[illegible]	<	[illegible]65E-0[illegible]
SiO2	83 [illegible]		1 [illegible]		1[illegible]E-0[illegible]
B	24 [illegible]00	1	0[illegible]		226E-0[illegible]
Li	5 930	1	01[illegible]		[illegible]E-0[illegible]
S	[illegible] 520		[illegible]		4[illegible]3[illegible]E-0[illegible]
[illegible]	D		5[illegible]	<	[illegible]9E-0[illegible]
Ag	N A	1	[illegible]00	<	1[illegible]5E-0[illegible]
As	N A		4[illegible]	<	[illegible]4E-0[illegible]
Au	N A	1	050	<	254E-05
Ba	N A	1	025		182E-0[illegible]
Be	N A		001	<	335E-0[illegible]
Bi	N A		501	<	[illegible]E-0[illegible]
Cd	N A		015	<	133E-0[illegible]
Co	N A	1	100	<	[illegible]E-0[illegible]
Cr	N A		035	<	394E-0[illegible]
Cu	N A	1	[illegible]	<	[illegible]E-0[illegible]
Ga	N A		100	<	157E-0[illegible]
Ge	N A	1	[illegible]	<	[illegible]E-05
Mn	5 [illegible]0		0[illegible]0		[illegible]E-0[illegible]
Mo	[illegible]	1	[illegible]	<	[illegible]E-0[illegible]
Ni	N A	1	100	<	[illegible]E-0[illegible]
Pb	N A	1	20	<	9[illegible]E-0[illegible]
Sb	N A		050		4[illegible]1E-[illegible]
Se	N A	1	[illegible]	<	[illegible]E-0[illegible]
Te	N A		[illegible]	<	[illegible]E-0[illegible]
Th	N A	1	[illegible]		[illegible]E-0[illegible]
Ti	N A	1	10[illegible]	<	209E-0[illegible]
U	[illegible]		1 [illegible]	<	4[illegible]E-0[illegible]
V	N A	1	100	<	196E-0[illegible]
W	N A	1	[illegible]		[illegible]E-0[illegible]
Zn	N A		[illegible]	<	[illegible]E-0[illegible]
NH4	12[illegible]		1[illegible]		[illegible]E-0[illegible]
Cs	N A	1[illegible]	200	<	150E-05
Rb	N A	1[illegible]	200	<	[illegible]34E-0[illegible]

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ANKAVAN 980801   DATE 08-24-98

SPECIES	CONCENTRATION (ppm)	ANALYTICAL METHOD	DETECTION LIMITS		CONCENTRATION (MOL/L)
TOTAL ALKALINITY AS					
HCO3	2371 000	2	500		389E-01
CO3	N D	2	500	<	833E-05
Cl	1953 000	3	2 000		551E-01
F	N A	5	010	<	526E-0[illegible]
SO4	227 000	11	2 000		236E-02
B	7 700	12	100		332E-04
I	N A	12	100	<	788E-06
NO3	N A	9	150	<	210E-05
S	N A	12	200	<	624E-05
PO4	N D	1	915	<	963E-05

TOTAL DISSOLVED SOLIDS

MEASURED	5567 00	4	4 00
CALCULATED	5582 44	6	
100*MEAS/CALC	99 72		
pH	6 85	7	

ADDITIONAL ANALYSIS

SiO2   83 9   PPM (BY AA ANALYSIS)

********** ***

ANALYTICAL METHODS

1 INDUCTIVELY COUPLED PLASMA SPECTROMETER 200 7
2 TITRATION 310 1
3 TITRATION 4500C
4 GRAVIMETRIC 160
5 SPECIFIC ION ELECTRODE 340 2
6 METHOD OF HEM (1970 USGS Water Supply Paper 1473
7 pH METER (LABORATORY) 310 1
8 GAS SENSING ELECTRODE 350 3
9 COLORIMETRIC
10 ATOMIC ABSORPTION
11 TURBIDIMETRIC 375 3
12 TITRATION
N D - NOT DETECTED
N A - NOT ANALYZED

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	Milliequivalents/Liter
CATIONS	
Na	[illegible] 40010
K	[illegible] 491
Ca	[illegible]
Mg	[illegible]
Fe	[illegible]
[illegible]	99801
S[illegible]	09800
[illegible]	01135
NH4	[illegible]
SUM OF CATIONS	97 39000
ANIONS	
HCO3	58 80[illegible]
Cl	[illegible]
SO4	4 [illegible]614
F	[illegible]
SUM OF ANIONS	[illegible]
CATION ANION BALANCE	- [illegible]
BALANCE DIFF CATION + ANION	- 3[illegible]

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ID # [illegible] 66930 GTX
DATE 08-24-98

SPECIES	CONCENTRATION (ppm)	ANALYTICAL METHOD	DETECTION LIMITS		CONCENTRATION (MOL/L)
[illegible]	973 000	1	999		4[illegible]3E-01
K	85 840	1	1 250		2 [illegible]4E-0[illegible]
C[illegible]	142 500	1	100		3[illegible]3E-0[illegible]
[illegible]g	54 100	1	020		223E-0[illegible]
F[illegible]	[illegible] 180	1	[illegible]		1[illegible]E-0[illegible]
Al	[illegible]	1	[illegible]00	<	185E-0
SiO2	15 120	1	1 000		252E-0[illegible]
B	5 200	1	0[illegible]		574E-03
[illegible]	1 140	1	015		164E-0[illegible]
[illegible]	3 230	1	015		371E-04
Zn	040	1	015		[illegible]E-0[illegible]
[illegible]g	N A	1	200	<	185E-0[illegible]
[illegible]	N A	1	400	<	534E-0[illegible]
Au	N A	1	050	<	254E-0[illegible]
Ba	N A		025		182E-0[illegible]
Be	N A	1	003	<	333E-0[illegible]
B[illegible]	N A	1	500	<	239E-0[illegible]
Cd	N A	1	015	<	133E-0[illegible]
C	N A	1	100	<	[illegible]14E-0[illegible]
C[illegible]	N A	1	035	<	594E-0[illegible]
C[illegible]	N A	1	020	<	385E-0[illegible]
Cu	N A	1	100	<	157E-0
La	N A	1	050	<	360E-0[illegible]
Mn	180	1	010		326E-0[illegible]
M[illegible]	N A	1	010	<	104E-0[illegible]
[illegible]	N A	1	100	<	170E-0[illegible]
P[illegible]	N A	1	200	<	[illegible]65E-0[illegible]
S[illegible]	N A	1	050	<	421E-0[illegible]
S[illegible]	N A	1	[illegible]	<	4[illegible]E-0[illegible]
Te	N A	1	500	<	3[illegible]E-0[illegible]
Th	N A	1	[illegible]	<	[illegible]15E-0[illegible]
T	N A		100	<	209E-0[illegible]
[illegible]	N A	1	1 000	<	420E-0[illegible]
[illegible]	N A	1	100	<	195E-0[illegible]
[illegible]	N A	1	050	<	[illegible]E-0[illegible]
Zr	N A	1	050	<	548E-0[illegible]
NH4	N D	6	100	<	554E-0[illegible]
Cs	N A	10	200	<	150E-0[illegible]
Rb	N A	10	200	<	2[illegible]4E-0[illegible]

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JERMUK 30/62 980805 1150 DATE 08-24-98

SPECIES	CONCENTRATION (ppm)	ANALYTICAL METHOD	DETECTION LIMITS		CONCENTRATION (MOL/L)
TOTAL ALKALINITY AS					
HCO3	2004 000	2	500		326E-01
CO3	N D	2	500	<	833E-05
Cl	316 000	3	2 000		891E-02
F	N A	5	010	<	526E-06
SO4	549 000	11	2 000		576E 02
Br	1 000	12	100		125E-04
I		12	100	<	788E-06
NO3	N A	9	130		210E-07
S	N A	12	200	<	624E-06
PO4	N D	1	910	<	960E-05

TOTAL DISSOLVED SOLIDS			
MEASURED	3290 00		4 00
CALCULATED	3243 92	6	
100*MEAS CALC	101 42		
pH	7.01	7	

ADDITIONAL ANALYSIS

SiO2 14 87 PPM (BY AA ANALYSIS)

****

ANALYTICAL METHODS

1 INDUCTIVELY COUPLED PLASMA SPECTROMETER 200 7
2 TITRATION 310 1
3 TITRATION 4500C
4 GRAVIMETRIC 160 1
5 SPECIFIC ION ELECTRODE 340 2
6 METHOD OF HEM 1970, USGS Water S pply Paper 1473)
7 pH METER (LABORATORY) 310 1
8 GAS SENSING ELECTRODE 350 3
9 COLORIMETRIC
10 ATOMIC ABSORPTION
11 TURBIDIMETRIC 375 3
12 TITRATION
N D - NOT DETECTED
N A - NOT ANALYZED

125

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GEOTHERMEX INC CHRIS KLEIN ID # A 63930 GTX
[illegible] 30/02 960605 1150 DATE 08-24-98

	Milliequivalents/Liter
CATIONS	
Na	4[illegible] 3[illegible]
[illegible]	4 [illegible]
Ca	[illegible] 46003
[illegible]	[illegible]
[illegible]	22 [illegible]
[illegible]	[illegible]
S	[illegible]
[illegible]	[illegible]
[illegible]	0355
SUM OF CATIONS	5[illegible] 84[illegible]
ANIONS	
[illegible]	[illegible]
Cl	[illegible]
SO4	[illegible] 218
S	[illegible]
SUM OF ANIONS	5[illegible]
CATION-ANION BALANCE	[illegible]
BALANCE DIFF CATION + ANION	[illegible]

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****

GEOTHERMEX INC   CHRIS KLEIN   ID # A 66932 GTX
JERMUK 1-K 980805 1000   DATE 08-24-98

****

SPECIES	CONCENTRATION (ppm)	ANALYTICAL METHOD	DETECTION LIMITS		CONCENTRATION (MOL/l)
Na	890 100	1	900		[illegible]E 0
K	59 980	1	1 250		[illegible]9E-0[illegible]
Ca	161 300	1	90		402E-0
Mg	45 010		020		185E-0[illegible]
Fe	8 170	1	010		[illegible]
Al	N A	1	500	<	185[illegible]
SiO2	10 100	1	1 000		168E-0[illegible]
B	0 510	1	020		510E-0
Li	1 030	1	015		146E-0
Sr	3 250	1	015		371E-0[illegible]
Zn	130	1	010		199E-0[illegible]
Ag	N A	1	200	<	185[illegible]-05
As	N A	1	400	<	534E 0[illegible]
Au	N A	1	050	<	254E-0[illegible]
Ba	N A		025	<	82E-0[illegible]
Be	N A	1	003		333E-0[illegible]
B[illegible]	N A	1	500	<	239E-05
Cd	N A	1	015	<	133E-0[illegible]
Cr	N A	1	100	<	[illegible]14[illegible]-0[illegible]
Co	N A	1	035	<	594E-0[illegible]
C[illegible]	N A	1	020	<	385E-0[illegible]
Cu	N A		100	<	157E-0[illegible]
La	N A	1	050	<	360E-0[illegible]
Mn	250	1	010		455E-05
Mo	N A	1	010	<	104E-0[illegible]
Ni	N A	1	100	<	170E-0[illegible]
Pb	N A	1	200	<	965E-0[illegible]
S[illegible]	N A	1	050	<	421E-0[illegible]
Sb	N A	1	500	<	411E-0[illegible]
Te	N A	1	500	<	392E-0[illegible]
Th	N A	1	500	<	215E-0[illegible]
Ti	N A	1	100	<	209E-0[illegible]
U			1 000	<	420E-0[illegible]
[illegible]	N A	1	100	<	196E-05
[illegible]	N A	1	050	<	272E-0[illegible]
Zr	N A	1	050	<	546E-0[illegible]
NH4	N D	8	100	<	.554E-05
Cs	N A	10	200	<	150E-0[illegible]
Rb	N A	10	200	<	234E-05

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GEOTHERMEX INC CHRIS KLEIN — ID # 66932 GTX
JERMUK 1-K 980805 1000 — DATE 08-24-98

SPECIES	CONCENTRATION (ppm)	ANALYTICAL METHOD	DETECTION LIMITS		CONCENTRATION (MOL/L)
TOTAL ALKALINITY AS					
HCO3	1925 000	2	500		315E-01
CO3	N D	2	500	<	833E-05
Cl	308 000	3	1 000		869E-02
F	N A	5	010	<	[illegible]E-0[illegible]
SO4	544 000	11	2 000	<	56[illegible]-0[illegible]
B	950	12	100		1[illegible]9E-0[illegible]
I	N A	12	100	<	[illegible]88E-0[illegible]
NO3	N A	9	100	<	[illegible]10E-0[illegible]
S	N D	2	200	<	624E-0[illegible]
PO4	N D	1	915	<	963E-0[illegible]

TOTAL DISSOLVED SOLIDS

MEASURED	3010 00	4	50
CALCULATED	2995 90	6	
100*(MEAS/CALC)	100 4		
pH	6 [illegible]	7	

ADDITIONAL ANALYSIS

SiO2 10 5 PPM (BY AA ANALYSIS)

****

ANALYTICAL METHODS

1. INDUCTIVELY COUPLED PLASMA SPECTROMETER 200 7
2. TITRATION 310 1
3. TITRATION 4500
4. GRAVIMETRIC 160 1
5. SPECIFIC ION ELECTRODE 340 2
6. METHOD OF CHEM 1973 USGS Water Suppl, Paper 1473
7. PH METER (LABORATORY) 310 1
8. GAS SENSING ELECTRODE 350 3
9. COLORIMETRIC
10. ATOMIC ABSORPTION
11. TURBIDIMETRIC 375 3
12. TITRATION

N D - NOT DETECTED
N A - NOT ANALYZED

****

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GEOTHERMEX INC CHRIS KLEIN ID [illegible] 36932 GTX
JERMJK 1-H 980805 1000 DATE 08-24-98

	Milliequivalents/Liter
CATIONS	
Na	38 [illegible] 935
K	1 [illegible]0950
Ca	8 [illegible]087
Mg	[illegible] 7565
Fe	514[illegible]
[illegible]	145 [illegible]
S[illegible]	0741
[illegible]	00 [illegible]6
Mn	0691[illegible]
SUM OF CATIONS	57 89[illegible]0[illegible]
ANIONS	
HCO_3	31 550[illegible]5
Cl	8 [illegible]8866
SO_4	1 52608
B	01185
SUM OF ANIONS	51 [illegible]7759
CATION - ANION BALANCE	[illegible] 3[illegible]400
BALANCE DIFF CATION + ANION	[illegible] 26

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****

GEOTHERMEX INC   CHRIS KLEIN   ID # A 66934 CTX
SISAIN 980805 1300   DATE 08-24-98

****

SPECIES	CONCENTRATION (ppm)	ANALYTICAL METHOD	DETECTION LIMITS		CONCENTRATION (MOL/L)
Na	3[illegible] 900	1	500		14[illegible]E-01
K	33 350		1 250		856E-03
Ca	182 500	1	1 [illegible]		455E-0[illegible]
Mg	[illegible] 200		020		495E-02
Fe	7 320	1	[illegible]		1[illegible]E-03
Al	N A	1	500	<	185E-04
SiO2	29 180	1	1 000		652E-03
B	2 220	1	020		205E-03
Li	300	1	015		5[illegible]E-04
Sr	780	1	015		890E-05
Zn	D	1	015	<	229E-06
Ag	N A	1	200	<	185E-05
As	N A	1	400	<	534E-05
Au	N A	1	050	<	254E-06
Ba	N A	1	025	<	182F-06
Be	N A	1	005	<	333E-0[illegible]
Bi	N A	1	500	<	239E-0[illegible]
Cd	N A	1	015	<	133E-06
Ce	N A	1	100	<	[illegible]14E-0[illegible]
Co	N A	1	035	<	594E-0[illegible]
Cr	N A	1	020	<	8[illegible]E-0[illegible]
Cu	N A	1	100	<	157E-05
La	N A	1	050	<	360E-06
Mn	820	1	010		149E-04
Mo	N A	1	010	<	104E-06
Ni	N A	1	100	<	70E-0[illegible]
Pb	N A	1	200	<	965E-0[illegible]
Sc	N A	1	050	<	421E-06
Sb	N A	1	500	<	411E-05
Te	N A	1	500	<	392E-05
Th	N A	1	500	<	215F-05
Ti	N A	1	100	<	209E-0[illegible]
U	N A	1	1 000	<	420E-05
V	N A	1	100	<	196F-05
W	N A	1	050	<	2[illegible]2E-06
Zr	N A	1	050	<	548E-06
NH4	840	8	100		465E-04
Cs	N A	10	200	<	150E-05
Rb	N A	10	200	<	234E-05

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GEOTHERMEX INC CHRIS KLEIN ID # A 66934 CTX
SISAIN 980805 1300 DATE 08-24-98

SPECIES	CONCENTRATION (ppm)	ANALYTICAL METHOD	DETECTION LIMITS		CONCENTRATION (MOL/L)
TOTAL ALKALINITY AS					
HCO3	1192 000	2	500		195E-01
CO3	N D	2	500	<	833E-0[illegible]
Cl	103 000	3	1 000		291E-02
F	N[illegible]	5	010	<	526E-00
SO4	[illegible] 000	11	2 000		609E-02
Br	[illegible] 700	12	100		338E-04
I	N A	1[illegible]	100		788E-0[illegible]
NO3	N A	9	130	<	210E-05
S	N A	12	200	<	[illegible]24E-05
PO4	N D		015	<	[illegible]03E-0[illegible]

TOTAL DISSOLVED SOLIDS

MEASURED	1959 00	4	4 00
CALCULATED	1994 48	6	
100*MEAS/CALC	97 [illegible]		
pH	6 20	7	

ADDITIONAL ANALYSIS

EC 1000 umhos/cm

****

ANALYTICAL METHODS

1 INDUCTIVELY COUPLED PLASMA SPECTROMETER 200 7
2 TITRATION 310 1
3 TITRATION 4500C
4 GRAVIMETRIC 160 1
5 SPECIFIC ION ELECTRODE 340 2
6 METHOD OF HEM (1970 USGS Water Supply Paper 1473)
7 pH METER (LABORATORY) 150 1
8 GAS SENSING ELECTRODE 350 3
9 COLORIMETRIC
10 ATOMIC ABSORPTION
11 TURBIDIMETRIC 375 3
12 TITRATION
N D - NOT DETECTED
N A - NOT ANALYZED

******************* **

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Salt Lake City, Utah 84119

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GEOTHERMEX, INC   CHRIS KLEIN   ID # A 56934 CTX

SJS/IN 98J805 1300   DATE 08-24-98

	Milliequivalents/Liter
CATIONS	
Na	1[illegible] 17635
[illegible]	8579
Ca	9 10675
Mg	9 [illegible] 765
Fe	[illegible]5 [illegible]2
Li	[illegible]
S[illegible]	01775
[illegible]	[illegible]
NH4	0465[illegible]
SUM OF CATIONS	34 [illegible]
ANIONS	
HCO3	19 53085
Cl	[illegible]
SO	2 [illegible]797C
B	03076
SUM OF ANIONS	[illegible]4 [illegible]
CATION-ANION BALANCE	- 2[illegible]
BALANCE DIFF CATION + ANIO	- [illegible]

17[illegible]

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GEOTHERMEX, INC   CHRIS KLEIN   ID # A 66930 GTX
DIERMUH 2   DATE 08-24-98

****

SPECIES	CONCENTRATION (ppm)	ANALYTICAL METHOD	DETECTION LIMITS		CONCENTRATION ([illegible])
[illegible]	756 14[illegible]	1	950		3 9E-01
	72 980	1	1 250		187[illegible]-02
C[illegible]	182 010	1	100		[illegible]
M[illegible]	39 350	1	020		[illegible]3[illegible]E-0[illegible]
[illegible]	0 [illegible]		010		[illegible]E-0[illegible]
Al	N A		500	<	85E-0[illegible]
S O2	17 00[illegible]	1	1 000		783E-03
P	3 290	1	070		789F-0[illegible]
[illegible]	870	1	015		125E-0[illegible]
S	4 030	1	015		[illegible]
[illegible]	N D	1	015	<	[illegible]29E 0[illegible]
As	N A	1	200	<	185E-[illegible]
[illegible]	N A	1	400	<	[illegible]E-0[illegible]
A[illegible]	N A	1	050	<	254[illegible]-0[illegible]
Ba	N A	1	025		[illegible]E-0[illegible]
Be	N A		003	<	[illegible]3[illegible]F-[illegible]
B	N A	1	500		[illegible]E-0[illegible]
Cd	N A	1	010		[illegible]
C[illegible]	N A	1	100	<	[illegible]E-0
Co	N A	1	035	<	[illegible]94F [illegible]
C[illegible]	N A	1	020	<	385E-0
Cu	N A	1	100	<	[illegible]
L[illegible]	N A	1	050	<	[illegible]
[illegible]	220	1	010		[illegible]75F 0[illegible]
[illegible]	N A	1	010		104E-0[illegible]
N[illegible]	N A		100	<	[illegible]9E 0[illegible]
Pb	N A	1	200	<	[illegible]3E-0[illegible]
S[illegible]	N A	1	050		4[illegible]1E-0
S[illegible]	N A	1	500	<	[illegible]1E-[illegible]
Te	N A	1	500	<	[illegible]9[illegible]E-0
T[illegible]	N A		500		[illegible]E-0
T	N A	1	100	<	[illegible]9[illegible]
U	N A	1	1 000		[illegible]E-0[illegible]
[illegible]	N A	1	100	<	19[illegible]F-0[illegible]
[illegible]	N A	1	050	<	[illegible]2E-0[illegible]
Z[illegible]	N A	1	050	<	[illegible]48E-
NH4	120	8	100		[illegible]E-0[illegible]
Cs	N A	10	200	<	1[illegible]F-0[illegible]
R[illegible]	N A	10	200	<	[illegible]4E-0[illegible]

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GEOTHERMEX INC CHRIS KLEIN — ID # A 60936 C1[illegible]
DJERMUK 2 — DATE 08-24-98

SPECIES	CONCENTRATION (ppm)	ANALYTICAL METHOD	DETECTION LIMITS		CONCENTRATION (MOL/L)
TOTAL ALKALINITY AS					
HCO3	2231.000	2	.500		35[illegible]E-0[illegible]
CO3	N.D.	2	.500	<	850E-05
Cl	229.000	[illegible]	2.500		546E-0[illegible]
F	N.D.	5	.010	<	[illegible]26E-0[illegible]
SO4	339.000	1	4.000		353E-07
B	4.600	12	.100		[illegible]75E-0[illegible]
I	N.D.	12	.100	<	788E-0[illegible]
NO3	N.A.	[illegible]	.130	<	210E-0[illegible]
S	N.A.	1[illegible]	.200	<	[illegible]24F-0[illegible]
PO4	N.D.	1	.010	<	[illegible]03E-05

TOTAL DISSOLVED SOLIDS

MEASURED	[illegible].00	4	4.00
CALCULATED	2764.12	3	
% MEAS/CALC	[illegible]		
pH	6.83	7	

ADDITIONAL ANALYSIS

SiO2 7.3 PPM (B[illegible] ANALYSIS)

****

ANALYTICAL METHODS

1 INDUCTIVELY COUPLED PLASMA SPECTROMETER [illegible]
2 TITRATION 310.1
3 TITRATION [illegible]
4 GRAVIMETRIC 160.1
5 SPECIFIC ION ELECTRODE [illegible]
6 METHOD OF HE[illegible] (1970 USGS [illegible] Page 14[illegible])
7 pH METER [illegible] 310.1
8 [illegible] SENSING ELECTRODE 350.3
9 COLORIMETRIC
10 ATOMIC ABSORPTION
11 TURBIDIMETRIC [illegible]
12 TITRATION
N.D. - NOT DETECTED
N.A. - NOT ANALYZED

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GEOTHERMEX, INC CHRIS KLEIN — ID # A 66936 GTX
[illegible] 2 — DATE 08-24-98

	Milliequivalents/Liter
CATIONS	
[illegible]	32 89209
[illegible]	[illegible] 80010
Ca	[illegible] 17721
Mg	[illegible] 72941
[illegible]	00 [illegible]8
[illegible]	[illegible]
[illegible]	00 39
[illegible]	0004[illegible]
NH	00300
SUM OF CATIONS	49 8[illegible]961
ANIONS	
HCO3	30 0[illegible]39
Cl	[illegible] 4600[illegible]
SO4	7 05793
F	[illegible]
SUM OF ANIONS	[illegible] 6[illegible]
CATION - ANION BALANCE	19960
BALANCE DIFF CATION + ANION	20

135

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RICHMOND CALIFORNIA 94804-5829

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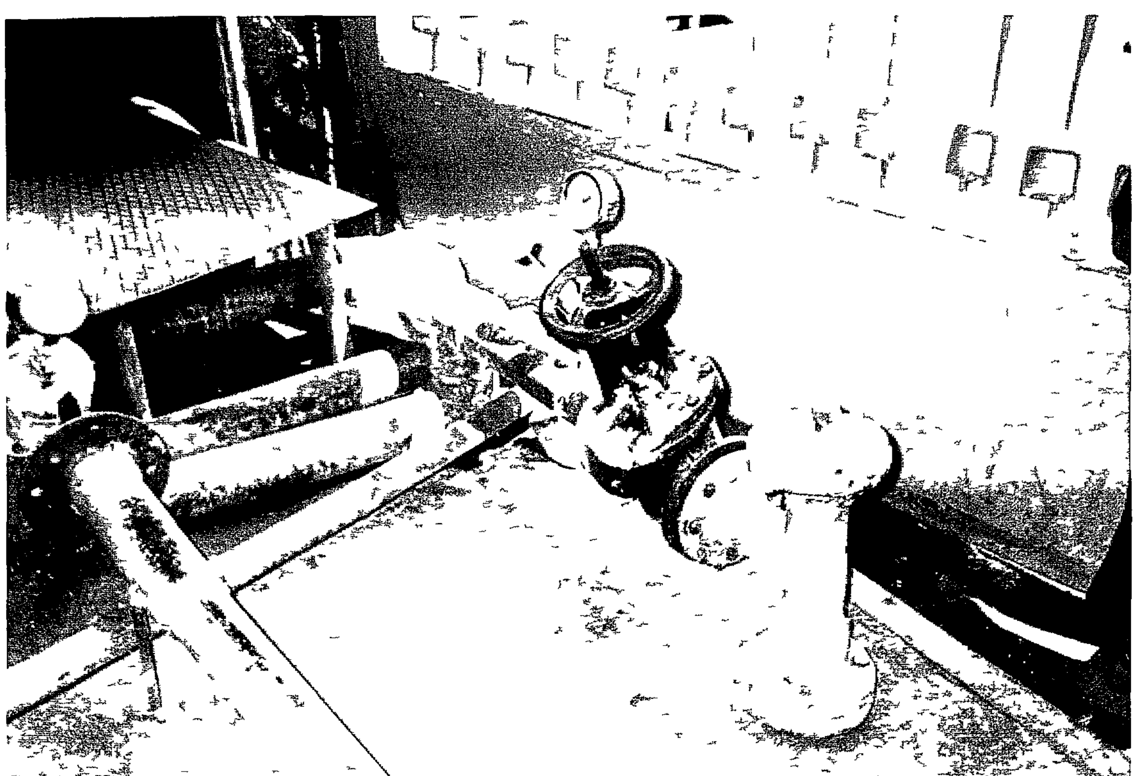
FAX (510) 527 8164
E MAIL 76612 1411@COMPUSERVE COM

APPENDIX D

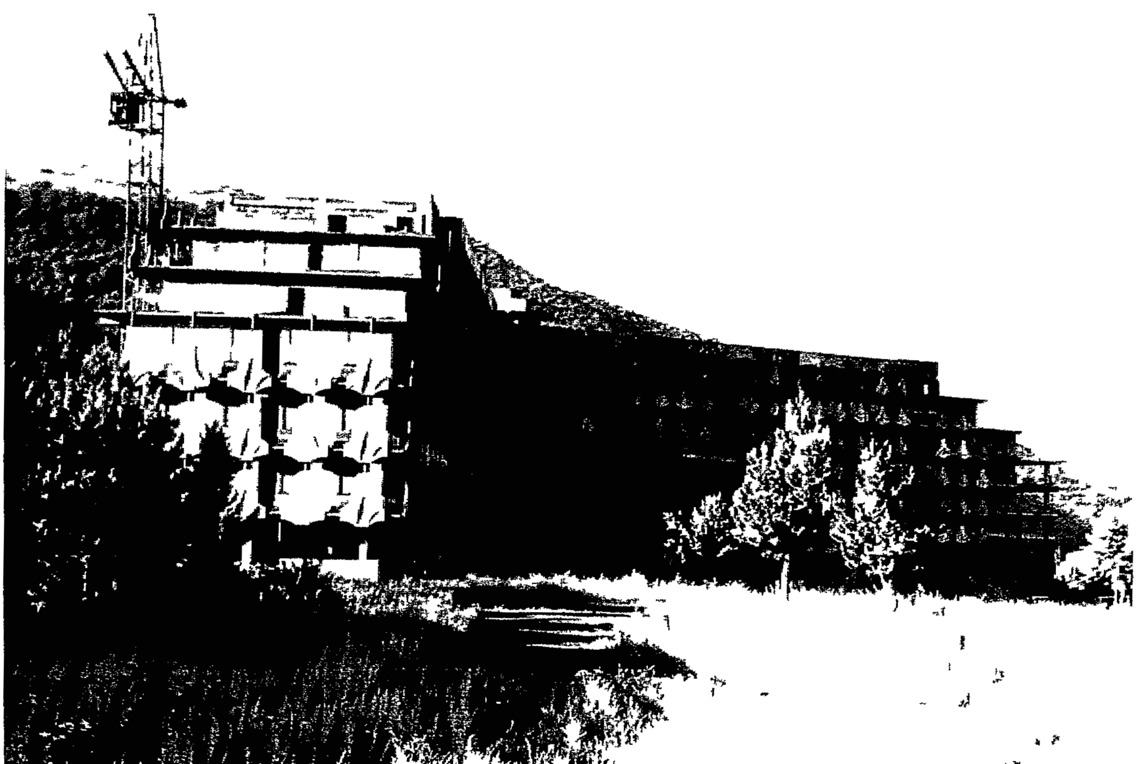
Photographs

Jermuk and the Arpa River Gorge



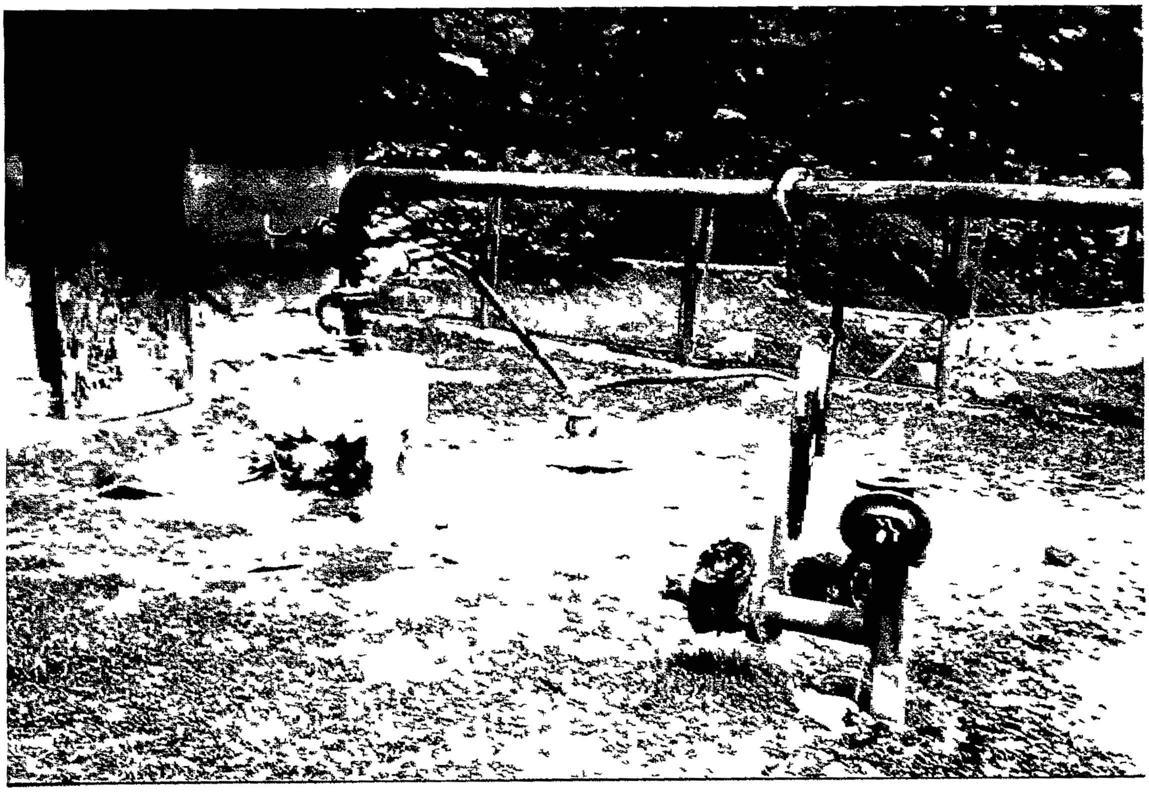
Well 30/62 at the Ararat Rest House, Jermuk

Ararat Rest House, Jermuk



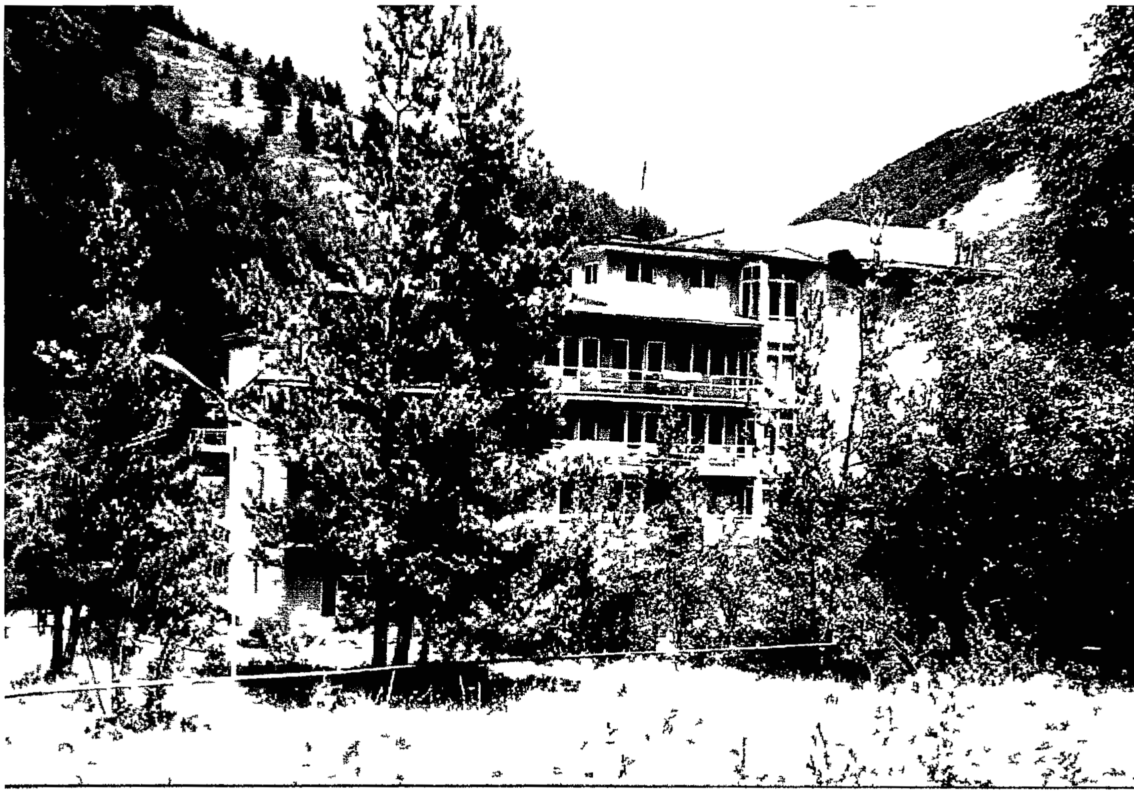
Unfinished resort hotel or rest house, Jermuk

57



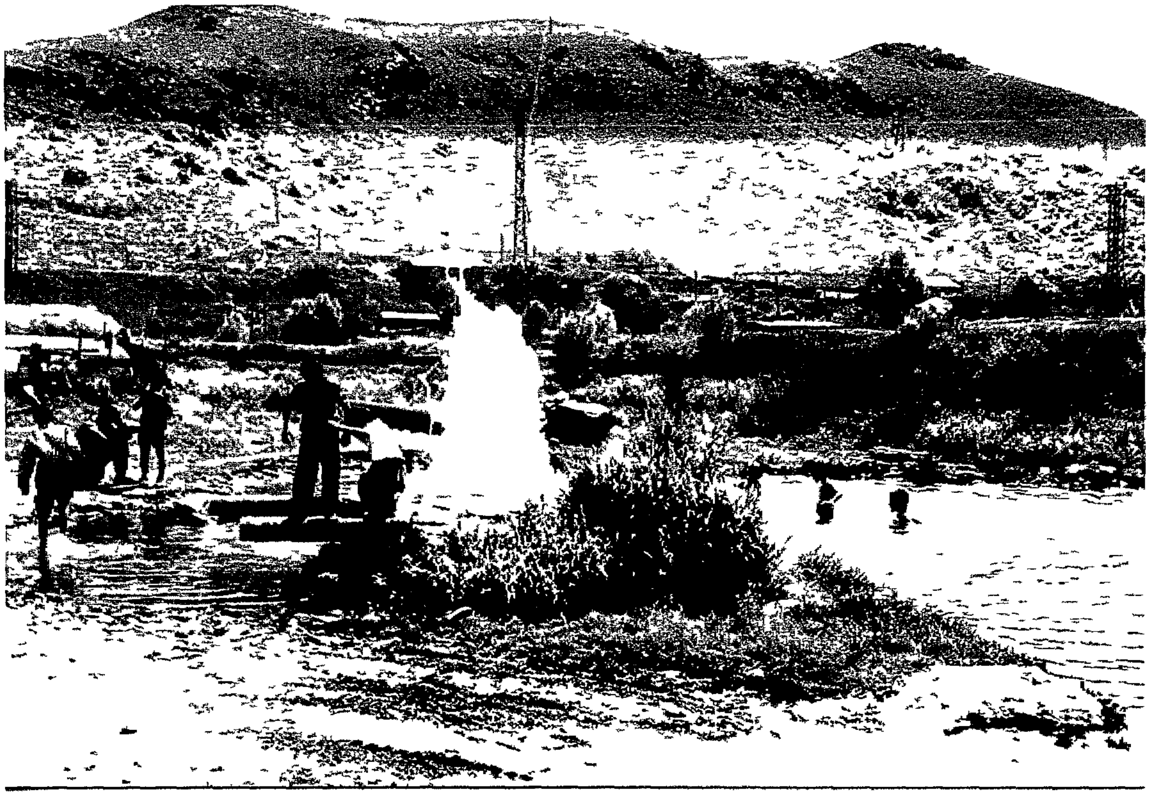
Wells 3/63? (left) and 18? (right), Ankavan well at left supplies the Ankavan Sanatorium and a dry ice factory from branching lines

Well 14 and CO_2 bottling plant, Ankavan



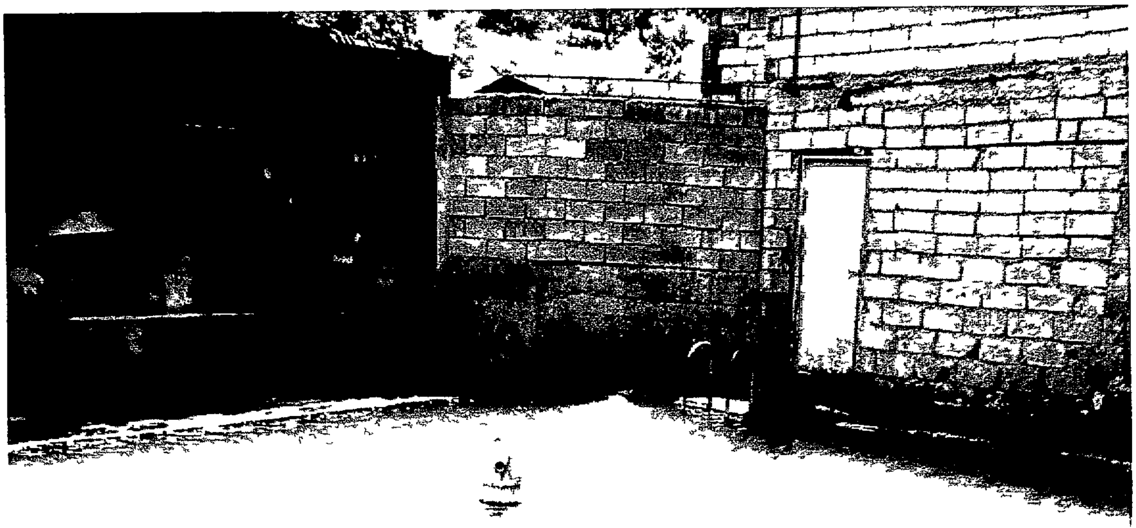
Ankavan Sanatorium

Well 47-T (?), Vorotan   this well is damaged and flows freely



Damaged, free-flowing well at Sisian this well fountains periodically, as shown

View of Sisian, looking north



Commercial swimming pool and bathhouse at Arzakan, supplied by well 16-T

Greenhouse at Arzakan, near well 16-T