Coal Exploration and Resource Assessment of Armenia

U.S. Geological Survey Open-File Report 99-567

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OVERVIEW

The U.S. Geological Survey (USGS) signed a Participating Agency Service Agreement (PASA) with the U.S. Agency for International Development (USAID), PASA Number CN-002-P-ID-3097-00, under the Energy Efficiency and Market Reform Project. The purpose of the PASA is to support the implementation, by the U.S. Geological Survey, of assistance and training activities in connection with petroleum, natural gas, and coal resources in the Newly Independent States (NIS) of the Former Soviet Union. These activities are aimed toward the establishment of environmental and scientific knowledge bases upon which NIS governments can make informed decisions regarding the establishment of resource development policies.

Annex 5 of the PASA is the Armenian Coal Exploration and Resource Assessment Program. This activity focused on training and providing equipment, facilities, and abilities necessary to conduct an extensive coal resource assessment, exploration, and development program. The Program, conducted from 1995 to 1999, consisted of geologic field work and mapping, exploration drilling, coal quality laboratory activities, geophysical logging activities, map production, database creation, resource assessment, and comprehensive training on all aspects of the program.

The Armenian Coal Exploration and Resource Assessment Program was a cooperative program between the USGS and Armenian counterparts, mainly the Republic of Armenia (RA) Ministry of Environment. A Memorandum of Understanding (MOU) and its amendments between USAID and the Ministry of Environment lays out the guidelines of the program and the responsibilities of both sides. USGS was not a signatory to this MOU, but was the implementing party, as stated in the MOU, and so acted on the behalf of USAID.

For the purposes of this report, the Coal Exploration and Resource Assessment Program can be organized into the following categories:

I Training
II Computerization of the Ministry's Geology Department, including
  building of databases and digitizing of all maps
III Creation of a coal quality laboratory
IV Creation of a geophysical logging station
V Exploration Drilling, including coalbed methane
VI Production of a Satellite Image Map of Armenia
VII Research concerning the major coal fields of Armenia, including
  (a) assembly, synthesization, and interpretation of all data (stratigraphic, coal quality, and resource estimates) in the archival reports on each Armenian coal field, and
  (b) new, detailed geologic mapping of each major coal field
VIII Detailed coal exploration in Antaramut-Kurtan-Dzoragukh coal field
IX Economic assessment of the Antaramut-Kurtan-Dzoragukh coal field
X Other activities
XI Uses for Armenia's coal resources
XII Recommendations for further work

MAJOR PROJECT ACCOMPLISHMENTS TO DATE

Training of 12 USGS counterpart Armenian Ministry geologists, geophysicists, geochemists, resource analysts in the United States. USGS created and provided a tailor-made coal geology course for one and a half months in the U.S. for these Ministry employees. They visited and received instruction at USGS offices in Virginia and Colorado and at underground and surface mining operations, large and small mining companies, exploratory drilling sites, reclamation sites, power plants, and coal quality laboratories in Virginia, West Virginia, Pennsylvania, Texas, Colorado, and Utah. USGS also drilled a borehole specifically for this course to illustrate all aspects of exploratory drilling, geophysical logging, and coal core desorption for coalbed gas (methane).

Procurement, shipment, and installation of equipment and instruments for all aspects of this project, including drilling equipment, geochemical laboratory instruments and equipment, geophysical logging probes, coalbed methane testing equipment, computers, office computers, printers, plotter, field and office supplies, and more.

Major repair of geochemical laboratory, including plumbing, electricity, floors, walls, ceilings, light fixtures, windows, ventilation, furniture, and security features.

Installation of instrumentation and equipment for a full coal quality laboratory in Armenia.

Training of geochemists on all aspects of coal quality analysis and coal preparation.

Visitation and inspection of the laboratory and chemists' analytical techniques by a laboratory inspector from an American coal testing laboratory.

Establishment of a Quality Assurance/Quality Control program within the coal quality laboratory and enrollment of the laboratory in an international round robin program.

Repair of geophysical logging truck and installation of a completely computerized geophysical logging operation to create a mobile, geophysical logging station.

Training of geophysicist on all aspects of core borehole geophysical logging.

Complete repair of Ministry drill rig and water truck shells to fully functional equipment. Repaired and modified a Russian core drilling rig to be able to do both coring and rotary drilling.

Training of geophysicist on all aspects of coalbed methane coal core desorption - theory, procedure, instrumentation, and interpretation.

Establishment of a core and cuttings warehouse facility at one of the Ministry sites in order to archive and inventory coal and rock samples from any drilling project in the country.

Development of a computer facility, including hardware and software for database creation, resource calculation and analysis, data manipulation, digitizing and production of maps, desk top publishing, and graphics.

Creation of stratigraphic databases of all major coal regions of Armenia - Antaramut, Shamut, Jajur, Ijevan, Nor Arevik, and Jermanis.

Creation of coal quality databases of all major coal, carbonaceous shale, peat, and oil shale regions in Armenia.

Creation and production of Satellite Image Map of Armenia, at two scales - 1:250,000 and 1:100,000. Distribution of this map to all major research institutions in Armenia, including the RA Archival Fund. Enough copies of the 1:250,000 scale map were provided to the RA Ministry of Education by the USGS to give every school in Armenia a satellite image of Armenia.

Detailed geologic field work in all major coal regions of Armenia, with the production of new geologic maps and cross sections.

Detailed geologic field work and exploration drilling in the Antaramut-Kurtan-Dzoragukh coal field of north-central Armenia.

> **Coal was found in previously unknown areas and this coal field, as a direct result of this project, was expanded from a known 1km^2 area to approximately a 20 km^2 area.**

Produced a detailed geologic map, 1:10,000 scale, of the Antaramut-Kurtan-Dzoragukh coal field.

New resource calculations of the Antaramut-Kurtan-Dzoragukh coal field.

Economic and mining pre-feasibility study of the Antaramut-Kurtan-Dzoragukh coal field.

The following discussion synopsizes the current state of knowledge of the coal resources in Armenia, as gathered, collated, and synthesized by this Project. It is stressed that this is only an overview. For more details of each coal deposit, a full discussion of the reporting categories (C_1, C_2, etc.) and other information please see the appropriate publications referenced throughout this report. All tonnage is in metric tonnes. A map of all the coal deposit locations is found in figure 1.

SHAMUT COAL DEPOSIT located in north-central Armenia

Officially Reported Resources by the Government of Armenia:	3,623,000 tonnes of C_2 category coal 5,000,000 tonnes of P category coal
Kacharava (1953):	3,623,000 tonnes $C_1 + C_2$
Aloyan and Hakopian (1995):	6,671,612 tonnes $C_1 + C_2$
Computerized recalculation:	4,055,088 tonnes $C_1 + C_2$ 14,646,822 tonnes $C_1 + C_2 + P_1$
Prognosis:	Detailed field work and mapping by USGS indicates that much more coal than this probably exists in the Shamut coal field. Field work indicates that the coal-bearing sediments have a wider occurrence than is currently reported and that the coal field extends further to the northwest than any previous studies considered.
Recommendation:	Exploration drilling is definitely needed in the Shamut coal field. Deeper drill holes in the Shamut area proper are needed to obtain information about the entire coal-bearing section and exploratory boreholes in a larger regional area are warranted, based upon field results. The extent of the Shamut coal field is unknown and can be obtained only with exploratory drilling and geophysical logging.

JAJUR COAL DEPOSIT located in northwestern Armenia

Officially Approved Resource, by the State Committee on Reserves: (remaining after mining)	64,700 tonnes A+B, 151,200 m tonnes C_1, 10,400 tonnes C_2 (economical), and 128,900 tonnes C_2 (non-economical) Total = 355,200 tonnes [This is the only coal deposit in Armenia with

officially approved resources by the State Committee on Reserves]

Tarayan (1942): 265,900 tonnes $A+B+C_1+C_2$ coal beds No. 2 and 6 - "In Balance" Resources
128,900 tonnes coal beds No. 3, 4, and 5 - "Out of Balance" Resources

Vardanian and Elbakian (1996): 392,734 tonnes C_1+C_2 coal beds No. 2 and 6 - "In Balance" Resources
119,340 tonnes C_1+C_2 coal beds No. 3, 4, 5 "Out of Balance" Resources

Computerized recalculation: 483,538 tonnes. No distinction made between "In Balance" and "Out of Balance," because beds 3, 4, and 5 are thick enough to strip mine and as good or better in quality than beds 2 and 6.

Prognosis: Based upon detailed field work by USGS and geologic mapping of the Shirak region, these resource numbers may represent the extent of the Jajur coal resources. While there are related coal and carbonaceous shale deposits in the Shirak region - Bandivan, Maissian, Sariar - the coal beds are not laterally continuous across the area.

Recommendation: Localized drilling is needed to restart and expand the small mining operation (the site of a USAID-funded strip mine), if continued mining is desired. The Jajur deposit may be an important local resource, especially for use in Gyumri. However, larger scale regional exploration drilling is probably not warranted.

IJEVAN COAL DEPOSIT located in northeastern Armenia

Officially Reported Resources: 9,780,000 tonnes C_2 and 88,000,000 tonnes P

Chubarian and others (1983): 9,778,922 tonnes C_2 and 88,293,750 tonnes P_2

Computerized recalculation: Pending (This coal deposit is very difficult to assess because of the steep dip of the coal-bearing strata and the sampling technique of previous geologists (often on a mm by mm scale) creating an abundance of data).

Prognosis:	Only preliminary field work was carried out by the USGS on the Ijevan coal field because the Scientific Technical Council of the Ministry's Geology Department determined that there were no geological, technological, nor economic reasons to conduct extensive work nor exploratory drilling on this deposit. We agree that Ijevan contains a great deal of coal and think that more work needs to be conducted. Coal may very well occur outside the central area of Ijevan, where most of the past work has been conducted.
Recommendation:	Exploration drilling is needed to understand this structurally complex coal deposit. The exact nature of the geologic structure containing the coal deposit is under debate, and more work is needed to determine the extent and resources of the coal in this deposit.

<u>NOR AREVIK COAL DEPOSIT</u> located in southern Armenia

Officially Reported Resources by the Armenian Government:	22,500 tonnes C_2 coal 228,200 tonnes C_1 combustible shale 127,400 tonnes C_2 combustible shale
Tarayan (1942):	22,285 tonnes C_1+C_2 coal 228,205 tonnes C_1 combustible shale 270,642 tonnes C_2 combustible shale
Drobotova and Saponjian (1996):	2,225,198 tonnes C_1+C_2 combustible shale 65,631,400 tonnes P_1 combustible shale
Recalculation:	A recalculation of the resources was not performed, for several reasons. Correlation of data between reports was difficult for reasons detailed in the Nor Arevik report (Pierce and

others, in review), but the main reason is that the coal field area is so small, that additional data are probably not needed to calculate the resource of the Nor Arevik coal field. The 1942 calculation is probably a very good representation of the resources at Nor Arevik.

Recommendation: Detailed field work and geologic mapping by USGS indicate that the Nor Arevik coal field is sufficiently understood. Because net coal thickness is not great and the areal extent of the coal probably does not extend much beyond that already studied, the Nor Arevik coal deposit can probably be considered a local resource. No further exploration is recommended.

JERMANIS COAL DEPOSIT located in south central Armenia

Officially Reported Resource by the Armenian Government: 2,251,000 tonnes

Nazarian (1941): 2,251,000 tonnes

Atabekian and others (1996): 393,414 tonnes

Recalculation: A recalculation of the Jermanis resource was not performed. The main reason for this is because most of the boreholes drilled and reported in the archival reports did not contain coal. The only coal in the database occurs in adits or trenches and there are not enough data to complete a good re-calculation. The latest calculation, in 1996, is probably a good representation of the Jermanis resource.

Recommendation: Detailed field work and geologic mapping by USGS indicate that the Jermanis coal field is not very laterally extensive and occurs in a fairly structurally complex area. In addition, net coal thickness is not great. The Jermanis coal field can be considered a local resource. No further exploration is recommended.

ANTARAMUT COAL DEPOSIT located in north central Armenia

Officially Reported Resource: No resources were ever calculated on the Antaramut coal deposit, and thus, no resources are reported.

Talanian and Bogdanova (1956):
Georgadze (1956):
Keshabian and others (1997): Although work was carried out by all of these workers, each report concluded that the Antaramut deposit was very small in lateral extent and recommended that no more work should be made on this deposit and the coal has no industrial value.

Recalculation: Each of the three reports above contained exploratory data. We built a database and recalculated resources, even though the original reports did not contain them. Results: 168,949 tonnes for an area of approximately 103,600 m^2.

Prognosis: The Antaramut coal field contains much more coal than thought by any previous worker. Through detailed field work and exploration drilling in the Coal Exploration Program, the USGS expanded the known or expected coal resource from an area of less than 1 km^2 to an area of approximately 20 km^2. Results are discussed in detail later in this report, but the results are as follows:

Total Area = 16,412,148 m^2
Total Resource = 31,597,040 metric tonnes of C_2 or Indicated coal

Smaller Area (described later in report) = 165,305 m^2
Resource of Upper Bed = 3, 605,707 metric tonnes of C_1 or Demonstrated coal
Resource of Lower Bed = 1,026,870 metric tonnes of C_1 or Demonstrated coal
Total Resource of Smaller Area = 5,518,439 metric tonnes of C_1 or Demonstrated coal

Recommendation: USGS conducted exploration drilling on a large portion of the Antaramut-Kurtan-Dzoragukh coal field, but the resource assessment could become a reserve assessment by drilling a few more boreholes. In addition, USGS conducted an Economic Analysis Prefeasibility Study. This prefeasibility study should become a feasibility study, with more drilling, trenching, surveying, and other necessary work.

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I. TRAINING

A major portion of the Coal Exploration and Resource Assessment Project consisted of training. Training took many shapes and forms throughout the project - some formal and some informal, and included classroom instruction, instrument-specific training, training on techniques, approaches, ways of thinking, etc. Some of the training was concrete, such as how to build a database, and some intangible, such as introducing new ways of doing things.

The first training within the project occurred in the United States and consisted of a one and a half month specialized Coal Geology Course, specifically designed for 12 Armenian Ministry counterparts. This training included classroom instruction at USGS headquarters in Reston, Virginia and at USGS Central Regional Office in Denver, Colorado. All aspects of coal exploration and resource assessment were covered by USGS specialists. In addition, field site visits to an underground coal mine, several surface mines, exploration drilling sites, reclaimed surface mines, coal-fired power plants, cleaning plants, and coal quality testing laboratories were arranged. At all of these locations, the group met with and talked to individuals in the coal business and toured the premises or mine. These locations were in the major coal-producing or -using areas of the U.S. including West Virginia, Pennsylvania, Virginia, Texas, Colorado, Utah, and Wyoming (unfortunately we got snowed out of the Wyoming portion of the trip). In addition to these site visits, the USGS set up one of our own drill rigs in Utah in an area known to contain coal and gave a training demonstration of coal exploration. By setting up this drill site and actually drilling for coal specifically for this small group of trainees, we were better able to communicate the ideas and techniques of coal exploration drilling. They were able to ask questions, look at everything first hand, etc. When the coal was cored, we demonstrated coal core desorption techniques used to analyze for coalbed methane. In addition, USGS brought one of our geophysical logging trucks to the site and geophysically logged the hole upon completion. All the drillers, geophysicists, geologists, and coalbed methane specialists were there during the entire training exercise in order to explain the procedure in detail and answer any questions.

The Armenian participants included a diverse group of geo-professionals, a cross section of the individuals we would be working with throughout the project. They originally included: two geochemists, one driller, three resource analysts, two geophysicists, and four field geologists from the three largest coal fields of Armenia. Unfortunately, at the last minute, the Geology Department substituted one of the field geologists with a Deputy Minister. Although this substitution did not hinder the training in a concrete way, things were more tenuous than they might have been otherwise because the trainees were no longer a cohesive group of counterpart peers, but included management as well.

Recommendation: For future training courses, keep individuals of equal status together and do not mix them in one training group.

By having the training early in the program, USGS project participants got to know the Armenian individuals, and our Armenian counterparts got to know the USGS individuals they would be working with in Armenia. In addition, the Ministry counterparts got to see, first hand, coal operations, drilling projects, USGS offices, our manner of working and our expectations. Having the training at the beginning of the project was a very good way to get to know each other before the actual exploration or implementation of the program began.

The cross section of professional participants was very helpful in the training as well. There were always one or two individuals comfortable with the aspect of the training going on at a particular time (their specialty) and these individuals helped the others during training in their areas of expertise. The group was able to see the diverse aspects of coal exploration, mining, preparation, and utilization, and also benefitted from having their own experts in each of these fields as well.

Recommendation: Have training early in the program and make the group as diverse as possible in terms of specialities.

Training has been a major focus throughout and in all aspects of the program. In addition to the training in the U.S., the USGS arranged for computer classes for all of the Ministry honoraria participants in Yerevan early in the program. Most of the Ministry employees had never used computers and computers are an integral part of all aspects of this program. Therefore, it was necessary to provide to our Armenian counterparts the basics of computer usage. The USGS established several computer centers, in the Ministry's Geology Department, GeoEconomic Center, Geophysics Expedition, and Coal Quality Laboratory, and then gave specialized computer instruction to each of these groups on the specific hardware and software. USGS has also been available throughout the program to answer all questions concerning the computerization of the Geology Department.

English was also important to the Ministry participants of this program. Although all instruction manuals in this program were translated into Russian, English is necessary to run the computers and computerized instruments, communicate with manufacturers, vendors, or other scientists, and to read much of the scientific literature. Therefore, USGS arranged for English classes for all the Ministry honoraria employees during each winter of the program.

For each major aspect of the project, including coal quality laboratory instruments, the geophysical logging probes and computer programs, the database and coal resource software, there was extensive and thorough individual training by USGS specialists and/or instrument manufacturers. This type of training was repeated throughout the program for all components of the program.

The Ministry honoraria computer specialist was trained on all of the software used in this program, as well as the procedure to register hardware and software. USGS also arranged for her to spend several weeks with a computer company to learn aspects of computer hardware. The Ministry honoraria computer specialist is trained to use all the software installed on the computers, how to install software, and maintenance of personal computers and hardware repair.

The Ministry honoraria geophysicist has shown an aptitude for computer programming and has been enrolled in many computer courses through the Coal Exploration program. He has used his training to write software programs for different aspects of the program. In addition, a USGS coalbed methane specialist trained the Ministry geophysicist in the theory, procedure, and instrumentation used in coal core desorption, so he would be able to test coal core for coalbed gas (methane).

All of the Ministry honoraria employees were registered by USGS to attend the First International Energy Conference in Armenia, hosted by the Armenian Chapter of the Association of Energy Engineers held in July 1998.

II. COMPUTER CENTER/DATABASES/MAP DIGITIZING

The RA Ministry of Environment now possesses the hardware, software, and expertise for geological database creation, map making, geological synthesization including borehole correlations, drafting, data manipulation, resource calculation, desktop publishing, and more.

In addition, the RA Ministry of Environment now possesses computerized databases of all coal, oil shale, and carbonaceous shale deposits in Armenia. All geologic and topographic maps of the major coal fields of Armenia are in digital format. All information pertaining to all coal deposits is housed in databases, so that should technological, ecological, or political parameters or needs change, resources may be re-calculated very quickly.

Furthermore, databases of other commodities (zeolite and copper/molybdenum) have been completed or started and Ministry of Environment employees now possess the knowledge and ability to create databases or create maps for most resources of interest in Armenia.

The USGS established a computer center within the Geology Department of the Ministry of Environment and set up a computer room in the GeoEconomic Scientific Center within the Ministry. Software that was installed at both locations and upon which Ministry employees were trained as part of the Coal Exploration Program include:

GSMCAD	a CAD digitizing program for the production of maps (freeware designed and distributed by the USGS)
Designer	a graphics package for creating maps from the digitized files or creating original graphics
WordPerfect	a word processing and desk top publishing software
QuattroPro	a spreadsheet program

Surfer	a two- or three-dimensional modeling program to model geologic or geochemical data
Stratifact	a geologic and stratigraphic relational database program that allows for housing not only stratigraphic data, but geophysical logs, coal quality information, fluid information, and other borehole condition information; the program also allows for contouring, creating fence diagrams, and has math and volumetrics modules; the program also has powerful graphics which allow for on-screen stratigraphic correlations throughout the extent of the deposit.
PC Cores	a reserve evaluation, completely compatible with Stratifact, which allows for borehole data capture, editing data, displaying borehole profiles, gridding, contouring, seam model evaluation, and report generation.

Miscellaneous virus protection software

USGS computer specialists installed all of the above mentioned software, with the exception of PC Cores, on Ministry computers. USGS computer specialists trained Ministry counterparts these software and have been available throughout the program, via e-mail or fax, to answer questions. The GSMCAD manual was translated into Russian.

The PC Cores program was installed by the computer programmer who wrote the program. This gentleman also trained all the Ministry counterparts on its usage and has been available throughout the program to answer any questions on its operation.

The USGS and Ministry honoraria employees have digitized more than 40 maps of all the coal, combustible shale, and oil shale areas of Armenia. All coal-related maps are now in digital format and are stored in the Ministry computers. Usually this is a multi-step process. First, a topographic base must be created. The topography needs to be digitized and every point, reference elevation, road, topographic line, town, and river, as well as other information receives its own code. Once this is finished, the geology is digitized to be placed on top. Care must be taken to orient and align coordinates. Digitizing takes practice and skill. Once all features (topography, roads, rivers, geology, and other necessary information) are digitized, this file or files are then taken into a graphics program and made into what one normally thinks of as a map. Polygons are created and closed within this step, appropriate age-related color is added, appropriate lithologic-related symbols are added, the legend is created, and the other necessary steps for completion of a map are finished.

Databases were created of all available coal archival information. This was a very ambitious undertaking and took years to complete. However, now complete stratigraphic databases exist of all available coal information in Armenia. These databases reside within Ministry computers. A great deal of time was spent searching for data, which were in chaotic order and difficult to locate and organize. Information on maps of different time periods of this century, coordinate systems, and different scales required correlation. Within the Soviet Union, an internal system of coordinates was used on all working (non-military) maps. This internal coordinate system changed with time and no guidelines exist to correlate these different systems. Maps of the same location from different time periods did not correlate with each other.

Topography and reference points on different maps, once digitized, often ended up being very different. Spatial coordinates are critical in a database in order to geographically locate and use the data (boreholes, trenches, etc.). In addition, none of the archival maps were in geodetic coordinates and therefore they needed to be georeferenced.

In addition, there were often disagreements within the archival reports between the geochemical data and their locations and/or sample intervals and the stratigraphic horizon of the coal. The intervals in the two data sets were often different and a good deal of time was spent researching and correlating the data for input into both the resource and geochemistry databases.

Databases were created at the geochemistry laboratory of all the archival coal quality data (described in more detail under the "Coal Quality Laboratory" section). The data points in the coal quality database had no data locality points because geologists never submitted localities with their orders. So, the honoraria computer specialist and resource analyst needed to look through all the resultant geologic reports for the data localities. This, also, took a great deal of time because the geologists often used different numbers on their orders and in their reports, there were often no cross referencing items such as sample intervals or even lithologies, and sometimes the data that were available simply disagreed.

Using the databases, coal resources were then calculated for all the major coal fields. An exercise was undertaken jointly by USGS and Ministry honoraria resource analysts to illustrate that the manual method of coal resource calculation used previously by the Ministry and the new computerized method used within this Project are similar and would yield similar resource estimates. Two coal fields - Ijevan and Jajur - were chosen for this exercise. Relatively small areas were chosen for this exercise mainly because only small areas had been calculated manually. Both the Jajur and the Ijevan results indicate that the two methods give very similar results. These numbers are not the full resource estimates for these deposits, but rather only estimates from small areas to compare the resource methodologies.

Jajur Coal Bed No. 2

Manually
Area = 118,806 m^2
2.33 m average thickness
Calculated Resource =
332,067 metric tonnes

By Computer (PC Cores)
Area = 128,000 m^2
2.16 m average thickness
Calculated Resource =
331,453 metric tonnes

Jajur Coal Bed No. 6

Manually
Area = 106,820 m^2
1.1 m average thickness
Calculated Resource =
144,930 metric tonnes

By Computer (PC Cores)
Area = 102,500 m^2
0.99 m average thickness
Calculated Resource =
122,254 metric tonnes

Ijevan Coal Bed

Manually
Surface area = 24,799 m^2
14.72 m average thickness
Calculated Resource =
618,504 metric tonnes

By Computer (PC Cores)
Surface area = 25,200 m^2
14.72 m average thickness
Calculated Resource =
626,882 metric tonnes

In addition to the compiled databases on coal, carbonaceous or combustible shale, and oil shale, the Ministry honoraria resource analyst, with help from the USGS, built a database of the Noyemberian zeolite deposit resources, using the software previously used for building coal databases (Stratifact). Resources were then calculated for the zeolite deposit. As with the coal comparisons, the zeolite results (below) are very similar between the manual method and the computerized method, well within the margins of error.

Bed No.	Manual Calculation		Computerized Calculation	
	Resource, tonnes	Zeolite content	Resource, tonnes	Zeolite content
I	1,184,600	52.7%	1,286,500	51.8%
III	1,402,700	52.9%	1,358,300	51.0%
IV	4,081,700	53.0%	3,761,500	51.6%
Total	6,669,000	52.8%	6,406,300	51.5%

This exercise illustrated the flexibility of the software used on this project and showed that it can be used for many resource purposes.

The computerization of any geologic information or data and the software and expertise to calculate resources with the computer is important because it better allows for meeting changing environmental, societal, or political needs or technological advances.

III. COAL QUALITY LABORATORY

The RA Ministry of Environment now possesses the equipment and expertise for complete coal quality analyses (ultimate and proximate analyses), coal preparation, and has a Quality Assurance/Quality Control program in place in the Ministry's Central Laboratory.

This is the only laboratory in the entire region with the ability to perform coal quality analyses with state of art equipment, well trained chemists, with an in-place Quality Assurance/Quality Control program, with results backed up by an international Round Robin Program. This is especially important since many countries surrounding Armenia use coal to produce electricity. This laboratory can provide the analyses needed concerning technological parameters and environmental/ecological concerns.

A complete coal quality laboratory was established within the Ministry of Environment at the Central Laboratory on Komitas Street as part of the Coal Exploration Program. The USGS purchased equipment for, shipped, set up, and trained the Ministry chemists on all aspects of coal preparation and coal quality analyses. USGS undertook extensive repairs and construction within the laboratory: plumbing and electrical wiring were completely overhauled; walls, ceilings, and floors were completely rebuilt; windows were replaced and security bars were added; a completely new room was added for the database and reporting computer; furniture was built to accommodate the new instruments; the ventilation system was repaired. The USGS also purchased and installed a generator for the laboratory and rewired the building to allow use of the generator to conduct coal quality analyses when electricity failed (especially in the early years of the project).

USGS purchased, shipped, and installed the following equipment, for a complete coal preparation facility and coal quality laboratory:

Coal Preparation Equipment includes:

Crushers, grinders, splitters, ventilation system, air drying oven, balances, scales, ultrasonic cleaner, sample bags, bottles, bag sealer, sample mixer, thermex (water heater), air compressor, wet/dry vac, and safety equipment such as dust masks, eye protection, hearing protection, and more.

Coal Analytical Equipment includes:

Oxygen Bomb Calorimeter (Parr 1281 Calorimeter). This instrument is designed to measure the heat of combustion of solid and liquid fuels (such as coal), combustible wastes, foods, feeds, and other oxygen combustible materials. Calorimetry is an established technology in which water is circulated around the bomb to bring all inner parts of the calorimeter to a uniform temperature rapidly, while true isoperibol operating conditions are maintained by an outer water jacket. Microprocessor based, real time heat leak corrections are applied to implement the isoperibol jacketing method and to support the prediction of the final temperature rise. Precise temperature measurements are made with thermistor thermometry providing 0.0001°C resolution over the operating range of the calorimeter.

IR Sulfur Analyzer (Houston Atlas 880M Sulfur Analyzer). This instrument is designed to determine total sulfur content within a sample. Weighed samples are burned in a vertical combustion tube, and the resultant combustion gases are drawn from the tube and transferred to the IR bench, where the SO_2 content is determined by infrared absorption. The measurement technique of the IR (infrared) detector is based on the fact that certain gases absorb infrared radiation at specific wavelengths. The amount of radiation absorbed is proportional to the concentration of the gas and the optical length occupied by that gas between the IR source and the detector. Sulfur content is determined by the IR analyzer after combustion of a premeasured sample in a 99.5% oxygen atmosphere. This environment ensures that sulfur species are quantitatively converted to SO_2. Combustion gases are drawn through desiccant and particulate filters to remove moisture and particulate matter before introducing the gas into the sample cell of the IR bench.

Thermogravimetric Analyzer (TGA) (a Leco TGA-601). Instrumentation for the characterization of organic/inorganic materials and microstructural analysis. The TGA-601 Thermogravimetric Analyzer is used to determine the composition of organic, inorganic, and synthetic materials. It measures weight loss as a function of temperature in a controlled environment. Thermogravimetric analysis methods can contain as many as six weight loss steps per method. The main usage of this instrument during this Program was to perform the determination of moisture, ash yield, volatile matter, and fixed carbon.

CHNS Analyzer (Fisons EA 1108 Elemental Analyzer). The Elemental Analyzer EA 1108 is an instrument designed for the micro, semi-micro, and macro determination of total carbon, hydrogen, nitrogen, sulfur, and oxygen present in a wide range of organic and inorganic substances such as coal, coke, organic chemicals, pharmaceuticals, fine chemicals, fuels, gasolines, oils, metal powders, steel, polymers, rubbers, catalysts, soils, sediments, ceramics, carbon fibers, and many others. The original analytical method is based on the complete and instantaneous oxidation of the sample by "flash combustion" which converts all organic and inorganic substances into combustion products. The resulting combustion gases pass through a reduction furnace and are swept into the chromatographic column by the carrier gas (helium) where they are separated and detected by a thermal conductivity detector which gives an output signal proportional to the concentration of the individual components of the mixture.

All of these instruments are on very large power conditioners which not only control fluctuations in the electricity that might damage sensitive electronics, but provide a battery back up should the electricity fail, to provide time to cool down and/or turn off the instruments without doing damage.

Manufacturers representatives installed all of the above mentioned equipment in the Central Laboratory. In addition, the chemists received extensive training on these instruments by both the manufacturer representatives as well as USGS specialists. Training included the operation of the instruments, as well as the theory behind the instrumentation, safety procedures, sample handling protocol, and data reporting and presentation.

All laboratory procedures conform to ASTM (American Society for Testing and Materials) standards and procedures. Reporting categories are presented in both ASTM and GOST (former Soviet State Standards, analogous to ASTM) so that all potential customers will be familiar with the results. All results are reported in all appropriate categories: for example, calorific value is reported in both calories/gram and Btu/pound.

All of the manufacturer instrument manuals were completely translated into Russian by the USGS at the beginning of the project, for the safe and efficient use of the instruments by the Armenian chemists.

The USGS undertook the responsibility of repairing all the equipment during the Program as well as interacting with all vendors and/or manufacturers about questions or problems. During the last six months of the program, the Ministry chemists undertook this responsibility, in order to be comfortable with the process when the program ended.

In addition to the training on the four instruments listed above, the chemists received in-depth training on coal preparation techniques from USGS specialists. Analytical results of coal are directly dependent upon the preparation procedures, so a great deal of time was spent concerning training on this subject. The chemists were trained on analytical techniques, operation of instruments, safety procedures, sample handling protocol, and sample reporting protocol. Control samples from the U.S. were routinely included with the chemists' other analyses, for instrument and analytical technique control.

USGS also arranged for computer lessons for the chemists, because all of the instruments are computerized. English lessons were also arranged for the chemists every winter of the program. Even though the instrument manuals were translated into Russian, English is necessary to actually run the instruments. English is also necessary to use the computers to build and manipulate coal databases, interact with potential customers, ask technical and operational questions of the instrument manufacturers, and deal with instrument repairers.

As part of this Program, the USGS arranged for a U.S. laboratory inspector from CT&E Inc. to visit the Central Laboratory twice. The first visit was spent inspecting preparation procedures, analytical techniques, sample handling, reporting procedures, and any other operational procedure necessary for a successful coal laboratory. The laboratory inspector made a number of suggestions, imposed quality standards, requested log books be created for each instrument, etc. His main concern and input to the laboratory was to implement critical standardization practices. After the laboratory inspector's visit, we implemented a Quality Assurance/Quality Control program within the laboratory. For a year and a half, until the laboratory inspector's return to Armenia, he continued oversight of the standardization practices, reviewing the round robin results, and log books, by keeping in touch with the chemists by fax or e-mail via the USGS. The laboratory inspector returned a year and a half later, saw great improvement, and his final report was translated into Russian for the chemists.

The USGS arranged for the Ministry coal laboratory to participate in a round robin program to ensure international acceptability of analytical results. The round robin program is run by Laboratory Quality Services International. Each month, the laboratory was sent two coal samples, upon which the chemists perform a complete series of analytical tests. The results were faxed back to LQSI and the laboratory's results compared to hundreds of other laboratories. The program provides an independent audit tool to confirm the effectiveness of a laboratory's quality control procedures (both preparation and analytical procedures). In addition, the round robin program provides the laboratory with quality control samples to be used in the evaluation of the lab's precision and bias of their analytical methods; provides proficiency testing and other interlaboratory comparisons; and develops evidence of repeatability and reproducibility of analytical test procedures through inter- and intra-laboratory studies.

The results of the round robin program will be the single most sought after evidence of a laboratory's abilities by potential customers.

The USGS also set up a computer in the geochemistry laboratory and USGS computer specialists trained the Ministry chemists on the use of the computer as well as the software (including QuattroPro, WordPerfect, and virus protection software) installed on the computer, including a specially designed and written program to automatically record some of the coal preparation parameters. This computer houses databases consisting of information and analyses for all newly analyzed samples.

In addition, the Ministry chemists and USGS personnel created databases of all archival coal quality analyses. This was a long term commitment, as there are huge amounts of archival data and the data were in a state of decay and confusion when we started this project. Every coal, carbonaceous shale, and oil shale field, and peat deposit in Armenia has a specific database and all available archival data for each deposit is housed in the computer. All databases reside at the Central Laboratory.

In addition, a great deal of time was spent by other honoraria members (the computer specialist and one of the resource specialists) and USGS in combing through many archival reports to get data locality points for the geochemical database. The geochemistry laboratory did not have any localities for their data (information was never submitted with the samples) and each separate order ended up in a different archival report. All of these reports needed to be examined to find information for each different borehole, trench, or adit locality in order to determine the location point for the data.

As explained above, the Coal Exploration Project provided the laboratory with an instrument capable of determining total sulfur content. However, the determination of pyritic, sulfate, and organic sulfur, important coal quality parameters desired by many potential customers, are still done manually.

The ability to determine pyritic and sulfate sulfur exists at the Central Laboratory and is now routinely being performed. For the past several months, these tests (forms of sulfur) have been performed on the round robin samples received each month.

Results for pyritic sulfur determination, probably one of the most important coal quality parameters, have been very good. This is an important addition to the laboratory's capabilities in offering different quality testing to potential customers.

The same chemist who performs the forms of sulfur analyses, has undertaken washability (cleaning) analyses. These are analytical techniques that simulate coal cleaning. Once the coal sample has been washed, coal quality analyses are run on the cleaned coal. These tests will be particularly important for potential customers, especially as cleaner sources of fuels are emphasized world wide.

IV. GEOPHYSICAL LOGGING STATION

The RA Ministry of Environment now possesses the equipment and expertise for completely computerized geophysical borehole logging exploration.

The USGS purchased, shipped, and installed all computerized geophysical borehole logging equipment necessary in coal exploration. The Coal Exploration Program purchased geophysical logging equipment capable of measuring the following parameters:

resistivity
spontaneous potential
natural gamma
gamma-gamma density
caliper
point resistance
temperature
fluid resistivity

USGS also purchased, shipped, and installed a 1000 meter capacity drawworks (1000 m cable), computers, support software, tool interface card, tools, and safety equipment at the Geophysical Expedition.

In addition to logging for coal exploration, this equipment can be used for almost any type of exploration that requires lithologic distinctions of rock or delineation of specific horizons (such as water-bearing horizons, and includes exploration for coal, oil, gas, salt, oil shale, gold, metals (such as copper, molybdenum), water well drilling, fracture studies, and more. The main limitation for using this equipment for such things as oil and gas exploration (post borehole drilling, not simultaneous logging) is the length of the cable. If potential clients or users need a tool or ability that is not listed above (such as an inclinometer), one can be easily purchased and installed. The equipment was purchased from a major US company (Century Geophysical) for this very reason - to have the ability to expand should the need arise in the future.

USGS geophysicists installed this equipment on a Ministry truck and trained Ministry geophysicists in all aspects of this computerized equipment. In addition, quite a bit of time was spent training Ministry geophysicists on logging specifically for coal. However, the theory and nuances of logging for other geologic materials were also covered.

The two USGS geophysicists returned to Armenia about a year after installing the equipment for follow up, hands-on training which took place during USGS drilling in the Antaramut coal field. Therefore, all the downhole functions and processes could be examined, recommendations made on the Ministry honoraria geophysicist's techniques, interpretations, and safety procedures.

One of the USGS geophysicists again visited Armenia to work with the Ministry geophysicist in spring of 1998. Several days was spent in the field at the USGS drilling site, perfecting techniques for coal logging, protocol, and safety procedures. The USGS geophysicist repaired and cleaned the logging probes that were operating at less than maximum capability and helped recalibrate the probes. The USGS specialist also installed the newest and most versatile version of the logging software from the company during this visit and trained the Ministry geophysicist on its usage.

Throughout the extent of the Program, USGS geophysicists have been in touch with the Ministry geophysicist to answer questions and offer advice, via fax and e-mail through the Yerevan USGS office.

In addition to the in-depth training the Ministry geophysicist received from USGS specialists, the USGS arranged several computer training courses for the geophysicist throughout the Project. He also attended the English classes arranged by the USGS every winter of the Program. The entire set of manuals for the geophysical logging station (for the probes as well as the computer programs) were translated into Russian for the safe and efficient use of the equipment.

In addition to the holes that were logged as part of the Coal Exploration and Resource Assessment Program, this equipment was used to log other holes that were drilled throughout Armenia in the last several years. These holes included boreholes for salt, gold, polymetals, and water exploration.

As part of the Coal Exploration Project, the Ministry geophysicist digitized many of the archival logs which date back to the 1950's. These were in a state of decay and maintenance was becoming difficult. Digitizing the data helped preserve these data, allowed for categorization of the holes by regions, and made this valuable information available for any exploration purpose. These are irreplaceable data that can benefit any exploration program.

A copy of all of the geophysical curves logged as part of the Coal Exploration Program as well as many of the archival geophysical logs are found in the following reference:

Pierce, Brenda S. and Grigorian, Grigor, 1999, A Brief Review of Borehole Geophysical Logging Activities in Armenia: U.S. Geological Survey Open-File Report 99-561, 140 p.

V. EXPLORATORY DRILLING

USGS repaired and modified a Russian SKB-4 (СКБ-4) core drilling rig to perform both rotary and core drilling to maximize drilling capabilities. This included obtaining a much larger mud pump and attaching it to the drill rig. A combination of Russian and U.S. manufactured equipment was used. American core barrels and drill steel were used. Both American and Russian drill bits were used to maximize drilling efficiency by allowing for a range of drilling sizes, easier procurement when bits wore out, and a range of prices and qualities. It was easy to use the combination with specially manufactured subs between the two systems of measurement (English and metric). Bentonite was obtained locally, in Ijevan, but chemical polymer was shipped from the U.S.

The USGS received the shell of a drill rig and the shell of a water truck from the Ministry Ijevan Expedition in the spring of 1996. The USGS basically rebuilt both trucks, installing engines, hydraulics, windows, doors, brakes, clutches, tires, and much more, as well as completely replacing the entire drilling system on the drill rig.

The USGS, together with the Ministry's Ijevan Expedition, started drilling in the Ijevan coal field in the summer of 1996. USGS had planned, with the Ijevan Expedition, to conduct much more exploration drilling (3000-4000 meters) than was actually done. USGS worked with Ministry accountants and Geology Department management for several months in order to legally realign the Ijevan Expedition's budget in order to drill cooperatively. However, the Scientific Technical Council of the Geology Department, in April of 1996, decided that there were no geologic, technical, or economic reasons to drill more than 500 meters and only in the central part of the Ijevan coal field. Therefore, the USGS worked with the Ijevan Expedition to complete what they could of their State Plan for Coal Exploration with the drilling equipment available. A USGS drilling expert, with expertise in coal exploration and this combined rotary-coring technique, trained Ministry drillers on the use of the new equipment and specific protocols for coal exploration.

With the joint Ijevan work completed, USGS moved to the Antaramut coal field and started working with the Ministry's Gugark Expedition. Together, the USGS and the Gugark Expedition drilled three holes during the fall of 1996, also in fulfillment of their State Plan for Coal Exploration. With the finalization of that drilling, USGS undertook drilling operations entirely on our own. Thus, after official amendment to the MOU signed by the AID Mission Representative and the Minister of Environment, the USGS undertook sole responsibility for drilling operations.

USGS took the drill equipment back to Yerevan over the winter of 1996-1997 to repair and overhaul the equipment. Unusually heavy snowfall and spring rains that year delayed the beginning of the drilling season until May of 1997. However, in May, USGS moved back to the Antaramut coal field and began two years of exploratory drilling. Results of that work is found under the section titled "Antaramut-Kurtan-Dzoragukh Coal Field."

V. a. Core Warehouse

The USGS established a core and cuttings facility at the Ministry's Geophysical Expedition. USGS built a core and cuttings storage facility, where none had existed before. This was necessary in order to inventory and archive coal and rock samples - core, cutting, and outcrop samples.

V. b. Coal Bed Methane

USGS purchased all of the equipment necessary to test for coalbed methane within Armenian coals. A USGS coalbed methane specialist trained the Ministry geophysicist in the theory, procedure, and instrumentation to test coal core for coalbed methane desorption. All of the equipment resides in the Geophysical Expedition. Unfortunately, USGS never drilled deep enough to test for coalbed methane (shallower than a certain depth, the methane, if once present, has bled off and is no longer present in the coal). The exploration drilling in the Antaramut-Kurtan-Dzoragukh coal field proved the field to be a bigger resource than anticipated, and we spent time drilling there, rather than wildcat drilling for coalbed methane. Unfortunately, no Ministry Expeditions drilled for coal in the last several years in order to test any other wells for the presence of coalbed methane, either.

VI. SATELLITE IMAGE MAP

` The USGS produced a Satellite Image Map of Armenia. This satellite image map was produced at two scales: 1:250,000 and 1:100,000. The 1:250,000 scale comes in two sheets - east and west. The 1:100,000 scale map comes as seven quadrangles covering the entire country: Shirak, Ijevan, Yerevan, Sevan Lake, Karabakh, Middle Araks, and Zangezur.

The images were recorded by Landsat Thematic Mapper in the multispectral mode composed of the bands: Band 2 (0.52 - 0.60 μm), Band 4 (0.76 - 0.80 μm), and Band 7 (2.08 - 2.35 μm). The imagery was controlled and geometrically corrected using the restoration resampling algorithm with 15 m cells and filtered with a 151 x 151 filter to which 85 percent of the unfiltered data were added back. Data are from imagery taken September 1984, September 1987, and August 1989.

The maps come with explanations in three languages - Armenian, Russian, and English - to maximize interest and usage. Half of the 1:250,000 scale maps come with place name overlays in three languages and half of the maps were produced without the text place name overlays for researchers who will need unobstructed views of the land, topography, and geology.

In addition, for research purposes, the USGS printed several photo copies of the 1:100,000 scale maps, both in normal ratio'd color and offset ratios. One complete set (7 quads) was given to the Ministry of Environment's Archival Fund and another set was given to the Armenian Academy of Sciences library. It is hoped that being housed in these two libraries will make it available to all interested parties.

These maps were published as a formal USGS series so as to be available to all interested parties. The citations are as follows:

U.S. Geological Survey, 1999, Satellite Image Map of Armenia and Surrounding Territory, 1:250,000 scale: U.S. Geological Survey Miscellaneous Investigations Series Map, I-2665, 2 sheets.

U.S. Geological Survey, 1999, Satellite Image Map of Armenia and Surrounding Territory, 1:100,000 scale: U.S. Geological Survey Miscellaneous Investigations Series Map, I-2678 A through E.

Even though these maps were published, all major research institutions in Armenia, as well as the AID Mission and Embassy, received copies of the satellite image map. After seeing copies of the maps, many other organizations also requested copies which were provided to them. The distribution list in Armenia is as follows:

Ministry of Environment
    and the Republic of Armenia Archival Fund

Ministry of Energy
    Fuel Department
    Engineering-Geological-Topographical Department -
        ArmEnergoHydro Proyekt

Ministry of Transportation

(At the time of writing this report, many of the Ministries were under reorganization, so copies had not been distributed. However copies of the map are also planned to be given to the Ministry of Agriculture and the Ministry of Civil Engineering)

RA Committee on Extreme/Hazardous Conditions (such as earthquake relief)

Institute of Nonferrous Metals - Geology Department

Armenian Academy of Sciences
    Institute of Geology
    Institute of Biology

Institute of Geography
Center for Environmental Investigations
Institute of Geophysics and Seismology

Geographical Society

National Center for Seismic Protection

GKZ (State Committee on Reserve Estimation)

American University of Armenia

Yerevan State University - Geology Department, Geography Department, and Biology (Environment) Department

Geography Department of the Ecological College of Yerevan

Gugark Marspet and Mars Geologist

Ministry of Education was provided 1400 copies - one for each school in Armenia

Already the maps are being used in a variety of research and teaching projects, which include: geological and environmental studies within the Ministry of Environment; geological studies in the Institute of NonFerrous Metals; environmental studies and course curricula at the American University of Armenia; the American University of Armenia also plans on using the satellite image as a base map in a GIS system to determine land use changes in Armenia over the last four decades; compilation of an "Atlas of Roads of Armenia" by the Ministry of Transportation; assessment of seismic, volcanic, and landslide hazards in Armenia and neighboring countries; and many other uses.

VII. COAL IN ARMENIA

There are six major coal fields in Armenia (fig. 1):

Antaramut, in north-central Armenia
Shamut, in north-central Armenia
Jajur, in north-western Armenia
Nor Arevik, in southernmost Armenia
Jermanis, in south-central Armenia
Ijevan, in north-eastern Armenia

Coal occurs all over Armenia and USGS conducted a great deal of work on each of these six areas.

VII. a. Archival Information

USGS collected, interpreted, and synthesized data for each of the major coal fields of Armenia from all of the previously unaccessible (government proprietary) data in the Republic of Armenia Archival Fund or the Armenian Academy of Sciences. All reports within the State Archives and Academy of Sciences related to coal in Armenia were obtained, translated, and analyzed. All of the basic data - stratigraphic, coal quality, and coal resource information - relating to each of the coal deposits were entered into databases as well as synopsized in the following reports. The archival material was often conflicting, even in small areas, and it took a great deal of time to sift through the material, correlate coal beds within a deposit, and match maps of different scales in different reports.

Much time was also spent in trying to convert coordinate systems into real-world coordinates, usually into latitudes and longitudes. Within the Soviet Union, an internal system of coordinates was used on all working (non-military) maps. This internal coordinate system was a systematic x-y coordinate system. The internal system of coordinates for the data points on the exploration works or maps from a coal field were converted into latitude/longitude. Matching different maps, however, was often very difficult. Sometimes, maps or coordinate localities were intentionally altered in the past for security reasons, especially on small or topical maps, such as mineral deposit maps. Conversion of the old, internal coordinate systems was necessary (when possible) not only for comparison purposes and illustrative purposes for exhibiting the data, but also necessary for the addition of new data or the combination of different data sets.

Often, we recalculated the coal resource information using computerized techniques and combining all data within the archives. For the first time, data on all coal deposits in Armenia appear in one place. The basic data from each of the archival reports on each coal field is supplemented with additional data from the USGS work. These reports will be published so that interested users have access to them. The following represent this synthesization of archival information and the following four manuscripts are currently in the process of being published:

Shamut Coal Deposit: Pierce, Brenda S., Malkhasian, Gourgen, and Martirosyan, Artur, 2000, The Shamut Coal Deposit, North-Central Armenia, U.S. Geological Survey Bulletin 2175, 71 p.

Jajur Coal Deposit: Pierce, Brenda S., Malkhasian, Gourgen, and Martirosyan, Artur, in review, The Jajur Coal Field of Northwestern Armenia, U.S.

Geological Survey Bulletin, 86 p., 3 figures, 16 tables.

Nor Arevik Coal Deposit: Pierce, Brenda S., Malkhasian, Gourgen, and Martirosyan, Artur, in review, The Nor Arevik Coal Field of Southernmost Armenia, U.S. Geological Survey Bulletin.

Antaramut Coal Deposit: Pierce, Brenda S., Malkhasian, Gourgen, and Martirosyan, Artur, in review, The Antaramut Coal Field of North-Central Armenia, U.S. Geological Survey Bulletin.

The following two manuscripts are currently in preparation and will be in review soon:

Jermanis Coal Deposit: Pierce, Brenda S., Malkhasian, Gourgen, and Martirosyan, Artur, in preparation, The Jermanis Coal Field of South-Central Armenia, U.S. Geological Survey Bulletin.

Ijevan Coal Deposit: Pierce, Brenda S., Malkhasian, Gourgen, and Martirosyan, Artur, in preparation, The Ijevan Coal Field of North-Eastern Armenia, U.S. Geological Survey Bulletin.

VII. b. New Field Work and Geologic Mapping

In addition, USGS conducted detailed field work and mapped each of these coal regions, utilizing new ideas to map with coal resources in mind. All areas, except one, were mapped in detail, coal quality samples were taken when possible, and the new information is in the process of being published. The Ijevan coal field was not mapped in detail, although work was done there, because the Ministry of Environment's Scientific Technical Council officially decided to cease work being conducted in the coal field after 500 m of drilling was completed.

Complications arose during the mapping of these coal fields because of the type of map available (or rather, not available) in Armenia. Only 1:25,000 scale maps are available in Armenia - all others are deemed government proprietary. Actually the 1:25,000 scale are also proprietary, but we managed to secure the necessary ones for our field areas. However, using this kind of scale - where 1 cm is equal to 250 m and often the topographic contour interval is 5 m - is very difficult for the detailed work required to map the coal areas. Often we either scanned or digitized the 1:25,000 map and changed the scale digitally to 1:5,000 or 1:10,000. However, both of these options introduce some errors. Using these converted maps to map our geology produced only minor problems; however, locating previously mapped data onto these maps created serious problems.

The following publications represent new information on each of the major coal deposits:

Jajur Coal Deposit: Dallegge, Todd A., Martirosyan, Artur, Maldonado, Florian, and Pierce, Brenda S., in review, Stratigraphy and Geology of Tertiary Coal-Bearing Deposits, Shirak Region, Northwestern Armenia, U.S. Geological Survey Open-File Report, 47 p., 4 figures, 1 geologic map.

Nor Arevik Coal Deposit: Johnson, Edward A., Martirosyan, Artur, Pierce, Brenda S., and Brownfield, Michael E., in review, Geology of the Nor Arevik Area, Megri Region, Southern Armenia: U.S. Geological Survey Open-File Report, 20 p., 4 figures, 1 geologic map.

Jermanis Coal Deposit: Brownfield, Michael E., Martirosyan, Artur, Pierce, Brenda S., and Johnson, Edward A., Geology and Coal Quality of the Jermanis Coal Field, central Armenia: U.S. Geological Survey Open-File Report.

Ijevan Coal Deposit: Warwick, P.D., Maldonado, F., Pierce, B.S., Tutunjian, M., Chubarian, G., and Brutian, H., 1996, A volcanogenic depositional model for a thick Jurassic coal-bearing interval, lesser Caucasus, Armenia:

Geological Society of America Abstracts with Program, vol. 28, p. A-209.
Warwick, P.D., Maldonado, F., Tutunjian, Mels, Chubarian, Grachik, and Brutian, Haik, in review, Geologic road log from Ijevan to Dilijan, northeastern Armenia: U.S. Geological Survey, Open-File Report.

The following manuscript is currently in preparation, is almost completed, and will be available soon:

Shamut Coal Deposit: Pierce, Brenda S., Martirosyan, Artur, Harutunian, Samvell, and Harutunian, Grigory, in review, Geology of the Shamut Coal Field, north-central Armenia, U.S. Geological Survey Open-File Report.

For the results on the **Antaramut Coal Deposit** see the separate section below.

VIII. THE ANTARAMUT-KURTAN-DZORAGUKH COAL FIELD

USGS conducted detailed field work and exploratory drilling in the Antaramut-Kurtan-Dzoragukh coal field of north-central Armenia. This coal field is located in the central part of the Lori Mars (region). Coal has been reported in and around the village of Antaramut since the turn of the century and it was mined by the French in 1915 for use in a copper smelter in Alaverdi. However, coal had always been thought to have occurred in a very small area of approximately 1 sq km. Other coal occurrences had been reported in the region, but none of the previous workers thought that the coal occurrences were related. All previous geologists thought that the small coal exposures at Antaramut, Kurtan, and Dzoragukh were isolated occurrences, unrelated to one another. Some workers even gave them different ages. As a direct result of this Program's work, USGS expanded a known or expected coal area of 1 km^2 to an area approximately 20 km^2. Thus, we have re-named the coal field the Antaramut-Kurtan-Dzoragukh coal field to include the three villages in the area that the coal field encompasses.

Drilling in the Antaramut region began in the fall of 1996. USGS drilled 3 boreholes jointly with the Ministry of Environment's Gugark Expedition in fulfillment of their State Plan for Coal Exploration. For these three holes, whose location had already been chosen by the Expedition, the Expedition provided the drill crew and the USGS provided the equipment, fuel, and consumables. After these three holes were drilled, the Expedition's plan for coal exploration was completed. USGS continued drilling in the area independently, with Ministry permission, primarily because the

USGS believed, based upon geologic field work, that the coal field extended well beyond this small area.

In total, the USGS drilled 41 boreholes at 32 locations in the Antaramut-Kurtan-Dzoragukh coal field from May 1997 to July 1999. A map of the drill hole localities is located in figure 2. Total drilling equaled 4162 meters - 1349 cored meters and 2813 rotary meters. In the beginning of the exploration drilling program, we twin holed most locations. That is, the boreholes were rotary drilled and geophysically logged. Then, a second borehole, usually 4 to 5 meters away from the first, was rotary drilled to intervals of interest, which were then cored. However, because we encountered technical difficulties because of the many fractures in the strata above the coal, we often had to core the entire hole. Often, rotary drilling was neither safe nor efficient. Further, because of the complicated geologic structure of the coal field, complete coring gave us more information than rotary drilling.

All boreholes were described in detail and the lithologic descriptions are found in the publication cited below. In addition, many borehole samples and outcrop samples were thin sectioned and analyzed petrographically. Often, this is the only way to determine the exact rock type and petrographic analysis is critical to correlation of lithologies across a region. The thin section descriptions are also found in the publication cited below. The borehole descriptions and the thin section descriptions appear in both English and Russian.

Pierce, Brenda S., Harutunian, Samvel, Martirosyan, Artur, and Harutunian, Grigory, 1999, Borehole and Thin Section Desciptions from Exploration

Drilling and Field Work in the Antaramut-Kurtan-Dzoragukh Coal Field, North-Central Armenia, U.S. Geological Survey Open-File Report 99-561, 140 p.

Each borehole, immediately upon completion of drilling, was geophysically logged. All of the logging equipment installed as part of this project is described under the section "Geophysical Logging" of this report. As described above, a few of the boreholes had to be abandoned because of technical difficulties. If these holes were shallow, they were not geophysically logged. All geophysical logs from this project are found in the citation:

Pierce, Brenda S. and Grigorian, Grigor, 1999, A Brief Review of Geophysical Logging Activities in Armenia: Part I. Geophysical Logs from Coal Exploration Boreholes of the Antaramut-Kurtan-Dzoragukh Coal Field, north-central Armenia; Part II. Geophysical Logs from Non-Coal Exploration Boreholes; Part III. Archival Geophysical Logs from Various Exploration Boreholes throughout the Republic of Armenia: U.S. Geological Survey Open-File Report, 99-561, 140 p.

In addition to the boreholes drilled, USGS conducted extensive geologic field work. The entire area was walked and field surveyed, to determine outcrops and map the geology. Exploratory trenches were dug where the coal in the boreholes was projected to occur at the surface or where soil formation had obscured outcrops of the coal. A regional geologic map, at a 1:10,000 scale, was created of the Antaramut-Kurtan-Dzoragukh coal field, based upon all of the detailed geologic field work, exploratory drilling, trenching, and petrographic analysis:

Pierce, Brenda S., Harutunian, Grigory, Harutunian, Samvel, Martirosyan, Artur, and Malkhasian, Gourgen, in review, Geologic Map of the Antaramut-Kurtan-Dzoragukh Coal Field, North-Central Armenia, U.S. Geological Survey I-map.

In addition, all coals encountered in the boreholes or outcrops were analyzed for full coal quality analyses at the Central Laboratory. The Antaramut-Kurtan-Dzoragukh coal is fairly high in ash yield, but also very high in calorific value. Washability analyses were conducted on some of the samples to see if the ash yield could be lowered. Results were very promising and the coal of the Antaramut-Kurtan-Dzoragukh coal field is very amendable to cleaning. A detailed analysis of the coal field, including coal quality analyses, stratigraphy, and interpretive analysis, such as depositional environment of the coal field and tectonic history is in review:

Pierce, Brenda S., Martirosyan, Artur, Malkhasian, Gourgen, Harutunian, Samvel, and Harutunian, Grigory, in review, Geology, Coal Quality, and Resources of the Antaramut-Kurtan-Dzoragukh Coal Field, north-central Armenia, submitted to the *International Journal of Coal Geology*.

However, all of the coal occurrence and thickness information is contained in the borehole and thin section publication cited above and all the coal quality information and coal resource calculations are listed below.

Throughout field work and exploratory drilling, USGS maintained close ties with Mars (regional) officials, who were interested in the results of this study and the potential usability of the coal.

Synopsis of the Antaramut-Kurtan-Dzoragukh Coal Field

The Antaramut-Kurtan-Dzoragukh coal deposit is a previously undiscovered coal field in north-central Armenia. Coal has been known to exist in the general region since the turn of the century, but coal was thought by all previous workers to be restricted to a very small (1 km^2) area, in the vicinity of the village of Antaramut (box A in fig. 2). However, through detailed field work and exploratory drilling, this coal deposit has been expanded to an area of at least 20 km^2, and thus renamed the Antaramut-Kurtan-Dzoragukh coal field for the three villages that the coal field encompasses.

The Antaramut-Kurtan-Dzoragukh coal field contains two coal beds, each greater than 1 m thick, and numerous small rider beds. The entire coal-bearing horizon, a series of tuffaceous sandstones, siltstones, and clays, is approximately 50 m thick. The coal is Upper Eocene in age, high volatile bituminous in rank, and although relatively high in ash yield (both beds have about 40 percent ash yield, as-received basis) and moderate in sulfur content (upper bed has about 3 percent sulfur and the lower bed has about 2.7 percent sulfur, as-received basis), this coal is low in moisture content (about 5 percent for both beds) and relatively very high in calorific value. Calorific values for the upper bed are 14,033 Btu/lb or 7796 cal/g (moist, mineral-matter-free basis) and for lower bed are 15,478 Btu/lb or 8599 cal/g (moist, mineral-matter-free basis). Samples from the Antaramut-Kurtan-Dzoragukh coal deposit were submitted for washability (cleaning) analyses as well. The results indicate that this coal is very amenable to cleaning: volatile matters were increased and ash yields were lowered significantly.

Coal quality results can be found in the following tables (sample localities are on the map in the Appendices).

Calorific Values of Samples from the Antaramut-Kurtan-Dzoragukh Coal Field

[SL = sample locality; CB = coal bed; CV-C_{ad} = calorific value, as-determined basis, in cal/g; CV-Cmmf = calorific value, moist mineral-matter-free basis, in cal/g; CV-B_{ad} = calorific value, as-determined basis, in Btu/lb; CV-Bmmf = calorific value, moist mineral-matter-free basis, in Btu/lb; CV-Bar = calorific value, as-received basis, in Btu/lb; bh = borehole; nd = no data; fl = floor; ncv = no calorific value; K oc 1 = Kurtan outcrop 1; K oc 2 = Kurtan outcrop 2; ukn = unknown]

SL	CB	CV-C_{ad}	CV-C_{mmf}	CV-B_{ad}	CV-B_{ar}	CV-B_{mmf}
bh 9	#2	nd	nd	nd	nd	nd
bh 15	#2	4139	7161	7450	7241	12890
bh 18	#1	3529	7808	6352	6229	14055
bh 18	#2	3118	7450	5613	5478	13410
bh 18	fl	2696	11027	4853	4780	19848
bh 18	fl	ncv	ncv	ncv	ncv	ncv
bh 19	#1	2568	6063	4622	4508	10914
bh 20	#1	5082	8020	9147	8905	14436
bh 20	#2	4810	7556	8657	8433	13601
bh 21	#1	6561	11637	11810	11470	20947
bh 24	#1	3260	5328	5867	5666	9591
bh 26	#1	5148	7919	9327	9071	14254
bh 26	#2	5142	8259	9256	8965	14867
bh 27	#2	5097	7650	9174	8949	13770
bh 31	#2	6220	13518	11196	10956	24333
K oc 1	ukn	1516	5242	2728		9436

K oc 2	ukn	2570	6068	4626	4358	10923
Avg bed #1		4716	8142	8501		14657
Avg bed #2		4754	8599	8558		15478

Proximate Analyses Results of Samples from the Antaramut-Kurtan-Dzoragukh Coal Field

[SL = sample locality; CB = coal bed; TM = total moisture, in percent; ADL = air dry loss moisture, in percent; AM = analytical moisture, in percent; A_{ad} = ash yield, as-determined basis, in percent; A_d = ash yield, dry basis, in percent; VM_{ad} = volatile matter, as-determined basis, in percent; VM_{daf} = volatile matter, dry ash free basis, in percent; bh = borehole; fl = floor; K oc 1 = Kurtan outcrop 1; K oc 2 = Kurtan outcrop 2; ukn = unknown]

SL	CB	TM	ADL	AM	A_{ad}	A_d	VM_{ad}	VM_{daf}
bh 9	#2	6.64	0.76	5.92	77.35	82.22	11.28	67.42
bh 15	#2	4.26	2.90	1.40	40.45	41.04	19.26	33.33
bh 18	#1	3.80	1.72	2.12	60.96	62.22	16.29	45.58
bh 18	#2	5.58	2.40	3.27	54.31	56.16	18.71	44.32
bh 18	fl	6.15	1.49	4.73	70.28	73.77	7.87	31.49
bh 18	fl	7.67	2.14	5.65	78.90	83.62	6.33	40.97
bh 19	#1	4.12	2.46	1.70	54.49	55.43	8.66	19.77
bh 20	#1	4.20	2.63	1.62	34.14	34.69	12.00	*18.94*
bh 20	#2	4.39	2.58	1.86	34.03	34.67	9.00	*14.08*
bh 21	#1	6.08	2.93	3.24	41.22	42.60	8.69	16.10
bh 24	#1	8.13	3.64	4.65	36.47	38.3	15.49	26.59
bh 26	#1	5.12	2.74	2.45	32.06	32.86	13.85	21.06
bh 26	#2	5.49	3.15	2.42	35.19	36.05	19.61	31.20
bh 27	#2	6.19	2.47	3.81	31.03	32.26	11.09	17.04
bh 31	#2	3.59	0.61	3.00	49.55	51.08	8.89	18.74

K oc 1	ukn	2.15	1.52	0.64	68.78	69.22	18.00	57.46
K oc 2	ukn	10.1	5.75	4.61	56.52	59.24	15.59	40.27

Ultimate Analyses from Samples of the Antaramut-Kurtan-Dzoragukh Coal Field

[SL = sample locality; CB = coal bed; C = carbon, as-determined basis, in percent; H = hydrogen, as-determined basis, in percent; N = nitrogen, as-determined basis, in percent; TS_i = total sulfur, as-determined basis, in percent, as-determined by instrumentation (sulfur analyzer or elemental analyzer); TS_m = total sulfur, as-determined basis, in percent, as-determined manually, done while determining pyritic and sulfate sulfur; PS = pyritic sulfur, as-determined basis, in percent; OS = organic sulfur, as-determined basis, in percent; SS = sulfate sulfur, as-determined basis, in percent; bh = borehole; fl = floor; nd = not determined]

SL	CB	C	H	N	TS_i	TS_m	PS	OS	SS
bh 9	#2	nd	nd	nd	2.7	nd	nd	nd	nd
bh 15	#2	52.51	1.73	0.00	0.27	nd	nd	nd	nd
bh 18	#1	38.83	2.73	0.48	4.5	nd	nd	nd	nd
bh 18	#2	37.47	2.76	0.40	4.9	nd	nd	nd	nd
bh 18	fl	21.84	1.02	0.00	2.6	2.6	2.3	0.1	0.2
bh 18	fl	nd	nd	nd	1.9	1.9	1.6	0.0	0.2
bh 19	#1	40.76	1.36	0.08	2.7	nd	nd	nd	nd
bh 20	#1	57.18	1.97	0.49	3.2	nd	nd	nd	nd
bh 20	#2	53.06	1.76	0.35	2.6	nd	nd	nd	nd
bh 21	#1	51.52	1.54	0.50	2.9	3.0	2.0	0.8	0.15
bh 24	#1	50.57	1.28	0.12	2.2/ 1.6*	nd	nd	nd	nd
bh 26	#1	54.11	2.47	0.55	3.8	nd	nd	nd	nd
bh 26	#2	53.74	2.66	0.86	3.4	nd	nd	nd	nd
bh 27	#2	55.26	1.72	0.47	3.3	nd	nd	nd	nd

bh 31	#2	43.68	1.15	0.00	2.3	2.3	1.9	0.1	0.3
K oc 1	ukn	22.04	0.84	0.20	1.1	nd	nd	nd	nd
K oc 2	ukn	31.42	1.77	0.42	1.8	nd	nd	nd	nd

*coal bed was divided into 6 subsamples for analysis. The top 5 subintervals (97.1-98.2 m) sulfur content was 1.6 percent. Bottommost horizon 0.2 m had the higher sulfur content.

Results of Washability Analyses from Samples of the Antaramut-Kurtan-Dzoragukh Coal Field

[DF = density fraction, specific gravity - f = float fraction, s = sink fraction; Rec = recovery at that density fraction, in percent - number at bottom of each series in parentheses is the total recovered as float; M_{ad} = moisture, as-determined, in percent; A_d = ash yield, dry basis, in percent; VM_d = volatile matter, dry basis, in percent; CV-B_{ad} - calorific value, as-determined basis, in Btu/lb; CV-C_{ad} = calorific value, as-determined basis, in cal/g; CV-B_d = calorific value, dry basis, in Btu/lb; CV-C_d = calorific value, dry basis, in cal/g; C_{ad} = carbon, as-determined basis, in percent; H_{ad} = hydrogen, as-determined basis, in percent; N_{ad} = nitrogen, as-determined basis, in percent; S_{ad} = sulfur, as-determined basis, in percent]

DF	Rec	M_{ad}	A_d	VM_d	CV-B_{ad}	CV-C_{ad}	CV-B_d	CV-C_d	C_{ad}	H_{ad}	N_{ad}	S_{ad}
Samples from Coal No. 1 from borehole 18												
1.3f	1.09	3.94	7.82	36.39	11421	6345	11889	6605	73.11	5.25	1.56	3.40
1.4f	3.59	1.61	13.02	34.94	11904	6613	12099	6722	69.48	4.99	1.65	3.69
1.5f	7.77	3.77	19.39	33.25	11104	6169	11539	6411	62.33	4.47	1.34	4.19
1.6f	11.96 (24.41)	3.48	59.91	33.08	12313	6841	12757	6921	56.76	4.00	0.51	4.71
Samples from Coal No. 1 from borehole 18a												
1.3f	1.89	3.95	5.82	36.58	12421	6901	12932	7184	73.11	5.25	1.56	3.40
1.4f	8.30	1.50	11.8	34.44	11950	6639	12132	6740	69.41	4.93	1.57	3.94
1.5f	16.82	3.82	18.76	33.30	11104	6169	11545	6414	66.76	4.76	1.31	4.27
1.6f	25.23 (52.23)	3.36	22.18	32.61	10495	5831	10860	6033	59.55	4.36	1.42	5.19
1.6s	47.77	2.94	51.83	20.51	6246	3470	6435	3575	46.84	3.24	0.48	5.63
Samples from Coal No. 1 from borehole 18												
1.3f	1.43	3.95	5.82	36.58	12421	6901	12932	7184	56.81	4.21	1.32	3.40
1.4f	5.62	1.21	12.98	35.72	11929	6627	12075	6708	61.99	4.48	1.36	4.21

1.5f	14.27	3.91	19.48	32.01	10929	6072	11374	6319	66.23	4.82	1.40	4.42
1.6f	25.17 (46.50)	3.64	25.06	30.00	9851	5473	10223	5679	73.11	5.25	1.56	4.32
Samples from Coal No. 2 of borehole 18												
1.3f	1.84	3.35	5.75	37.04	12458	6921	12890	7161	70.45	4.85	0.89	3.66
1.4f	5.84	2.60	13.22	35.13	11670	6483	11982	6657	67.23	4.69	0.73	4.27
1.5f	12.06	3.59	19.19	33.43	10967	6093	11375	6319	61.30	4.38	0.84	5.06
1.6f	18.00 (37.74)	3.52	23.52	31.53	10412	5784	10792	5996	nd	nd	nd	nd
1.6s	62.26	1.57	57.47	18.87	5423	3013	5509	3061	nd	nd	nd	nd
Samples from borehole 20												
1.3f	1.26	3.60	3.92	38.85	12976	7209	13461	7478	75.99	5.62	1.72	1.95
1.4f	3.90	2.58	9.55	37.15	12303	6835	12629	7016	69.85	5.10	1.72	2.57
1.5f	7.36	3.17	15.68	34.52	11486	6381	11862	6590	69.34	5.10	1.67	3.39
1.6f	14.26 (26.78)	2.68	17.13	25.41	11368	6316	11681	6489	69.86	3.86	1.45	3.09
1.6s	73.22	3.53	35.56	12.29	8971	4984	9299	5166	56.99	1.99	0.45	3.41
Samples from borehole 20												
1.4f	3.80	2.40	10.35	35.62	12262	6812	12564	6980	76.20	3.06	1.37	2.62
1.5f	10.16	3.31	15.56	32.79	11660	6478	12059	6699	70.80	5.39	1.68	2.89
1.6f	16.95 (30.91)	2.68	16.63	25.65	11421	6345	11736	6520	67.51	4.77	1.69	3.21
1.6s	69.09	1.86	34.14	9.01	8718	4843	8883	4935	53.81	1.76	0.36	3.02

Another set of washability analyses were conducted on some of the samples as well. Rather than combine samples before testing them, such as was done for those results found above, a number of samples from each coal bed were compared directly. That is, ash yield and volatile matter were determined before and after density separations. The results of these tests, also indicative of the Antaramut-Kurtan-Dzoragukh coals' amenability to cleaning, are found in the table below.

Results of Other Washability Analyses

[SN_1 = sample number; A_d before ds = ash yield, dry basis, in percent, before density separation; SN_2 = combined sample number of resultant coals; A_d after ds at 1.6 = ash yield, dry basis, in percent after density separation at 1.6 specific gravity; VM_d before ds = volatile matter yield, dry basis, in percent, before density separation; VM_d after ds (1.6) = volatile matter yield, dry basis, in percent, after density separation at 1.6 specific gravity]

SN_1	A_d before ds	SN_2	A_d after ds (1.6)	VM_d before ds	VM_d after ds (1.6)
Samples from Bh 18					
UC-1	75.65		20.61	17.46	33.87
UC-2	72.36	UC2+UC3	24.59	9.57	32.73
UC-3	87.90				
UC-4	50.14	UC4+UC5 +UC6	21.12	19.92	32.78
UC-5	74.56				
UC-6	41.06				
LC-1	60.95		21.26	17.46	31.37
LC-2	46.30		23.69	22.79	32.70
LC-3	61.22		24.46	17.77	30.93

As can be seen from this table, cleaning resulted in much lower ash yields and higher volatile matters. Thus, it can be concluded that the Antaramut-Kurtan-Dzoragukh coals are very susceptible to cleaning techniques, should one need a better quality coal.

All exploration data were entered into a stratigraphic database, similar to the ones which were created of all the archival information. From these data, resource tonnage of the Antaramut-Kurtan-Dzoragukh coal field was calculated for two areas. The first area was the entire resource area, an area of approximately 20 km^2 (box C shown on figure 2). Resource calculations, with a density of 2.0 g/cm^3 and no exclusions, such as for ash yield, for this area are:

Area measurement totals 16,412,148 m^2 or 1641 hectares

Tonnage totals **31,597,040 metric tonnes**

In addition to the total area calculations, a resource tonnage was calculated for a small area from Dzoragukh westward approximately 4 km (box B on figure 2). This is an area where we have very good borehole control and the coals outcrop at the surface. It is also the area of the prefeasibility study, explained in more detail in the next section of this report, conducted as part of this program.

Resource calculations for this smaller area, with a density of 2.0 g/cm^3, and no exclusions, such as for ash yield, are as follows:

Area measurement totals 165,305 m^2 or 165 hectares

Tonnage for Upper Bed totals 3,605,707 metric tonnes

Tonnage for Lower Bed totals 1,026,870 metric tonnes

Tonnage for all coal in this area totals 5,518,439 metric tonnes

IX. ECONOMIC ASSESSMENT OF THE ANTARAMUT-KURTAN-DZORAGUKH COAL FIELD

As part of the Coal Exploration and Resource Assessment Program, an economic assessment (pre-feasibility study) of the Antaramut-Kurtan-Dzoragukh Coal Field was conducted. However, it must be stated here that the USGS program is a resource assessment and not a mine development program. Thus, the exploration boreholes were placed for purposes of resource assessment, not for mine development. The boreholes are too widely spaced for purposes of mine development. However, trenches were specifically selected and dug for this economic analysis in order to verify projected outcrop localities from coal occurrences in boreholes.

Results from the prefeasibility study indicate that a small surface mine with about a 20 year life could be developed in the Antaramut-Kurtan-Dzoragukh coal field, specifically at the Dzoragukh site. The mining business organization that is interested in developing this site will need to conduct the necessary development drilling and other other development works (trenching, coal quality analyses, surveying, etc.) to establish a final feasibility study for the mine.

The small mine suggested is a typical surface outcrop stripping, contour mining operation. In addition, subsequent auger mining is strongly recommended because the recovery of these low cost mining reserves will help to ensure that the operation is a viable, economic enterprise.

There is an immediate market for this coal according to Lori Mars officials - for use in an acetylene manufacturing facility. It is also believed that this coal could be sold once it is known that coal exists for sale. However, it is recommended that before proceeding with the coal mining development project, that the interested business assess the coal market in a more formal manner.

For the economic analysis of the Antaramut-Kurtan-Dzoragukh coal field, coal reserves were calculated for an area near Dzoragukh approximately 4 km from Dzoragukh westward. Overburden along this strip was also calculated in order to give an economic limit to the strip mining with a reasonable overburden to coal ratio (usually 10:1 in this study). The coal reserve calculations were broken down into minable reserves and recoverable reserves. Auger reserves were also calculated, but separately. However, it is again emphasized that auger mining is a low cost addition to the strip mining for obtaining additional coal.

The reserve and overburden calculations, description of the type of mine, mine production objective, and all details of this proposed mine - including coal sales and storage facility, the mining sequence, mining procedure, capital required, pre-production expenses, equipment and asset list, personnel required and annual payroll, a cost per annual ton of production, and a proposed sales price (with a 25 percent profit before taxes) can be found in the following report, which is contained in the Appendices:

Huber, Douglas W. and Pierce, Brenda S., in review, Potential Minability and Economic Viability of the Antaramut-Kurtan-Dzoragukh coal field, north-central Armenia: A Prefeasibility Study, U.S. Geological Survey Bulletin, 46 p.

It is noted and emphasized that environmental and safety concerns played an important role in this prefeasibility study. There are guidelines and considerations for: top soil removal, storage, maintenance, and return; water quality and quantity control with drainage plans and water retention ponds for maintenance at pre-mining levels; minimization of erosion and environmental degradation with water control facilities and care of the top soil and spoil piles; and mandatory surface reclamation. Consideration is also given to the improvement of agricultural land after mining. With land owner agreement, current pasture land or currently nonusable land can be easily turned into crop land during reclamation activities. Reduced angle of slopes and better drainage distribution over the mined-reclaimed lands will not only improve crop acreage, but crop and pasture yield as well. In addition, employee training should be mandatory should a mine be developed, not only to take care of environmental concerns, but to ensure the safety of both workers and local citizens.

In addition, a comparison, on an energy content basis, is made of this coal's estimated cost price to that of natural gas in Armenia. For the comparison purposes, prices for natural gas were taken from the Burns and Roe, Inc. feasibility study of a proposed 50 MW circulating fluidized bed (CFB) combustor and the cost of natural gas for home heating in Yerevan. The comparison can be found at the end of this section.

This prefeasibility study has been translated, in its entirety, into Russian and copies given to Lori Mars officials, Ministry of Environment officials, Ministry of Energy officials, and the Ministry of Environment's Gugark Expedition.

To synopsize the figures found in the report cited above (for details please see the full report), the following is offered:

Initial Investment:

Following an investment of US $85,000 over a 12 month period in mine development drilling, and other activities, a decision must be taken regarding further investment in an on-going mining operation. If the new data support the opening of the surface mine, the $85,000 development cost is amortized over the first ten years of mine production. If the new data do not support the opening of the mine, the $85,000 is considered as a business development expense which may be written off against profits from other operations for income or other tax purposes, or simply as a business loss.

Total Capital Required:

The equipment costs will reach a total of $900,500 which will be amortized over a 7 year period to establish estimated coal mining costs. Estimated working capital costs are $300,000 which are to be borrowed.

Surface Mining Reserves:

Approximately 840,200 metric tonnes of surface minable coal reserves at 9.3 cubic meters of overburden per metric tonne of minable coal is indicated. Recovery of the minable coal at 85 percent will yield 714,000 recoverable metric tonnes of marketable as-mined coal.

Auger Mining Reserves:

Auger mining reserves of 576,000 metric tonnes are indicated. Recoverable auger mining reserves of 202,000 metric tonnes (at 35 percent recovery) can be expected. Auger mining production will vary according to what hole size is being used, but in either case, it is a very profitable addition to the mining operation.

Cost and Sales Price:

A cost price range of $16.03 to $20.43 per tonne at the coal sales yard is estimated. Sale or market price for such coal is suggested to range from

$20.04 to $25.54 per tonne at the coal sales yard. The cost and prices stated depend upon whether the production level is 42,000 or 30,000 metric tonnes per year and if coal is produced by use of low cost auger mining. The sales prices are also dependent upon the as-mined quality and market demand.

Comparison of Projected Energy Prices:

To match the $8.81/Gcal price for natural gas fueling a proposed 50 MW (electricity generating) CFB plant, the subject coal, at 4,673 kcal/kg (8,412 Btu/lb) (as-received basis), could be sold for as high as $40.67/tonne on an energy-content basis.
A comparison to home heating natural gas in Yerevan, at 0.9 cents/m^3, indicates that the subject coal could be sold for as high as $51.32/tonne on an energy-content basis. It is pointed out that the above energy comparisons are on an energy basis, and do not include coal transportation or coal and ash handling costs.

X. OTHER ACTIVITIES

The USGS co-sponsored the First International Energy Conference in Armenia hosted by the Armenian Chapter of the Association of Energy Engineers, July 1998. USGS attended this meeting, presented an invited talk, and submitted a paper for the proceedings volume on the Coal Resources of Armenia. USGS also arranged for all of the Ministry of Environment honoraria members to attend this meeting.

The USGS helped the Ministry of Environment with their exhibit for the International Expo '98 meeting, held in Lisbon, Portugal (September 1998). In particular, the USGS edited, corrected, digitized, and plotted the Geologic and Structural Map of Armenia that was an integral part of the Republic of Armenia's exhibition.

The USGS gave an invited presentation at the Environmental Protection Workshop organized and hosted by the Environmental Protection Advocacy Center, in the spring of 1998. USGS spoke about the environmental laws in the U.S. connected with coal exploration, mining, transportation, and use, as well as giving an overview of coal in Armenia and it's general uses.

The USGS arranged for the Ministry honoraria employees to tour a new, private power plant in Yerevan. Although it was a hydropower plant, the general theory of power generation is the same for coal.

USGS participated in and spoke at a conference to encourage private investment in the Armenian power sector and/or natural resources in the fall of 1998. This meeting was hosted by USAID and the RA Ministry of Energy.

USGS partipated in and spoke at a conference to encourage private investment in Armenia held in Los Angeles California during the summer of 1996.

XI. USES FOR ARMENIA'S COAL RESOURCES

Coal has historically been used in Armenia in a copper smelter, in district heating facilities, for home heating, for small industry, for heating greenhouses, and in the making of briquettes. All of these historical uses are still potential uses.

The USGS talked to individuals in Gyumri (the second largest city in Armenia) and visited a heating facility in the home for the elderly and disabled. We were told that this heating facility is representative of most of the ones in Gyumri. This particular facility, as many in Gyumri and other cities, has not had fuel to heat the facility since 1991. There are many schools, hospitals, orphanages, neighborhood facilities that could make use of coal in the heating facilities. This is especially the case in Gyumri, where earthquake damage is still quite severe. One estimate from Mr. Ararat Gomtsian, former Shirak Marspet (mayor), indicated that it would only take 9200 metric tonnes of coal to meet all of the humanitarian heating needs for one winter: schools, hospitals, families with orphans placed with them, families with invalids, and homes for orphans, elderly, or disabled in Gyumri. The relief centers, such as hospitals, built right after the earthquake cannot use coal to heat them. However, all of the older facilities can use coal without any retrofitting to the facilities.

Many of the small and medium sized heating facilities throughout Armenia can use coal and have done so in the past. Coal can be used in many of the heating facilities throughout Armenia without any retrofitting or repair to the facilities. Many of these facilities were originally designed to be able to use gas, coal, or mazut. Discussions with the Chief of District Heating of the Ministry of Public Facilities (or

Public Works) in Yerevan indicated that should enough coal be found for a minimum supply and should the price be competitive with gas or mazut, they would be happy to use coal in these facilities. Although the price comparisons between coal and natural gas found earlier in this discussion did not take into account transporation and ash handling costs, they were on an energy equivalent basis, so there is reason to believe that coal could indeed be used competitively in the district heating facilities throughout Armenia.

In addition to these uses, there is an immediate market for the Antaramut-Kurtan-Dzoragukh coal in Vanadzor, according to Mars (regional) officials. Mars officials would like to use the Antaramut-Kurtan-Dzoragukh coal in the chemical plant in Vanadzor. The chemical plant contains an acetylene manufacturing facility, which converts carbide using heat and water into acetylene. They are looking for coal to use as a raw material in the manufacture of carbide. This chemical plant uses coal at a rate of 1,000 metric tonnes per 10,000 tonnes of acetylene. A supply of 1,000 metric tonnes of coal per month would yield 120,000 tonnes of acetylene per year in this plant. Currently no acetylene is being manufactured because there is no affordable coal source.

The other potential use for Armenia's coal resources, of course, is in power plants. Using the Burns and Roe. Inc. report on the "New Circulating Fluidized Bed Coal Fired Unit Final Report" and the specifications and parameters listed in that report for such things as necessary calorific value, turbine and generator and other specifications, we offer the following information.

For a 35-year 50 MW CFB plant, operating at maximum capacity, for the 337 days per year that the report says the plant will operate, a maximum coal tonnage will reach 297,000 metric tonnes per year. On a practical basis, however, this may only be 250,000 metric tonnes per year. The reserves required for 35 years are approximately 8.75 to 9 million metric tonnes of recoverable coal (coal to be delivered) which means approximately 11 million metric tonnes of minable tonnes, at 80 percent recovery for strip mining.

A 25 MW power plant would take approximately half of the tonnage listed above. Therefore, if 125,000 metric tonnes per year is needed, this equates to approximately 5.5 million metric tonnes of surface minable coal (at 80 percent recoverable reserves) needed for a 35-year life 25 MW power plant.

Not enough is known about the Antaramut-Kurtan-Dzoragukh coal field to know exactly how many of the resource tonnes present in the coal deposit are available for mining. This work still needs to be done. However, the Antaramut-Kurtan-Dzoragukh coal field may very well be able to fuel a 25 MW power plant.

The resources in the Antaramut-Kurtan-Dzoragukh coal field, together with the resources in the Shamut coal field, may very well be able to fire a 50 MW power plant. The plant could be located between the two coal fields, as they are only approximately 40 km apart. Exploratory resource drilling needs to be conducted in the Shamut coal field to prove out the resource, but as mentioned above, based on detailed geologic mapping, there are probably more resources in the Shamut coal field than thought previously.

XII. RECOMMENDATIONS FOR FUTURE WORK

An economic analysis of the entire Antaramut-Kurtan-Dzoragukh coal field needs to be done. This is needed in order to determine exactly how many of the resource tonnes present are available for mining. If this work is to be done, a few more boreholes placed along the southern edge of the field would benefit the resource, and resultant reserve, estimates as well.

Exploratory drilling of the Shamut coal field is needed. Shamut may prove to be a large deposit, but exploratory drilling is needed to obtain coal core for analyses, true thickness measurements, and a better understanding of the coal field. The coal-bearing horizon definitely extends beyond the areas of previous investigations and previous coal resource calculations. Therefore, more resources than previously calculated may exist at Shamut.

Exploratory drilling of the Ijevan coal field is needed. Much work has been done on the central part of the Ijevan coal field. However, no exploratory drilling has been conducted outside this small area. Exploratory drilling is needed in this very structurally complex coal field to prove out the lateral extent of the coal, determine the overall coal quality, and determine the exact nature of the resources.

Exploratory drilling of the Dilijan oil shale deposit may be needed. This deposit may prove to be a huge reserve of oil shale. Samples from the Dilijan oil shale field analyzed during the preliminary USGS study indicate that they are indeed low grade oil shales. However, this is also a burnable resource, albeit much higher in ash yield and lower in calorific value than the coal fields listed above. However, in order to understand the full extent of Armenia's hard fuel resources, exploration of the Dilijan field should also be undertaken.

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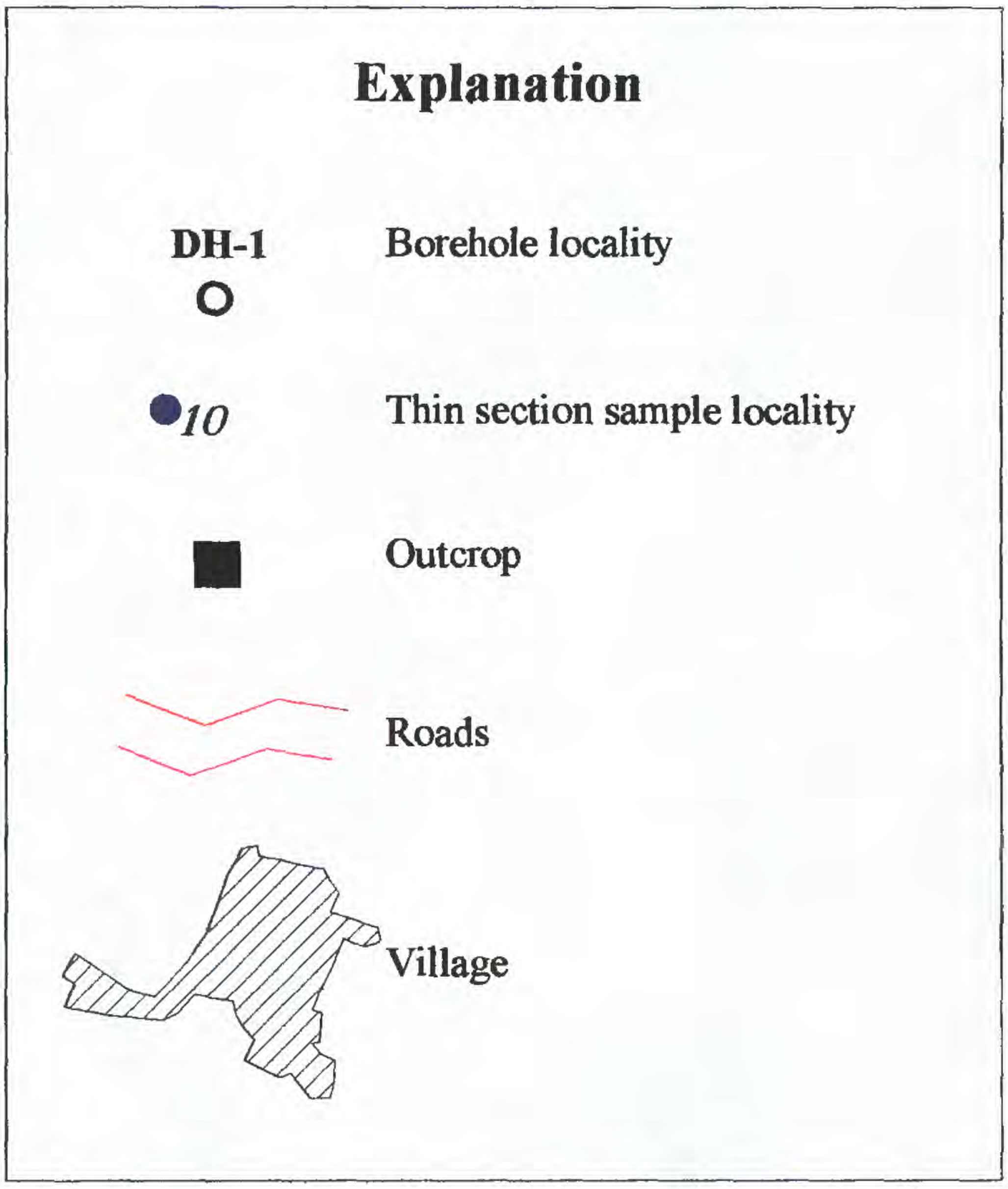
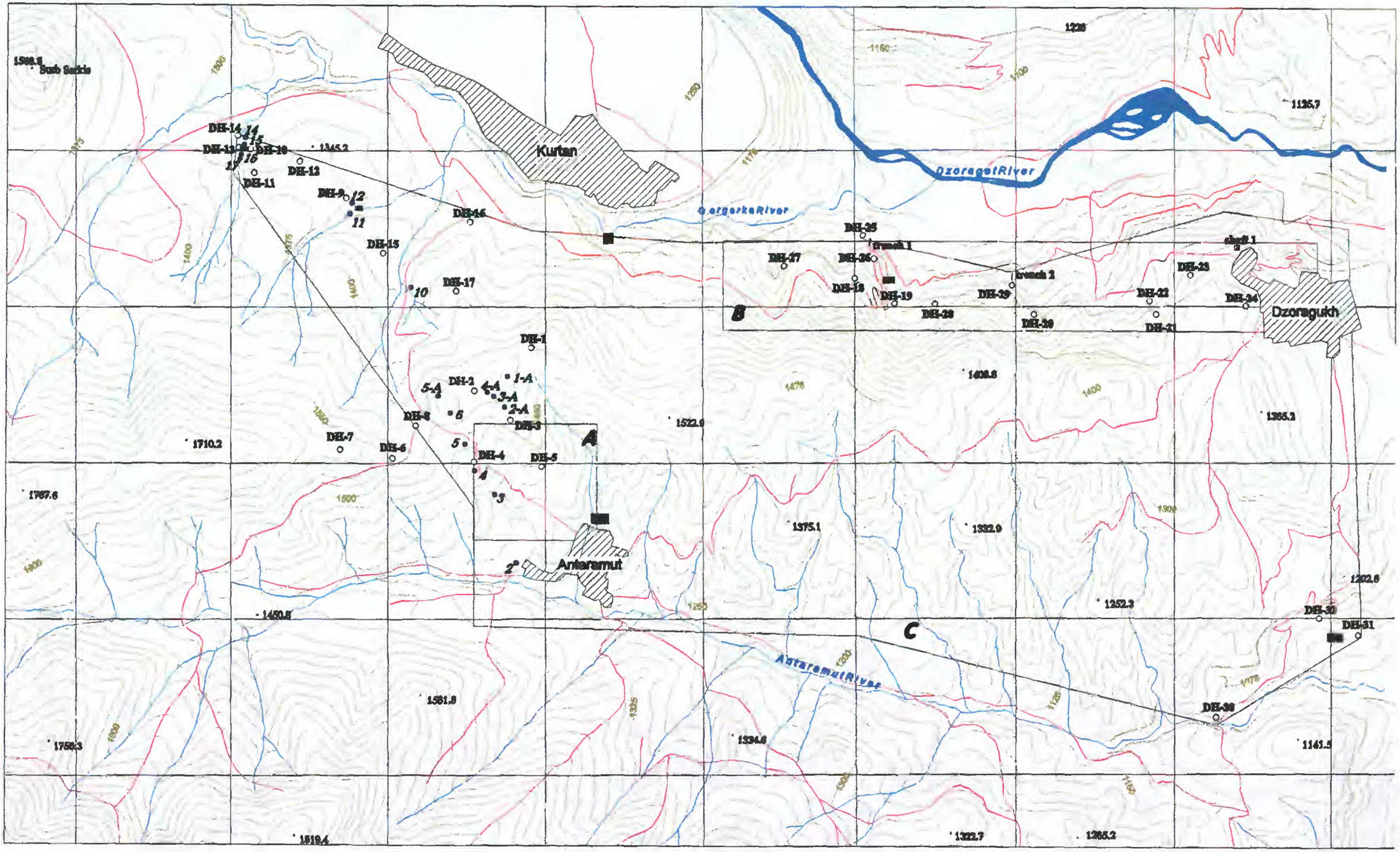
Figure 2. Topographic and locality map of the Antaramut-Kurtan-Dzoragukh coal field, in north-central Armenia. Each grid square is 1 sq km and the contour interval is 5 m. Boxes of resource areas are explained in the text.

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Dzoraguikh
Antaramut
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DH-28
DH-29
DH-30
DH-31
trench 1
trench 2
shaft 1
1-A
2-A
3-A
4-A
5-A
1710.2
1767.6
1522.9
1375.1
1332.9
1252.3
1409.8
1365.2
1126.7
1202.6
1141.5
1581.9
1334.6
1322.7
1819.4
1345.2
1228

Figure 1. Location of coal, carbonaceous shale, and oil shale deposits in Armenia.