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Geology, coal quality, and resources of the Antaramut–Kurtan–Dzoragukh coal field, north-central Armenia

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Abstract

The Antaramut–Kurtan–Dzoragukh (AKD) coal deposit is a previously unrecognized coal field in north-central Armenia. Coal has been known to exist in the general vicinity since the turn of the century, but coal was thought to be restricted to a small (1 km^2) area only near the village of Antaramut. However, through detailed field work and exploratory drilling, this coal deposit has been expanded to at least 20 km^2, and thus renamed the Antaramut–Kurtan–Dzoragukh coal field, for the three villages that the coal field encompasses. The entire coal-bearing horizon, a series of tuffaceous sandstones, siltstones, and claystones, is approximately 50 m thick. The AKD coal field contains two coal beds, each greater than 1 m thick, and numerous small rider beds, with a total resource of approximately 31,000,000 metric tonnes. The coals are late Eocene in age, high volatile bituminous in rank, relatively high in ash yield (approximately 40%, as-determined basis) and moderate in sulfur content (approximately 3%, as-determined basis). The two coal beds (No. 1 and No. 2), on a moist, mineral-matter-free basis, have high calorific values of 32.6 MJ/kg (7796 cal/g) and 36.0 MJ/kg (8599 cal/g), respectively. Coal is one of the few indigenous fossil fuel resources occurring in Armenia and thus, the AKD coal field could potentially provide fuel for heating and possibly energy generation in the Armenian energy budget. Published by Elsevier Science B.V.

Keywords: Armenia; coal resources; coal quality; Eocene coals

1. Introduction

Coal occurs near the village of Antaramut, in the north-central part of Armenia (Fig. 1) about 15 km north of Vanadzor (Fig. 2). Coal has been known to occur in this area since at least the turn of the century and was mined by French concessionaires around 1915 for use in a copper smelter in Alaverdi, Armenia (Fig. 2). Although the Antaramut coal was known and locally utilized, almost all previous workers thought that the coal was restricted to an area of less than 1 km^2, near Antaramut.

As part of a technical assistance program to the Republic of Armenia, the US Geological Survey (USGS) (with funding from the US Agency for

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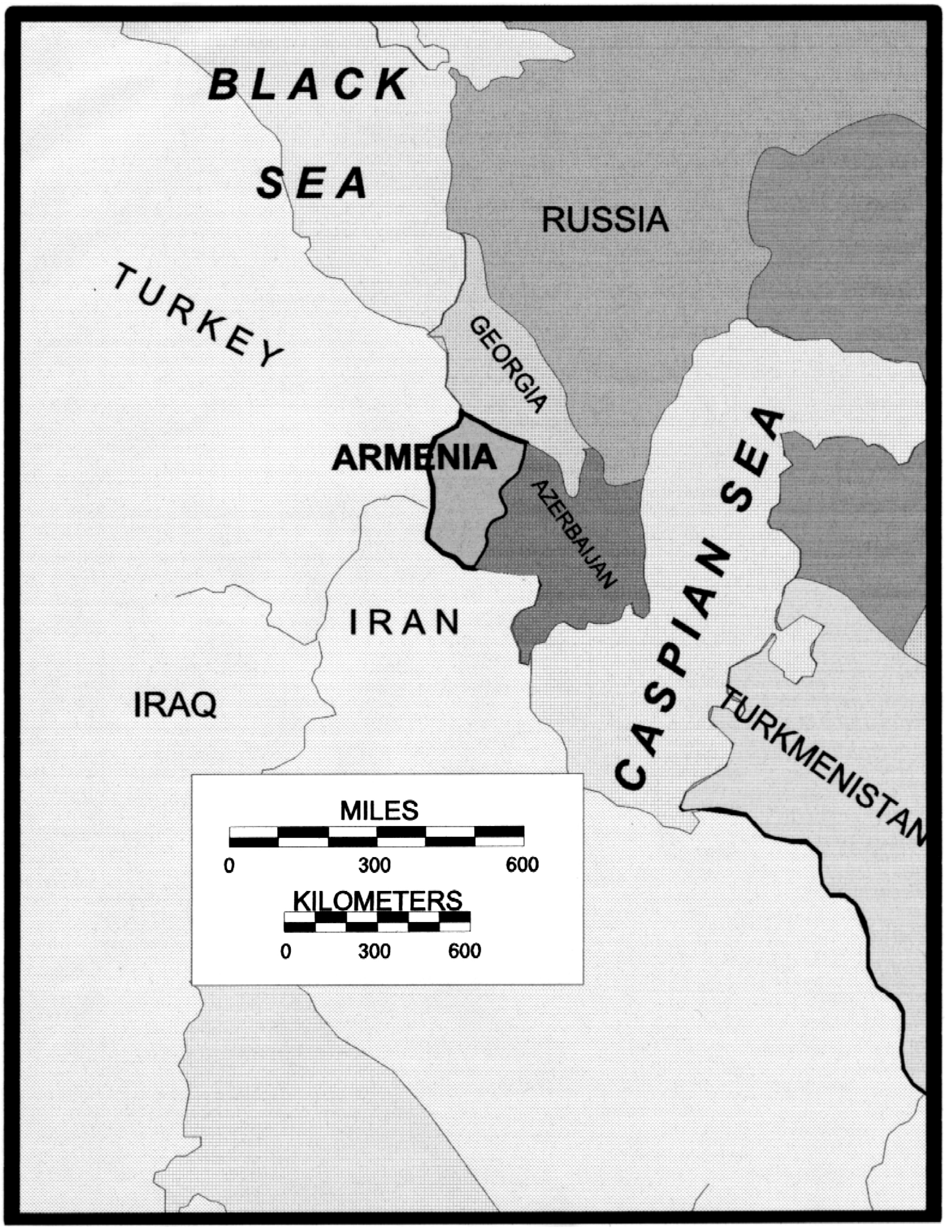

Fig. 1. Location of Armenia and surrounding countries.

International Development), undertook a detailed exploration program of the Antaramut–Kurtan–Dzoragukh (AKD) coal field. Exploration covered approximately 40 km^2 and allowed us to create a geological and structural map of the area at 1:10,000 scale (Pierce et al., in preparation). In addition, results of this work reveal new information on the stratigraphy, tectonics, and magmatism in this region. In particular, the work allowed us to determine the structure and orientation of the coal deposit and

Fig. 2. Location of Antaramut–Kurtan–Dzoragukh coal field, north-central Armenia.

to identify the coal quality and coal resources in this coal field, which is the focus of this study.

2. Study area

The AKD coal deposit is located in the central part of the Lori region in the Republic of Armenia (Fig. 1). The deposit is located approximately 15 km north of Vanadzor, which is the capital of the region, and the third largest city in Armenia (Fig. 2). The coal deposit encompasses the villages of Antaramut toward the southwest, Kurtan to the north, Dzoragukh to the northeast (Fig. 3), and Vaagni to the southeast (about 2 km southeast of the mapped area displayed in Fig. 3).

The border of the deposit is roughly defined on the north by the Gergerka and Dzoraget Rivers, on the south by the Antaramut River, and on the east by the Pambak River (off the map to the east approximately 5 km on Fig. 3). The coal deposit is located along the southeast section of an unnamed spur that lies on the northeast slope of the Bazum Mountain Range. This spur is a water divide, separating the

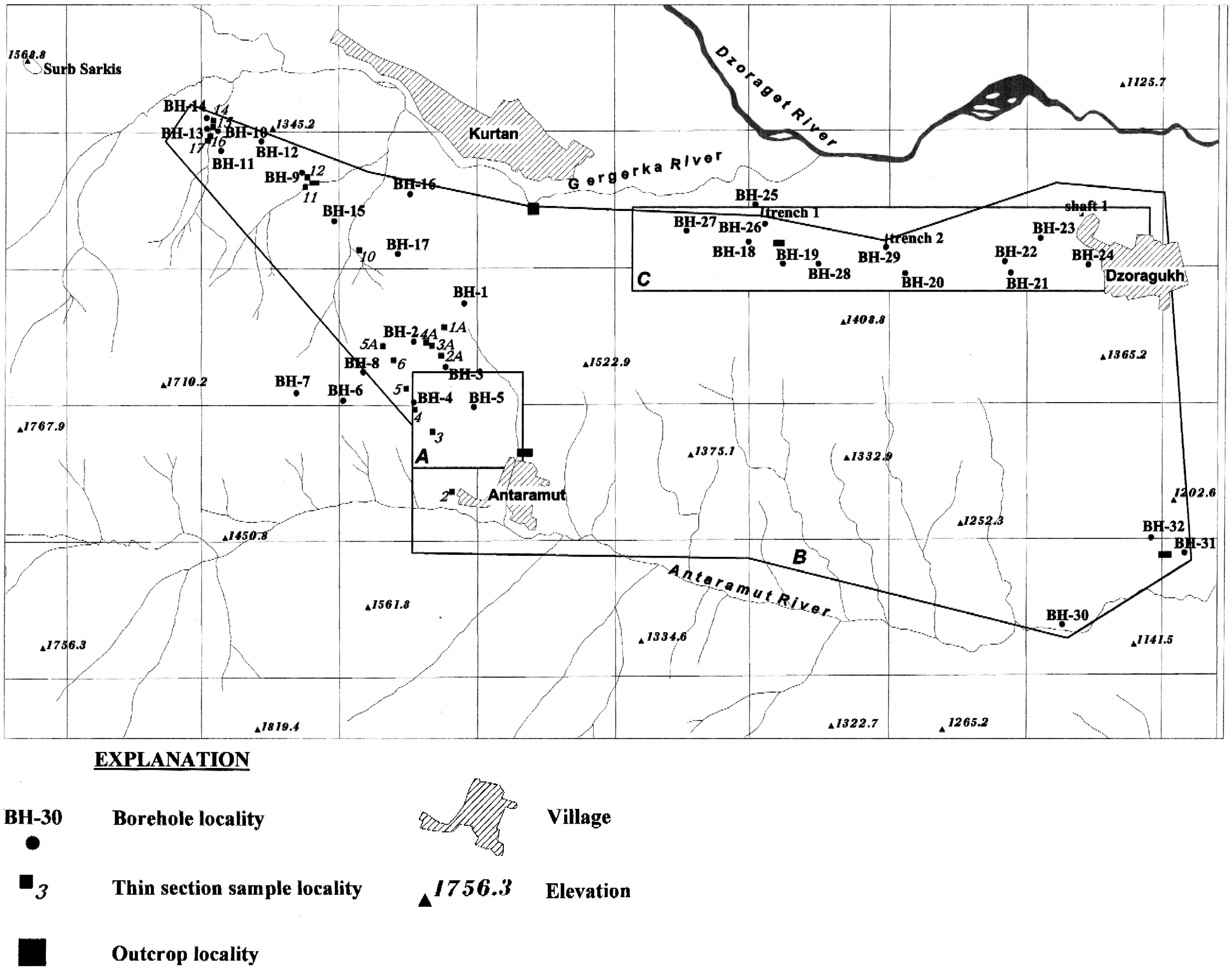

Fig. 3. Locality map of the Antaramut–Kurtan–Dzoragukh coal field, in north-central Armenia. Each grid square is 1 km^2. Boxes of resource areas (A, B, and C) are explained in the text.

Dzoraget and Antaramut Rivers. This unnamed small mountain range is cut by many river valleys. The average elevation of this spur is 1500 m and the coal-bearing horizon outcrops at approximately 1100 to 1300 m elevation.

3. Previous investigations

Although the specific coal occurrence at the village of Antaramut has been known for a long time, little is known about this coal and little work has been done on this deposit. Localized studies, concentrated near the Antaramut outcrop (solid black box just north of Antaramut on Fig. 3), were conducted in the 1950s (Kacharava, 1953; Talanian and Bogdanova, 1956; Georgadze, 1956) and again in the early 1990s (Keshabian et al., 1997). Of these workers, only Kacharava (1953) thought the Antaramut coal deposit provided any interest for further study. In fact, all of the other workers, including the most recent (Keshabian et al., 1997), dismissed the Antaramut coal deposit as not being economically viable, nor warranting further scientific interest, and recommended no further geological exploration. Keshabian et al. (1997), Talanian and Bogdanova (1956), and Georgadze (1956) all thought that the Antaramut coal deposit was confined to an area less than 1 km^2 (box A on Fig. 3).

The area has also been included in several very large regional studies. The large regional studies include Paffenholts (1932), Ter-Mesropian (1953), Mkrtchian (1959), Dadayan and Mansrian (1974), and Tumanian (1998). These studies defined the regional structure and the age of the coal-bearing sediments of this coal field. Ter-Mesropian (1953) is still the definitive work for the structure of the region.

4. Methods

Detailed and extensive exploration was conducted on the AKD coal field of north-central Armenia. This included exploratory borehole drilling, borehole geophysical logging, detailed field mapping, and other surface exploratory works such as trenching and digging shafts. Detailed mapping was conducted at a 1:10,000 scale. The entire field area including all stream drainages were walked and mapped. Outcrop samples were taken for petrographic analyses for specific rock identification and correlation purposes. Thirty-two sites were drilled (diamond cored) as part of the exploration effort of the AKD coal field. Geophysical logging was an integral part of drilling and gamma gamma density, natural gamma, spontaneous potential, resistivity, and caliper were routinely run on the boreholes. Coal core, whenever encountered, was submitted for geochemical analyses. Complete borehole descriptions can be found in Pierce et al. (1999). All of the borehole geophysical logs can be found in Pierce and Grigorian (1999). Borehole, trench, shaft, and outcrop locations are found in Fig. 3.

For every available coal sample, moisture, ash yield, volatile matter, fixed carbon, calorific value, sulfur, carbon, hydrogen, and nitrogen were analyzed. For some samples, pyritic, sulfate, and organic sulfur were also determined. All analyses were in accordance with American Society for Testing and Materials Standards (ASTM, 1999). Washability analyses by density separation were also conducted on some of the coal samples because of the high ash yield. Cleaning tests were confined to those samples with enough bulk or on combined samples within a core.

5. Discussion

5.1. Geologic age

There is some disagreement over the age of the units found in the greater AKD coal field. The ages were originally defined by Paffenholts (1932) and Ter-Mesropian (1953), who distinguished two age groupings of rocks in this region: (1) Quaternary doleritic basalts and andesitic basalts, and (2) the older volcanogenic suite, containing dacite, andesitic dacites, andesites, tuffs, and tuff breccias, which they thought were middle Eocene in age. Mkrtchian (1959) was the first to define and map the locally developed upper Eocene sediments including tuffaceous sandstones and conglomerates, clay, and coal. He was also the first to define these rocks as late Eocene, which had previously been called middle Eocene.

Dadayan and Mansrian (1974) agreed with Mkrtchian (1959) and dated the volcanogenic sedimentary strata in this region as late Eocene, based upon regional correlations. Keshabian et al. (1997) state that the coal-bearing strata of Antaramut are confined to the middle Oligocene non-marine suite, but they do not specify what this age designation is based upon. Tumanian (1998) dated the coal-bearing tuffaceous sediments near Kurtan (Fig. 3) as late Eocene to early Oligocene in age, but he dated the Antaramut coal-bearing strata as early Oligocene in age.

Through exploration work carried out in this study, it was determined that the two coal deposits—Kurtan and Antaramut—are actually part of one continuous, laterally extensive coal field. Thus, they are the same general age. Work conducted in the early stages of this exploration project indicates that hornblende from the tuff breccia unit overlying the AKD coal beds was dated at 40.45 + 0.38 Ma using $^{40}Ar/^{39}Ar$ dating (Maldonado et al., 1998), indicating a late Eocene age for the strata directly overlying the coal.

5.2. Stratigraphy

There are two laterally continuous coal beds in the AKD coal field and numerous small rider beds. For the purposes of this study, the coal beds are numbered Bed No. 1 and Bed No. 2, upper and lower, respectively. Each coal bed is greater than a meter thick throughout most of their present extent.

The AKD coal beds are found in a volcaniclastic sequence of tuffaceous sandstones, siltstones, clays, and carbonaceous shales. The coal-bearing sequence ranges from 40 to 60 m thick and is overlain by thick sequences of tuff breccia and dacitic lava breccia, which are in turn sometimes overlain by or interbedded with andesite. A representative cross section is found in Fig. 4.

According to Talanian and Bogdanova (1956), the total thickness of the volcaniclastics in the area is 600 to 700 m. These volcaniclastics are covered by Quaternary basalts, whose thickness is approximately 250 to 300 m. Younger alluvial rocks occur near the Dzoraget River.

The eastern extent of the deposit is found very close to a rhyolite volcanic neck (Surb Sarkis, Fig. 3). Surb Sarkis is older than the basalts but younger than the rocks comprising the AKD stratigraphic package. This is evidenced by the fact that the rhyolitic rocks of Surb Sarkis often intrude into or cut across the lava and tuff breccia horizons overlying the sedimentary coal-bearing suite.

Talanian and Bogdanova (1956) and Georgadze (1956) reported from one to five coal beds in the Antaramut coal deposit. Keshabian et al. (1997) believed that the coal beds are actually repeated and that the repetition of strata is due to landslides. However, after detailed mapping of the area, we found no landslide blocks in the region and agree with the earlier studies that there are two to five coal horizons present in different parts of the study area—two main coal beds and numerous smaller rider beds and additional coal lenses. There is a great deal of faulting in the Antaramut region with some hydrothermal alteration along the faults. Often, this late-stage movement resulted in coal being observable only in petrographic samples in boreholes along the faults (Pierce et al., 1999). The coals along these faults were probably preferentially pulverized because of their relative softness compared to the other lithologies in the section.

5.3. Structure

The Antaramut–Kurtan–Dzoragukh coal deposit is situated in a northwest–southeast trending syncline that is approximately 4 km in width. This syncline is truncated to the north by a large regional fault running east–west more or less parallel with the Dzoraget and Gergerka Rivers (Fig. 3) and to the east by a large regional fault running north–south parallel to the Pambak River, approximately 5 km to the east of the map in Fig. 3. To the north of the Dzoraget and Gergerka Rivers, and to the east of the Pambak River, only Jurassic and Cretaceous strata are present and all younger rocks have been eroded away. There is also a fault running east–west at the southern edge of the coal deposit, more or less subparallel with the Antaramut River (Fig. 3). The stratigraphic section on the southern side of this fault has been down thrown relative to the northern side, and therefore the coal-bearing sediments are covered with a much thicker section of tuffs, andesites, and basalts than that found in the study area. The coal-bearing sediments, at the western edge of the study area shown in Fig. 3, are disrupted, cut, faulted, or

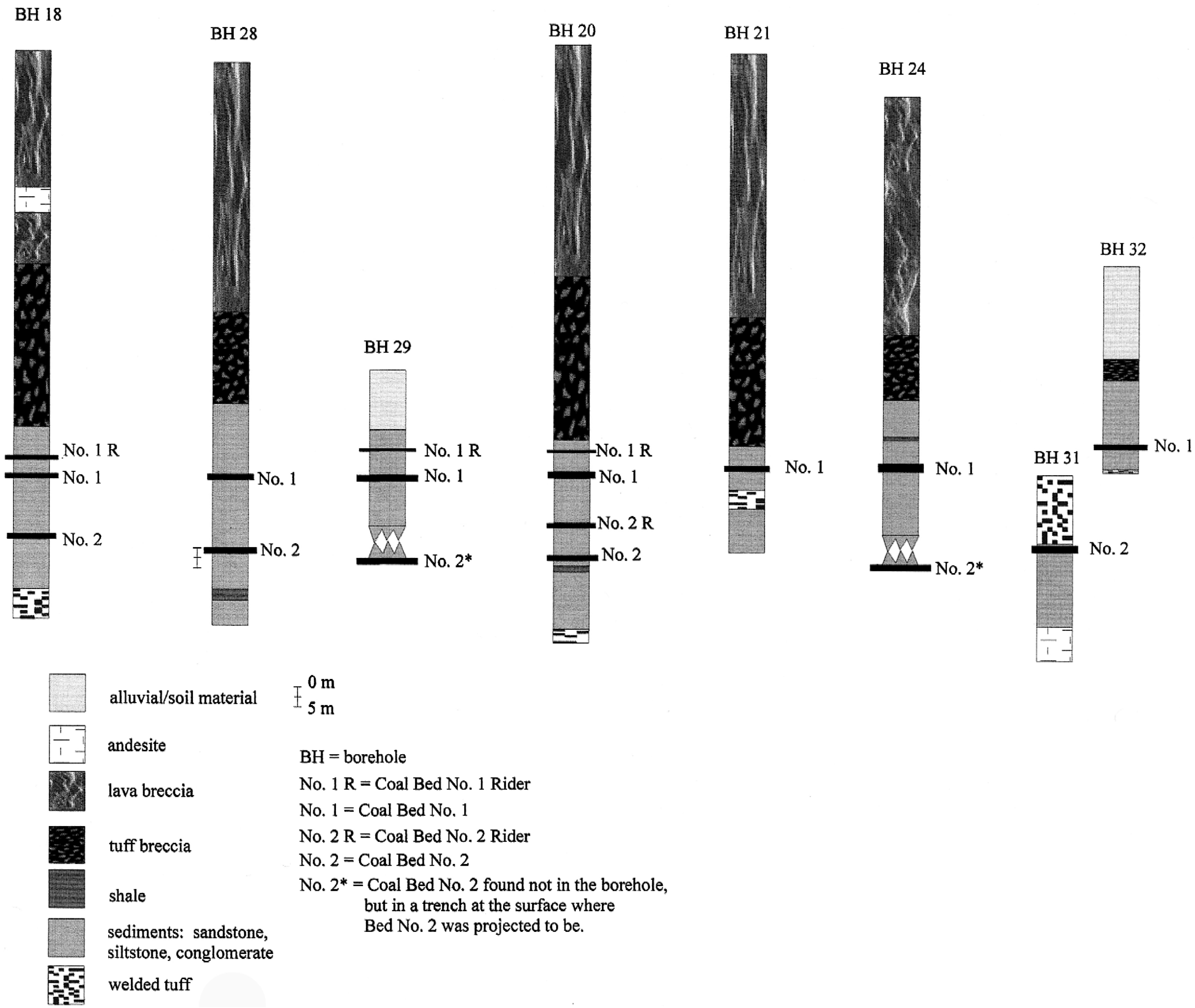

Fig. 4. Representative cross section of coal-bearing strata of the Antaramut–Kurtan–Dzoragukh coal field. Borehold locations may be found in Fig. 3.

completely replaced by stratigraphically younger volcanics including the rhyolitic volcanic neck Surb Sarkis (in northwest corner of Fig. 3).

5.4. Coal quality

The Antaramut coal has a vitrinite reflectance of 0.68% R_r and 0.72% R_{max} (Charles Barker, USGS, unpublished data). Thus, the rank of the Antaramut coal bed near the village of Antaramut is high volatile bituminous. Calorific values from samples of the AKD coals, although variable (Table 1), are all are in general agreement with this rank determination (American Society for Testing and Materials (ASTM), 1999).

Coal quality analyses performed on coal core samples from the two main coal beds in the AKD coal field are found in Table 1. Results indicate relatively high ash values, averaging about 40% (as-received basis) for and moderately high sulfur values, averaging around 3% (as-received basis) for both coal beds. Calorific values, on an as-received basis, are 16.94 MJ/kg (4232 cal/g) and 19.41 MJ/kg (4636 cal/g) for Bed No. 1 and Bed No. 2, respectively. On a moist, mineral-matter-free basis, these coals have very high calorific values (Table 1), averaging 32.6 to 36.0 MJ/kg for Bed No. 1 and Bed No. 2.

Although the ash yields of the AKD coals are relatively high, results of washability tests (Tables 2 and 3) on these coals indicate that they are amenable to cleaning (Fig. 5). For example, compare samples from borehole 18 (Table 2). The volatile matters, on a dry basis, for the upper and lower halves of coal bed No. 1 and for coal bed No. 2 are 15.03%, 19.08%, and 19.44%, respectively. Ash yields, on a dry basis, for the same samples are 66.94%, 55.14%, and 56.16%. Compare these values to the washed samples in Table 2. The volatile matters, on a dry basis, for washed samples from both coal beds in borehole 18 have been raised well over 30%. Correspondingly, the ash yields have been decreased as well. A plot of ash yields at the different float fractions from Table 2 is found in Fig. 5. The last value on the plot (right hand side of graph) is the ash yield of the whole sample, for comparison purposes. Ash yields were reduced significantly in the washed fractions as compared to the whole coal sample. The same trend may be seen by comparing results before and after density separations found in Table 3. These results are also indicative of the AKD coals' amenability to cleaning.

5.5. Coal resources

Resources have never been calculated for the AKD coal field before this study. The area calculated for the coal field's full resource is outlined in Fig. 3 (box B). Using a density of 2.0 g/cm^3, no exclusions for depth or ash yield, for an area measurement of 1641 ha, the resource equals to 31,597 Mt of indicated category[1] coal. Average coal bed thickness was approximately 1.67 m for each bed.

In addition to the total area calculation, we calculated a resource tonnage for a small area from Dzoragukh westward approximately 4 km (box C in Fig. 3). This is an area where we have very good borehole control and is the site of a pre-feasibility study concerning the minability and economic viability of the AKD coal field (Huber and Pierce, 2000). Using a density of 2.0 g/cm^3, and no exclusions, for an area measurement of 165 ha, the resource for Bed No. 1 totals 3606 Mt, tonnage for Bed No. 2 equals 1027 Mt, and the total resource for this area equals 5518 Mt. of demonstrated resources (measured + indicated). Results from the pre-feasibility study (Huber and Pierce, 2000) indicate that a profitable small surface mine with a 20-year lifespan could be developed within the AKD coal field.

5.6. Depositional history

Georgadze (1956) and Keshabian et al. (1997) believe that the abrupt changes in coal bed thicknesses near the village of Antaramut were caused by unstable conditions during deposition of the coal-bearing sediments and plant material. These authors

[1] Resource tonnage reporting categories follow standard USGS methodology and are modeled after Wood et al. (1983) and are as follows: measured coal resources are those within a radius of 0 to 0.4 km of a known data point; indicated resources are those within a radius of 0.4 to 1.2 km of a known data point; inferred resources are those located from 1.2 to 4.8 km from a known data point; and hypothetical resources are those located more than 4.8 km from a known locality.

Table 1
Calorific values, and proximate and ultimate analyses of samples from the Antaramut–Kurtan–Dzoragukh coal field

SL	CB	CV_{ad} (cal/g)	CV_{ar} (cal/g)	CV_{ar} (MJ/kg)	CV_{mmf} (MJ/kg)	TM (%)	ADL (%)	AM (%)	Ash_{ad} (%)	Ash_{ar} (%)	VM_{ad} (%)	VM_{daf} (%)	C (%)	H (%)	N (%)	S_i (%)	S_m (%)	PS (%)	OS (%)	SS (%)
bh 15	#2	4139	4015	16.81	30.0	4.26	2.90	1.40	40.45	39.24	19.26	33.33	50.94	1.68	0.00	0.26	nd	nd	nd	nd
bh 18	#1	3529	3458	14.48	32.7	3.80	1.72	2.12	60.96	59.74	16.29	45.58	38.05	2.65	0.47	4.4	nd	nd	nd	nd
bh 18	#2	3118	3056	12.79	31.2	5.58	2.40	3.27	54.31	52.68	18.71	44.32	36.35	2.68	0.39	4.8	nd	nd	nd	nd
bh 19	#1	2568	2517	5.85	25.4	4.12	2.46	1.70	54.49	53.13	8.66	19.77	39.74	1.33	0.08	2.6	nd	nd	nd	nd
bh 20	#1	5082	4930	20.64	33.6	4.20	2.63	1.62	34.14	33.12	12.00	18.94	55.46	1.91	0.48	3.1	nd	nd	nd	nd
bh 20	#2	4810	4666	19.54	31.6	4.39	2.58	1.86	34.03	33.01	9.00	14.08	51.47	1.71	0.34	2.5	nd	nd	nd	nd
bh 21	#1	6561	6364	26.64	48.7	6.08	2.93	3.24	41.22	39.98	8.69	16.10	49.97	1.49	0.49	2.8	2.9	1.9	0.8	0.15
bh 24	#1	3260	3130	13.10	22.3	8.13	3.64	4.65	36.47	35.01	15.49	26.59	48.55	1.23	0.12	2.1/ 1.5*	nd	nd	nd	nd
bh 26	#1	5148	4994	20.91	33.2	5.12	2.74	2.45	32.06	31.10	13.85	21.06	52.49	2.40	0.53	3.7	nd	nd	nd	nd
bh 26	#2	5142	4977	20.84	34.6	5.49	3.15	2.42	35.19	34.06	19.61	31.20	52.02	2.57	0.83	3.3	nd	nd	nd	nd
bh 27	#2	5097	4944	20.70	32.0	6.19	2.47	3.81	31.03	30.10	11.09	17.04	53.60	1.67	0.46	3.2	nd	nd	nd	nd
bh 31	#2	6220	6158	25.78	56.6	3.59	0.61	3.00	49.55	49.05	8.89	18.74	43.68	1.15	0.00	2.3	2.3	1.9	0.1	0.3
K oc 1	ukn	1516	1486	6.22	22.0	2.15	1.52	0.64	68.78	68.38	18.00	57.46	21.60	0.82	0.20	1.1	nd	nd	nd	nd
K oc 2	ukn	2570	2416	10.12	25.4	10.10	5.75	4.61	56.52	53.13	15.59	40.27	29.53	1.66	0.39	1.7	nd	nd	nd	nd
Avg bed #1		4358	4232	16.94	32.6	5.25	2.69	2.63	43.22	42.00	12.50	24.67	47.38	1.84	0.36	3.0	nd	nd	nd	nd
Avg bed #2		4754	4636	19.41	36.0	4.92	2.35	2.63	40.76	39.69	14.43	26.45	48.01	1.91	0.34	2.7	nd	nd	nd	nd

[Analyses are as-received basis ($_{ar}$) unless otherwise stated; $_{ad}$ = as-determined basis; $_{mmf}$ = moist, mineral-matter-free basis; $_{daf}$ = dry, ash-free basis; SL = sample locality; CB = coal bed; CV = calorific value; TM = total moisture; ADL = air dry loss moisture; AM = analytical moisture; Ash = ash yield; VM = volatile matter; C = carbon; H = hydrogen, N = nitrogen; S_i = total sulfur as determined by instrumentation (sulfur analyzer or elemental analyzer); S_m = total sulfur as determined manually, done while determining pyritic and sulfate sulfur; PS = pyritic sulfur; OS = organic sulfur; SS = sulfate sulfur; bh = borehole; nd = not determined; K oc 1 = Kurtan outcrop 1; K oc 2 = Kurtan outcrop 2; ukn = unknown; Avg = average; * coal bed was divided into six subsamples for analyses—sulfur content in the top five intervals was 1.5 %.]

Table 2
Results of washability analyses from samples of the Antaramut–Kurtan–Dzoragukh coal field

DF	Rec (%)	M_{ad} (%)	A_d (%)	VM_d (%)	CV-M_{ad} (MJ/kg)	CV-C_{ad} (cal/g)	CV-M_d (MJ/kg)	CV-C_d (cal/g)	C_{ad} (%)	H_{ad} (%)	N_{ad} (%)	S_{ad} (%)
Upper half of coal bed no. 1, borehole 18												
WS		3.43	66.94	15.03	17.44	4166	17.82	4257	43.18	3.10	0.85	4.21
1.3f	1.09	3.94	7.82	36.39	26.57	6345	27.65	6605	73.11	5.25	1.56	3.40
1.4f	3.59	1.61	13.02	34.94	27.69	6613	28.14	6722	69.48	4.99	1.65	3.69
1.5f	7.77	3.77	19.39	33.25	25.83	6169	26.84	6411	62.33	4.47	1.34	4.19
1.6f	11.96 (24.41)	3.48	59.91	33.08	28.64	6841	29.67	6921	56.76	4.00	0.51	4.71
Lower half of coal bed no. 1, borehole 18												
WS		4.36	55.14	19.08	13.44	3210	13.86	3310	36.66	2.55	0.30	5.05
1.3f	1.43	3.95	5.82	36.58	28.89	6901	30.08	7184	56.81	4.21	1.32	3.40
1.4f	5.62	1.21	12.98	35.72	27.75	6627	28.09	6708	61.99	4.48	1.36	4.21
1.5f	14.27	3.91	19.48	32.01	25.42	6072	26.46	6319	66.23	4.82	1.40	4.42
1.6f	25.17 (46.50)	3.64	25.06	30.00	22.91	5473	23.78	5679	73.11	5.25	1.56	4.32
Coal bed no. 2, borehole 18												
WS		5.58	56.16	19.44	13.06	3118	13.49	3223	37.47	2.76	0.40	4.9
1.3f	1.84	3.35	5.75	37.04	28.98	6921	29.98	7161	70.45	4.85	0.89	3.66
1.4f	5.84	2.60	13.22	35.13	27.14	6483	27.87	6657	67.23	4.69	0.73	4.27
1.5f	12.06	3.59	19.19	33.43	25.51	6093	26.46	6319	61.30	4.38	0.84	5.06
1.6f	18.00 (37.74)	3.52	23.52	31.53	24.22	5784	25.10	5996	nd	nd	nd	nd
1.6s	62.26	1.57	57.47	18.87	12.61	3013	12.81	3061	nd	nd	nd	nd
Coal bed no. 1, borehole 20												
WS		4.20	34.69	12.20	21.28	5082	21.63	5166	57.18	1.97	0.49	3.2
1.3f	1.26	3.60	3.92	38.85	30.18	7209	31.31	7478	75.99	5.62	1.72	1.95
1.4f	3.90	2.58	9.55	37.15	28.62	6835	29.38	7016	69.85	5.10	1.72	2.57
1.5f	7.36	3.17	15.68	34.52	26.72	6381	27.59	6590	69.34	5.10	1.67	3.39
1.6f	14.26 (26.78)	2.68	17.13	25.41	26.44	6316	27.17	6489	69.86	3.86	1.45	3.09
1.6s	73.22	3.53	35.56	12.29	20.87	4984	21.63	5166	56.99	1.99	0.45	3.41
Coal bed no. 2, borehole 20												
WS		4.39	34.67	9.17	20.14	4809	20.52	4900	53.06	1.76	0.35	2.6
1.4f	3.80	2.40	10.35	35.62	28.52	6812	29.22	6980	76.20	3.06	1.37	2.62
1.5f	10.16	3.31	15.56	32.79	27.12	6478	28.05	6699	70.80	5.39	1.68	2.89
1.6f	16.95 (30.91)	2.68	16.63	25.65	26.57	6345	27.30	6520	67.51	4.77	1.69	3.21
1.6s	69.09	1.86	34.14	9.01	20.28	4843	20.66	4935	53.81	1.76	0.36	3.02

[DF = density fraction, specific gravity—f = float fraction, s = sink fraction; Rec = recovery at that density fraction, number in parentheses is the total recovered as float; M_{ad} = moisture, as-determined; A_d = ash yield, dry basis; VM_d = volatile matter, dry basis; CV-M_{ad} = calorific value, as-determined basis, in MJ/kg; CV-C_{ad} = calorific value, as-determined basis, in cal/g; CV-M_d = calorific value, dry basis, in MJ/kg; CV-C_d = calorific value, dry basis, in cal/g; C_{ad} = carbon, as-determined basis; H_{ad} = hydrogen, as-determined basis; N_{ad} = nitrogen, as-determined basis; S_{ad} = sulfur, as-determined basis; WS = whole sample.]

Table 3
Results of additional washability analyses on samples from the Antaramut–Kurtan–Dzoragukh coal field

Coal Bed	A_d before ds (%)	A_d after ds (1.6) (%)	VM_d before ds (%)	VM_d after ds (1.6) (%)
Bed No. 1	75.65	20.61	17.46	33.87
Bed No. 1	72.36	24.59	9.57	32.73
Bed No. 1	87.90			
Bed No. 1	50.14	21.12	19.92	32.78
Bed No. 1	74.56			
Bed No. 1	41.06			
Bed No. 2	60.95	21.26	17.46	31.37
Bed No. 2	46.30	23.69	22.79	32.70
Bed No. 2	61.22	24.46	17.77	30.93

All analyses on a dry basis. [A_d before ds = ash yield before density separation; A_d after ds at 1.6 = ash yield after density separation at 1.6 specific gravity; VM_d before ds = volatile matter yield before density separation; VM_d after ds (1.6) = volatile matter yield after density separation at 1.6 specific gravity].

believe that the coal is further complicated by tectonic movements and, in addition, Keshabian et al. (1997) state that repetition of the coal strata are due to landslides. Unfortunately, no previous worker recognized just how far the Antaramut–Kurtan–Dzoragukh coal field extends and they all confined their studies to Antaramut proper. There is a large fault running roughly north-northwest to south-southeast through the village of Antaramut and this is most likely the reason that the coals exposed at

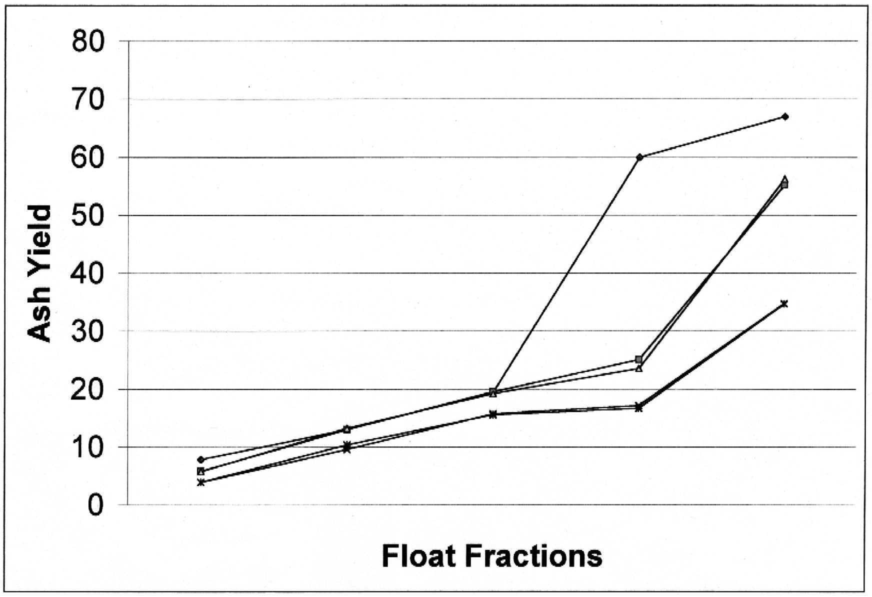

Fig. 5. Washability curves of samples from the Antaramut–Kurtan–Dzoragukh coal field. Ash yield is plotted at float fractions 1.3, 1.4, 1.5, and 1.6; the last value on the curve, at the right hand side, is the ash yield for the whole coal sample for comparison purposes. Washability data are found in Table 2.

Antaramut (Fig. 3) are thin, discontinuous, and occasionally grade into carbonaceous shale, rather than any instability during peat formation.

Our exploratory work has shown that the Antaramut–Kurtan–Dzoragukh coal is found in a set of continuous beds, occasionally being eroded or faulted away, post-depositionally, and there are no major landslides in the area. As shown in Fig. 4, the stratigraphic package, except where faulted out, is continuous across the entire coal field, at least an area of approximately 20 km^2 (Fig. 3).

In all likelihood, the mires that formed the upper and lower AKD coal beds were probably considerably larger than what is present today. Both coal beds thicken toward Dzoragukh, from the south and west. Unfortunately, the entire coal-bearing horizon at Dzoragukh is truncated to both the east and the north by large, regional faults and only Jurassic and Cretaceous strata are present in these surrounding areas and no trace of the upper Eocene coal-bearing sediments of the AKD coal field remain there.

Talanian and Bogdanova (1956) stated that all of the Tertiary stratigraphic sequences, as defined by Ter-Mesropian (1953), were sub-aqueously formed. They believed that all of the volcanic rocks found in the Eocene section of the AKD coal field were either erupted into or flowed under the ocean, and described these strata as marine. However, Talanian and Bogdanova (1956) went into no further detail other than stating this interpretation.

The Antaramut–Kurtan–Dzoragukh coals most likely developed within a near-shore fluvial environment. The concept of a fluvially dominated series of mires is supported by the high ash yields throughout both coal beds and the relatively large grain size of some of the enclosing sandstones. The interior of the mire was situated more toward Dzoragukh, because the coal relatively thickens and is somewhat lower in ash yield there. However, as mentioned earlier, much of the original coals that formed from these mires are probably faulted and/or eroded away to the north and east of Dzoragukh. This absence hinders detailed depositional evaluation of the AKD coal field. Depositional reconstruction is also hampered by the lack of significant outcrops in the study area; only the igneous rocks are exposed to any degree.

The sediments comprising the coal-bearing interval are composed of mostly tuffaceous sandstones, siltstones, and clays. The grains in the sandstones are occasionally very slightly rounded and are much more often angular, indicating a proximity to the igneous source area.

The mire environment, or series or mires, was fairly stable for a long period of time, as testified to by the thickness of the sedimentary package which houses the coal beds (Fig. 4). Those few boreholes where we drilled through the entire sedimentary interval average about 50 m in current (compacted) thickness. The coal forming environment must have been relatively quite stable to develop such a widespread set of coal bodies in such an actively volcanic environment.

Although there was a considerably large input of volcanogenic material throughout the section, either as ash fall or washed in through the fluvial system, there is also a lot of organic material throughout the sedimentary section. These series of fluvial mires, although fairly near the volcanic source, must have developed during a fairly long period of volcanic quiescence to develop two coal beds that sometimes reach 2 m in thickness each, numerous small rider beds, and many coal lenses throughout the section. The sedimentary mire environment was able to incorporate the abundance of volcanic material introduced while maintaining peat accumulation for a long period of time.

The coal-bearing sedimentary package is overlain by thick sequences of tuff breccia and dacitic lava breccia. The demise of the mire probably resulted from the peat being buried as a result of a significantly increased resurgence in volcanism. The same system that had sporadically contributed tuffaceous material into and through the system for so long eventually deposited a continuous series of breccias which now overlie the sedimentary package throughout the study area.

6. Conclusions

The regional extent of the Antaramut–Kurtan–Dzoragukh coal field was previously unrecognized and the deposit, as now defined, contains a resource of more than 31,000 Mt. The Antaramut–Kurtan–Dzoragukh peat mire(s) formed in an actively volcanic environment, presumably not too far from the volcanic source, which ultimately buried and killed the mires. Coal is one of the few fossil fuel resources present in Armenia and although the coal is relatively high in ash yield and moderate to high in sulfur content, it is amenable to cleaning and a pre-feasibility study indicates that a profitable small surface mine with a 20-year lifespan could be developed within this coal field.

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