

Depositional Environment and Coal Petrology of Afsin-Elbistan Coals, Turkey

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ABSTRACT: In this study, petrographical investigations of lignite samples taken from Kislakoy and Collolar sectors of the Afsin-Elbistan lignite basin, Turkey, was made in order to determine petrographic composition and peat-forming environment of the lignite seam. Lignite seam is located in the Upper Miocene-Pliocene Ahmetcik Formation represents fluvial-lacustrine facies. It is 80 m thick in the whole lignite zone, but it is 105 m thick in the Kislakoy sector. Upper part of the lignite seam, lignite layers alternate with gyttja that is rich for gastropoda shells whereas lower part of the seam, lignite layers alternate with clayey layers.

Petrographic composition indicates huminite-rich lignite (81.9 % in open-pit mine samples and 67.8 % in borehole samples), followed by inertinite (4.29 % in open-pit mine samples and 4.37 % in borehole samples) and liptinite (1.16 % in open-pit mine samples and 0.65 % in borehole samples). Atrinite is the most abundant maceral type of the huminite group in the samples, and also considerable amount of textinite and ulminite macerals were determined.

The dominance of humodetrinite suggests that herbaceous types of vegetation dominated the plant communities. Furthermore, geochemical gelification can be neglected because of the low rank. Ulminite macerals can be derived from biochemical gelification of cellulose-rich plant remains. This suggests the presence of shrub-like and small arboreous plants. Based on the Tissue Preservation Index – Gelification Index facies concept, the seam was deposited in an open marsh.

KEY WORDS: coal, coal petrology, depositional environment, Afsin, Elbistan.

Introduction

Coals deposits of Turkey generally occur in Carboniferous and Tertiary. Carboniferous coals are located at the Western Black Sea region (e.g. Zonguldak, Bartın) of Turkey. Eocene (Yozgat-Sorgun, Amasya-Celtek etc.), Oligocene (Tekirdag-Malkara etc.), Miocene (Mugla-Milas, Balıkesir-Dursunbey etc.) and Pliocene (e.g. Sivas-Kangal, Erzurum-Horasan, Adana-Tufanbeyli etc.) coals deposited in different basins which formed with different geodynamic processes and developed one after the other in different times.

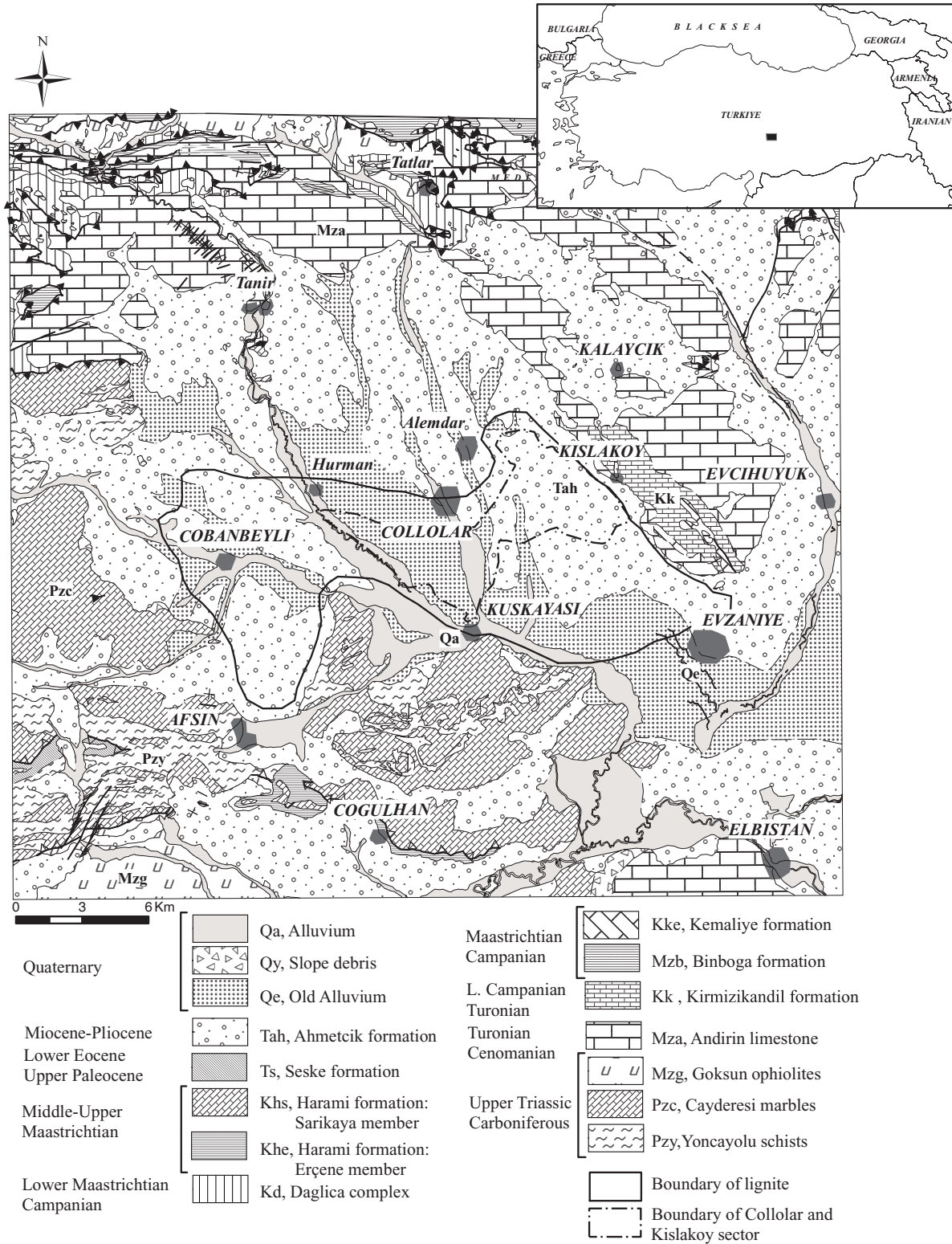
Following the complete elimination of the Bitlis Ocean by the middle Miocene, the Arabian Platform had collided, through the Anatolian orogenic collage, with Laurasia. The post-collisional intracontinental convergence and the continuous squeezing of eastern Anatolia between the Arabian and the Laurasian plates caused a progressive thickening and shortening of the crust and forced the Anatolian land mass to move away from the high strain area. Consequently, an Anatolian wedge have been driven westwards along two major strike-slip faults on the dextral North Anatolian and sinistral East Anatolian Transform Faults to override the oceanic lithosphere of the Mediterranean along the Hellenic and Cyprus subduction zones (Sengor 1979, Dewey et al. 1986). As Sengor et al. (1985) pointed out, these escape tectonics represent the neotectonic regime of Turkey. This regime generated in eastern Turkey a number of large ramp-valley basins filled with Neogene-Quaternary sediments and volcanics. Within the escaping Anatolian wedge, both west Anatolian extensional and central Anatolian provinces developed. The former is characterized mainly by the western Turkish graben complexes, whereas the latter by large, roughly equant, and complex basins mostly filled with evaporitic fluvio-lacustrine sediments and associated volcanic (Gorur et al. 1998).

In the study area, Pehlivan et al. (1991) reported that squeezing of the region started in Upper Cretaceous was continued during lower Miocene and transgressive units were deposited when tectonic activity was low effective. After lower Miocene, the region was turned in continental depositional areas and lacustrine sedimentation were started during Pliocene in the Afsin-Elbistan basin.

The Afsin-Elbistan lignite basin, which has the largest lignite reserve ($3,357 \times 10^6$ ton) of Turkey, is located at the south-eastern Turkey (Fig. 1). Lignite basin is divided into three major sector (Kislakoy (A), Collolar (B), Afsin (C)) and three subsector (Kuskayasi (D), Elbistan (E and F)). Lignite production is carried on Kislakoy sector as an open-pit mine. Major part of the lignite is used in Afsin-Elbistan A and B thermal power plants having supply 7 % energy of Turkey.

Previous studies around lignite basin generally focused on the basement rocks of the basin and calculation of lignite reserve (e.g. Onen 1936, Lüttig 1969, Gold 1969, Staesche 1970, Aydoğan 1978, Metin et al. 1982, Perincek and Kozlu 1983, Pehlivan et al. 1991, Onalan 1986). In this study, petrographical investigation of lignite samples taken from Kislakoy and Collolar sectors of the lignite basin was made in order to determine petrographic composition and peat-forming environment of the lignite seam.

The petrography of coal and its relation to the depositional environment have been the subject of many studies (e.g. Teichmüller 1989, Diessel 1986, Kalkreuth et al. 1991, Calder et al. 1991, Kalkreuth et al. 2000 etc.). Maceral analyses provide a wealth of information that may be useful in defining depositional environments if facies-critical macerals can be selected (Kalkreuth and Leckie 1989).



■ Fig. 1. Geological map of the study area (modified from Yilmaz et. al. 1997).

Geological setting

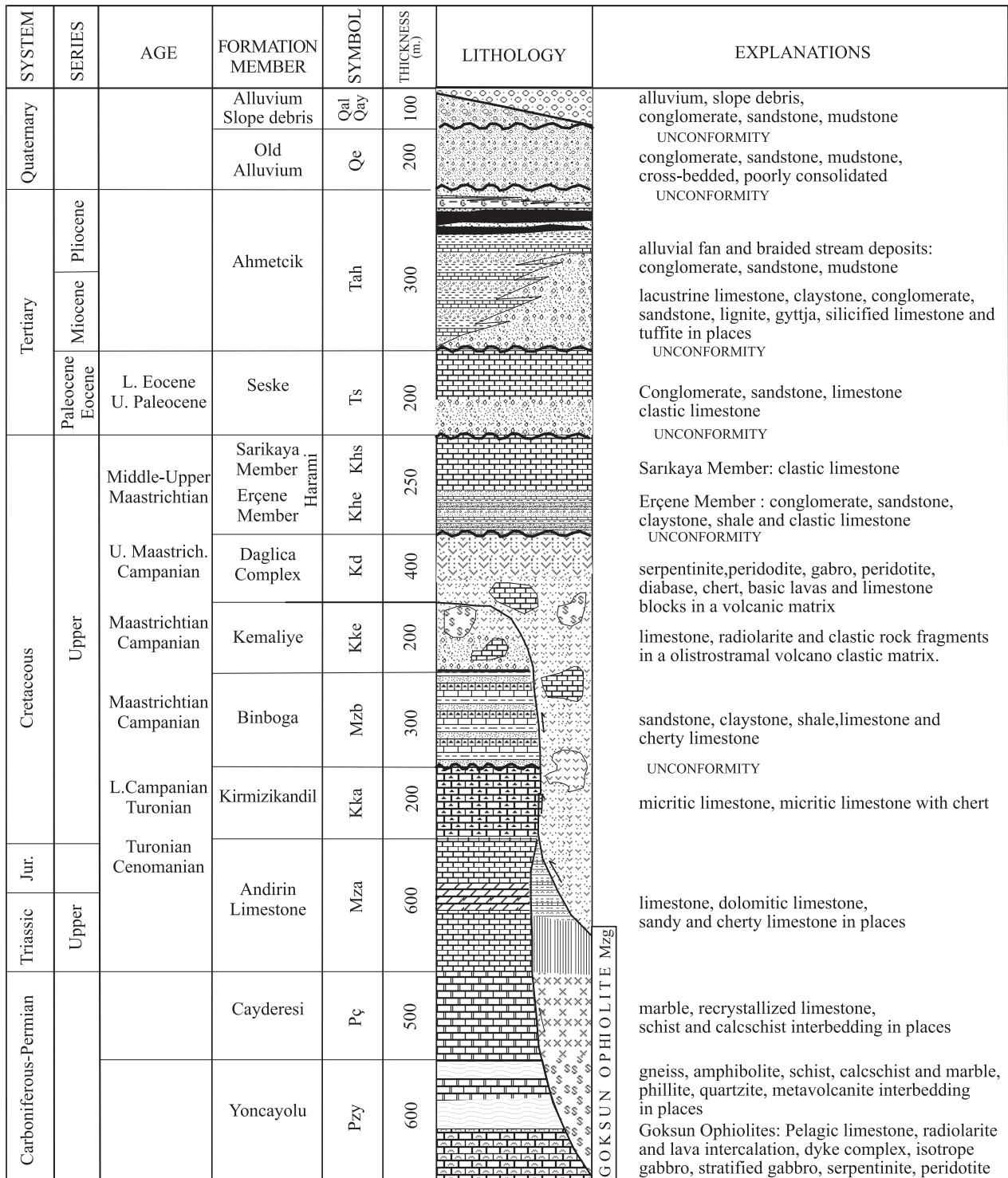
Study area undergone two geologic phase during pre-Maastrichtian and Maastrichtian to recent times. The pre-Upper-Maastrichtian tectonic units shows east-west general direction and different depositional characteristics were exposed in the western part of

Eastern Taurus. The tectonic units can be divided into two groups. These are the Gurun Parautochthon and allochthonous units to the south of the parautochthon. In the study area, allochthonous units and Maastrichtian-recent aged units overlying on the allochthonous units are exposed (Fig. 1). Allochthonous units are divided into three groups. The first group is called Keban-Malatya

Metamorphics that consist of Yoncayolu Schists and Cayderesi Marble. Second group contains Andirin Limestone, Kirmizikandil Formation, Binboga Formation, Kemaliye Formation and Daglica Complex, their ages vary between Triassic and Upper Cretaceous. Goksun Ophiolites are the third group of the allochthonous units (Yilmaz et al. 1997).

Maastrichtian-Campanian aged Kemaliye Formation represented by conglomerate, sandstone and shale containing vari-

ous blocks of different lithology and age, unconformably lies over the metamorphics (Fig. 2). The Andirin Limestone is in tectonic contact with the underlying Kemaliye Formation. Shallow water condition left their place to the conditions of pelagic fossiliferous limestone and radiolarites in the post-Cenomanian times. Following the deep-marine conditions of Turonian-Lower Campanian, the ophiolitic complex took place over the succession. The unit, known as the Daglica Complex, moved from



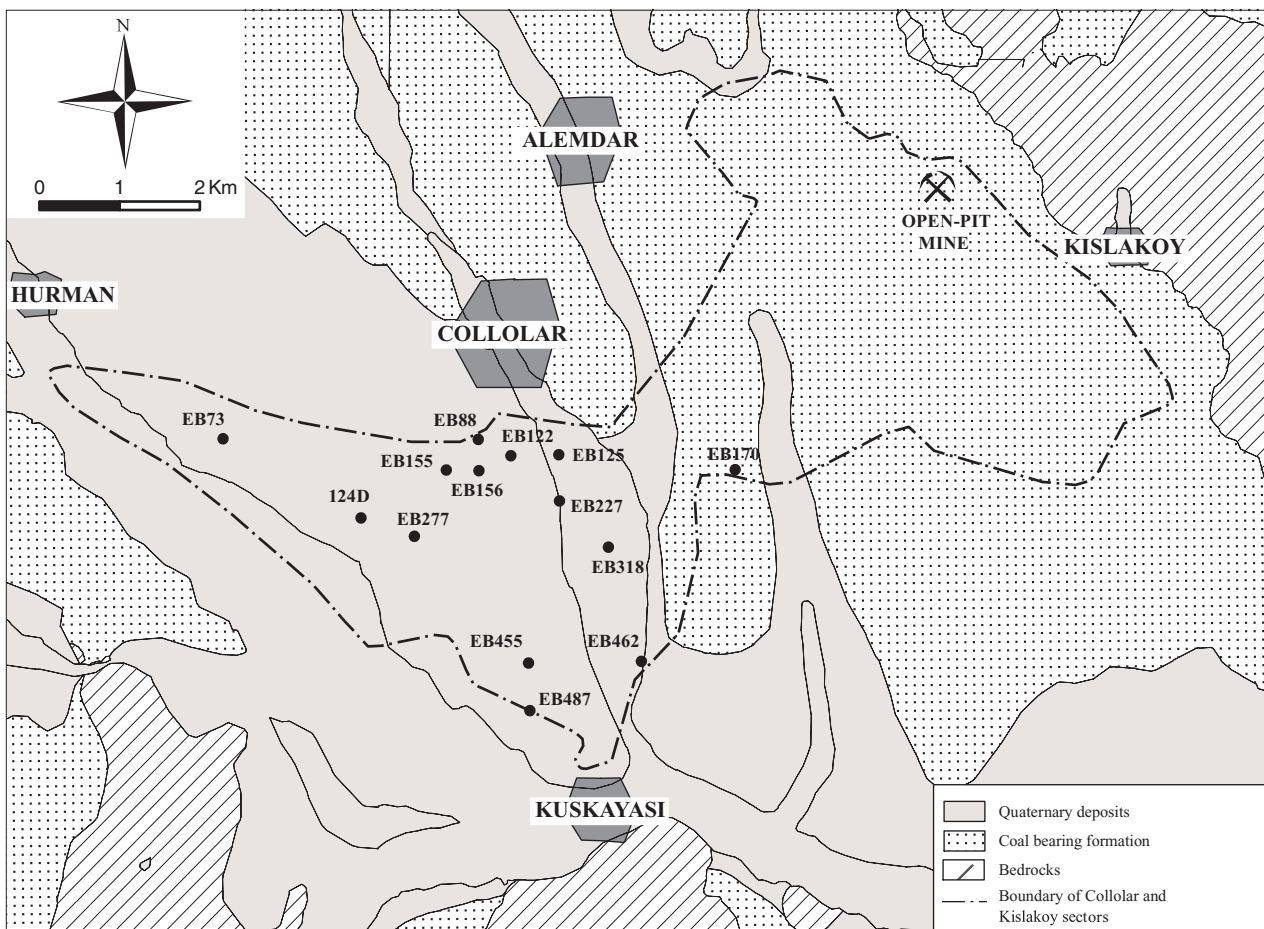
■ Fig. 2. Generalized stratigraphic section of the Afsin-Elbistan lignite basin (modified from Perincek and Kozlu 1984).

north to the south upon the Mesozoic succession in the region. The Keban-Malatya Metamorphics which formed a single platform at the beginning of this event and the Andirin Limestone were imbricated towards south, while the Daglica Complex and Andirin Limestone in the north were providing material for the Kemaliye Formation that was in the process of forming over the Malatya Metamorphics (Perincek and Kozlu 1983).

The allochthonous units are covered by Middle Maastrichtian to recent units called Harami Formation, Seske Formation, Ahmetcik Formation and Quaternary deposits. Harami Formation is represented by conglomerate, sandstone, claystone, shale and clastic limestone. Middle to Upper Maastrichtian unit probably deposited in pelagic and neritic conditions. Seske Formation occurs between two slices of the Keban-Malatya Metamorphics observed in a single outcrop in the nearwest of Afsin. The unit starts with conglomerate and sandstone at the base, and continues with intercalation of middle to coarse bedded limestone containing abundant fossils and fossiliferous limestone. The Miocene-Pliocene coal bearing Ahmetcik Formation overlies unconformably on the older units and is covered again unconformably by Quaternary deposits. The formation is represented by limnic and fluvial sediments. Limnic deposits are developed in the centre of the basin and pass to the fluvial deposits towards the basin margin. Limnic deposits start with bluish-gray coloured marl/claystone and continue with intercalation of lignite and claystone at the lower parts, however towards the

upper parts they continue with intercalation of lignite and gytja which is rich for gastropoda shells. There is thick claystone layer with lignite lenses in places over these layers. At the top of the limnic deposits, there are grey-brown coloured conglomerate, sandstone and lacustrine limestone in the open-pit mine. Upper Pliocene lignite seam is 80 m thick in whole lignite zone, but it is 105 m thick in the Kislakoy sector. The fluvial deposits of the Ahmetcik Formation are represented by conglomerate and sandstone (Cicioglu 2001).

Lignite basin were divided into zones by Lüttig (1969). Lüttig proposed that in the basin margin, there was wide reed zone and lignite were deposited in this zone called telmaticum. Alluvial fan deposits and coarse clastic materials were deposited in the outer margin of the telmaticum zone. The lignite zone passes to clayey limestone and lacustrine limestone towards the basin centre. According to Lüttig (1969), after the subsidence of Elbistan basin, groundwater level increased in the north of the basin and a very large lake occurred towards the northwestern part of the basin. In this stage, limnic-calcerous sediments were generally deposited. Reed zone were developed in the basin margin since there was water supply mostly from the karst and flooding was not important during this period. Telmatic and limnic occurrences occasionally were deposited alternately. Basin subsidence rate started decreasing so water level of the lake decreased and fluvial regimes began more effective so alluvial sediments were deposited at the end of Pliocene and Quaternary times, (Lüttig 1969).



■ Fig. 3. Location map of the boreholes and open-pit mine.

Quaternary deposits are represented by fluvial sediments such as alluvium terrace and channel deposits and overlie the older units.

Sampling and analytical procedures

During the field study, 40 samples (coal, claystone and gytja) from open-pit mine and 63 samples from 14 boreholes drilled by General Directorate of Mineral Research and Exploration (MTA) for coal exploration were taken. 23 lignite samples of the open pit mine (Fig. 3) and whole borehole samples were analysed due to the insufficient laboratory support. Distributions of the samples which were analysed are given in the Fig. 4.

Open pit mine samples were taken according to the channel sampling method. These samples represent upper part of lignite seam (30 m of the upper part). Borehole samples were obtained from Afsin-Elbistan Lignite Enterprise (EB 73, 88, 122, 125, 155, 156, 227, 277, 318, 455, 462, 487 boreholes) and MTA Core Databank (124D and EB170 boreholes). Borehole samples were selected from representative undisturbed segments of the cores. Macroscopically, lignite is dull, grey, hard and finely stratified. It contains small fossil shell fragments. Detailed litho-type determinations were not done in the field. Seam section descriptions of the boreholes were taken from original borehole log lithology descriptions. Macroscopically, gytja samples contain 70-80 % fossil shells. Lignite with fossil traces contains lesser amount of fossil shells than gytja. Samples taken from lignite, fossiliferous lignite and lignite-gytja intercalation levels were analysed.

All samples were crushed to a maximum particle size of 850 µm and mounted in epoxy resin and then ground and polished. Leitz MPV-SP reflected-light microscope was used for petrographical analysis. Petrographic composition was determined by maceral analyses based on 500 points each samples. Rank was determined by measuring random ulminite reflectances.

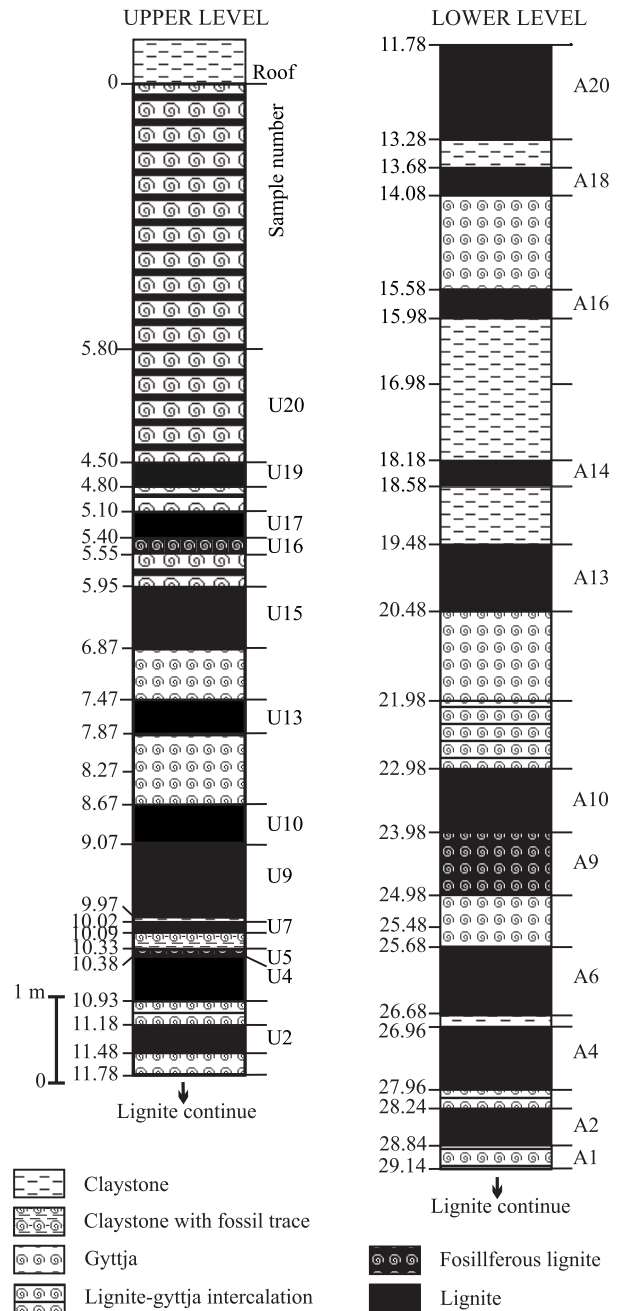
Results and discussion

Coal Rank

Reflectance measurements of the samples were carried out on ulminite macerals (Table 1). Reflectance values range from 0.21 to 0.27 % R_r due to the young coals. Average reflectance value is 0.25 % in the open-pit mine and 0.23 % in the borehole samples. According to the ASTM and DIN classifications, the rank of the coals is in lignite and soft brown coal stage.

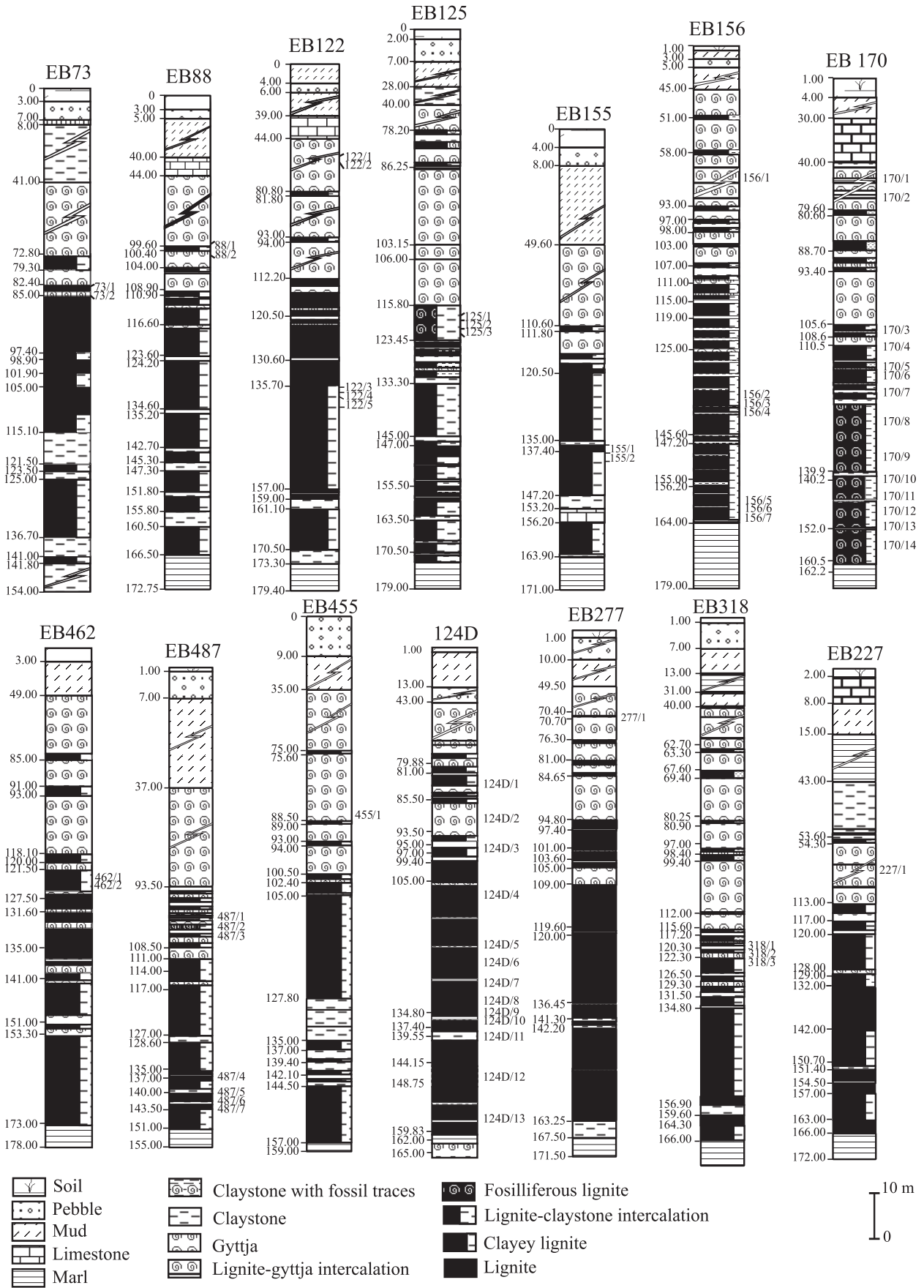
Petrographic composition

Maceral analyses results are given in the Table 2. Petrographic composition indicates huminite-rich lignite (81.9 vol. % in the open-pit mine samples and 67.8 vol. % in the borehole samples), followed by inertinite (4.29 vol. % in the open-pit mine samples and 4.37 vol. % in the borehole samples) and liptinite (1.16 vol. % in the open-pit mine samples and 0.65 vol. % in the borehole samples) (Fig. 5).



■ Fig. 4a. Sample distributions in the open-pit mine.

Within the huminite group, textinite, ulminite, corpohuminate, gelinite, atrinite, densinite macerals were determined. Atrinite is the most abundant maceral (57.51 vol. % in the open-pit mine samples and 39.74 vol. % in the borehole samples) in the samples, and also considerable amount of textinite and ulminite macerals (average 15.71 vol. % textinite and 6.36 vol. % ulminite in the open-pit mine samples and 14.25 vol. % textinite and 11.19 vol. % ulminite in the borehole samples) were determined. Liptinite contents are low in the samples. Sporinite and liptodetrinite macerals were observed. During the maceral analyses, generally it was difficult to distinguish liptinite macerals from clay minerals in the samples. Within the inertinite group, sclerotinite, micrinite, fusinite and inertodetrinite macerals were



■ Fig. 4b. Sample distributions in the boreholes.

Sample No	Thick. (m)	Reflec. %Ro	Stan. Dev.	Sample No	Thick. (m)	Reflec. %Ro	Stan. Dev.	Sample No	Thick. (m)	Reflec. %Ro	Sand Dev.
Open-Pit Mine			Boreholes								
U20	4.5	0.23	0.02	EB73/1	1	0.24	0.03	EB170/12	3	0.25	0.03
U19	0.3	0.25	0.03	EB73/2	1	0.23	0.03	EB170/13	8.2	0.22	0.03
U17	0.3	0.23	0.03	EB88/1	2	0.26	0.03	EB170/14	4	0.23	0.02
U16	0.2	0.26	0.03	EB88/2	1	0.23	0.02	EB227/1	1	0.2	0.03
U15	0.9	0.26	0.02	EB122/1	1	0.29	0.03	EB277/1	1	0.22	0.03
U13	0.4	0.28	0.03	EB122/2	1	0.22	0.03	EB318/1	1	0.28	0.03
U10	0.4	0.27	0.03	EB122/3	1	0.25	0.03	EB318/2	1	0.25	0.03
U9	0.9	0.24	0.04	EB122/4	1	0.21	0.04	EB318/3	2	0.26	0.02
U7	0.1	0.25	0.03	EB122/5	2	0.23	0.03	EB455/1	1	0.24	0.03
U5	0.1	0.24	0.03	EB125/1	1	0.24	0.03	EB462/1	1	0.28	0.03
U4	0.6	0.25	0.03	EB125/2	2	0.24	0.02	EB462/2	1	0.26	0.03
U20	0.3	0.27	0.03	EB125/3	1	0.22	0.03	EB487/1	1	0.28	0.04
A20	1.5	0.24	0.03	EB155/1	2	0.21	0.03	EB487/2	1	0.25	0.03
A18	0.4	0.21	0.03	EB155/2	2	0.2	0.02	EB487/3	1	0.26	0.03
A16	0.4	0.23	0.03	EB156/1	1	0.24	0.03	EB487/4	1	0.22	0.03
A14	0.4	0.24	0.02	EB156/2	1.3	0.26	0.03	EB487/5	1	0.21	0.02
A13	1	0.25	0.03	EB156/3	2	0.24	0.03	EB487/6	1	0.25	0.03
A10	1	0.26	0.03	EB156/4	1	0.25	0.03	EB487/7	1	0.21	0.03
A9	1	0.27	0.02	EB156/5	1	0.27	0.03	124D/1	12.6	0.19	0.03
A6	1	0.26	0.04	EB156/6	1	0.26	0.03	124D/2	2.4	0.22	0.03
A4	1	0.25	0.03	EB156/7	1	0.2	0.03	124D/3	7.4	0.22	0.03
A2	0.6	0.26	0.03	EB170/1	3.5	0.24	0.03	124D/4	17.6	0.2	0.03
A1	0.3	0.27	0.02	EB170/2	3	0.25	0.03	124D/5	4	0.2	0.03
				EB170/3	5.2	0.25	0.04	124D/6	4	0.21	0.03
				EB170/4	5.5	0.25	0.03	124D/7	4	0.22	0.03
				EB170/5	2.6	0.26	0.03	124D/8	4	0.21	0.03
				EB170/8	3.7	0.25	0.03	124D/10	3	0.21	0.03
				EB170/7	9.4	0.26	0.03	124D/9	1	0.22	0.03
				EB170/9	10.2	0.23	0.03	124D/11	4	0.23	0.03
				EB170/10	2.2	0.23	0.03	124D/12	12.5	0.21	0.03
				EB170/11	6.9	0.23	0.03	124D/13	7.5	0.21	0.03
Open-pit mine Average		0.25	0.3	Boreholes average				0.23	0.3		

■ **Tab. 1.** Results of the ulminite reflectance measurements.

Sample No	Depth (m.)	Thick. (m.)	Text. vol%	Ulm. vol%	Corp. vol%	Gel. vol%	Atr. vol%	Dens. vol%	Spor. vol%	Ldet. vol%	Fus. vol%	Scle. vol%	Idet. vol%	Pyr. vol%	F.shell vol%	Ot.Min. vol%
Open-pit mine lignite samples (upper and lower level)																
U-20	0-4.5	4.5	8.65	1.88	0.38	0.00	72.18	0.00	2.26	0.00	0.00	0.00	2.26	0.75	11.65	0.00
U-18	4.5-4.8	0.3	16.73	10.55	0.00	0.00	54.55	0.00	0.73	0.00	4.00	0.73	7.64	0.73	0.00	3.64
U-17	5.1-5.4	0.3	33.45	6.27	0.00	0.35	26.13	0.00	0.00	0.00	1.05	0.00	0.70	1.05	9.06	21.95
U-16	5.4-5.55	0.2	6.07	3.57	0.00	0.00	55.36	0.00	0.00	0.00	2.50	0.71	0.00	0.00	10.36	21.43
U-15	5.95-6.87	0.9	7.43	8.45	3.72	0.00	56.08	0.00	0.34	0.00	2.70	0.00	7.77	0.00	3.38	10.14
U-13	7.47-7.87	0.4	37.67	13.90	0.00	0.00	40.36	0.00	0.00	0.00	1.79	0.00	1.79	2.69	0.00	1.79
U-10	8.67-9.07	0.4	8.39	15.38	0.00	1.05	58.74	0.00	0.00	0.00	2.80	0.00	1.75	3.15	0.70	7.69
U-9	9.07-9.97	0.9	25.62	8.33	0.00	1.54	30.25	0.00	0.31	0.00	0.31	0.00	3.70	1.54	3.09	25.31
U-7	10.02-10.09	0.1	1.73	2.97	0.00	2.97	25.00	41.34	0.99	0.00	0.25	0.00	0.00	0.99	23.76	0.00
U-5	10.33-10.38	0.1	0.00	0.17	0.35	0.52	60.94	0.00	0.00	0.00	2.78	0.00	0.00	1.74	25.17	8.33
U-4	10.38-10.93	0.6	6.73	3.21	1.60	3.21	41.03	32.37	0.32	0.00	0.32	0.32	0.00	3.53	4.49	2.88
U-2	11.18-11.48	0.3	16.32	17.80	0.30	14.24	19.88	9.50	2.97	0.00	0.00	0.59	0.00	3.56	9.79	5.04
A-20	11.78-13.28	1.5	19.79	5.56	0.35	0.00	65.35	0.00	0.69	0.63	5.21	0.00	0.00	2.43	0.00	0.00
A-18	13.68-14.08	0.4	28.76	4.25	0.65	0.00	57.17	0.00	0.00	1.00	0.65	0.00	0.00	6.54	0.98	0.00
A-16	15.58-15.98	0.4	20.00	19.41	0.00	0.00	55.23	0.00	0.00	0.07	3.53	0.59	0.00	1.18	0.00	0.00

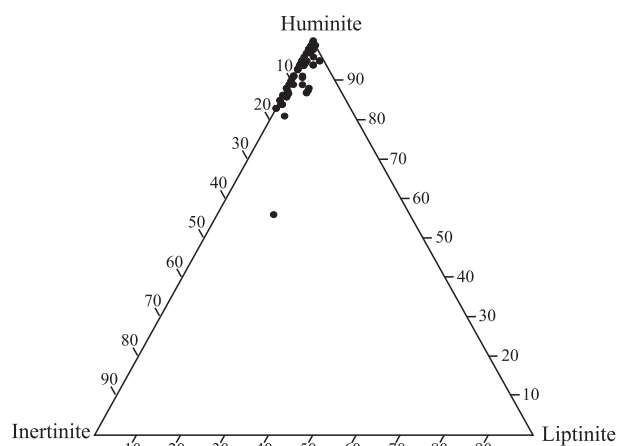
■ **Tab. 2.** Results of the maceral analyses (mineral matter containing basis).

Sample No	Depth (m.)	Thick. (m.)	Text. vol%	Ulm. vol%	Corp. vol%	Gel. vol%	Atr. vol%	Dens. vol%	Spor. vol%	Ldet. vol%	Fus. vol%	Scle. vol%	Idet. vol%	Pyr. vol%	F.shell vol%	Ot.Min. vol%
A-14	18.18–18.58	0.4	24.17	17.50	0.00	0.83	41.67	0.00	0.83	0.00	4.17	0.00	0.00	0.83	10.00	0.00
A-13	19.48–20.48	1.0	8.15	6.58	1.25	0.00	75.73	0.00	0.00	1.07	4.08	0.00	0.31	2.19	0.63	0.00
A-10	22.98–23.98	1.0	24.62	0.00	0.00	0.00	60.08	0.00	0.00	0.30	6.54	0.00	0.00	0.77	7.69	0.00
A-9	23.98–24.98	1.0	0.47	1.64	0.00	0.00	62.77	0.00	0.00	1.40	3.04	0.00	2.11	0.23	27.63	0.70
A-6	25.68–26.68	1.0	25.63	8.36	1.11	0.00	52.81	0.00	0.56	1.23	1.11	0.00	0.56	3.90	1.39	3.34
A-4	26.96–27.96	1.0	25.94	11.32	0.94	0.00	46.66	0.00	0.00	0.51	9.43	0.00	0.00	5.19	0.00	0.00
A-2	28.24–28.84	0.6	29.80	15.92	0.00	0.00	36.95	0.00	0.00	0.60	2.86	0.00	0.82	5.31	6.53	1.22
A-1	28.84–29.14	0.3	1.50	1.00	0.00	0.00	46.59	0.00	0.00	0.53	0.25	0.00	8.52	1.75	25.81	14.04
Average			15.71	6.36	0.58	0.49	57.51	1.35	0.80	0.37	2.52	0.05	1.75	1.94	7.15	3.40
Boreholes samples																
EB73/1	83–84	1.0	0.00	0.00	0.00	0.00	52.07	0.00	0.00	0.00	0.00	0.00	0.00	9.47	34.91	3.55
EB73/2	84–85	1.0	1.79	1.79	0.00	2.68	23.21	0.00	0.00	0.00	0.00	0.00	0.00	8.93	48.21	13.39
EB88/1	99–101	2.0	34.68	10.48	0.81	0.00	39.52	0.00	0.00	0.00	0.00	0.81	0.00	0.81	12.90	0.00
EB88/2	101–102	1.0	5.31	0.88	0.00	0.88	38.05	0.00	0.00	0.00	0.00	0.00	1.77	15.93	37.17	0.00
EB122/1	61–62	1.0	1.65	3.31	0.00	1.65	11.57	0.00	0.00	0.00	0.00	0.00	0.00	12.40	69.42	0.00
EB122/2	63–64	1.0	2.99	4.48	1.49	5.22	27.61	0.00	0.00	0.00	0.75	0.75	0.00	4.48	30.60	21.64
EB122/3	136–137	1.0	22.40	15.20	0.80	0.00	45.60	0.00	0.00	0.00	1.60	0.00	1.60	3.20	0.00	9.60
EB122/4	137–138	1.0	9.15	7.93	1.83	8.54	61.59	0.00	0.00	0.00	0.61	0.00	3.66	3.66	3.05	0.00
EB122/5	138–140	2.0	17.68	9.76	1.22	0.61	31.10	0.00	0.00	0.00	1.83	0.00	0.61	7.32	1.22	28.66
EB125/1	118–119	1.0	19.85	0.00	0.00	2.21	6.62	0.00	0.00	0.00	1.47	0.00	1.47	25.00	29.41	13.97
EB125/2	119–121	2.0	5.14	3.43	1.14	0.00	72.57	0.00	0.00	0.00	0.57	0.00	2.29	6.29	8.57	0.00
EB125/3	121–122	1.0	25.33	9.33	0.00	1.33	28.67	0.00	0.00	0.00	0.00	0.00	0.00	9.33	22.67	3.33
EB155/1	136–138	2.0	3.33	14.44	0.00	2.22	54.44	0.00	0.00	0.00	0.00	0.00	8.89	11.11	5.56	0.00
EB155/2	138–140	2.0	20.22	11.24	0.00	0.00	19.66	0.00	0.00	0.00	0.00	0.00	1.12	30.90	0.00	16.85
EB156/1	77–78	1.0	26.16	12.21	1.74	3.49	11.63	0.00	0.00	0.00	0.58	0.00	0.00	6.40	32.56	5.23
EB156/2	134.7–136	1.3	7.41	10.19	0.00	0.00	30.56	0.00	0.00	0.00	0.00	0.00	0.93	3.70	9.26	37.96
EB156/3	136–138	2.0	32.90	4.52	0.65	1.94	54.84	0.00	0.00	0.00	1.94	0.00	1.29	1.94	0.00	0.00
EB156/4	138–139	1.0	18.40	7.20	0.00	0.00	52.00	0.00	0.00	0.00	0.00	1.60	2.40	2.40	16.00	0.00
EB156/5	160–161	1.0	30.32	14.84	3.23	0.00	43.23	0.00	0.00	0.00	0.00	0.65	0.65	7.10	0.00	0.00
EB156/6	161–162	1.0	31.94	10.47	1.57	0.00	22.51	0.00	0.00	0.00	2.62	0.00	0.00	3.14	27.75	0.00
EB156/7	162.5–163.5	1.0	22.82	10.07	3.36	0.00	41.61	0.00	0.00	0.00	3.36	0.67	4.03	4.03	0.00	10.07
Boreholes samples																
EB170/1	64.2–67.7	3.50	2.65	1.18	0.00	0.00	34.19	0.00	0.32	0.00	0.00	0.00	0.00	5.01	12.98	43.66
EB170/2	74–77	3.00	22.15	2.01	0.00	0.00	41.66	0.00	0.29	0.00	0.00	0.00	0.00	4.03	27.18	2.68
EB170/3	103–108,2	5.20	35.48	3.87	0.00	0.00	34.79	0.65	0.05	0.65	0.32	0.00	0.00	0.97	13.55	9.68
EB170/4	108,2–113,7	5.50	9.39	1.08	0.00	0.00	36.46	0.00	0.36	0.00	0.72	0.00	0.00	2.17	38.27	11.55
EB170/5	113,7–116,3	2.60	18.71	3.37	0.61	0.00	53.30	0.00	0.38	0.92	0.00	0.00	0.00	4.91	14.72	3.07
EB170/6	116,3–116,9	0.60	19.80	4.44	0.00	0.00	38.73	0.00	0.17	0.00	0.00	0.00	0.00	0.68	20.48	15.70
EB170/7	116,9–126,3	9.40	19.56	3.15	0.00	0.00	59.16	0.63	0.46	0.00	0.00	0.00	0.00	2.84	7.89	6.31
EB170/8	126,3–130	3.70	16.08	3.22	0.00	0.00	42.77	0.00	0.32	0.64	0.00	0.00	0.00	7.72	7.40	21.86
EB170/9	130–140,2	10.20	20.74	5.07	0.00	0.00	39.06	0.46	0.12	0.00	0.00	0.00	0.00	0.00	9.22	25.35
EB170/10	140.2–142.4	2.2	8.85	3.61	0.00	0.00	33.03	0.33	0.09	0.98	0.00	0.00	0.00	4.92	14.43	33.77
EB170/11	142.4–148.3	6.9	18.38	17.65	3.68	0.00	41.17	0.74	0.01	2.21	0.00	4.41	4.41	7.35	3.68	0.74
EB170/12	148.3–149.3	3.0	24.28	6.16	0.00	0.00	52.26	0.00	0.27	0.72	0.00	0.00	0.00	4.35	0.72	11.23
EB170/13	149.3–152.3	8.2	18.54	15.23	0.66	0.00	41.04	1.32	0.02	2.65	1.99	0.66	0.66	13.91	3.31	0.66
EB170/14	152.3–160.5	4.0	19.26	28.15	0.74	0.00	39.26	0.00	0.00	1.48	0.00	0.74	0.74	6.67	3.70	0.00
EB227/1	105–106	1.0	0.44	3.10	0.88	0.00	41.59	0.00	0.00	0.00	0.00	0.00	0.00	0.88	53.10	0.00
EB277/1	70–71	1.0	12.14	2.86	0.00	0.71	28.57	0.00	0.00	0.00	0.00	0.00	0.00	5.00	49.29	1.43
EB318/1	120–121	1.0	8.85	11.50	0.00	5.31	45.13	0.00	0.00	1.77	0.00	0.00	0.88	4.42	22.12	0.00
EB318/2	121–122	1.0	17.61	3.98	0.00	1.70	65.34	0.00	0.00	0.00	0.57	0.00	0.00	2.84	0.57	7.39
EB318/3	122–124	2.0	36.11	15.28	0.46	1.85	31.48	0.00	0.00	0.46	0.46	0.00	0.00	1.85	12.04	0.00
EB455/1	141.3–142.3	1.0	1.92	0.00	0.00	4.81	20.19	0.00	0.00	0.00	0.00	0.00	2.88	9.62	60.58	0.00
EB462/1	122.5–123.5	1.0	4.31	6.03	0.00	0.00	65.52	0.00	0.00	0.00	1.72	0.00	1.72	7.76	0.00	12.93
EB462/2	123.5–124.5	1.0	4.11	4.11	0.00	0.68	70.55	0.00	0.00	1.37	0.68	0.00	2.05	4.11	0.00	12.33

■ Tab. 2. Results of the maceral analyses (mineral matter containing basis) (*continued*).

Sample No	Depth (m.)	Thick. (m.)	Text. vol%	Ulm. vol%	Corp. vol%	Gel. vol%	Atr. vol%	Dens. vol%	Spor. vol%	Ldet. vol%	Fus. vol%	Scl. vol%	Idet. vol%	Pyr. vol%	F.shell vol%	Ot.Min. vol%
Boreholes samples																
EB487/1	99–100	1.0	7.46	4.98	0.00	0.00	79.10	0.00	0.00	1.49	0.50	0.00	1.99	4.48	0.00	0.00
EB487/2	101–102	1.0	5.61	8.41	2.80	0.93	65.42	0.00	0.00	1.87	0.93	0.00	7.48	1.87	4.67	0.00
EB487/3	103–104	1.0	38.57	2.86	0.71	0.00	50.71	0.00	0.00	0.00	0.00	0.00	0.00	5.71	1.43	0.00
EB487/4	136–137	1.0	11.11	16.67	0.69	1.39	62.50	0.00	0.00	1.39	0.00	0.00	3.47	2.78	0.00	0.00
EB487/5	140–141	1.0	6.62	7.28	0.00	0.66	45.03	0.00	0.00	0.00	0.00	0.00	0.00	8.61	31.79	0.00
EB487/6	141–142	1.0	14.68	1.59	0.79	0.00	42.06	0.00	0.00	0.00	0.00	0.00	0.00	13.89	8.33	18.65
EB487/7	142–143	1.0	8.65	19.46	1.08	0.00	28.11	0.00	0.00	2.16	0.00	0.00	0.00	24.32	0.00	16.22
124D/1	77–89.6	12.6	6.06	6.06	0.76	1.52	40.76	0.00	3.03	0.00	1.52	0.00	3.79	18.18	13.64	1.52
124D/2	89.6–92	2.4	9.36	9.94	3.51	6.43	45.91	0.00	0.00	0.00	1.17	1.17	2.92	6.43	8.77	4.09
124D/3	92–99.4	7.4	1.69	16.95	2.54	5.93	54.96	0.00	2.54	0.00	5.93	0.85	0.85	7.63	0.00	0.00
124D/4	99.4–117	17.6	12.87	17.54	0.58	2.34	40.76	0.00	0.00	0.00	0.58	0.00	2.92	11.70	0.00	4.09
124D/5	117–121	4.0	6.82	18.94	0.76	0.00	56.63	0.00	0.00	0.00	1.52	1.52	0.76	9.09	3.79	0.00
124D/6	121–125	4.0	13.41	16.46	1.22	6.10	40.06	0.00	0.00	0.00	1.83	0.00	1.22	14.63	1.83	2.44
124D/7	125–129	4.0	8.57	16.43	0.00	2.86	54.68	0.00	0.71	0.00	0.71	0.71	2.14	5.71	5.71	0.00
124D/8	129–133	4.0	0.78	4.65	0.00	0.00	11.63	0.00	3.88	0.00	1.55	7.75	0.00	20.93	44.19	4.65
124D/9	133–134	1.0	4.55	20.00	1.82	0.00	16.91	0.00	2.73	0.00	0.00	0.91	2.73	23.64	20.00	6.36
124D/10	134–137	3.0	7.69	17.95	1.71	2.56	39.96	0.00	0.00	0.00	4.27	1.71	5.13	11.97	5.13	1.71
124D/11	137–141	4.0	10.14	13.04	1.45	4.35	14.49	0.00	1.45	0.00	2.90	0.00	5.80	30.43	14.49	1.45
124D/12	141–153.5	12.5	16.67	21.53	1.39	2.08	22.15	0.00	0.00	0.00	2.78	5.56	2.78	22.92	0.00	2.08
124D/13	153.5–161	7.5	13.94	26.67	3.03	5.45	21.12	0.00	0.00	0.00	4.85	4.85	4.24	6.67	1.21	6.06
Average			14.25	11.39	0.88	1.55	39.74	0.16	0.5	0.44	1.16	1.02	1.75	9.69	9.98	6.75

■ **Tab. 2.** Results of the maceral analyses (mineral matter containing basis) (*continued*).

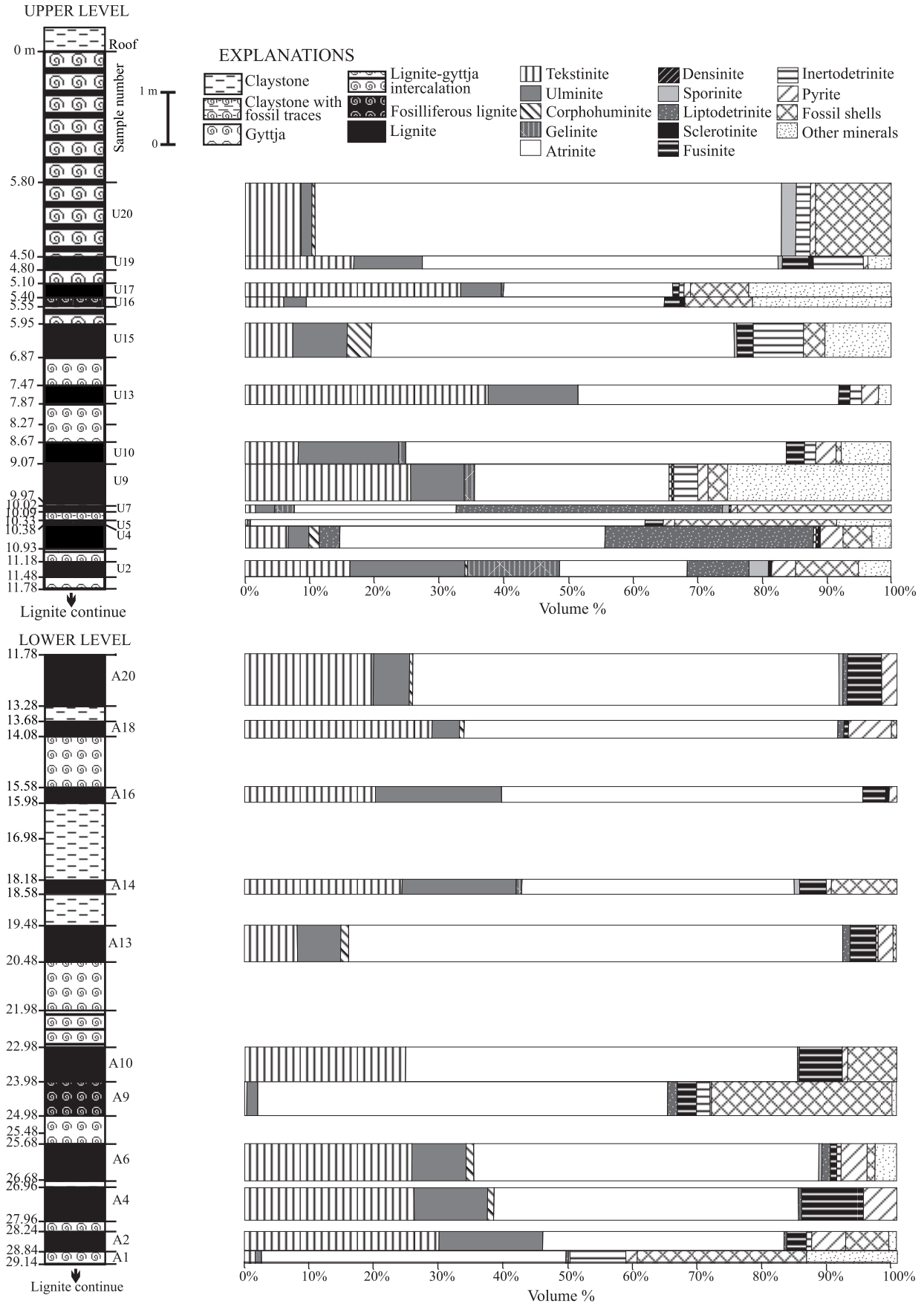


■ **Fig. 5.** Ternary diagram showing maceral group composition of the samples.

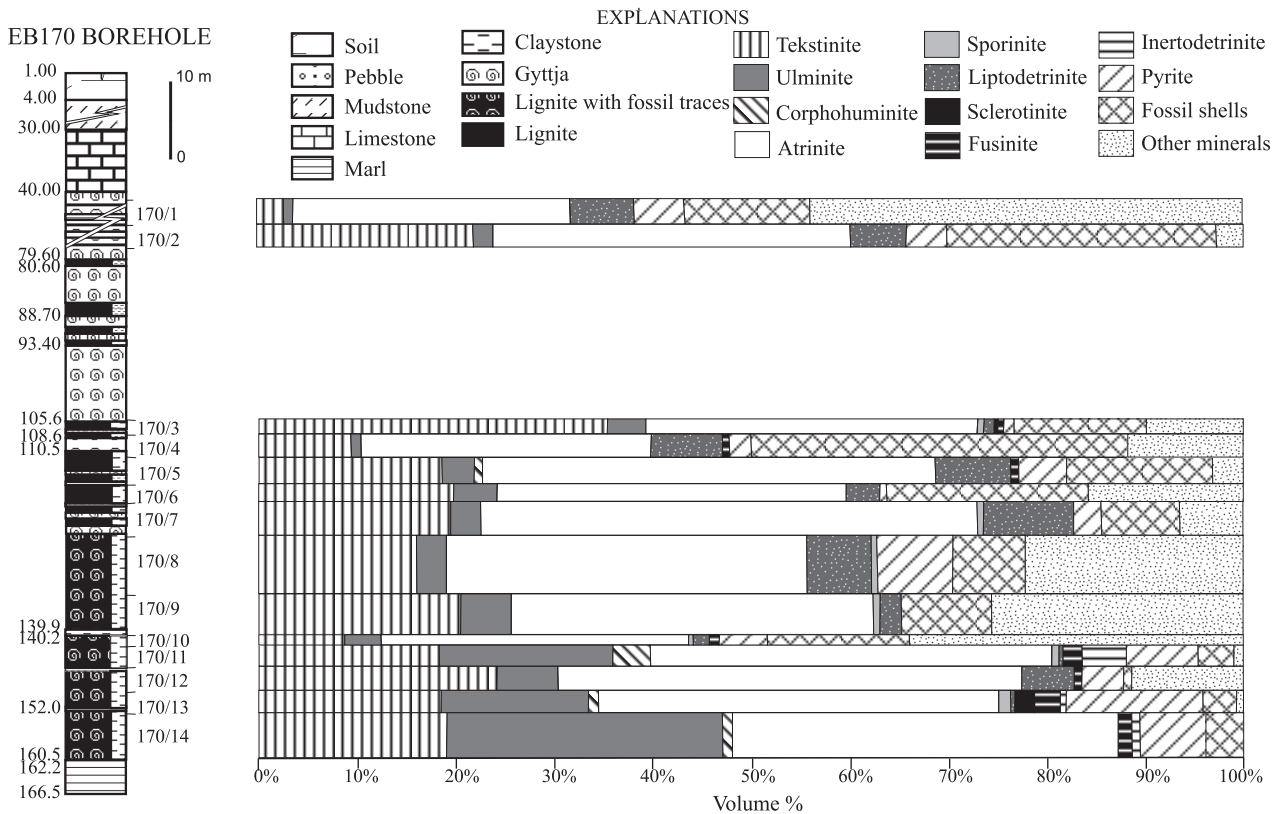
determined. Inertinite contents are generally below 5 vol. %, but in some samples, increase to 10 vol. %. EB170 and open-pit mine samples were selected in order to see maceral distributions of the samples with depth (Fig. 6). As it is seen in the Fig 6, the amounts of textinite and atrinite are nearly same in the samples. Ulminite content is different in some samples. For example, it is higher in the EB170 borehole samples taken from the base of the coal seam. Amounts of liptodetrinite and sporinite content in the EB170 borehole samples are generally close to each other. But they are high in the samples taken at the base of upper level of the open-pit mine. In contrast in these samples inertinite group macerals (fusinite, sclerotinite and inertodetrinite) are low. Similarly liptinite group maceral contents are low in the

lower level samples which have relatively high inertinite maceral contents (Fig. 6).

Fossil shells, pyrite and other minerals were described as mineral matter in this study. Fossil shells were determined average 1.16 vol. % in the open-pit mine samples and 0.65 vol. % in the borehole samples. The variation of their amounts is related to the nearness of the gyttja layers (Fig. 6). In the samples, crystal and framboidal pyrites were determined. Pyrite contents are generally below 3 vol. %. During the maceral analyses, clay minerals, quartz and some minerals (feldspar, gypsum, opal-CT etc.) were called as other minerals. Their average contents are 3.40 vol. % in the open-pit mine samples and 6.75 vol. % in the borehole samples. Cicioglu (2001) indicated that according to the XRD analyses, there were quartz, calcite, clay minerals, pyrite, feldspar, aragonite, opal-CT, gypsum and jarosite minerals in the samples. In addition that according to the results of the element and SEMEDX analyses, calcium is the most abundant major element in the Afsin-Elbistan lignites and calcium were determined in the organic materials in the some samples. Stach et al. (1982) said that calcereous shells and skeletal elements of swamp faunas, which in most peats are dissolved by humic acids, are preserved in calcium-rich peats and coals. Calcereous basements, or influx of calcium-rich waters from surrounding swamp areas, reduce the acidity of the peat to a much greater degree than does sea water. In the Afsin-Elbistan basin, basement rocks are represented by Cretaceous, Jurassic and Triassic formations which are generally composed of limestone hence swamp water may have been riched for calcium. Lüttig (1969) said that peat forming swamp in the Afsin-Elbistan basin was nourished from karstic waters. Consequently, fossil shells may have been preserved due to the calcium riched swamp water



■ Fig. 6a. Maceral and mineral matter distributions in the open-pit mine samples.



■ Fig. 6b. Maceral and mineral matter distributions in the EB170 borehole samples.

and calcium determined in the organic materials may have been taken from swamp water by peat forming plants.

Depositional environment of lignite

Facies critical macerals and petrographic indices derived from maceral analyses can be used to assess depositional environments during accumulation of the ancient peats. The proportions of the macerals in coals reflect the organic source materials contributing to the accumulation of peat and the conditions during accumulation; i.e. height of water tables, pH, decay by aerobic and anaerobic bacteria and mechanical breakdown of the organic matter related to transportation prior to final sedimentation (Kalkreuth 1991).

Humotelinite and liptinite are facies-critical macerals in lignites. Others like alginate, semifusinite and fusinite are indicators of the relative position of the water tables during the peat accumulation. Teichmüller (1962) shown that coals rich in well preserved humotelinite are related to an accumulation in a forest type swamp whereas coals rich in humodetrinite and spores are thought to accumulate in a reed marsh depositional environment. Subaquatic conditions are indicated by an association of humodetrinite, sporinite and clay minerals.

Diessel (1986), introduced two petrographic indices (GI = Gelification Index and TPI = Tissue Preservation Index) and related these indices by comparison with sedimentologically well characterized associated strata to prevailing swamp types (dry forest swamp, wet forest swamp, fen marsh). GI and TPI values were also used to define depositional environments such as upper delta plains, back barrier etc. (Kalkreuth 1991). The gelifica-

tion index is considered to reflect the height of the water table during peat accumulation, whereas tissue preservation index represents the effects of the input of woody material and its preservation prior to final deposition (Kalkreuth et al. 2000).

Diessel's (1986) TPI and GI concepts were modified by Kalkreuth et al (1991). In that study hard coal terminology was substituted by brown coal terminology. In this study, Tissue Preservation Index–Gelification Index facies concepts modified by Kalkreuth et al (1991) were used.

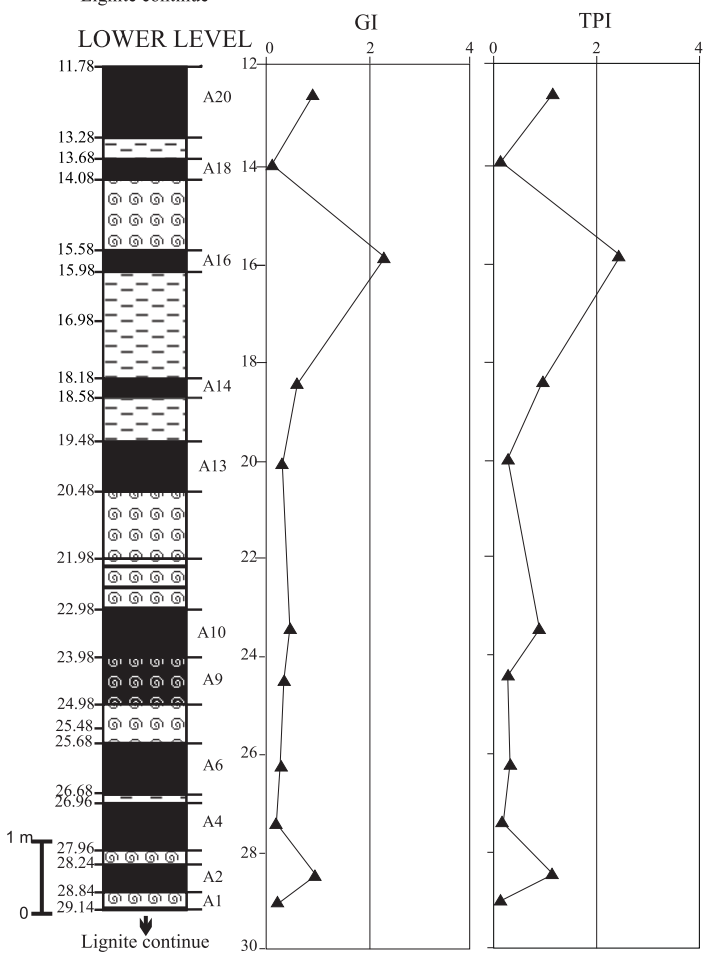
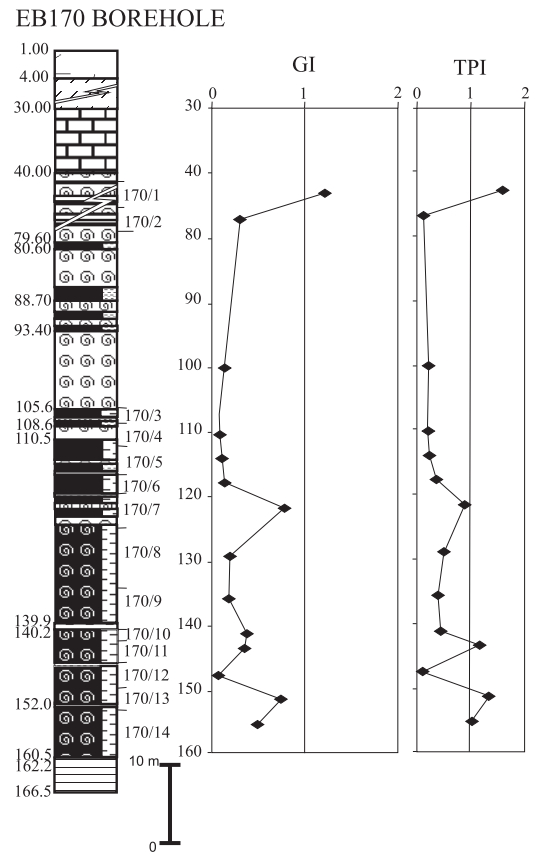
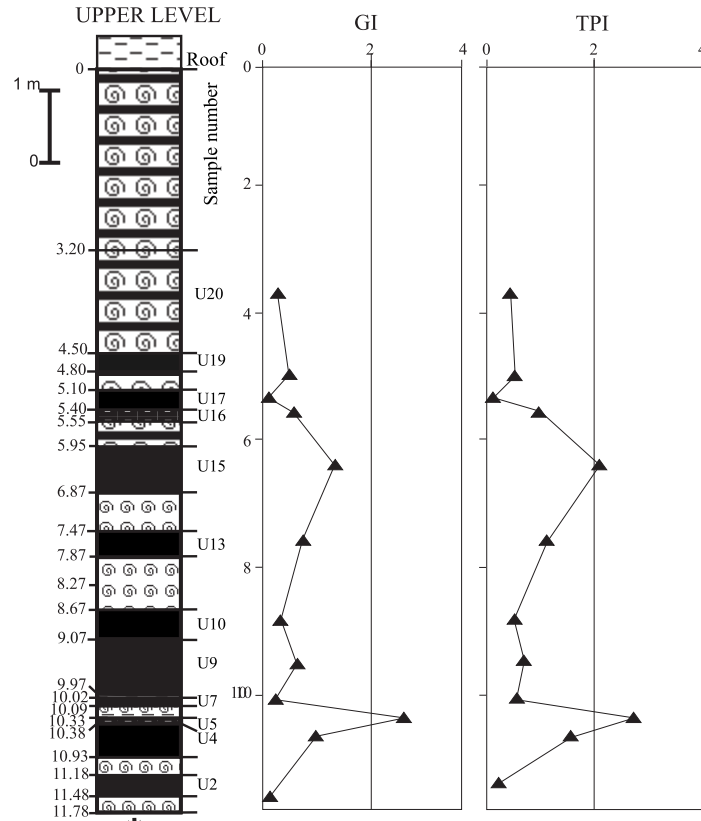
Gelification Index:

$$GI = \frac{\text{all huminite (except texto-ulminite and detrohuminite) + macrinite}}{\text{semifusinite + fusinite + inertodetrinite + texto-ulminite + humodetrinite}}$$

Tissue Preservation Index:

$$TPI = \frac{\text{humotelinite + korpohuminite (in-situ) + fusinite + semifusinite}}{\text{gelinite + macrinite + humodetrinite}}$$

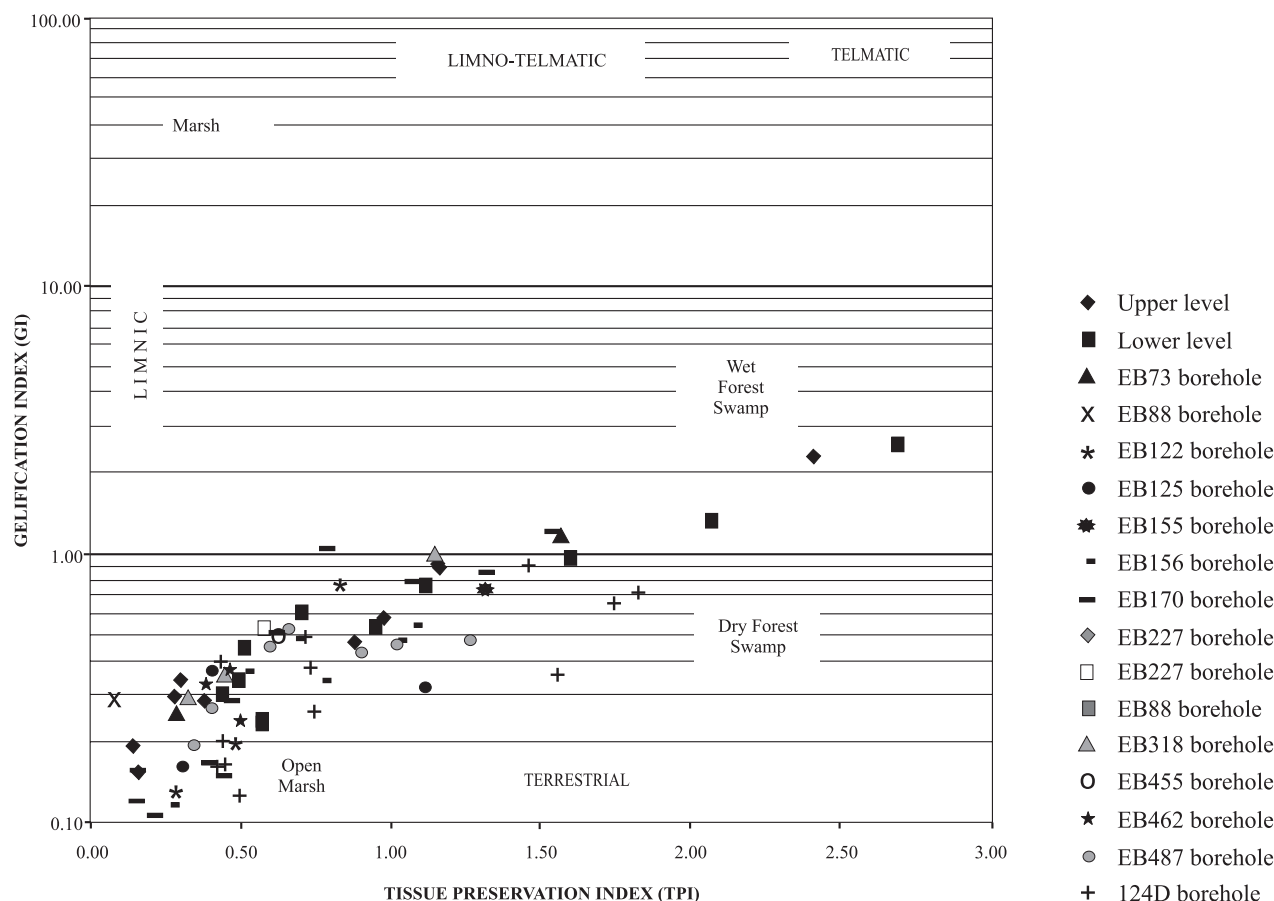
Gelification and Tissue preservation indices of the samples were low. GI and TPI values of the EB170 borehole and open-pit mine samples were selected in order to see their variations with depth (Fig. 7). GI and TPI values are variable in the EB170 and Upper Level samples, but they are generally close to each other (except two samples) in the Lower Level samples. A low TPI suggests either predominance of herbaceous plants in the mire or large-scale destruction of wood because of extensive degradation. The dominance of humodetrinite in the Afsin-Elbistan lignites suggests that herbaceous types of vegetation dominated the plant communities and furthermore, geochemical



EXPLANATIONS

- Soil
- Pebble
- Mudstone
- Limestone
- Marl
- Claystone
- Claystone with fossil traces
- Gyttja
- Lignite-gyttja intercalation
- Lignite with fossil traces
- Lignite

Fig. 7. GI and TPI variations in the EB170 borehole and open-pit mine samples.



■ Fig. 8. Facies diagram based on TPI and GI indices (from Diessel 1986).

gelification can be neglected because of the low rank. Ulminite macerals can be derived from biochemical gelification of cellulose-rich plant remains. Liptodetrinite and inertinite group maceral contents and GI variations in the samples indicate that water level of the peat swamp was variable and it may have been affected by high seasonal variations.

Based on the Tissue Preservation Index–Gelification Index facies concept (Fig. 8), Afsin-Elbistan lignites was deposited in an open marsh. Two samples, which have higher tissue preservation index, fell into wet forest swamp area.

Conclusion

The Miocene to Pliocene coal-bearing Ahmetcik Formation is represented by limnic and fluvial sediments. Limnic deposits were developed in the centre of the basin and are transitional to the fluvial deposits towards the basin margin. Upper Pliocene lignite seam is 80 m thick in the whole lignite zone, but it is 105 m thick in Kislakoy sector.

Rank: Huminite reflectances were measured on the ulminite macerals. Random reflectance values range from 0.21 to 0.27 %. According to the ASTM and DIN classifications, rank of the Afsin-Elbistan lignites is in the lignite and soft brown coal stage.

Petrographic composition: Main organic components are huminite group macerals (81.9 vol. % in the open-pit mine sam-

ples and 67.8 vol. % in the borehole samples), mainly humodetrinite and lesser amount of humotelinite in lignites. Liptinite (<3.88 vol. %) and inertinite (4.29 vol. % in the open-pit mine samples and 4.37 vol. % in the borehole samples) contents are also lower than huminite group.

Depositional environment of lignites: Herbaceous types of vegetation was dominant in the peat forming plant communities. Based on Tissue Preservation Index–Gelification Index facies concepts, lignites were deposited in an open marsh (reed marsh) and in subaquatic conditions.

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