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Geological and Geochemical Features of Alborz Basin Coal Deposits, Iran

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Abstract

The Alborz coal basin is located in northern part of Iran. The coal deposits of Shahrood in eastern Alborz, Zirab in central Alborz and Abyek in western Alborz were studied as typical coalfields of the basin. Shemshak Formation which is the main coal-bearing sequence was formed during the Triassic-Jurassic in the basin. It consists of sandstone, siltstone, shale and claystone, which variedly alternate with coal seams. The coal seams have relatively low quality because of highly disturbed and tectonized, having been subjected to multiple phases of orogenic deformation. The coals of Alborz basin are bituminous type and are dominated by macerals of vitrinite group and have relatively low proportions of exinite and fusinite. They contain different minerals such as clays (mostly argillite), pyrite and quartz as well as plant remains such as Cladophlebis, Marattia and Pachypteris. To compare the main geochemical characters of three typical coalfields of Alborz basin, we analyzed 18 samples for major oxides, ash and SO_3 content. The geochemical data show that the enrichment factor for major elements is less than 2. The Ti, P and Mn are enriched with high enrichment factor of 3, 18 and 7, respectively. The mineralogical and petrographic characters of the samples indicate that the coals were formed in lagoons and peat-swamps, fluvial flood plain to lacustrine depositional systems that experienced subtropical to tropical climatic conditions.

Keywords: Coal; Geochemistry; Geology; Alborz basin; Iran

Introduction

Iran coal basins are located mostly in its northern and central parts. Alborz coal basin located in the north of Iran that has been divided into three parts from west to east: the western Alborz, central Alborz, and eastern Alborz basins (Fig. 1). Lushan, Zirab and Shahroud are typical coalfields of western, central and eastern Alborz respectively. They are subject of the present study. The aim of the present paper is to determine relations of the coal ash and sedimentary features to the coal depositional environments in Alborz basin. Exploration activities since 1966 have led to discovery of many coal occurrences, and 50 coal deposits have been explored in

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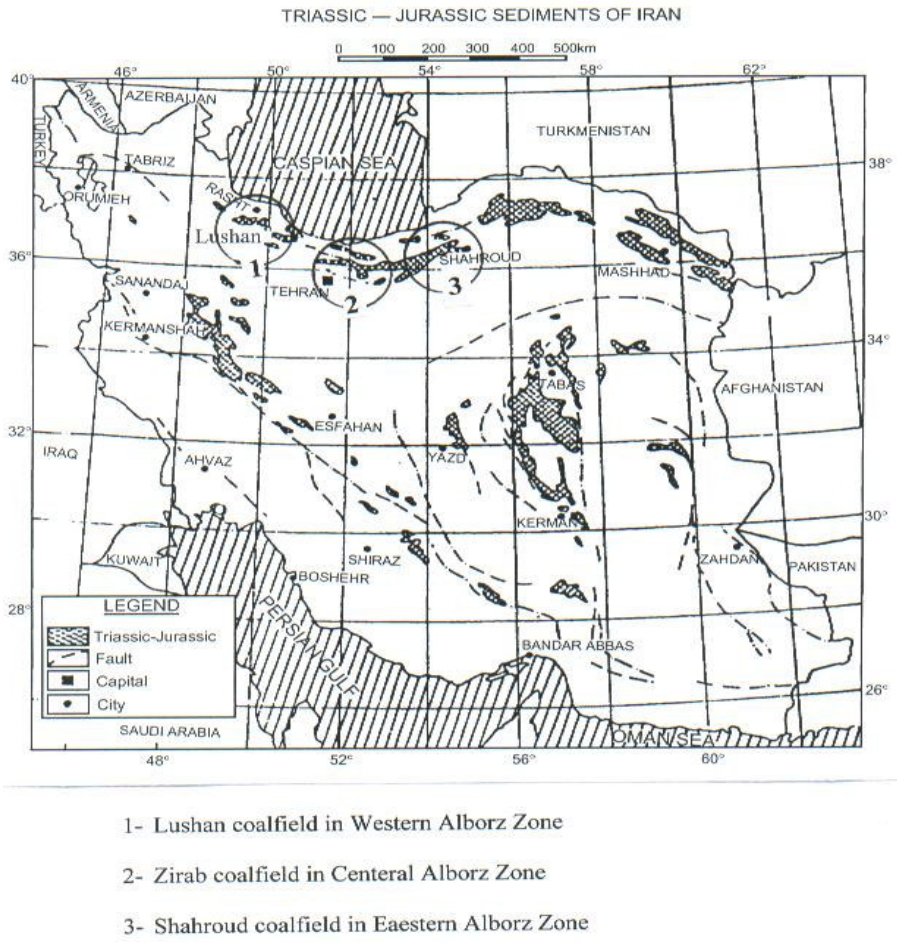

Figure 1. The Alborz coal basin location in northern Iran, showing the coalfields studied [8].

Age	Formation name	Lithology
Douger	Delichai or Lar	Limestone and Marl
Bajocian - Bathonian	Shemshak	Upper Carbonaceous zone + coal
Rhaetian - Liass		Upper Sandstone zone
		Lower Carbonaceous zone + coal
		Lower Sandstone zone
Norian – Rhaetian	Geirud and Elika	Limestone

Figure 2. Schematic stratigraphic column of the Shemshak Formation in the Alborz basin [3].

the Alborz basin in northern part [1]. The coal geology of Alborz basin is relatively poorly understood. A few Russian geologists have explored this area for coking coals. The coal deposits in Alborz basin are highly disturbed and tectonized, having been subjected to multiple phases of orogenic deformation. Coal occurs as discrete lenses, several tens of meters in their lateral dimension, between steeply dipping, overturned, and thrusted carbonaceous beds of Triassic-Jurassic age.

The main geological structures of present-day Iran were formed by Cretaceous orogenic [2]. Alborz mountain ranges (Alborz zone) in the northern of Iran were probably developed at this time. At the end of Middle Triassic or in late Triassic Alborz zone was uplifted from under the sea by Samarian orogeny. For this reason, there is an unconformity between the Late Triassic and the Early Jurassic strata. Under these conditions the lagoonal and swamp environments were formed with large forest areas. Deltaic and peat-swamp sediments and some traces of marine environments can be seen in the succession. Shemshak Formation which is the main coal-bearing sequence was formed during the Rhaeto-Liassic to Bajocian and Bathonian periods. It consists of sandstone, siltstone, shale and claystone, which variedly alternate with coal seams. The Upper Triassic (Norian-Raetian) sediments were deposited on an eroded surface of Middle Triassic fossiliferous limestones and argillaceous-ferruginous weathering residues. Beneath Shemshak Formation overlies the Geirud and Elika Formations, unconformably (Fig. 2). During the Douger (150-175 Ma) Delichai (limestone and marl) or Lar (fossiliferous limestone) Formations were deposited over Shemshak Formation. The coal-bearing strata in Alborz basin were developed in single sedimentary cycle and form a distinct stratigraphic unit. Deposition took place in an alluvial plain and coastal environment. Shemshak Formation in Alborz basin has continental and liminic facies but it is more marine in Central Iran.

Shemshak Formation has been subdivided into four lithozones: the lower sandstone zone (sandstone, greywacke, and shale), the lower carbonaceous zone (carbonates, siltstone and coal seams), the upper sandstone zone (sandstone, siltstone and shale), and the upper carbonaceous zone (carbonates, siltstone, argillaceous shale and coal seams). The coal seams commonly occur within the clastic to carbonaceous parts of Shemshak Formation [3]. The main coal seams throughout Alborz basin were formed at the base of Shemshak Formation (Kelariz and Alasht members) deposited in deltaic and peat-swamp environments. Coal seams also occur at the top of Shemshak Formation (Dancerite and Anen members), in the southern part of Alborz basin. Dancerite member consists of siltstone, argillite and sandstone deposited in alluvial and lacustrine environments.

The Anen member consists of siltstone, argilite, thin beds of limestone, and sandstone deposited in the southern part of Alborz mountain range in shallow marine to lacustrine environments. The geological structure of Alborz basin is very complicated. The coal mine area is dominated by a highly faulted east-west trending syncline. The faults are mainly normal but thrust faults are also present [4]. The coal seams have been affected highly by these faults.

Materials and Methods

To compare the main geochemical characters of three typical coalfields of Alborz basin, we analyzed 6 samples (totally 18 samples) from each coal field for major oxides, ash and SO_3 content. Because of analytical limitation we also analyzed only 1 sample from each coalfield for trace elements.

The samples were chosen to represent a significant variation in rank. Most of the coals were selected seam samples and consequently have lower mineral contents than the whole-seam or run-of-mine coal. The result of analyses is given in Tables 1 and 2. The coal samples initially were crushed, homogenized to less than 850μc. The crushed samples were stored in sealed containers under an inert atmosphere to avoid oxidation [5-7]. 100 gram from each samples are heated at 850°C for three hours and the coal ash percent is measured by analytical balance (conventional method). Also, we used new made dual energy gamma-ray technique for ash measurement. The concentrations of the major and trace elements were determined using a wavelength X-ray fluorescence spectrometer (XRF Philips 1400) in Research Center of Atomic Energy Agency of Iran.

Results and Discussions

Petrological studies show that coals of Alborz basin cover wide range of ranks. The active mines produce primarily coking coal; some mines also produce steaming coal with a relatively high ash yield. The coking coal has relatively high vitrinite (60-90%), and low inertinite (10-20%) and liptinite contents. The dominant macerals of vitrinite group are telinite and collinite. Previous mineralogical studies of Alborz basin have revealed that syngenetic pyrite, marcasite, detrital quartz, siderite, calcite, illite, and kaolinite are the main minerals in these coals. Coals of Alborz basin coals have low to medium (3-26%) ash contents combined with variable sulphur contents (0.5-4%) and medium to

high heating values (27-29 MJ/Kg). The moisture content of Alborz coals range from 0.2% to 3.5%, and are commonly around 2.0%). Although the coal characteristics in Alborz basin are broadly similar, some differences exist among various coalfields of the basin [6-8].

a. Coal Characteristics in Western Alborz

The coal seams of Lushan coalfield were formed between the conglomerates, sandstones, siltstones and gravelly sands of Alasht and Kelariz members of Shemshak Formation. The dominant mineral phases are pyrite, detrital quartz, siderite, calcite, illite, kaolinite and bauxite.

Vitrinite (50-80%) is the dominant constituent in the coal seams of Lushan coalfield followed in abundance by inertinite (10-30%), liptinite (2-8%), and mineral matter (1-10%). Lushan coals are low to medium in ash (3-22) but have relatively low to medium sulphur (0.5-4%). They have high light vitrinite reflectance in oil immersion (0.94-1.03 in randomly studied samples) and intermediate heating values (27-33 MJ/Kg). The high values of vitrinite reflectance confirm the very high coalification levels of the coals in Lushan coalfield.

The coals of western Alborz coalfields are characterized by low sulphur (0.5-4%), low volatile matter (3-22%), high C content (88%), and relatively low H content (5%). Sulphur occurs in this coalfield as organic, pyritic and sulphate forms. Pyrite is present in either epigentic or syngentic forms. The syngentic pyrite is fine and deeply embedded in the coal fabric (pyrite framboids). The epigenetic pyrite normally occurs as coarse grains. Average concentrations of some major and trace elements such as Sr, Ba, Si, Ca, Mg and Mn, are higher than those of most coals in the world, while that of others fall within global ranges. It seems that aluminum-silicate, carbonate and sulphide minerals (mainly detrital minerals) are responsible for occurrence and distribution of most of these elements (Sr, Ba, Si, Ca, Mg and Mn) in the studied coal samples [6-9].

b. Coal Characteristics in Central Alborz

The coal is mainly found within Kelariz, Alasht, Anen, and Dancerite members of Shemshak Formation alternating with sandstone, siltstone, and claystone. In Zirab coalfield the constituents are: vitrinite (48-95%), inertinite (20-45%), liptinite (5-11%) and mineral matter (less than 10%). The dominant mineral phases in these coals are pyrite and detrital materials such as quartz, siderite, calcite, and clay minerals. These minerals can mainly be seen in fractures. These coals

Table 1. Average of major elements (as %) in 3 representative samples from Alborz coal basin [6-10]

Oxides	Shahrud coalfield	Zirab coalfield	Lushan coalfield	UCC
SiO_2	53.87	54.21	60.34	60.6
Al_2O_3	24.99	29.35	22.16	15.9
Fe_2O_3	8.76	3.14	1.94	6.7
TiO_2	2. 34	1.29	1.01	0.72
CaO	1.45	1.15	5.05	6.4
MgO	1. 53	2.32	1.1 7	4.66
Na_2O+K_2O	3. 1	5	5.83	4.88
P_2O_5	1. 55	2.35	0.21	0.13
MnO	0.12	0.33	0.7	0.1
SO_3	0. 47	0.91	1.19	*
Ash	37.72	28.11	14.44	*

UCC : Upper Continental Crust

Table 2. Average of trace elements (as ppm) in 3 representative samples from Alborz coal basin [6-10]

Elements	Shahrud coalfield	Zirab coalfield	Lushan coalfield	UCC
V	100	1200	1300	53
Cr	749	655	411	35
Co	350	187	425	11.6
Ni	453	308	2300	18.6
Cu	489	442	737	14.3
Pb	526	211	430	17
Zn	1600	520	320	52
Ga	94	145	323	14
Ge	56	26	283	1.4
As	73	4	88	2
Au	0.311	0.146	0.130	0.146
Ag	10	9	8	0.055
Hg	0.152	0.94	0.116	0.056
Sn	38	36	21	2.5
Sb	15	9	41	0.31
Sc	8	201	320	7
Th	73	98	81	10.3
U	25	27	24	2.5
Zr	898	1500	954	237
La	160	131	54	32.3
Nb	134	293	53	26
Ta	2	83	2	1.5
Ce	304	308	127	65.7
Y	237	317	237	20.7
Ba	1700	1300	251	668
Sr	2500	2100	440	316
Rb	228	398	98	110
Br	*	*	11	*
Cl	*	*	115	*

* not detected UCC : Upper Continental Crust

are mainly humite to saprolite of clarodurite types. The coals of Zirab coalfield were formed in alluvial-fluvial flood plains, lacustrine and peat bog environments [3]. Zirab coals have low ash content (1-37%), low sulphur content (0.2-1.1%), variable moisture contents (0.4-24%), variable volatile matters (4-46%) and high calorific value (30-37 MJ/Kg) [6-10].

c. Coal Characteristics in Eastern Alborz

The coal seams in Shahroud coalfield, which is typical of eastern Alborz basin, are interbeded with sandstones, siltstones, and claystones of Kelariz, Ekraser and Lellah Band members, at the base of Shemshak Formation. The common mineral phases in these coals are pyrite, quartz, siderite, calcite, illite, and clay minerals. These coals were formed in interdeltaic, peat bog and coastal plain environments [3].

The analyses confirm that Shahroud coal contains low ash (3-9%) with medium to high sulphur (1.3-6.7%), low moisture (0.8%) and high calorific value (34-37 MJ/Kg). The heating values indicate a high volatile humic rank for Shahroud coals. The coal samples from eastern Alborz coalfields are geochemically characterized by low sulphur (1.2-6.7%), low moisture (0.4-1.1%), average values of C (86%) and H (3.7-6.4%). Sulphur occurs in this coalfield as organic, pyritic and sulphate.

In the studied samples amount of major oxides such as SiO_2, Al_2O_3, TiO_2, MgO, $Na_2O + K_2O$, CaO, and FeO_t are indicate of presence of minerals like kaolinite, free SiO_2 (quartz) and aluminum silicate fractions like clay minerals, carbonates, and sulphides [6-10]. Chemical analyses show that C values in the coal samples from Shahroud coals is high and quite variable, ranging from 76% to 93%. Ash contents range from 1% to 41%, but are commonly less than 10%. The ash values in the studied samples were measured by conventional and new dual energy gamma-ray technique [10].

d. Geochemical Characteristics

The enrichment or depletion of an element will be a function of that association and the origins of the various coal fractions [6]. Enrichment of an element in coal may be described by an enrichment factor which is the ratio of the concentration of elements in coal to the average concentration in the upper continental crust (Tables 1-2 and Figs. 3-4) [11]. All the major elements have an enrichment factor less than 2 with the exception of P (up to 11). The Ti, P and Mn are enriched with high enrichment factor of 3, 18 and 7, respectively. High enrichment of P indicates that the organic and phosphate minerals are the major source of this element. The elements Si, Al, Ti and K are mainly associated with quartz and the clay minerals. The variations in Si and Al are primarily attributed to kaolinite, although illite and phosphate minerals make significant contributions to Al. The low enrichment for Si, Fe, Mg, Ca, Na and K is to be expected because firstly, the detrital mineral matter is greatly diluted by the organic matter in comparison with shales and secondly, diagenetic kaolinite in the coal is volumetrically a minor component. Ca and Mg are indicating the importance of the carbonate minerals for these elements. The content of Fe is mainly controlled by pyrite. The contributions of carbonate minerals to Fe are also important. Low value of Na can be due to pore fluids. Although Na is also present in the pore fluids, it is depleted because Na is a major element in crustal rock-forming silicates [5, 11, 12].

The trace elements Ni, Ge and Ag are enriched with high enrichment factors of 100-200, As, Hg, Ga and Ta with enrichment factors of 50-100, Sb, Sn, Pb, Zn, Cu, Co, Cr, V, U and Y with enrichment factors of 10-50 and Ba, Sr, Rb, La, Ce, Th, Nb, Zr, Hg and Au with enrichment factors of less than 10, respectively (Fig, No.4). The distribution of the trace elements can be

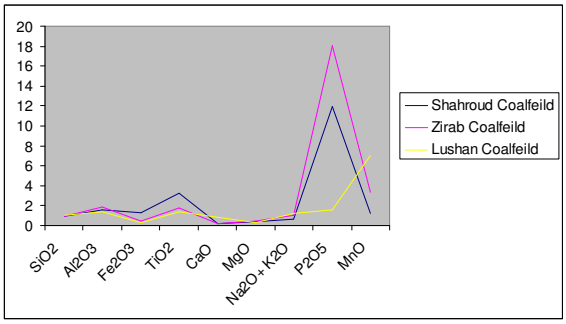

Figure 3. Extended plot of major elements (normalized to upper continental crust) for coals of Alborz coal basin, Iran.

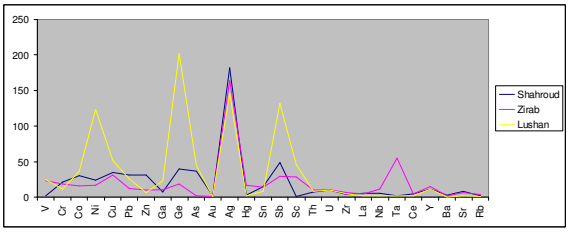

Figure 4. Extended plot of trace elements (normalized to upper continental crust) for coals of Alborz coal basin, Iran.

related to the mineralogy by reference to the major elements. The trace elements of Rb, Cr, Th, Ce, Zr, Y, Ga, La, Ta, Nb and V and Si and Al, due to the clay minerals. Sr and Ba are due to the presence of Al-phosphate minerals. Ce, Y, La and V appear to be hosted in the non-illite clay minerals. The chalcophile elements such as As, Cu, Sb, Pb and Zn due to the sulphide minerals such as pyrite. Carbonate minerals are found to make little contribution to the trace element enrichment. Cl and Na are major components in the porewaters and the main source of these elements. High enrichment of these elements in the Shahroud coalfeild is thought to be from in seawater, where the latter is thought to be salinity controlled; and enrichment factor of these elements are comparable with marine shales. The high enrichment of Ge and P in these coals is found to be controlled by the organic matter. In the above discussion, the major and trace elements possibly associated either directly or indirectly with the organic matter, clay minerals, sulphides (pyrite) and quartz.

Detailed geological and geochemical investigation of the Triassic- Jurassic Shemshak Formation in Alborz basin were undertaken to determine relations of coal composition, quality and ash yields [6-10,13,14]. In Alborz basin, Shemshak Formation is divided into four units based on abundance and lateral continuity of facies. These lithozones are lower sandstone (sandstone, greywacke, and shale), lower carbonaceous (carbonates, siltstone, and coal seams), upper sandstone (sandstone, siltstone and shale) and upper carbonaceous (carbonates, siltstone, argillaceous shale and coal seams). The lower sandstone unit consists of flood plain facies sediments. In eastern Alborz basin, this unit was deposited in an interdeltaic coastal plain environment that was protected from marine incursions by the beach sandstones. The upper sandstone unit of Shemshak formation in central Alborz basin was deposited in a distal fluvial flood plain environment and has similar facies to the lower unit, but sandstones in the lower unit includes greywacke.

The coal seams commonly occur within carbonaceous units (lacustrine sediments) of Shemshak Formation, whereas the alluvial-fluvial flood sediments are poor in coal seams. Characteristics of few coal seams in the lower carbonaceous unit suggest that this unit developed probably during hiatus in clastic deposition, whereas upper unit coals appear to have been formed almost contemporaneously with clastic sediments like shales [1, 4, 6-10 and 13-14].

The vitrinite content relatively increases upwards at the expense of semifusinite, possibly reflecting an increase in the proportion of vegetation in these coals. The vitrinite reflectances are relatively high in the coals of Alborz basin but the highest values can be seen in coals of Lushan coalfield in the west, which probably result from intrusive phases in Lushan area [9].

In summary, data from the study area support a scenario that the coals in Alborz basin were deposited in fluvial flood plains, but mainly within lacustrine and peat bog environments to deltaic coastal plain. The deposition system was protected from marine influences. Generally, the marine -influenced coals have high sulphide and lower dolomite and siderite contents, with higher fractions of aluminosilicates. This is in agreement with the continental sedimentations of Alborz basin. The coals also contain various continental plant remains such as Cladophlebis, Marattia and Pachypteris [4].

Shemshak Formation (Triassic-Jurassic) coals from Alborz basin were investigated for their geochemical and petrographic properties. This formation mainly consists of sandstone, shale, siltstone and claystone. Several coal seams are interbedded within the sequence. The distributions of these sediments and coal seams are different in the eastern, central and western parts of Alborz basin. In the eastern parts conglomerates, sandstones, siltstones, and claystone are more common while in the western part gravel quartz, siltstones, and claystone dominate. Geological structure of the basin is very complicated and dominated by highly faulted synclines. For this reason, many coal seams in the basin have no economic value. Geology and mineralogy of these coals suggests that they were deposited in a lagoon to peat-swamp to fluvial flood plain environments, under fresh water conditions with no definite indicators of marine influence.

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