
Geochemistry and Mineralogy of Meting-Jhimpir Coal, Sindh, Pakistan

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RECEIVED ON 14.06.2011 ACCEPTED ON 15.03.2012

ABSTRACT

The Meting-Jhimpir coalfield covers an area of about 90 square kilometers. The coal in the Meting-Jhimpir area was deposited in Early Eocene age, in the east of Karachi. The coal is enriched in Fe, Zn, Pb, Ni, Cu, Cr, Sb, As, Co, Cd, Mn, Na, K, Ca and Mg. The study also shows that in Meting-Jhimpir coal quartz is dominant mineral and calcite and dolomite as accessory minerals.

The comparison of studied coal with Clarke values shows that the coal is slightly enriched with Co, Cr, As, Ca, Mg, and U and Cu, K, Na, Ni, Pb and Zn are depleted.

Key Words: Elemental Studies, Enrichment and Depletion Factor, SEM, XRD.

1. INTRODUCTION

The Meting-Jhimpir coal is lignite to sub-bituminous coal. Its calorific value and sulphur content range from 9608-5338 kcal/kg and 2.00-5.20% respectively. Fixed carbon and ash content in studied coal vary between 38.43-45.67, 9.52 and 12.42% respectively [1].

The Meting-Jhimpir coalfield lies approximately 150 km to the east of Karachi lying between latitudes 25° 03' - 25° 07' N and longitudes 68° 02' - 68° 08' E in the vicinity of Jhimpir and Meting railway stations on the main railway line. The coalfield covers an area of about 422 sq.kms. in Thatta District (Fig. 1). The coal in the Meting-Jhimpir area was deposited on the erosional surface of the Palaeocene rocks [2]. It is now grouped in the lower part of the Laki Formation of Early Eocene age. Only one workable coal seam is present which is generally thin and lenticular. Its

thickness varies from 0.3-1.0 metre with an average thickness of about 0.5 metre. The coal is of lignite-A to sub-bituminous-B in rank. It is soft and friable and suffers from spontaneous combustion on exposure. Total available resources of coal in the Meting-Jhimpir area are presently estimated as 0.016 billion tonnes, and the average annual production is of the order of 40,000 tonnes [3].

2. GEOLOGY OF THE AREA

Meting-Jhimpir coal basin is located as a small coal basin in between Sonda and Lakhra coalfields, small lenticular bed ranging in thickness from 0.3-1 meter, with an average of 0.5 meter at the depth of 50 meters.

The coal is associated with basal part of laterite. In this zone a sequence of shale and lateritic clay is associated

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with beds of arenaceous sandstone of Laki formation. [4]. The lower contact of the Laki Formation is unconformable with Lakhra Formation and is marked by Sonhari member. Fatmi, et. al. [5] have divided the Laki Formation into four members named as Sonhari member, Meting limestone, Shale member and Laki limestone member [5] (Fig. 2).

The Sonhari Member, comprises of lateritic clay of reddish brown to yellowish brown colour, sandstone and gypsiferous shales are silty, sandy, and highly ferruginous with local patches of fire clay and lenticular lignite beds [6].

Sandstones are yellowish brown to light brown and dark grey in color, fine to coarse grained and gritty. Shales are

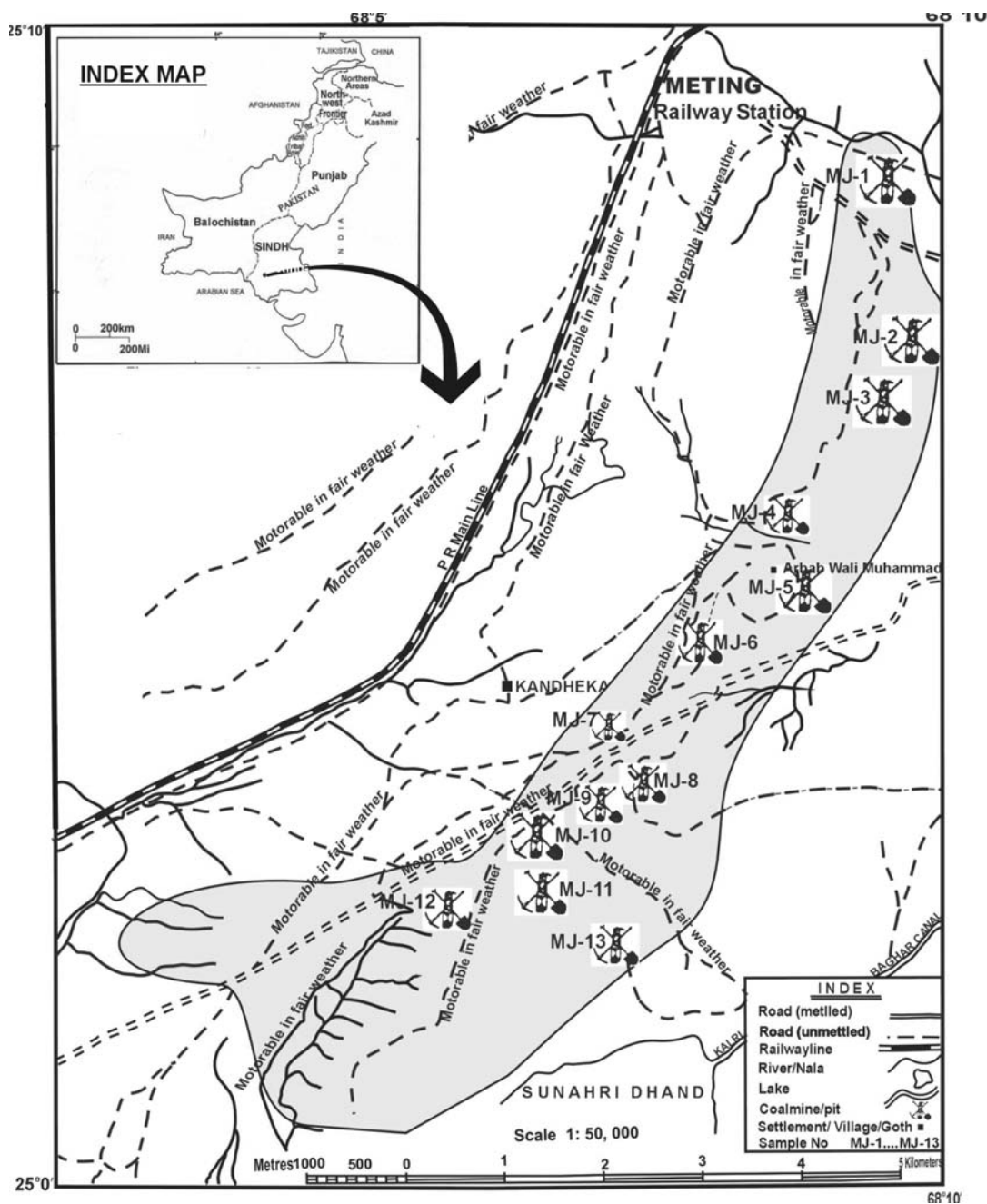


FIG. 1. SHOWING LOCATION OF METING-JHIMPIR COALFIELD

of various colours like blackish grey and dirty brown, containing carbonaceous shale with poorly developed lignitic material and pyrite crystals. Small bands of laterite occur in the middle part of the beds. Sonhari units vary in thickness from 10-30 meters.

Lithologically in Meting limestone and Meting shale, limestone is nodular and light creamy in colour, while subordinate sandstone is deposited in upper part. The shale weathers into dark rusty brown, ferruginous and gypsiferous. The limestone is thin bedded and arenaceous where as the sandstone is commonly

ferruginous. The Meting Member is about 70 meters thick at the type locality [7]. The limestone of Laki limestone member is light yellowish-grey and nodular, hard, resistant and massive.

The Lakhra Formation is highly calcareous and consists of argillaceous sandstone. At the type locality, the sandstones beds are followed by shale of variable thickness. The sandstone is grey, yellowish-brown in colour, fine to medium-grained, with traces of dark minerals (rock forming minerals having specific gravity 2.8). Thin layers of highly ferruginous hard sandstone occur at various intervening time/periods. The shale is variegated with red, brown, yellow, and gypsiferous. The unit is followed by argillaceous limestone, which is thick bedded to massive. Overlying this unit is a thick sandstone member which is yellow in colour and is generally calcareous fossiliferous. The rest of formation comprises alteration of shale and limestone with subordinate variegated sandstone.

The limestone units although thin, and at different intervals variegated shale with ferruginous concretions and subordinate sandstone becomes a prominent member. The beds are unconformable and cutting progressively younger beds. In Jherruck area younger beds crop out and a highly coral limestone occurs towards the top of the formation [5].

The Bara formation is composed of sandstone, shale, and lignite. The sandstone is coarse-grained, occasionally pebbly and contains sub rounded pyrite and glauconite. The shale is dark-grey to dark-brown, sandy and occurs at different intervals. Lignite is found in upper 30 meters.

3. MATERIALS AND METHOD

Thirteen fresh bed coal samples were collected from the coal mines located in the area, and pulverized to 75 μ (200 mesh size); a portion of individual sample was collected after quartering and coning and air dried in oven at 110°C for two hours in order to remove the moisture.

ERA	PERIOD	EPOCH	FORMATION	MEMBER	LITHOLOGY	DESCRIPTION
C E N O Z O I C	T E R T I A R Y	E O C E N E	L A K H R A	Laki Limestone		Lakilimestone white, medium light grey, weathers to yellowish grey, yellowish white and buff colour; cherty, argillaceous, some are compact, dense, silty forming vertical cliffs. Weathering products are cave and honeycomb like features mostly developed in the thick or massive beds
				Meting Shale		It consists of predominantly of shale claystone with subordinate interbedded limestone. Shale and claystone weather to greenish yellow, greenish grey, thinny laminated on weathered surface.
				Meting Limestone		Meting limestone member consists of predominantly of limestone and marl with subordinate amount of claystone; limestone light grey and light yellowish grey, and argillaceous, nodular, claystone is grey, olive grey to chocolate brown, weathers to yellowish brown.
				Sohanri		Surface exposure of consists of highly ferruginous claystone and sandstone of multi colour, varying from yellowish brown, dark yellowish brown. The lenticular bands of limonite, ochre, fire clay and lignitic coal seams of varying thickness are characteristic units. Sandstone is fine to medium grained, poorly sorted, loose, friable and lenticoid.
P A L E O C E N E	B A R A	L A K H R A			Formation comprises of sandstone, limestone and shale. Limestone beds are more frequent in the upper part of the formation. Sandstone is grey, yellowish brown, fine to medium grained with traces of dark minerals. Rest of the formation comprises alteration of shale and thin and hard limestone with subordinate variegated sandstone	
					Formation mainly consists of sandstone, with subordinate shale, siltstone with layers of conglomerate. Sandstone is variegated with chocolate and brown colour.	

FIG. 2. STRATIGRAPHIC SECTION OF METING-JHIMPIR COALFIELD [5]

For trace element geochemistry, samples were prepared by acid digestion method in concentrated HF, HNO₃ and HCl as described by Jeffery, et. al. [8]. For the elemental analysis (i.e., Pb, Zn, Cu, Ni, Cr, Co, Cd, As, Fe, Mn) samples were analyzed by Perkin Elemer AAnalyst-700 graphite furnace Atomic Absorption Spectrophotometer at geochemistry laboratory of NCE in Geology, University of Peshawar. Bruker-AXS, S4-PIONEER X-ray fluorescence was used for the analyses of arsenic (As), antimony (Sb) and uranium (U) [9-11]. The mineral constituents of coal were determined on the Rigaku x-ray diffractometer. In this case, the method of Klug and Alexander was followed [12].

For the interpretation of XRD patterns, Hanawalt method of quantitative analysis was used [13]. The XRD peaks/patterns of the studied coal are displayed in Fig. 3.

The surface characteristics in studied coal samples were determined by JEOL-6490 LV Scanning Electron Microscope. JEOL-JEE-420 coating unit was used for mounting the polished broken coal samples. The operating voltages were 15 and 25kv; while the collection time for X-Rays was 20s.

The images for image analysis were taken at 450x, 600x, 3,700x magnification and saved in jpg (1280x960 pixels) format, and a count time of 20s was fixed. For image processing and analyses QUANTAX ESPRIT 1.8.2 software was used. The micrographs of investigated samples are displayed in Fig. 4.

4. RESULTS AND DISCUSSION

4.1 Geochemistry of the Meting-Jhimpir Coal

Table 1 summarizes the results of geochemical analyses of Meting-Jhimpir coal. This table shows the minimum and maximum concentrations of heavy and trace metals in coal and their standard deviation (for indicating the degree of variability). The concentration of sulphur ranges from 2.00-5.20%; mean 3.65% [14].

Arsenic is usually associated with pyrite in coal [15]. The arsenic content in studied coal is ranging from 1.8-3.4 ppm with a mean value of 2.61 ppm (Table 1). It is lower than the

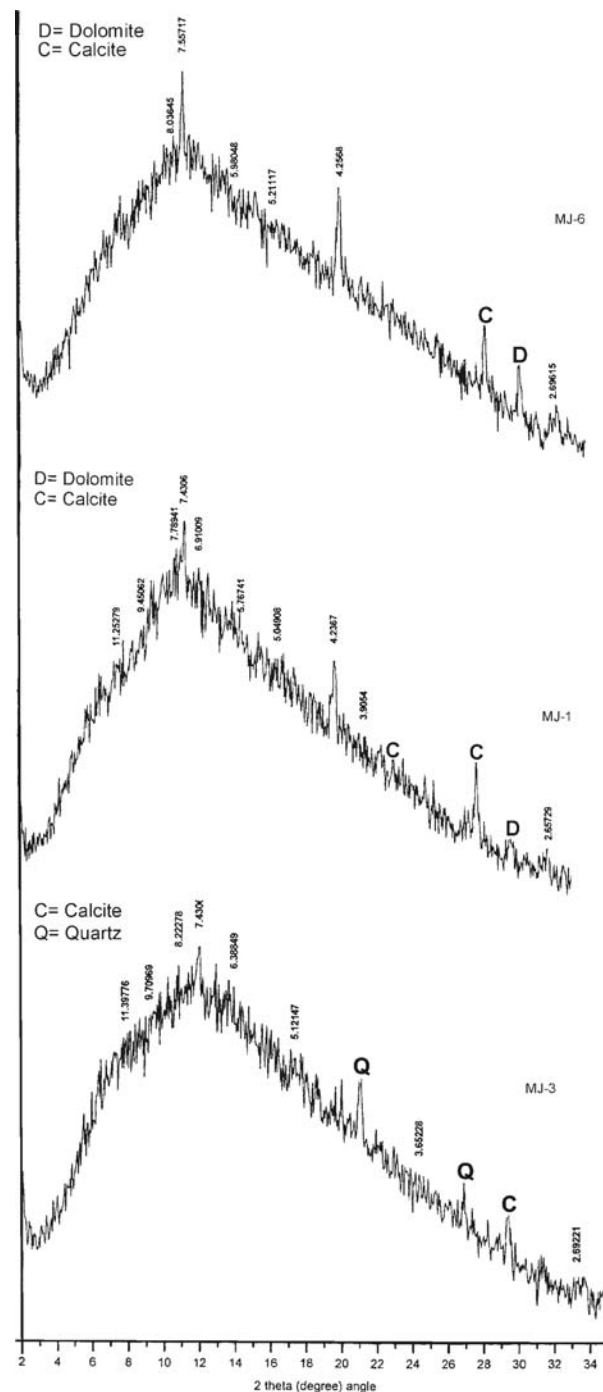


FIG. 3. X-RAY DIFFRACTOGRAM SHOWING THE PEAK POSITION OF MINERALS IN COAL SAMPLES FROM METING-JHIMPIR COALFIELD OF SINDH, PAKISTAN

mean for coal elsewhere in the world [15-17] have associated the arsenic to the inorganic matter present in the coal. In coal, sometimes arsenic is found as sulphide-rich fraction and it is also found as the solid solution because of the pyritization in coal [18]. In addition, arsenic and antimony may occur as essential constituents in organic matter [11]. Due to dispersion of stibnite (Sb_2S_3) grains in organic matter, antimony may be present in the form of solution in coal [19].

The mean worldwide value for cadmium in coal is 0.5 ppm [15]; the cadmium content in studied coal ranges from 0.1-0.4 ppm with a mean value of 0.34 ppm (Table 1). It is lower than the mean values for coal elsewhere in the world [20].

In coal the presence of cadmium is either due to the sphalerite or because of calcite and dolomite in organic matter [21].

Cobalt is thought to be related to the sulphide minerals, [20-22]. Table 1 reveals the minimum content of cobalt in studied coal as 0.05 ppm and the maximum content as 0.55 ppm with a mean value of 0.25 ppm. The mean value of cobalt in studied coal is lower than the coals of elsewhere in the world. Chromium content in studied coal ranges from 0.8-22 ppm, with mean value of 12 ppm. Chromium is one of the elements of most concern with respect to environmental concerns because of possible toxicity [23].

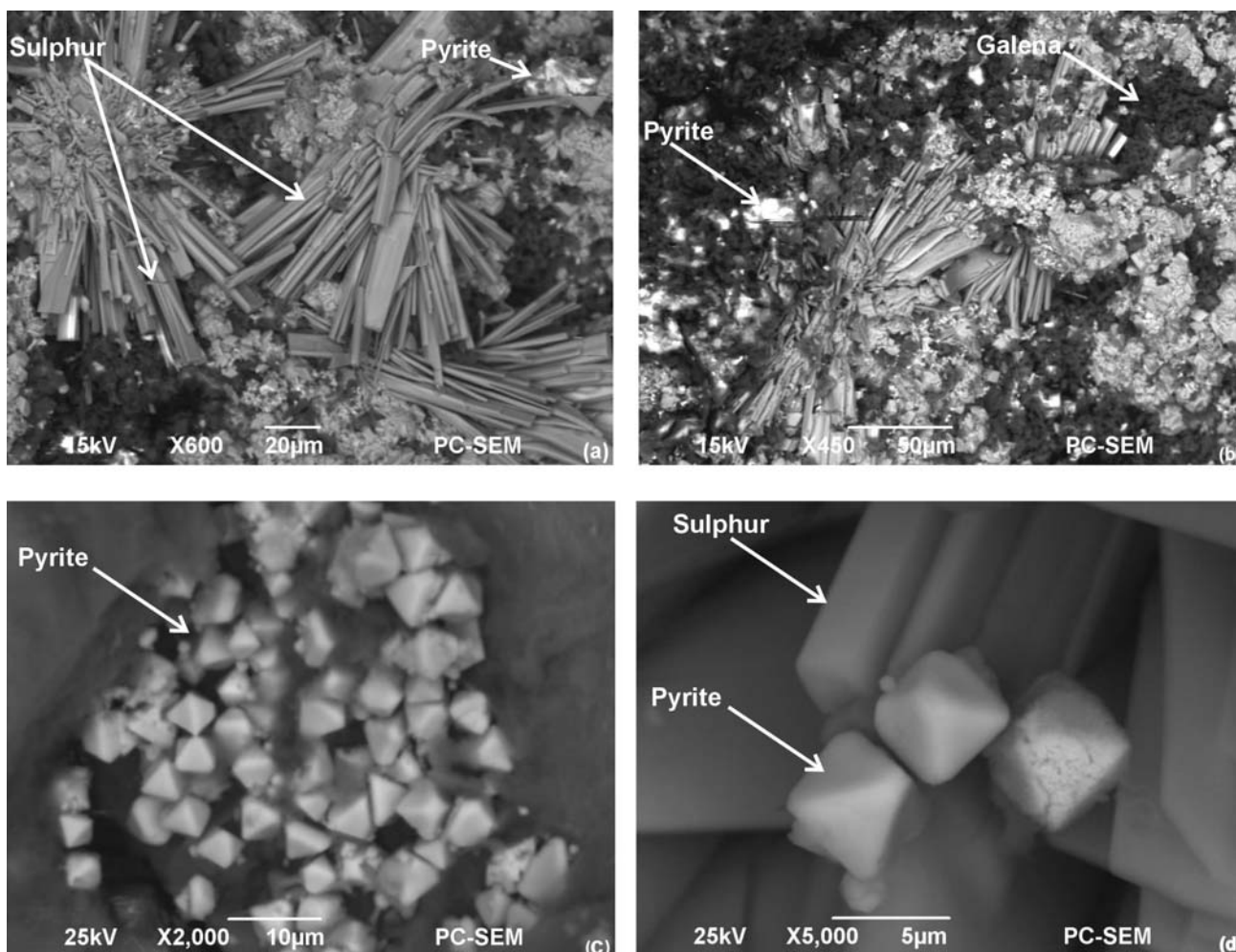


FIG. 4. SHOWING MICROPHOTOGRAPHS OF METING-JHIMPIR COAL (a) SULPHUR FLAKES IN STUDIED COAL (b) SULPHIDE MINERALS (PYRITE GRAINS AND GALENA) (c) PYRITE GRAINS AND (d) SULPHUR FLAKES AND INDIVIDUAL PYRITE GRAINS IN COAL

The concentration of copper in Meting-Jhimpir coal varies from 6-51 ppm with the mean content of 22 ppm. It is higher than the mean value of coal elsewhere in the world [15]. The presence of copper in the coal is generally due to the chalcopyrite [22].

Iron is associated with sulphides and carbonates. The iron content in studied coal ranges from 724-6834 ppm with a mean value of 4500. Its mean worldwide values are not available so it cannot be compared with the coals elsewhere in the world.

The minimum content of manganese in studied coal is 0.04 ppm and the maximum content as 0.49 ppm, with a mean value of 0.19 ppm. The mean value of manganese in studied coal is lower than the coals elsewhere in the world.

The presence of nickel in the coal may be due to sulphide phase [21,22,24], as well as the inorganic or organic matter

[20]. The nickel content in studied coal is ranging from 8-41 ppm with a mean value of 23 ppm (Table 1). It is higher than the mean value for coal elsewhere in the world [15].

Yadovich, et. al. [25] had determined Clarke values for worldwide lignite and sub-bituminous coals, (the term 'Clarke' is defined as the average value of an element in the earth's crust, studied by Cahill, et. al. [26] and Clarke, et. al. [27]). Table 2 displays the amount by which the element has enriched or depleted against the Clarke value. The EF (Enrichment Factor) or DF (Depletion Factors) of the element is the function of that association and the origins of the various coal fraction [23]. The EF or DF of the elements are obtained by computing mean values and the resulting means are divided by their Clarke value. Elements having a Clarke value greater than 10 are considered highly enriched; those with values less than 0.1 are considered depleted. Table 2 shows that Co, Cr, As, Ca, Mg and U in

TABLE 1. MEAN, MINIMUM, MAXIMUM CONCENTRATIONS OF METALS IN METING- JHIMPIR COAL SAMPLES AND THEIR COMPARISON WITH THE WORLDWIDE RANGES FROM SWAINE 1990

Elements	Meting-Jhimpir Coal (ppm)			Swaine's Worldwide Range (ppm)		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum
As	0002.61	001.80	0003.40	10.00	0.50	080.00
Cd	0000.34	000.10	0000.40	05.00	0.10	003.00
Ca	0241.00	145.00	0390.00	NA	N. A	NA
Co	0000.25	000.05	0000.55	05.00	0.50	030.00
Cr	0012.00	008.00	0022.00	20.00	0.50	060.00
Cu	0022.00	006.00	0051.00	15.00	0.50	050.00
Fe	4500.00	724.00	6834.00	NA	NA	NA
K	0252.00	104.00	0440.00	NA	NA	NA
Mg	0060.00	040.00	0072.00	NA	NA	NA
Mn	0000.09	000.04	0000.49	70.00	5.00	300.00
Na	0515.00	321.00	0681.00	NA	NA	NA
Ni	0023.00	008.00	0041.00	20.00	0.50	050.00
Pb	0023.00	007.00	0039.00	40.00	2.00	080.00
Sb	0003.93	002.30	0006.10	NA	0.10	010.00
U	0001.23	000.80	0001.80	02.00	0.50	010.00
Zn	0040.00	012.00	00075.00	50.00	5.00	300.00

studied coal are slightly enriched. The elements like Cu, K, Na, Ni, Pb and Zn in studied coal have depleted, and Cd and Mn show no trend in studied coal.

4.2 Mineralogy of Meting-Jhimpir Coal

For the mineralogical studies, XRD and SEM instruments were used. The XRD patterns of studied coal are shown in Fig. 3. These patterns show that quartz is dominant mineral in the studied coal; the quartz in coal may have deposited as detrital mineral. Among the carbonate minerals such as calcite and dolomite in these coal may have deposited as subordinate or accessory mineral within the peat as syngenetic mineral, during early stages of coalification. The interpretation of XRD pattern reveals that the two mineral phases in the studied coal

are present. The first is detrital while the other is authigenic in nature. The first phase is composed of quartz while the constituents of the authigenic phase are calcite, pyrite and dolomite. The origin of quartz can be associated with the plant silica in the marine environment. The calcite and dolomite minerals found in coal minerals may have been originated from clay minerals, these clays might be diagenetic in origin. Due to sulphur reducing environment pyrite may have been deposited in the studied coal [28].

The Scanning Electron Microscopic investigation of submicron size minerals shows that among the sulphide minerals such as the sulphur flakes, galena, pyrite and marcasite had deposited in cleats as epigenetic minerals (Fig. 4).

TABLE 2. SUMMARIZES THE CONCENTRATION OF ELEMENTS IN METING-JHIMPIR COAL ALONG WITH RESPECTIVE CLARKE VALUE FOR COAL AND THE CALCULATED ENRICHMENT FACTOR

Element	Meting-Jhimpir Coal (ppm)				Clarke* Value for Coal	EDF**
	Mean	Minimum	Maximum	Standard Deviation		
As	0002.61	001.80	0003.40	0000.62	0014.00	00.19
Cd	0000.34	000.10	0000.40	0000.14	0000.30	01.13
Ca	0241.0	145.00	0390.00	0085.54	0460.00***	00.52
Co	0000.25	000.05	0000.55	0000.16	0003.40	00.07
Cr	0012.00	008.00	0022.00	0004.28	0012.00	01.00
Cu	0022.00	006.00	0051.00	0017.48	0007.50	02.93
Fe	4500.00	724.00	6834.00	1382.95	1300.00***	03.46
K	0252.00	104.00	0440.00	0101.88	0180.00***	01.40
Mg	0060.00	040.00	0072.00	0011.08	0110.00***	00.55
Mn	0000.09	000.04	0000.49	0000.18	0100.00	00.00
Na	0515.00	321.00	0681.00	0103.82	0080.00***	06.44
Ni	0023.00	008.00	0041.00	0010.79	0008.00	02.88
Pb	0023.00	007.00	0039.00	0009.87	0002.50	10.00
Sb	0003.93	002.30	0006.10	0001.13	0001.30	03.02
U	0001.23	000.80	0001.80	0000.32	0002.10	00.59
Zn	0040.00	012.00	0075.00	0022.49	0018.00	02.22

* Clarke value for lignite and sub-bituminous coals worldwide [26]

** Enrichment/depletion factor-ratio of the mean element content in studied coal samples to the respective Clarke value in coal

*** Clarke value for USA coals [27].

Sulphur occurs in two forms in coal i.e. inorganic and organic. The inorganic sulphur occurs as dispersed and discrete mineral while organic sulphur bounds directly to the organic coal matrix [29]. The organic sulphur in coal is present mainly in two forms, such as disulphides (pyrite and marcasite) and sulphates [30]. Sulphur in studied coal in the form of inorganic and organic; both (pyrite and sulphur) are deposited as cleat filling minerals in studied coal.

The Galena (PbS) in studied coal occurs as micro grains (Fig. 4). Pyrite and marcasite in the studied coal is the dominant sulphide mineral phase, which occurs in intimate association with organic matter, and represents sulphide mineralization during or just after the peat accumulation.

5. CONCLUSIONS

- (i) The enrichment of Co, Cr, As, Ca, Mg, U and depletion of Cu, K, Na, Ni, Pb and Zn in Meting-Jhimpir coal may be used as a parameter for the evaluation of the degree of contaminants during combustion. This will also help us from environmental point of view to assess the extent of contamination.
- (ii) XRD patterns indicate two mineral phases in studied coal. The first is quartz (detrital) while the others are calcite and dolomite (authigenic).
- (iii) SEM investigation of submicron size minerals shows that among the sulphide minerals, sulphur flakes, galena, pyrite and marcasite these submicron size minerals have deposited as cleat filling minerals in studied coal.
- (iv) For the removal of cations associated with carbonates, mono-sulfides, carbonates, iron oxides and chelated organic compounds,

disulfides, such as pyrite and marcasite, and silicates, the sequential leaching method may be applied by using $\text{NH}_4\text{C}_2\text{H}_3\text{O}_2$, HCl, HF and HNO_3 , acids.

ACKNOWLEDGEMENTS

The authors are highly thankful to the authorities of National Center of Excellence in Geology, University of Peshawar, and Director, Center for Pure Applied Geology, University of Sindh, Jamshoro, Pakistan, for providing the analytical facilities to accomplish this research work.

REFERENCES

- [1] Siddiqui, I., and Shah, M.T. "Environmental Impact Assessment of the Thar, Sonda and Meting-Jhimpir Coalfields", *Journal of Chemical Society*, Volume 29, No. 3, pp. 222-230, Pakistan, 2007.
- [2] Outerbridge, W.F., Frederiksen, N.O., Khan, M.R., Khan, R.A., Qureshi, M.J., Niamatullah, M.Z., and Khan, S.A., "The Sonhari Formation in Southern Pakistan", *Stratigraphic Notes*. 1989, US Geological Survey, Bulletin, Volume 1935, US Geological Survey of Pakistan, pp. 27- 40, 1991.
- [3] Abbas, G., and Atique, M., "A Brief on Coal Deposits of Sindh. Pakistan", *Geological Survey of Pakistan, Special Publication*, Volume 27, Pakistan, 2005.
- [4] Shah, S.M.I., "Lithostratigraphic Units of Sulaiman and Kirthar Province, Lower Indus Basin, Pakistan", *Geological Survey of Pakistan, Information Release*, Pakistan, pp. 519, 1987.
- [5] Fatmi, S.F., Akhtar, T., and Muhammad, A., "Stratigraphy of Eocene Epoch of Sindh Province, Pakistan", *Geological Survey of Pakistan*, Volume 613, pp. 30, Pakistan, 1995.
- [6] Schweinfurth, S.P., and Hussain, F., "Coal Resources of the Lakhra and Sonda Coalfields, Southern Sindh Province, Pakistan", *Geological Survey of Pakistan, Project Part-I*, Pakistan, pp. 36, 1988.

- [7] Ahmed, W., Gauhar, S.H., and Siddiqui, R.A., "Coal Resources of Pakistan", Geological Survey of Pakistan, Volume 73, pp. 55. Quetta, 1986.
- [8] Jeffery, P.G., and Hutchison, D., "Chemical Methods of Rocks Analysis", Pergamon Press, New York, 1986.
- [9] Kiss, L.T., "X-Ray Fluorescence in Determination of Brown Coal Inorganics", Analytical Chemistry, Volume 38, pp. 1713-1715, 1966.
- [10] Kuhn, J.T., Harfst, W.F., and Shimp, N.F., "X-Ray Fluorescence Analysis of Whole Coal", Trace Elements in Fuel, (Babu, S.P. (Editor). Advanced Chemistry Series, Volume 141, American Chemical Society, pp. 66-73, Washington, DC, 1975.
- [11] Gluskoter, H.J., Ruch, R.R., Miller, W.G., Cahill, R.A., Dreher, G.B., and Kuhn, J.K., "Trace Elements in Coal: Occurrence and Distribution", Circular, Volume 499, pp. 154, Illinois State Geological Survey, Urbana, Illinois, 1977.
- [12] Klug, H.P., and Alexander, L.E., "X-Ray Diffraction Procedures", 2nd Edition, New York, 1974.
- [13] Joint Committee on Powder Diffraction Standards, "Mineral Powder Diffraction File Search Manual and Data Book", Swarthmore, pp. 1601 Park Lane, Pennsylvania, 1980.
- [14] Siddiqui, I., "Environmental Impact Assessment of the Thar, Sonda and Meting-Jhimpir Coalfields of Sindh", Ph.D. Thesis, University of Peshware, Pakistan, 2008.
- [15] Swaine, D.J., "Trace Elements in Coal", Butterworths and Co., pp. 278, London, 1990.
- [16] Finkelman, R.B., "Abundance, Source, and Mode of Occurrence of the Inorganic Constituents in Coal" Coal: Resources, Properties, Utilization, Pollution, Kural, O., (Editor), pp. 115-125, Istanbul Technical University, Turkey, 1994.
- [17] Zhang, J.Y., Ren, D.Y., Zheng, C.G., Zeng, R.S., Chou, Liu, C. J., "Trace Element Abundances in Major Minerals of Late Permian coals from Southwestern Guizhou Province, China", International Journal of Coal Geology, pp. 53, 55-64, 2002.
- [18] Karayigit, A.I., Gayer, R.A., Querol, X. and Onacak, T., "Contents of Major and Trace Elements in Feed Coals from Turkish Coal-fired Power Plants", International Journal of Coal Geology, Volume 44, pp. 169 -184, 2000.
- [19] Finkelman, R.B., Palmer, C.A., Krasnow, M.R., Aruscavage, P.S. and Sellers, G.A., "Heating and Leaching Behavior of Elements in the Eight Argonne Premium Coal Samples", Energy and Fuels, Volume 4, No. 6, pp. 755-767, 1990.
- [20] Finkelman, R.B., "Mode of Occurrences of Environmentally Sensitive Trace Elements of Coal", Trace Elements of Coal, Swaine, D.J., (Editor), pp. 24-50, Kluwer Academic Publishers, Netherlands, 1995.
- [21] Goodarzi, F., "Mineralogy, Elemental Composition and Modes of Occurrence of Elements in Canadian Feed-Coals", Fuel, Volume 81, pp. 119-1213, 2002.
- [22] Querol, X., Finkelman, R.B., Alstuey, A., Huerta, A., Palmer, C.V., Mroczkoki, S., Kolker, A., Chunery, S.N.R., Robinson, J.J., Juan, R., and Lopez-Solar, A., "Quantitative Determination of Modes of Occurrence of Major, Minor and Trace Elements in Coal: A Comparison of Results from Different Methods, AIE 8th Australian Coal Science Conference, pp. 51-56, Australia, 1998.
- [23] Clarke, L.B., and Sloss, L.L., "Trace Elements Report IEACR/49", International Energy Agency Coal Research, pp. 111, London, 1992
- [24] Spears, D.A., and Zheng, Y., "Geochemistry and Origin of Elements in Some UK Coals", International Journal of Coal Geology, Volume 38, pp. 161-179, 1999.

- [25] Yudovich, Ya.E., Ketris, M.P., and Merts, A.V., "Trace Elements in Fossil Coals", Nauka Science Publication House, pp. 239, Leningrad, 1985.
- [26] Cahill, R.A., Kuhn, J.K., Dreher, G.B., Ruch, R.R., Gluskotar, H.J., and Miller, W.G., "Occurrence and Distribution of Trace Elements in Coal", Illinois State, Geological Survey, Illinois, Circular 61801, pp. 90-92, 1976.
- [27] Clarke, F.W., and Washington, H.S., "The Composition of the Earth's Crust: US", Geological Survey Professional Paper 127, pp. 117, 1924.
- [28] Siddiqui, I., Irshad, A., and Shah, M.T., "XRD Analyses of Sindh Coal: The Sindh Coals", Sindh University Resesearch Journal (Science Series), Volume 41, No. 1, pp. 05-14, Jamshoro, Pakistan, 2009.
- [29] Tsai, S.C., "Fundamentals of Coal Beneficiation and Utilization", Elsevier Publishers, Amsterdam, 1982.
- [30] Jorjani, E., "Desulphurization of Tabas Coal with Microwave Irradiation/ Peroxyacetic Acid Washing at 25, 55, 85°C", Fuel, Volume 83, pp. 943-949, 2004.