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Distribution and Geochemistry of Selected Trace Elements in the Lignites of Cambay Basin, Gujarat, Western India

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Abstract: In the present investigation all the working lignite seams of Cambay basin of Gujarat have been studied to see the distribution and geochemistry of selected major/minor elements like Fe, Ca, Na, K, Mg, and Mn and trace elements like Cu, Co, Cr, Cd, Ni, Pb and Zn. The vertical variation of these elements along the seam profiles has been studied to see the pattern of distribution of these elements and also to know the horizons of their enrichment and the probable cause. Further, these elements have been correlated among themselves and also with organic and inorganic matter of lignite. The correlation study indicates that in Tadkeshwar upper seam Fe has its affinity with huminite while Mg and Na have their affinity with liptinite and in Tadkeshwar lower seam Na has an affinity with liptinite. In Vastan upper seam Mn and Cu are associated with inertinite and Na with huminite while in Vastan lower seam Cu relates to huminite and Cd to liptinite and huminite. In Rajpardi seam Ca and Co are associated with huminite. The study provides information on the mode of occurrence of elements of less studied lignites of western India.

Keywords: Lignite, Trace elements, Maceral, Cambay basin, Correlation, Gujarat.

INTRODUCTION

Study of trace elements in coal and lignite has been given more impetus these days owing to their environmental implications. They not only provide informations pertaining to coal bearing horizons and their paleo-depositional environment but also reveal the regional tectonic history (Ren, 1996). Their distribution is related to peat accumulation, coalfication process, diagenesis, and interaction of organic matter with the basinal fluids (Dai et al., 2008; Ren et al., 2006; Ward, 2002). The major minerals in coal such as silicates, carbonates and sulphides, incorporate most of the elements. But there are also elements like Ge, B, Br, Be and Cl which are normally associated with the organic matter (Finkelman, 1995). Ren et al. (2004) worked on the enrichment mechanism of trace elements in the Shanbei lignites of China. Through sequential chemical extraction they could separate the water-soluble elements, ion-exchangeable elements, fluvic acid and humic acid bonded elements, organic macromolecular-bonded elements, carbonate bonded elements and aluminosilicate and sulphide bonded elements. Such studies were carried out by Riley et al. (2012) on the Australian coals. Significant contributions have also been made by Zhou and Ren (1992), Wang et al. (1996), Zhao (1997), Feng and Hong (1997), Zeng et al. (1998), Liu et al. (1999, 2001), Prachiti et al. (2011), Singh et al. (2012a).

The trace elements also reveal useful informations required to address the environmental implications resulting from coal utilization. Contributions in this field have been made by Dai et al. (2005), Dai et al. (2012), Finkelman (1995), Finkelman et al. (2002), Liu et al. (2005), Prachiti et al. (2011), Ribeiro et al. (2010), Silva et al. (2011), Singh et al. (2015), and Tang et al. (2009). Some coal and ashes are potential source of elements like Ge, Ga, Nb, Zr, U and REEs (Dai et al., 2012, 2014; Hower et al., 1999; Seredin and Dai, 2012).The understanding of distribution and concentration of trace elements in coal is helpful in designing suitable strategies to minimize the environmental pollution and the related health hazards (Dai et al., 2012; Liu et al., 2005a; Tang et al., 2009). Indian coals have not been studied in detail with respect to the distribution of trace elements and whatever data are available are only from the sporadic samples. Prachiti et al. (2011) have studied the geochemical systematics and precious metal content in coal and associated sediments from Sattupalli coalfield of Andhra Pradesh, India. Singh et al. (2015) have studied the geochemistry of environmentally sensitive trace elements in the lignite samples of Barsingsar and Gurha mines of

Rajasthan. Similar study has been taken up by Saikia et al., (2015) on the mineralogy and geochemistry of elements in north-east Indian coals. In the present investigation distribution of selected elements in the Cambay basin of Gujarat is undertaken and their geochemistry is discussed especially in light of their inter-relationship and also with the organic matter.

GEOLOGY OF THE AREA

The regional geology of the basin is shown in Fig.1 and the general stratigraphic succession is furnished in Table 1a-c.

Geology of Vastan lignite field: This mine is located in Surat district and is a significant lignite mining centre of Gujarat. The lignite bearing sequence is of Eocene and belongs to Cambay Formation and is a part of an intracratonic basin called Cambay basin. This basin covers a large area of Gujarat and continues to Barmer region of Rajasthan in north. The formation encloses thick beds (75-150 m) of clay and shale with lignite seams (Table 1a) and its detailed geology has been discussed by Singh (2012) and Singh et al. (2010). Studies on the regional geology of the area have been made by Mathur et al. (1968), Raju (1968) and Biswas (1987).

Geology of Rajpardi Lignite field: The lignite bearing sequence is Tadkeshwar Formation. The formation is a 150 m thick litho-unit comprising of clay, carbonaceous

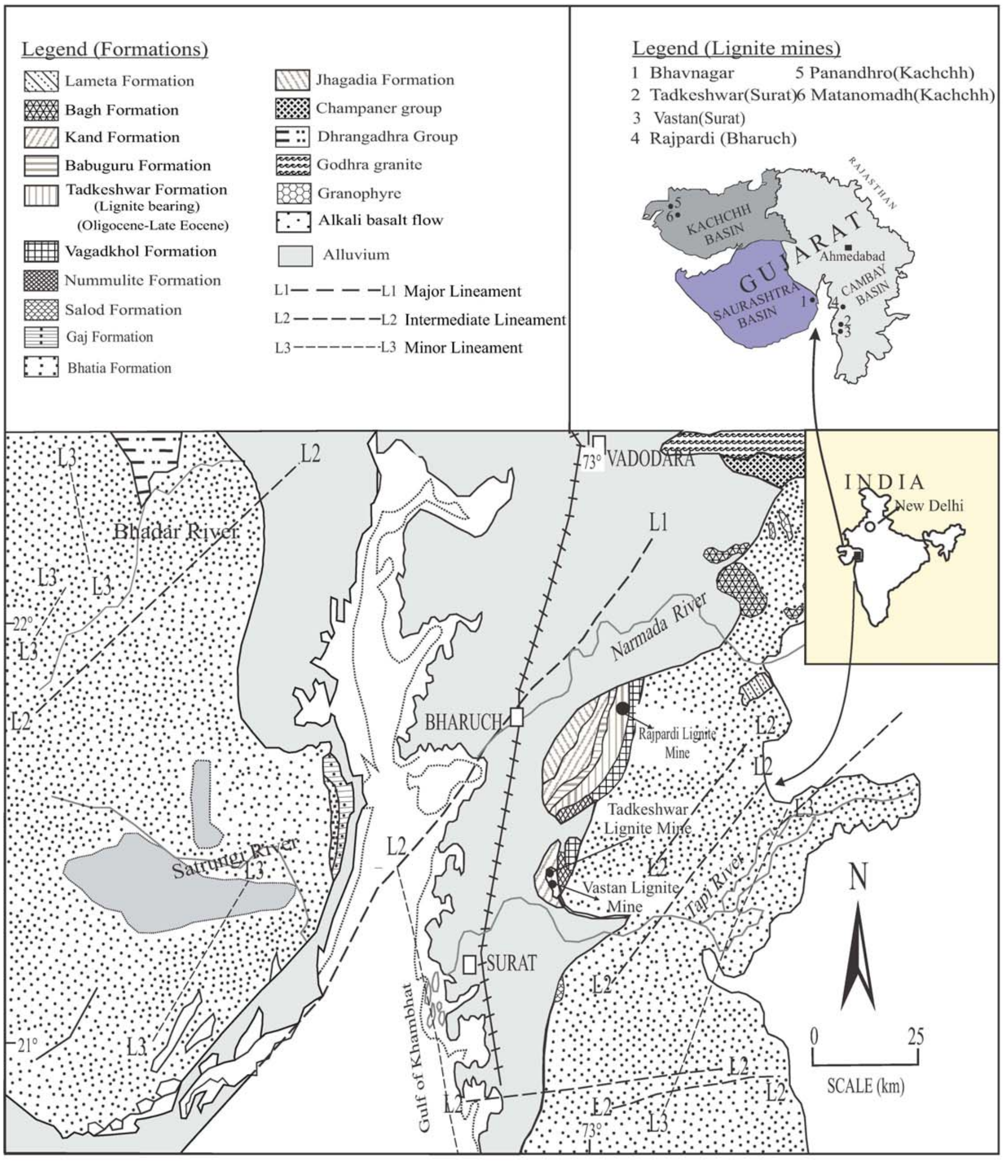

Fig.1. Geological map of Cambay basin and location of lignite fields (redrawn from GSI, 2012)

Table 1a. A general succession of the Vastan region, Gujarat (after Sahni et al., 2006).

Lithology	Age	Thickness (in m)
Alluvium & Black shale	Recent	75-150 (total Cambay Formation)
Calc Bentonitic Clay	Late Eocene	
Lignite with clay	Early Eocene	20-145 (in Vastan area)
Lithomargic clay	Paleocene	
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Deccan Trap	Late Cretaceous	–

Table 1b. Regional stratigraphic sequence with lithounits in and around Rajpardi, Gujarat (based on the work of Oil & Natural Gas Corporation).

Age	Formation	Lithounits	Thickness (in m)
Pleistocene to Recent	Alluvium	Varied coloured sands, soil and Kankar	—
Middle Miocene to Pliocene	Jhagadia Formation	Light coloured sandstones, marls, limestone and conglomerate	300
Early Miocene	Kand Formation	Limestone, marls, clays with sandstone bands and agate bearing conglomerate	450
Early most Miocene	Babaguru Formation	Agate Conglomerates - - - - - - - - - - - - - - - - - - - Ferruginous sandstone - - - - - - - - - - - - - - - - - - - Sandy	150
Oligocene to Late Eocene	*Tadkeshwar Formation	Grey Clay Carbonaceous Clay Lignite Carbonaceous Clay Lenses of sandstone Carbonaceous Clay, lignite Grey Clay -	150
Late Eocene to Early Eocene	Numulitic Formation	Numulitic limestone, clays with sandstone lenses	120
Early Eocene	Vagadkhol Formation	Bentonitic clays, friable sandstone and conglomerates	120
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Cretaceous	Deccan Traps	Basalts with basic intrusives	—

*Now established as early Eocene in age (Sahni et al., 2006).

Table 1c. Geological succession around Tadkeshwar lignite field, southern Cambay Basin (Source: Gujarat Mineral Development Corporation Mine Report.1989).

Age	Formation	Lithology and their thickness
Pleistocene to Recent	Alluvium	Varied coloured sands, soil and kankar
Middle Miocene to Pliocene	Jhagadia	Light coloured sandstones, marls, limestone and conglomerate (304m)
Early Miocene	Kand	Limestone, marls and clays with sandstone bearing conglomerate (457 m)
Early most Miocene	Babaguru	Ferruginous sandstone, agate bearing conglomerates and varied clays, grey sandstone and white sands (152m)
Oligocene to Late Eocene	Tadkeshwar*	Grey, yellow and brown friable sandstones with clay lenses of carbonaceous clays, sandstone and lignite (152m)
Late Eocene to Early Eocene	Nummulite	Numulitic limestone, clays with sandstone lenses (122m)
Early Eocene	Vagadkhol	Bentonitic clays, friable sandstone and conglomerates (304m)
Cretaceous	Deccan Traps	Basalts with basic intrusive

*Now established as early Eocene in age (Sahni et al., 2006).

clay, lignite and sandstone. This formation is overlain by Babaguru Formation and underlain by Nummulite Formation. The detailed geology of the area has been discussed by Singh et al. (2012b). The lignite mine is located in Bharuch district. The details of the formation, lithounits and their thickness are furnished in Table 1b. Here two lignite seams occur which are persistent in nature. The top seam is 4.2-8.8 m thick while bottom seam is 1.0-3.4 m thick. In addition, few local seams have also been reported (Singh et al., 2012b) but they are non-persistent in nature.

Geology of Tadkeshwar Lignite field: This mine is located in Surat district and in this field also the lignite bearing sequence is the Tadkeshwar Formation (Table 1c). This formation is overlain by Babaguru Formation and underlain by Nummulite Formation. Tadkeshwar Formation begins with the deposition of grey bentonite clay which is successively followed by lignite bed, carbonaceous clay, lenses of sandstone, carbonaceous clay, lignite bed, carbonaceous clay, grey clay, sandy clay, and ferruginous sandstone.

MATERIALS AND METHODS

Lignite Samples

Lignite samples from the workings of all the lignite mines of Cambay basin have been collected following pillar coal sampling method (Schopf, 1960) so that the full seam thickness is represented at the sampling point and the same may be reconstructed in laboratory. The mines include Tadkeshwar (both upper and lower seams), Vastan (both upper and lower seams) and Rajpardi. The maceral analysis was carried out in coal and organic petrology lab, Banaras Hindu University by Leitz Orthoplan Pol Microscope following Taylor et al. (1998). The samples have been crushed to -70 mesh size. The samples have been subjected to proximate analysis to determine the constituents like moisture, ash, volatile matter and fixed carbon. The samples were analysed for selected minor and trace elements namely, Fe, Ca, Mg, Mn, K, Na, Cu, Co, Ni, Cr, Zn, Pb and As on ‘whole coal samples’.

Digestion of Lignite Samples

Digestion of lignite samples was carried out following standard method of Eaton et al. (1995). The sample (½ gram dry weight) is taken in a digestion vessel and mixed with 10 ml of digestion mixture (10 part conc. HNO_3 and 1 part $HClO_4$). After refluxing the mixture for 30 min the step is repeated again until brown fumes ceases. The mixture is then filtered with the help of Whatman filter paper (No. 41). Subsequently, the digested samples are rinsed with 1% concentrated HNO_3 and transferred in a separate test tube and the volume is made up to 20 ml. The samples have been analyzed under Atomic Absorption Spectrophotometer (AAS, Model Perkin Elmer Analyst 800) to see the concentrations of various elements.

RESULT AND DISCUSSION

Petrographic Composition

Huminite is the most dominant among the three maceral groups in the lignites of Cambay basin while liptinite and inertinite maceral groups occur in subordinate concentrations.

Tadkeshwar Upper Lignite seam: In this seam huminite varies in concentration from 54.74 to 75.90% while liptinite (8.38 to 24.40%) and inertinite (1.39 to 14.82%) groups occur in relatively low concentration. The mineral matter varies from 7.34 to 12.77%.

Tadkeshwar Lower Lignite seam*:* Huminite dominates among the macerals and varies from 51.98 to 66.47% while liptinite (6.76 to 22.57%) and inertinite (1.39 to 8.58%) occur in low concentration. The mineral matter varies from 12.57 to 30.82%.

Vastan Upper Lignite seam*:* Petrographically it is dominated by huminite (58.0 to 82.07%) while liptinite (6.94 to 16.57%) and inertinite (1.80 to 17.93%) occurs in low concentration. The mineral matter varies from 6.60 to 14.0%.

Vastan Lower Lignite seam*:* Huminite (72.06 to 83.07%) dominates over liptinite (6.94 to 12.52%) and inertinite (1.0 to 5.57%). The mineral matter varies from 6.77 to 15.17%.

Rajpardi Lignite seam*:* Huminite is the chief maceral group and varies in concentration from 67.86 to 80.04% while liptinite (8.70 to 16.30%) and inertinite (2.77 to 9.31%) are the subordinate maceral groups. Mineral matter varies from 6.94 to 14.88%.

The XRD study of low temperature ash of the Cambay lignites has revealed the presence of chiefly mixed layer of clay, kaolinite, anhydrite, quartz and hematite (Fig.2a). The details of macerals, mineral matter and chemical constituents of various lignite seams of the Cambay basin are furnished in Table 2a-c and the mean petrographic constituents are shown in Fig.2b.

Distribution of Selected Minor/Trace Elements

Na occurs in high concentration in all the lignite seams of Cambay basin and in some of the sections it is over ten times higher than the Clarke values of brown coals. K is

Table 2a. Data of Petrography (in vol %) and proximate (in wt %) constituents of Vastan Lignite Seams, Gujarat

S. No.		Sample No.	Megascopic Characteristics	Humi	Lipt	Inert	Mineral Matter		Ash	VM (daf)	FC (daf)
							Pyrite	Other			
1	VASTAN UPPER LIGNITE SEAM	V11	Unstratified, matrix rich, brown inhomogeneous lignite	68.79	9.54	12.13	3.98	5.57	4.18	58.91	41.09
2		V10	Unstratified, matrix rich, brown inhomogeneous lignite with pyrite specks	65.20	12.60	15.60	4.8	1.8	4.35	54.61	45.39
3		V9	Stratified, matrix rich, brown inhomogeneous lignite with pyrite specks	80.64	9.18	1.80	3.79	4.59	5.88	56.81	43.19
4		V8	Unstratified, matrix rich, brown inhomogeneous lignite with pyrite specks	67.27	13.17	9.38	7.39	2.79	4.68	54.34	45.66
5		V7	Unstratified, matrix rich, black inhomogeneous lignite	69.64	9.33	8.33	11.31	1.39	4.61	68.81	31.18
6		V6	Stratified, matrix rich, brown inhomogeneous lignite	67.80	9.00	9.20	12.4	1.60	4.50	54.62	45.38
7		V5	Unstratified, matrix rich, black inhomogeneous lignite	66.93	8.37	17.93	3.98	2.79	5.41	62.57	37.43
8		V4	Unstratified, matrix rich, brown inhomogeneous lignite with pyrite specks	60.88	16.57	8.58	10.78	3.19	4.63	59.97	40.03
9		V3	Stratified, matrix rich, brown inhomogeneous lignite	75.40	6.94	6.35	7.54	3.77	4.48	56.20	43.80
10		V2	Unstratified, matrix rich, brown inhomogeneous lignite with pyrite specks and resin patches	58	16.00	17.20	6.0	2.8	4.61	61.12	38.87
11		V1	Stratified, matrix rich, brown inhomogeneous lignite	82.07	8.57	2.59	3.98	2.79	4.50	55.35	44.65
12		Mean		69.33	10.84	9.92	6.90	3.01	4.71	58.48	41.52
13	VASTAN LOW LIGNITE SEAM	VL6	Unstratified, matrix rich, black inhomogeneous lignite.	75.55	7.55	2.39	7.16	7.36	11.92	54.63	45.37
14		VL5	Stratified, matrix rich, brown inhomogeneous lignite.	78.17	6.94	2.58	5.56	6.75	5.76	44.32	55.68
15		VL4	Unstratified, matrix rich, brown inhomogeneous lignite	78.29	11.95	2.99	5.58	1.20	6.57	42.06	57.94
16		VL3	Unstratified, matrix rich, brown inhomogeneous lignite	74.95	12.52	5.57	5.57	1.39	6.75	44.21	55.79
17		VL2	Unstratified, matrix rich, brown inhomogeneous lignite	83.07	7.17	1	7.37	1.39	10.95	65.05	34.95
18		VL1	Unstratified, matrix rich, brown inhomogeneous lignite	72.06	8.18	4.59	6.59	8.58	17.52	69.79	30.21
19		Mean		77.01	9.06	3.18	6.30	4.44	9.91	53.68	46.66

Humi-huminite, lipt-liptinite, inert-inertinite, VM-volatile matter, FC-fixed carbon

Table 2b. Data of Petrography (in vol %) and proximate (in wt %) constituents of Rajpardi Lignite Seam, Gujarat.

S. No.		Sample No.	Megascopic Characteristics	Humi	Lipt	Inert	Mineral Matter		Ash	VM (daf)	FC (daf)
							Pyrite	Other			
1	RAJPARDI LIGNITE SEAM	R10	Unstratified, matrix rich, brown inhomogeneous lignite with pyrite specks and resin patches	68.71	11.88	9.31	7.92	2.18	7.99	68.14	31.86
2		R9	Unstratified, matrix rich, brown inhomogeneous lignite	80.04	8.70	2.77	4.94	3.56	7.47	54.85	45.15
3		R8	Unstratified, matrix rich, brown inhomogeneous lignite with pyrite specks and resin patches	71.29	15.45	6.14	5.54	1.58	5.23	60.94	39.06
4		R7	Stratified, matrix rich, brown inhomogeneous lignite with pyrite specks and resin patches	76.39	12.30	4.37	5.95	0.99	5.28	67.63	32.37
5		R6	Unstratified, matrix rich, brown inhomogeneous lignite with pyrite specks and resin patches	70.78	16.30	5.57	5.96	1.39	7.99	64.10	35.90
6		R5	Stratified, xylite rich, brown inhomogeneous lignite with pyrite specks	71.09	16.24	3.17	5.94	3.56	7.83	63.61	36.39
7		R4	Stratified, matrix rich, brown inhomogeneous lignite with pyrite specks and resin patches	67.86	11.58	5.79	9.38	5.39	13.38	57.90	42.10
8		R3	Stratified, matrix rich, brown inhomogeneous lignite.	76.10	10.16	5.58	4.58	3.59	6.53	59.32	40.68
9		R2	Stratified, matrix rich, brown inhomogeneous lignite.	70.44	11.31	3.37	13.10	1.79	7.82	65.95	34.05
10		R1	Stratified, matrix rich, black inhomogeneous lignite with pyrite specks	73.21	9.92	8.73	4.17	3.97	4.53	70.69	29.31
11		Mean		72.59	12.38	5.48	6.75	2.80	7.41	63.31	36.69

Humi-huminite, lipt-liptinite, inert-inertinite, VM-volatile matter, FC-fixed carbon

also high in Tadkeshwar upper seam and Vastan upper seam samples compared to Clarke values. Cu is continuously high in the samples of Tadkeshwar lower seam, Vastan lower seam and Rajpardi seam and in few sections it is more than 100 times higher than the Clarke values. Similarly, Ni occurs in high concentration in almost all the samples of Tadkeshwar upper seam and Vastan upper seam and in few samples of other seams of the basin. Cd is high in most of the samples of Tadkeshwar lower seam and Vastan lower seam and in few samples of rest of the seams. The concentration of Cr is high in few samples of Rajpardi seam. The concentration of Co is up to ten times high in Rajpardi samples compared to Clarke values while Pb is high only in a few samples. The other elements have a normal distribution. The values of the elements are furnished in Table 3a-c.

Correlation of Elements

To understand the mode of occurrence of elements in the lignites of Cambay basin, the indirect evidences have been discussed which include correlation coefficient of

Table 2c. Data of Petrography (in vol %) and proximate (in wt %) constituents of Tadkeshwar Lignite Seam, Gujarat

S. No.		Sample No.	Megascopic Characteristics	Humi	Lipt	Inert	Mineral Matter		Ash	VM (daf)	FC (daf)
							Pyrite	Other			
1	TADKESHWAR UPPER LIGNITE SEAM	T 10	Unstratified, matrix rich, brown inhomogeneous lignite with pyrite specks and resin patches	65.67	24.40	1.39	2.78	5.75	7.68	53.66	46.33
2		T 9	Unstratified, matrix rich, brown inhomogeneous lignite with pyrite specks and resin patches	58.38	23.47	10.65	2.96	4.54	6.83	56.08	43.92
3		T 8	Unstratified, matrix rich, brown inhomogeneous lignite	75.90	10.16	6.18	3.39	4.38	6.08	49.58	50.42
4		T 7	Unstratified, matrix rich, black inhomogeneous lignite with pyrite specks and resin patches	55.40	19.80	14	5.2	5.60	9.53	60.64	39.36
5		T 6	Unstratified, matrix rich, brown inhomogeneous lignite	64.48	14.88	13.29	3.17	4.17	5.80	51.85	48.15
6		T 5	Unstratified, matrix rich, brown inhomogeneous lignite with pyrite specks	58.50	19.37	14.23	3.36	4.55	5.19	51.58	48.42
7		T 4	Stratified, matrix rich, brown inhomogeneous lignite with pyrite specks	54.74	18.18	14.82	10.47	1.78	5.16	62.28	37.72
8		T 3	Unstratified, matrix rich, brown inhomogeneous lignite with pyrite specks and resin patches	72.85	8.38	5.99	3.99	8.78	4.96	50.49	49.51
9		T 2	Unstratified, matrix rich, brown inhomogeneous lignite with pyrite specks	69.84	18.25	4.56	1.79	5.56	5.64	57.15	42.85
10		T 1	Stratified, matrix rich, brown inhomogeneous lignite with pyrite specks	75.89	12.06	3.95	2.96	5.14	7.19	48.79	51.20
11		Mean		65.17	16.90	8.91	4.01	5.02	6.41	54.21	45.79
12	TADKESHWAR LOWER LIGNITE SEAM	TL7	Stratified, matrix rich, brown inhomogeneous lignite with pyrite specks	66.47	14.09	1.39	5.95	12.10	9.55	62.62	37.38
13		TL6	Unstratified, matrix rich, brown inhomogeneous lignite	56.83	22.57	4.75	3.37	12.48	10.91	74.26	25.74
14		TL5	Stratified, matrix rich, brown inhomogeneous lignite with pyrite specks	61.51	21.23	4.17	4.76	8.33	9.83	66.31	33.69
15		TL4	Untratified, matrix rich, brown inhomogeneous lignite with pyrite specks	58.33	10.71	3.97	7.94	19.05	10.06	65.41	34.59
16		TL3	Stratified, matrix rich, brown inhomogeneous lignite with pyrite specks	57.46	6.76	4.97	1.79	29.03	23.28	71.00	29.00
17		TL2	Unstratified, matrix rich, brown inhomogeneous lignite with pyrite specks and resin patches	51.98	17.86	7.74	2.98	19.44	9.70	67.82	32.18
18		TL1	Stratified, matrix rich, brown inhomogeneous lignite with pyrite specks and resin patches	61.88	16.97	8.58	4.59	7.98	10.65	68.47	31.53
19		Mean		59.21	15.74	5.08	4.48	15.49	12.11	67.99	32.01

Humi-huminite, lipt-liptinite, inert-inertinite, VM-volatile matter, FC-fixed carbon

elements with ash content, pattern of distribution of elements with increase in ash content, correlation of elements with Fe content and correlation matrix among the elements. Similar study has been carried out by Eskenzy (2009) on Bulgarian coals. The vertical variation of all the elements along the seam profile is shown in Figure 3a-e. The figure shows that there is no definite pattern of variation in the concentration of the elements from bottom to top of the seam. However, those sections having high ash content record a noticeable fall in the Fe, Ca, Mg and Na contents in most of the seam profiles. The relationship of ash content with various elements is shown in Figure 4. In Tadkeshwar upper seam organic matter has a strong positive correlation with Fe (chiefly with huminite), Mg (chiefly with liptinite) and

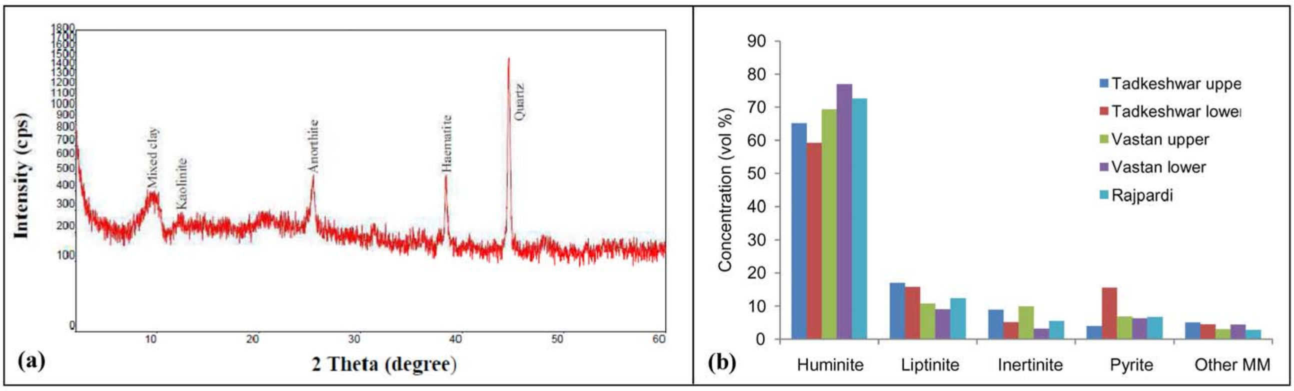

Fig.2. (a) XRD spectrum of Tadkeswar lignite ample (low temperature ash), Cambay basin, Gujarat. **(b)** Mean values of petrographic constituents in various lignite seams of Cambay basin.

Table 3a. Major, minor and trace element contents (in ppm) of Vastan lignite, Gujarat.

	VASTAN UPPER LIGNITE SEAM													VASTAN LOWER LIGNITE SEAM						
Metals	WCBC*	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11	Mean	VL1	VL2	VL3	VL4	VL5	VL6	Mean
Fe	10000	1940	998	1324	1226	988	1184	1080	954	1266	1234	1286	1225.45	536	528	406	488	512	496	494.33
Cu	15±1	1.72	34.2	-0.6	0.84	59.2	0.58	0.18	1.22	9.18	4.24	9.6	10.94	1552	5180	1220	296	164.4	688	1516.73
Co	4.2±0.2	2.12	1.44	2.2	2.1	0.12	1.64	1.84	1.32	5.74	2.06	5.02	2.33	3.06	3.34	1.54	2	3.34	6.88	3.36
Ni	9	14.8	12.4	10	13.6	22.4	16	30	13.2	11.6	65.6	31.2	21.89	9.32	7.42	5.48	4.2	8.9	10.46	7.63
Cr	15±1	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	0	13.7	6.36	4.32	2.8	3.44	5.82	6.07
Zn	18±2	0.74	0.62	0.5	0.68	1.12	0.8	1.5	0.66	0.58	3.28	1.56	1.09	11.06	8.84	2.64	2.24	10.7	6.12	6.93
Pb	6.6±0.7	NIL	7.36	6.28	NIL	0.24	4.74	NIL	NIL	NIL	0.14	NIL	1.71	3.3	3.16	1.76	2.26	3.82	4.04	3.06
Mg	200	93	94.2	94.4	99.2	105.6	102.8	99.4	99	100.8	101	91.2	98.24	46.4	46.4	47.2	47	47	47.4	46.90
Cd	0.20±0.24	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	0	0.38	0.84	0.94	0.74	0.56	0.7	0.69
Na	200	1910.8	1556.4	1535.8	1360	1763.4	1303	1515	1758.2	1934	1763.4	1608.2	1637.11	2084.8	2104.8	2365.2	2326.8	2355.4	2206.2	2240.53
K	100	289.2	401.4	547.6	256.4	272	296.6	402.2	310	369.4	477.4	379	363.75	56	70.2	53.2	81.2	74	217.8	92.07
Ca	10000	4123.8	4274.2	7104.8	4844.4	4914.2	4552.4	5732.4	6381	6961.6	0	5581	4951.80	1722	3400	4320	3800	4340	2900	3413.67
Mn**	100±6	6.76	8.98	4.24	4.04	13.42	5.22	6.96	9.66	9.08	7.56	13.4	8.12	68.2	30.6	56.6	58.2	55.4	155.2	70.70

Table 3b. Major, minor and trace element contents (in ppm) of Rajpardi lignite, Gujarat.

Metals	WCBC*	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	Mean
Fe	10000	624	2040	1446	2220	2100	1078	1860	346	316	1702	1373.20
Cu	15±1	8.6	12.36	33.8	7.88	123.6	31.8	9.8	2.56	27.76	22.36	28.05
Co	4.2±0.2	12.4	15.2	13.2	15.68	17.4	12	40.04	23.64	15.88	18.56	18.40
Ni	9	2.12	3	5.12	7	18.2	5.12	11.48	6.2	6.8	8.16	7.32
Cr	15±1	11.56	23.24	23.52	45.6	18.8	16.12	11.12	9.6	36.2	13.04	20.88
Zn	18±2	2.56	1.88	10.44	10.48	20.96	7.48	10.2	3.88	4.84	7.48	8.02
Pb	6.6±0.7	1.8	0.84	2.84	8.16	4	0.64	1.2	NIL	NIL	NIL	1.95
Mg	200	16	616	1772	1128	1260	844	1588	316	636	1696	987.20
Cd	0.20±0.24	0.04	0.16	0.4	0.48	1.4	0.44	0.52	0.12	0.2	0.32	0.41
Na	200	1238	806	312	710	2904	582	1058	472	234	836	915.20
K	100	27.6	39.4	30	45.6	23	18.4	37.4	47	48.4	49.2	36.60
Ca	10000	7676	8664	7724	2914	10488	6592	11812	3598	4328	8696	7249.20
Mn**	100±6	42	72	50.8	64.4	55.6	29.6	54.4	11.6	13.2	48.2	44.18
AS	7.6	0	0.171	0.404	0.001	NIL	NIL	0.35	NIL	NIL	0.547	0.15

Table 3c. Major, minor and trace element contents (in ppm) of Tadkeshwar lignite, Gujarat.

	TADKESHWAR UPPER LIGNITE SEAM											TADKESHWAR LOWER LIGNITE SEAM							
Metals	WCBC*	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	Mean	TL1	TL2	TL3	TL4	TL5	TL6	TL7	Mean
Fe	10000	1930	2200	2560	1732	2320	2020	2440	2960	2180	1972	2231.40	328	380	394	182.4	150	262	114	258.63
Cu	15±1	3.02	1.2	3.04	4.16	2.18	11.88	0.74	0.06	3.58	0.04	2.99	1282	1328	950	1604	2080	578	916	1248.29
Co	4.2±0.2	1	1.24	1.94	1.24	0.64	0.82	0.56	1.5	1.44	0.38	1.08	1.02	1.44	3.7	2.34	1.48	2.12	1.3	1.91
Ni	9	20	24.8	38.8	24.8	12.8	16.4	11.2	30	28.8	7.6	21.52	3.16	3.08	3.66	2.96	2.1	3.56	2.8	3.05
Cr	15±1	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	0	7.96	8.42	21.6	11.84	3.36	9.14	1.74	9.15
Zn	18±2	1.5	1.22	0.4	0.36	0.86	0.44	1.66	0.44	0.5	0.48	0.79	2.78	5.98	7.22	3.74	2.76	4.82	4.12	4.49
Pb	6.6±0.7	NIL	NIL	3.02	19.18	12.12	0.1	NIL	NIL	NIL	0.18	3.46	3.18	2.86	4.44	2.84	2.58	3.06	9.12	4.01
Mg	200	91.4	92.4	89.4	83.2	102.8	94.8	99.6	95.6	96	102	94.72	46.8	46.2	46.4	46.6	46.6	46.8	47.2	46.66
Cd	0.20±0.24	NIL	NIL	0.12	0.36	0.9	NIL	NIL	NIL	NIL	NIL	0.14	0.44	0.88	0.78	0.52	0.32	0.64	0.36	0.56
Na	200	1432.4	1349.6	1393.6	1163.4	1391	1670.2	1556.4	1427.2	1463.4	1701.2	1454.84	1278.2	1474.2	1071.8	1165.4	1740.2	1442.6	1412.8	1369.31
K	100	533.2	260.2	231	369.4	132.6	274	287.8	289.8	362.2	313	305.32	45.8	20.6	40.2	48.2	47	34	56.2	41.71
Ca	10000	2754.8	3492	3733.4	2414.2	3581	3333.4	3287.6	1873	3504.8	3514.2	3148.84	1178	754	1448	2920	492	2200	2980	1710.29
Mn**	100±6	10.46	20.6	9.1	9.38	23	9.44	10.12	5.62	22.2	14.54	13.45	48.4	33.6	54.4	43.2	30.2	41.6	54.8	43.74

World av values of Ca, Fe, Mn, Na, K and Mg are after Valkovic (1983). *World Clarke for Brown coal by Yudovich and Ketris (2006); **by Ketris and Yudovich (2009); na- not available.

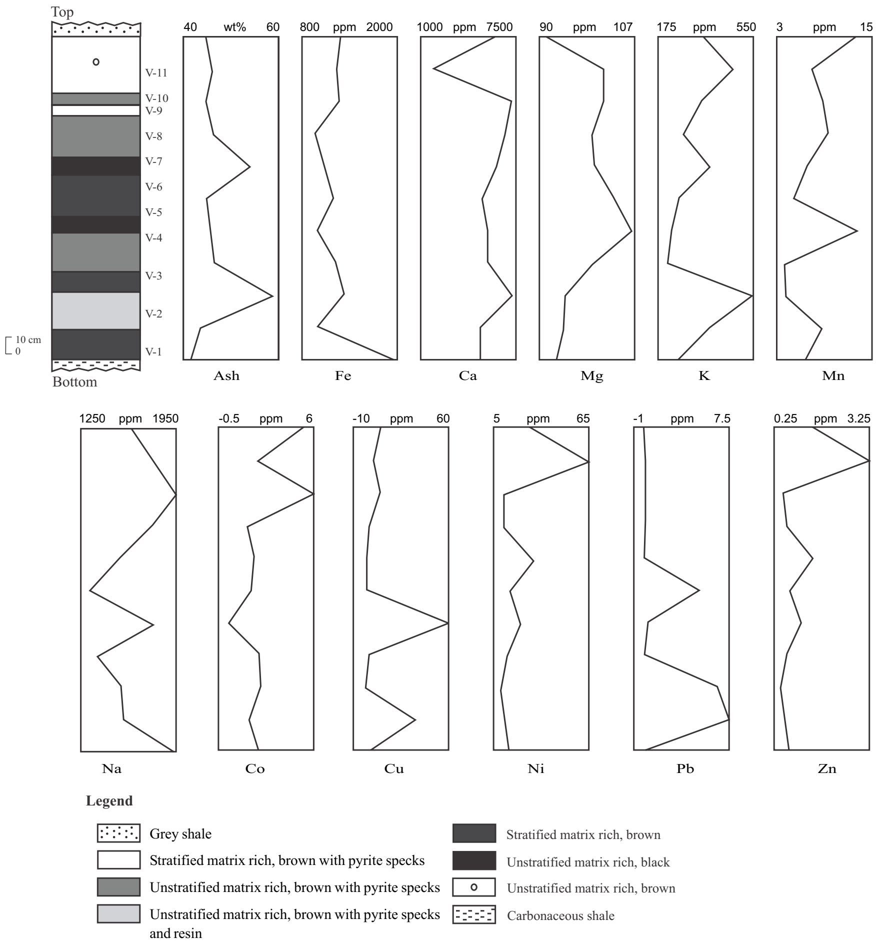

Fig.3a. Vertical variation of ash and some elements in Vastan upper lignite seam.

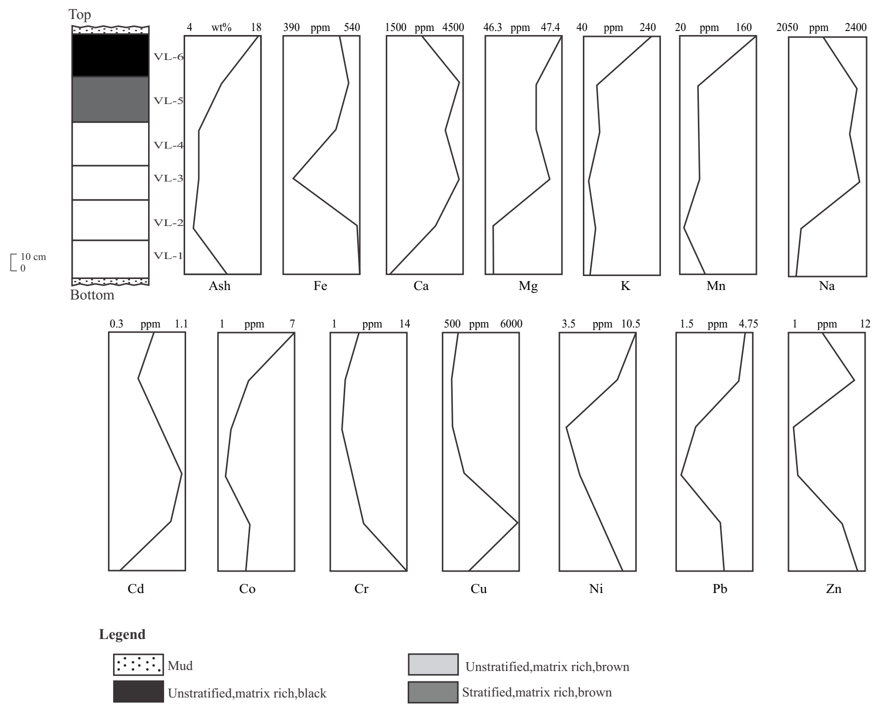

Fig.3b. Vertical variation of ash and some elements in Vastan lower lignite seam.

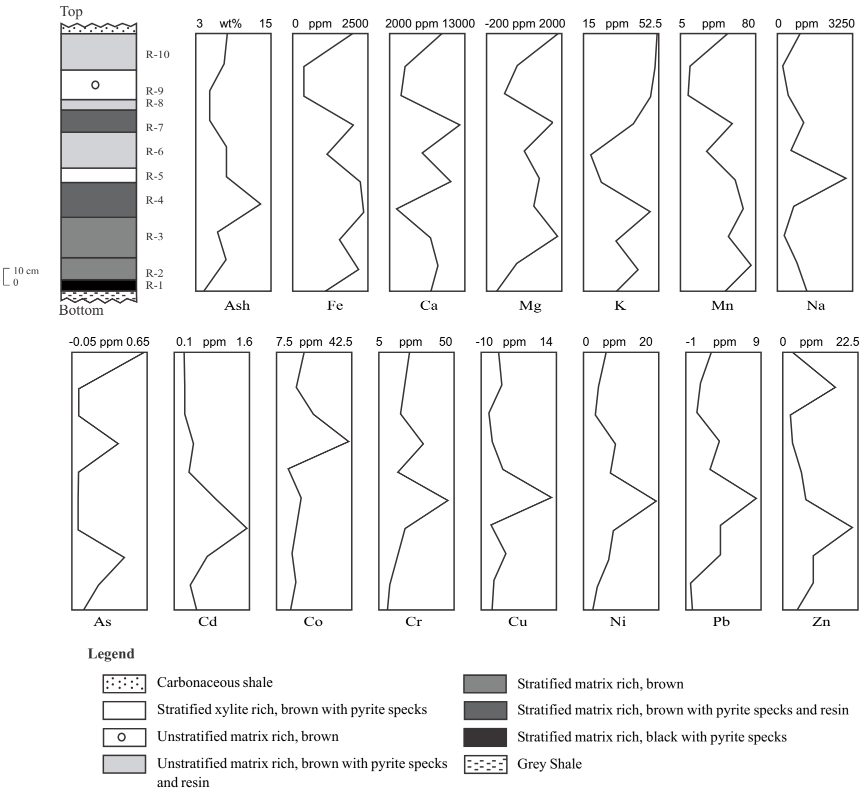

Fig.3c. Vertical variation of ash and some elements in Rajpardi lignite seam.

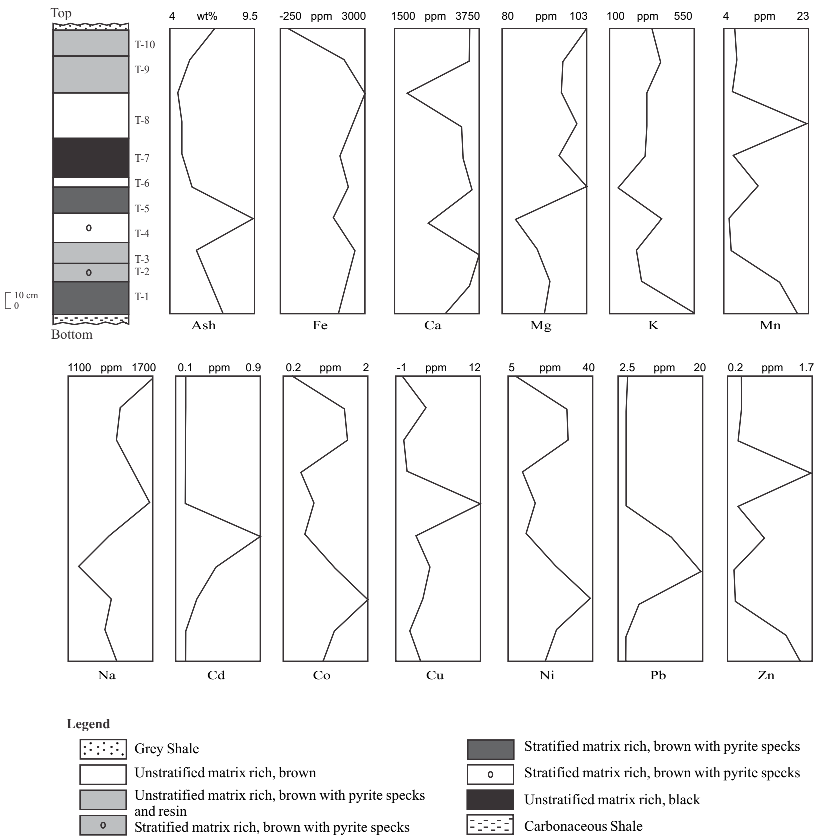

Fig.3d. Vertical variation of ash and some elements in Tadkeswar upper lignite seam.

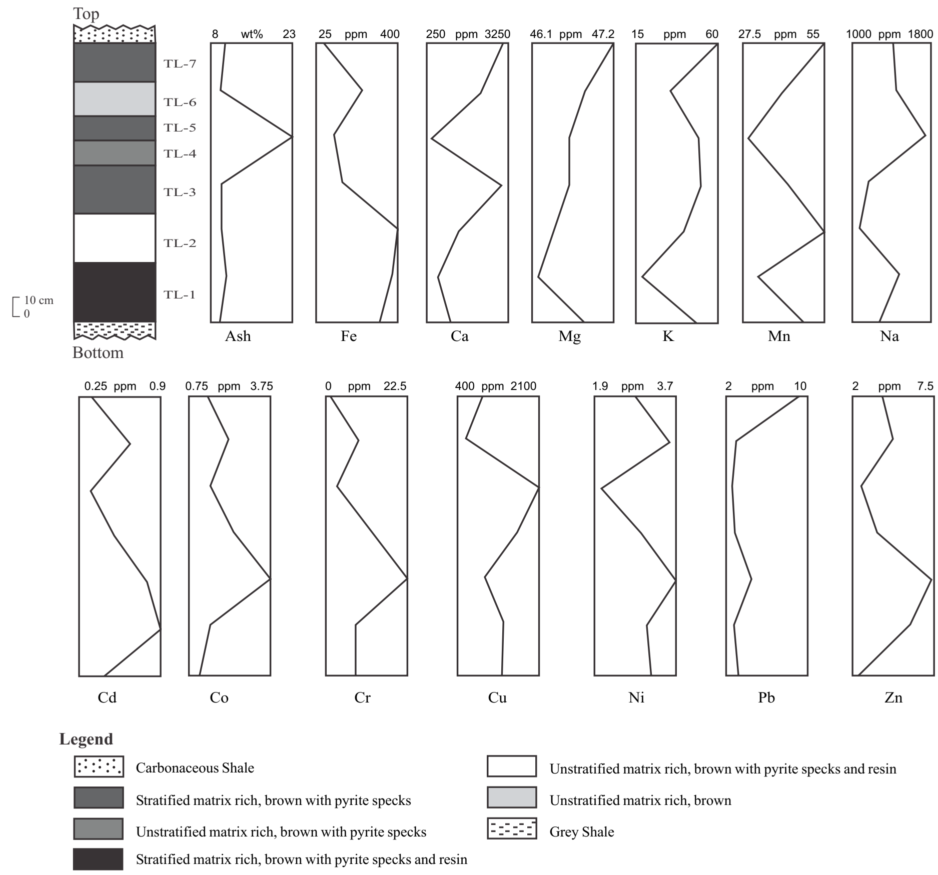

Fig.3e. Vertical variation of ash and some elements in Tadkeswar lower lignite seam.

Na (chiefly with liptinite) contents showing their affinity with organic matter while Pb and K maintain a positive correlation with inorganic matter. This indicates that Pb and K would have been derived from some inorganic source or pre-existing rocks. Similarly in Tadkeshwar lower seam organic matter has positive correlation with Na (chiefly with liptinite) while Fe, Mn, Co, Ni, Zn and Cd maintain a positive correlation with inorganic matter. In Vastan upper seam organic matter has a medium positive correlation with Mn (chiefly with inertinite), Na (chiefly with huminite) and Cu (chiefly with inertinite) while Ca, K and Pb have low positive correlation with inorganic matter. In Vastan lower seam the inorganic matter has a strong positive correlation with Mn, K, Co and Ni while organic matter maintains a moderate positive correlation with Cd (with liptinite and huminite) and Cu (chiefly with huminite). In Rajpardi seam the inorganic matter has a positive correlation with Fe, Mn and Pb while organic matter relates positively with Ca and Co (chiefly with huminite). The association of Ca with macerals is in agreement with the study of Ward et al. (2007) who could see significant proportion of Ca in the macerals in Australian coals. The correlation matrix among the elements and with organic matter in all the lignite seams of the Cambay basin has been furnished in Table 4a-e.

Iron bearing minerals are considered as hosts for several elements. Though the occurrence of Fe in Cambay basin lignites is well within the Clarke value, nevertheless it seems to have good affinity with Cd, Ni, Cr, Zn and Co in Tadkeshwar lower seam with Pb, Zn, Mn and Mg in Rajpardi seams.

Based on the sympathetic correlation of pyrite with elements it may be inferred that in Tadkeshwar lignite the elements Fe, Pb, Co, Ni, Cr and Zn are associated with pyrite and in Vastan lignites the elements Fe, Mn, Co, Ni, Cr, Zn and Pb have been derived from pyrite. In Rajpardi lignite the elements Fe, Mn, K and Cr have shown their affinity with pyrite.

CONCLUSIONS

In the present investigation full seam lignite samples were collected from Tadkeshwar mine (lower and upper seams), Vastan mine (lower and upper lignite seams) and

Table 4a. Correlation matrix between Major, minor and trace elements in Vastan upper lignite seam.

	Fe	Ca	Mg	Mn	K	Na	Cu	Co	Ni	Zn	Pb	Ash	O.M.	Humi	Lipt	Inert	Pyrite
Fe	1	-0.119	-0.481	-0.297	-0.033	0.328	-0.393	0.281	-0.052	-0.052	-0.167	-0.189	0.189	.685*	-0.35	-.609*	-0.278
Ca	-0.119	1	-0.166	0.047	-0.065	-0.05	-0.063	0.283	-.787**	-.787**	0.106	0.379	-0.379	0.359	-0.327	-0.492	0.133
Mg	-0.481	-0.166	1	0.028	-0.326	-0.034	0.312	-0.367	0.168	0.168	-0.231	-0.028	0.028	-0.17	-0.037	0.224	0.248
Mn	-0.297	0.047	0.028	1	-0.184	0.466	.654*	0.151	0.179	0.179	-0.328	-0.386	0.386	-0.073	-0.121	0.47	-.650*
K	-0.033	-0.065	-0.326	-0.184	1	0.015	-0.227	0.201	0.343	0.343	0.42	.630*	-.630*	0.1	-0.214	0.045	-0.126
Na	0.328	-0.05	-0.034	0.466	0.015	1	0.203	0.261	0.134	0.134	-0.459	-0.331	0.331	0.575	-0.252	-0.2	-.838**
Cu	-0.393	-0.063	0.312	.654*	-0.227	0.203	1	-0.349	-0.045	-0.045	0.11	-0.266	0.266	-0.313	0.023	.668*	-0.435
Co	0.281	0.283	-0.367	0.151	0.201	0.261	-0.349	1	-0.003	-0.003	-0.236	-0.116	0.116	0.454	-0.179	-0.493	-0.33
Ni	-0.052	-.787**	0.168	0.179	0.343	0.134	-0.045	-0.003	1	1.000**	-0.353	-0.036	0.036	-0.214	0.048	0.444	-0.189
Zn	-0.052	-.787**	0.168	0.179	0.343	0.134	-0.045	-0.003	1.000**	1	-0.353	-0.036	0.036	-0.214	0.048	0.444	-0.189
Pb	-0.167	0.106	-0.231	-0.328	0.42	-0.459	0.11	-0.236	-0.353	-0.353	1	0.253	-0.253	-0.248	0.047	0.195	0.237
Ash	-0.189	0.379	-0.028	-0.386	.630*	-0.331	-0.266	-0.116	-0.036	-0.036	0.253	1	-1.000**	0.096	-0.346	-0.141	0.388
O.M.	0.189	-0.379	0.028	0.386	-.630*	0.331	0.266	0.116	0.036	0.036	-0.253	-1.000**	1	-0.096	0.346	0.141	-0.388
Humi	.685*	0.359	-0.17	-0.073	0.1	0.575	-0.313	0.454	-0.214	-0.214	-0.248	0.096	-0.096	1	-.752**	-.795**	-0.337
Lipt	-0.35	-0.327	-0.037	-0.121	-0.214	-0.252	0.023	-0.179	0.048	0.048	0.047	-0.346	0.346	-.752**	1	0.365	0.176
Inert	-.609*	-0.492	0.224	0.47	0.045	-0.2	.668*	-0.493	0.444	0.444	0.195	-0.141	0.141	-.795**	0.365	1	-0.116
Pyrite	-0.278	0.133	0.248	-.650*	-0.126	-.838**	-0.435	-0.33	-0.189	-0.189	0.237	0.388	-0.388	-0.337	0.176	-0.116	1

OM- organic matter, Humi-huminite, lipt-liptinite, inert-inertinite, **. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed).

Table 4b. Correlation matrix between Major, minor and trace elements in Vastan lower lignite seam.

	Fe	Ca	Mg	Mn	K	Na	Cu	Co	Ni	Cr	Zn	Pb	Cd	Ash	O.M.	Humi	Lipt	Inert	Pyrite
Fe	1	-0.59	-0.639	-0.026	0.079	-0.695	0.304	0.367	0.535	0.489	0.776	0.712	-0.692	0.274	-0.274	0.215	-0.789	-0.613	0.498
Ca	-0.59	1	0.484	-0.327	-0.191	.851*	-0.18	-0.374	-0.535	-.913*	-0.454	-0.384	0.645	-0.47	0.47	0.468	0.367	-0.051	-0.599
Mg	-0.639	0.484	1	0.631	0.596	0.709	-0.672	0.317	-0.037	-0.631	-0.594	-0.04	0.366	0.392	-0.392	-0.213	0.336	0.184	-0.013
Mn	-0.026	-0.327	0.631	1	.929**	-0.061	-0.437	.842*	0.572	0.063	-0.111	0.495	-0.151	.899*	-.899*	-0.442	-0.188	-0.014	0.543
K	0.079	-0.191	0.596	.929**	1	-0.091	-0.233	.919**	0.529	-0.13	-0.117	0.569	0.02	0.796	-0.796	-0.079	-0.312	-0.356	0.366
Na	-0.695	.851*	0.709	-0.061	-0.091	1	-0.652	-0.352	-0.493	-0.804	-0.56	-0.407	0.38	-0.204	0.204	-0.006	0.557	0.304	-0.331
Cu	0.304	-0.18	-0.672	-0.437	-0.233	-0.652	1	-0.044	0.002	0.258	0.266	-0.012	0.305	-0.427	0.427	0.589	-0.315	-0.453	-0.361
Co	0.367	-0.374	0.317	.842*	.919**	-0.352	-0.044	1	0.798	0.121	0.273	.818*	-0.21	.866*	-.866*	-0.051	-0.645	-0.47	0.584
Ni	0.535	-0.535	-0.037	0.572	0.529	-0.493	0.002	0.798	1	0.497	0.734	.906*	-0.582	.834*	-.834*	-0.271	-.842*	-0.235	.876*
Cr	0.489	-.913*	-0.631	0.063	-0.13	-0.804	0.258	0.121	0.497	1	0.583	0.256	-0.649	0.287	-0.287	-0.526	-0.337	0.256	0.578
Zn	0.776	-0.454	-0.594	-0.111	-0.117	-0.56	0.266	0.273	0.734	0.583	1	0.728	-0.717	0.311	-0.311	-0.006	-.868*	-0.291	0.679
Pb	0.712	-0.384	-0.04	0.495	0.569	-0.407	-0.012	.818*	.906*	0.256	0.728	1	-0.578	0.76	-0.76	0.031	-.926**	-0.558	0.771
Cd	-0.692	0.645	0.366	-0.151	0.02	0.38	0.305	-0.21	-0.582	-0.649	-0.717	-0.578	1	-0.51	0.51	0.486	0.501	-0.066	-.846*
Ash	0.274	-0.47	0.392	.899*	0.796	-0.204	-0.427	.866*	.834*	0.287	0.311	0.76	-0.51	1	-1.000**	-0.498	-0.501	-0.058	.846*
O.M.	-0.274	0.47	-0.392	-.899*	-0.796	0.204	0.427	-.866*	-.834*	-0.287	-0.311	-0.76	0.51	-1.000**	1	0.498	0.501	0.058	-.846*
Humi	0.215	0.468	-0.213	-0.442	-0.079	-0.006	0.589	-0.051	-0.271	-0.526	-0.006	0.031	0.486	-0.498	0.498	1	-0.229	-0.808	-0.59
Lipt	-0.789	0.367	0.336	-0.188	-0.312	0.557	-0.315	-0.645	-.842*	-0.337	-.868*	-.926**	0.501	-0.501	0.501	-0.229	1	0.635	-0.623
Inert	-0.613	-0.051	0.184	-0.014	-0.356	0.304	-0.453	-0.47	-0.235	0.256	-0.291	-0.558	-0.066	-0.058	0.058	-0.808	0.635	1	0.075
Pyrite	0.498	-0.599	-0.013	0.543	0.366	-0.331	-0.361	0.584	.876*	0.578	0.679	0.771	-.846*	.846*	-.846*	-0.59	-0.623	0.075	1

OM- organic matter, Humi-huminite, lipt-liptinite, inert-inertinite, **. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed).

Table 4c. Correlation matrix between Major, minor and trace elements in Rajpardi lignite seam.

	Fe	Ca	Mg	Mn	K	Na	Cu	Co	Ni	Cr	Zn	Pb	Cd	As	Ash	OM	Humi	Lipt	Inert	Pyrite
Fe	1	0.469	0.625	.914**	-0.099	0.44	0.306	0.158	0.429	0.226	0.551	0.571	0.559	0.356	0.543	-0.543	-0.481	0.138	-0.162	0.613
Ca	0.469	1	0.446	0.491	-0.422	0.566	0.397	0.412	0.447	-0.546	0.377	-0.21	0.436	0.51	-0.416	0.416	0.104	0.116	-0.077	0.015
Mg	0.625	0.446	1	0.426	0.016	0.092	0.283	0.304	0.486	0.072	0.606	0.22	0.476	.750*	0.254	-0.254	-0.004	0.017	-0.029	0.034
Mn	.914**	0.491	0.426	1	-0.146	0.374	0.14	0.03	0.147	0.19	0.31	0.54	0.324	0.344	0.395	-0.395	-0.413	-0.115	-0.049	.634*
K	-0.099	-0.422	0.016	-0.146	1	-0.46	-0.507	0.272	-0.14	0.307	-0.379	-0.094	-0.442	0.235	0.216	-0.216	0.012	-0.42	0.085	0.307
Na	0.44	0.566	0.092	0.374	-0.46	1	.798**	0.082	.749*	-0.23	.709*	0.285	.812**	-0.177	-0.026	0.026	-0.255	0.448	-0.156	-0.029
Cu	0.306	0.397	0.283	0.14	-0.507	.798**	1	-0.172	.775**	-0.013	.831**	0.205	.902**	-0.148	0.073	-0.073	-0.024	0.439	-0.389	-0.18
Co	0.158	0.412	0.304	0.03	0.272	0.082	-0.172	1	0.42	-0.35	0.137	-0.17	0.107	0.318	-0.31	0.31	0.233	0.13	-0.154	-0.067
Ni	0.429	0.447	0.486	0.147	-0.14	.749*	.775**	0.42	1	-0.061	.885**	0.237	.904**	0.033	0.102	-0.102	-0.015	0.474	-0.37	-0.152
Cr	0.226	-0.546	0.072	0.19	0.307	-0.23	-0.013	-0.35	-0.061	1	0.102	.632*	0.05	-0.278	.803**	-.803**	0.038	-0.41	-0.387	0.305
Zn	0.551	0.377	0.606	0.31	-0.379	.709*	.831**	0.137	.885**	0.102	1	0.516	.966**	0.038	0.28	-0.28	-0.103	0.438	-0.291	-0.186
Pb	0.571	-0.21	0.22	0.54	-0.094	0.285	0.205	-0.17	0.237	.632*	0.516	1	0.432	-0.239	.722*	-.722*	-0.363	-0.006	-0.071	0.181
Cd	0.559	0.436	0.476	0.324	-0.442	.812**	.902**	0.107	.904**	0.05	.966**	0.432	1	-0.075	0.252	-0.252	-0.152	0.532	-0.395	-0.076
As	0.356	0.51	.750*	0.344	0.235	-0.177	-0.148	0.318	0.033	-0.278	0.038	-0.239	-0.075	1	-0.15	0.15	0.035	-0.27	0.331	0.112
Ash	0.543	-0.416	0.254	0.395	0.216	-0.026	0.073	-0.31	0.102	.803**	0.28	.722*	0.252	-0.15	1	-1.000**	-0.502	0.011	-0.13	0.524
OM	-0.543	0.416	-0.254	-0.395	-0.216	0.026	-0.073	0.31	-0.102	-.803**	-0.28	-.722*	-0.252	0.15	-1.000**	1	0.502	-0.011	0.13	-0.524
Humi	-0.481	0.104	-0.004	-0.413	0.012	-0.255	-0.024	0.233	-0.015	0.038	-0.103	-0.363	-0.152	0.035	-0.502	0.502	1	-0.491	-0.411	-0.556
Lipt	0.138	0.116	0.017	-0.115	-0.42	0.448	0.439	0.13	0.474	-0.41	0.438	-0.006	0.532	-0.27	0.011	-0.011	-0.491	1	-0.085	-0.023
Inert	-0.162	-0.077	-0.029	-0.049	0.085	-0.156	-0.389	-0.154	-0.37	-0.387	-0.291	-0.071	-0.395	0.331	-0.13	0.13	-0.411	-0.085	1	-0.182
Pyrite	0.613	0.015	0.034	.634*	0.307	-0.029	-0.18	-0.067	-0.152	0.305	-0.186	0.181	-0.076	0.112	0.524	-0.524	-0.556	-0.023	-0.182	1

Table 4d. Correlation matrix between Major, minor and trace elements in Tadkeshwar upper lignite seam.

	Fe	Ca	Mg	Mn	K	Na	Cu	Co	Ni	Zn	Pb	Cd	Ash	O.M.	Humi	Lipt	Inert	Pyrite
Fe	1	-0.179	0.285	-0.207	-0.454	0.042	-0.392	0.383	0.383	-0.024	-0.352	-0.065	-.728*	.728*	0.376	-0.459	-0.112	-0.327
Ca	-0.179	1	0.37	0.602	-0.415	0.358	0.128	-0.19	-0.19	0.101	-0.192	0.123	-0.212	0.212	-0.241	0.382	-0.015	-0.409
Mg	0.285	0.37	1	0.404	-0.42	.683*	-0.268	-.646*	-.646*	0.207	-0.382	0.159	-0.612	0.612	-0.146	0.462	-0.047	-0.58
Mn	-0.207	0.602	0.404	1	-0.302	-0.055	-0.149	-0.195	-0.195	0.123	0.065	0.403	-0.042	0.042	-0.348	.645*	0.06	-0.375
K	-0.454	-0.415	-0.42	-0.302	1	-0.062	0.036	0.05	0.05	0.245	-0.173	-0.516	0.48	-0.48	0.232	-0.064	-0.296	0.146
Na	0.042	0.358	.683*	-0.055	-0.062	1	0.193	-0.547	-0.547	0.039	-.683*	-0.412	-0.538	0.538	0.077	0.249	-0.227	-0.563
Cu	-0.392	0.128	-0.268	-0.149	0.036	0.193	1	0.013	0.013	-0.301	0.063	-0.033	-0.071	0.071	-0.139	-0.158	0.441	0.089
Co	0.383	-0.19	-.646*	-0.195	0.05	-0.547	0.013	1	1.000**	-0.378	0.011	-0.18	-0.003	0.003	0.41	-0.605	-0.148	0.08
Ni	0.383	-0.19	-.646*	-0.195	0.05	-0.547	0.013	1.000**	1	-0.378	0.011	-0.18	-0.003	0.003	0.41	-0.605	-0.148	0.08
Zn	-0.024	0.101	0.207	0.123	0.245	0.039	-0.301	-0.378	-0.378	1	-0.285	-0.102	-0.054	0.054	0.012	0.06	-0.033	-0.21
Pb	-0.352	-0.192	-0.382	0.065	-0.173	-.683*	0.063	0.011	0.011	-0.285	1	.763*	0.599	-0.599	-0.52	0.092	0.555	.789**
Cd	-0.065	0.123	0.159	0.403	-0.516	-0.412	-0.033	-0.18	-0.18	-0.102	.763*	1	0.144	-0.144	-0.41	0.118	0.499	0.273
Ash	-.728*	-0.212	-0.612	-0.042	0.48	-0.538	-0.071	-0.003	-0.003	-0.054	0.599	0.144	1	-1.000**	-0.117	0.131	-0.107	0.594
O.M.	.728*	0.212	0.612	0.042	-0.48	0.538	0.071	0.003	0.003	0.054	-0.599	-0.144	-1.000**	1	0.117	-0.131	0.107	-0.594
Humi	0.376	-0.241	-0.146	-0.348	0.232	0.077	-0.139	0.41	0.41	0.012	-0.52	-0.41	-0.117	0.117	1	-.704*	-.783**	-0.534
Lipt	-0.459	0.382	0.462	.645*	-0.064	0.249	-0.158	-0.605	-0.605	0.06	0.092	0.118	0.131	-0.131	-.704*	1	0.176	0.018
Inert	-0.112	-0.015	-0.047	0.06	-0.296	-0.227	0.441	-0.148	-0.148	-0.033	0.555	0.499	-0.107	0.107	-.783**	0.176	1	0.555
Pyrite	-0.327	-0.409	-0.58	-0.375	0.146	-0.563	0.089	0.08	0.08	-0.21	.789**	0.273	0.594	-0.594	-0.534	0.018	0.555	1

OM- organic matter, Humi-huminite, lipt-liptinite, inert-inertinite, **. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed).

Table 4e. Correlation matrix between Major, minor and trace elements in Tadkeshwar lower lignite seam.

	Fe	Ca	Mg	Mn	K	Na	Cu	Co	Ni	Cr	Zn	Pb	Cd	Ash	O.M.	Humi	Lipt	Inert	Pyrite
Fe	1	-0.485	-0.681	0.068	-0.724	-0.431	-0.298	0.366	0.688	0.685	0.654	-0.403	.825*	0.558	-0.558	-0.697	-0.216	.773*	0.545
Ca	-0.485	1	0.614	0.576	0.493	-0.435	-0.451	0.15	0.234	-0.027	-0.034	0.553	-0.211	-0.112	0.112	0.366	-0.347	-0.648	0.086
Mg	-0.681	0.614	1	0.492	0.75	0.094	-0.313	-0.383	-0.158	-0.551	-0.515	0.687	-0.737	-0.342	0.342	.865*	0.144	-0.563	-0.582
Mn	0.068	0.576	0.492	1	0.48	-0.728	-0.616	0.345	0.529	0.348	0.264	0.68	-0.047	0.498	-0.498	0.461	-0.666	-0.281	0.309
K	-0.724	0.493	0.75	0.48	1	-0.093	0.173	-0.1	-0.396	-0.286	-0.562	0.534	-.855*	-0.072	0.072	.927**	-0.271	-0.622	-0.335
Na	-0.431	-0.435	0.094	-0.728	-0.093	1	0.404	-0.626	-0.719	-.776*	-0.446	-0.101	-0.371	-0.613	0.613	0.114	.836*	-0.095	-0.668
Cu	-0.298	-0.451	-0.313	-0.616	0.173	0.404	1	-0.274	-.814*	-0.27	-0.52	-0.42	-0.388	-0.306	0.306	0.06	0.097	0.091	-0.247
Co	0.366	0.15	-0.383	0.345	-0.1	-0.626	-0.274	1	0.566	.896**	0.709	-0.09	0.494	.870*	-.870*	-0.334	-0.654	-0.186	.851*
Ni	0.688	0.234	-0.158	0.529	-0.396	-0.719	-.814*	0.566	1	0.72	0.678	-0.022	0.685	0.575	-0.575	-0.428	-0.349	0.281	0.569
Cr	0.685	-0.027	-0.551	0.348	-0.286	-.776*	-0.27	.896**	0.72	1	0.71	-0.281	0.654	.869*	-.869*	-0.498	-0.673	0.235	.856*
Zn	0.654	-0.034	-0.515	0.264	-0.562	-0.446	-0.52	0.709	0.678	0.71	1	0.088	.868*	0.714	-0.714	-0.59	-0.47	0.056	.880**
Pb	-0.403	0.553	0.687	0.68	0.534	-0.101	-0.42	-0.09	-0.022	-0.281	0.088	1	-0.297	0.036	-0.036	0.66	-0.306	-0.648	-0.008
Cd	.825*	-0.211	-0.737	-0.047	-.855*	-0.371	-0.388	0.494	0.685	0.654	.868*	-0.297	1	0.456	-0.456	-.884**	-0.234	0.448	0.746
Ash	0.558	-0.112	-0.342	0.498	-0.072	-0.613	-0.306	.870*	0.575	.869*	0.714	0.036	0.456	1	-1.000**	-0.183	-0.669	0.02	.771*
O.M.	-0.558	0.112	0.342	-0.498	0.072	0.613	0.306	-.870*	-0.575	-.869*	-0.714	-0.036	-0.456	-1.000**	1	0.183	0.669	-0.02	-.771*
Humi	-0.697	0.366	.865*	0.461	.927**	0.114	0.06	-0.334	-0.428	-0.498	-0.59	0.66	-.884**	-0.183	0.183	1	-0.048	-0.551	-0.527
Lipt	-0.216	-0.347	0.144	-0.666	-0.271	.836*	0.097	-0.654	-0.349	-0.673	-0.47	-0.306	-0.234	-0.669	0.669	-0.048	1	0.187	-.763*
Inert	.773*	-0.648	-0.563	-0.281	-0.622	-0.095	0.091	-0.186	0.281	0.235	0.056	-0.648	0.448	0.02	-0.02	-0.551	0.187	1	-0.011
Pyrite	0.545	0.086	-0.582	0.309	-0.335	-0.668	-0.247	.851*	0.569	.856*	.880**	-0.008	0.746	.771*	-.771*	-0.527	-.763*	-0.011	1

OM- organic matter, Humi-huminite, lipt-liptinite, inert-inertinite, **. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed).

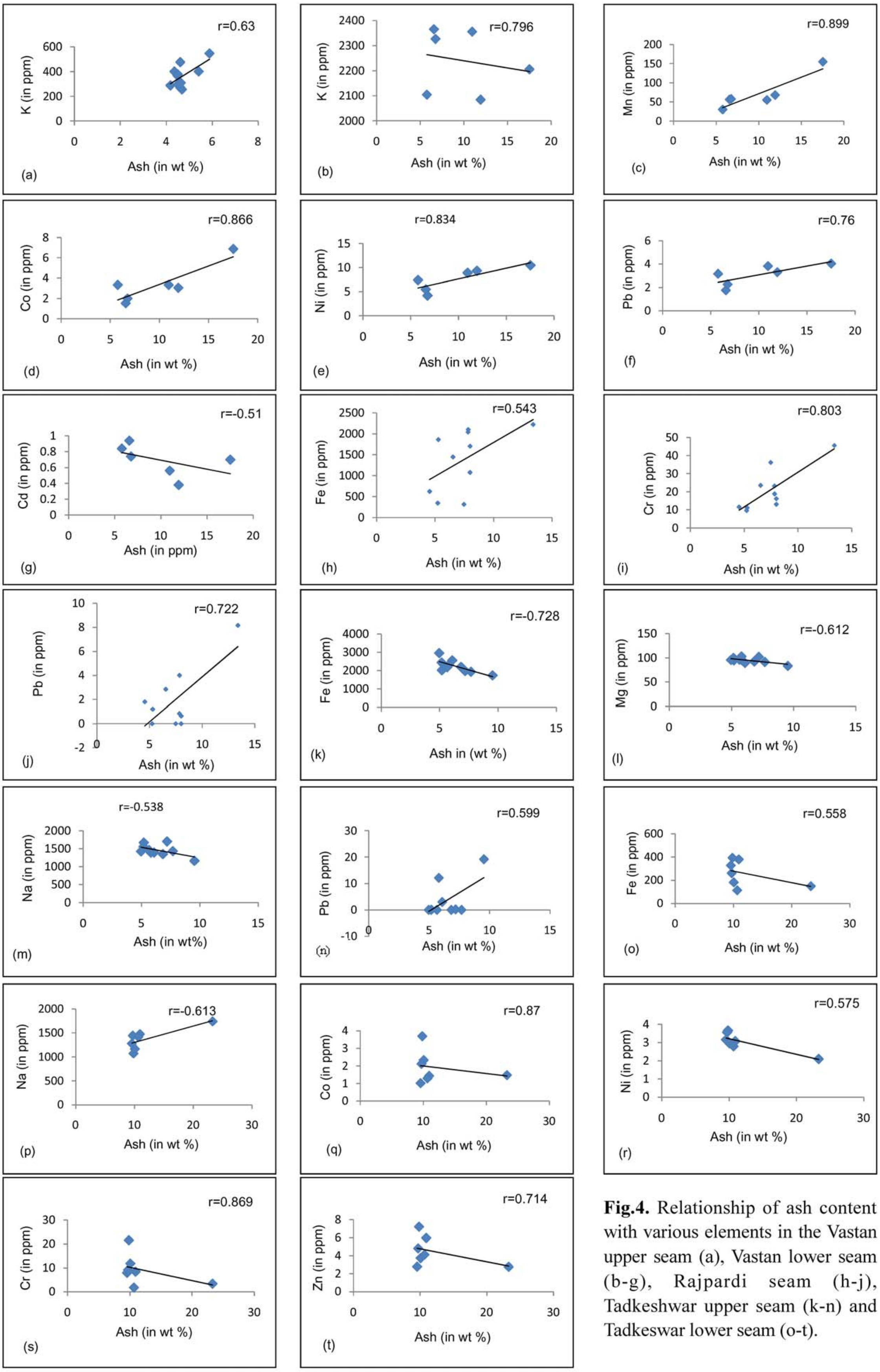

Fig.4. Relationship of ash content with various elements in the Vastan upper seam (a), Vastan lower seam (b-g), Rajpardi seam (h-j), Tadkeshwar upper seam (k-n) and Tadkeswar lower seam (o-t).

Rajpardi mines of Cambay basin. The samples were subjected to petrographic and chemical studies and were analysed for major and minor elements like Fe, Ca, Na, K, Mg, and Mn and trace elements like Cu, Co, Cr, Cd, Ni, Pb and Zn with the help of Atomic Absorption Spectrophotometer. Based on the study the following conclusions are drawn:

1. Cambay basin lignites have a dominance of huminite group (59-77%) whereas liptinite (9-17%) and inertinite (3-10%) occur in subordinate amounts. The mineral matter varies from 9-20% in various seams.
2. Element analysis shows that Cu content is high in all the lignite seams and in few sections of Rajpardi seam it is over 100 times higher when compared with the Clarke values. Ni, Cd, Cr, Co and Pb occur in very high concentration in few sections.
3. Occurrence of elements in these lignites has been discussed on the basis of indirect evidences such as correlation coefficient of elements with ash content, pattern of distribution of elements with increase in ash content, correlation of elements with Fe content and correlation matrix among the elements.
4. The elements have shown their affinity with various macerals. Correlation study reveals that in Tadkeshwar upper seam Fe is associated with huminite while Mg and Na have their affinity with liptinite: in Tadkeshwar lower seam Na is associated with liptinite. In Vastan upper seam Mn and Cu relate with inertinite and Na with huminite whereas in Vastan lower seam Cu has an affinity with huminite and Cd with liptinite and huminite. Ca and Co relate to huminite in Rajpardi seam.

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