CHAPTER - V

CORRELATION OF TRACE ELEMENTS
5.1 Organic and Inorganic affinities of coal

It is an accepted fact that trace elements in coal may have organic affinity or inorganic affinity. Fundamentally trace element association is connected with the history of coal swamp, geological changes that have occurred and the atmospheric input which would have taken place from time to time. A knowledge of organic geochemistry of coal is essential in determining the affinity of humic substances for different elements. Given (1984) and Horton and Aufbray (1950) studied organic affinity of trace elements.

Zubovic et al. (1960) used float and sink technique for determining organic affinity of trace elements. In general, a large number of trace elements have been found in almost all coals. Hallam and Payne (1958) investigated organic association in coal. They found Germanium 100% in organic combination, whereas Sn is 100% inorganic combination. In the same way Nicholls (1968) reported boron 100% organic fraction of coal. Elements like Be, Cr, Co, Pb, Sr, V are in most cases associated with inorganic part of coal. Elements like Ni, Ga, Ge, Mo, Cu may be either with organic fraction or with both fractions. It has been observed that the concentration of trace elements in general is greatest in immature or young coals and least in mature or old coals (Bethel 1963).

Goldschmidt (1922) classified all the elements into three groups viz, sedorophile, chalcophile and lithophile on the basis of elements concentrated in the iron, sulphide and silicate phases respectively. He also used the term Atmophile for elements which occur in atmosphere and Biophile for elements found in Biosphere. The trace elements which are reported from coal belong to all the geochemical affinity groups of Goldschmidt. Duel et al. (1956) found Vanadium, Iron, Cobalt, Nickel, Copper, Zinc and Molybdenum from organic complexes in...
coal and Si, Al, Ca, Mg, Na, K, Ba, Sr, Ti, and Zr in inorganic association. Some are found in both.

Ruch et al. (1971) showed that Be, B, and Ge concentrate in organic substances and As, Cd, Pb, Mn, Hg, Mo, Zn, Zr associate with inorganic fractions. Gluskoter et al. (1977) separated different specific gravity fractions of coal and carried out trace element analysis of each fraction. He found Ge, Be, B, and Sb in organic group where Ge has the highest organic affinity. Eskenazy (1978) explained that rare earth elements associate with inorganic fractions of coal. According to Chou et al. (1982), most of the trace elements in coal are associated with mineral matter. Mukherjee et al. (1982) explained that Ni, Cu, and Y accumulate through primary biological process, and Zr, V, Co, and Ba concentrate in inorganic fraction of coal. According to Singh et al. (1983), the elements like V, Co, Ni, W, Cr, Sc, and Y are associated with organic matter. Be is associated with clay minerals and quartz, with Cu, Pb with Pyrite and Ba with carbonates. Pareek and Bardhan (1985) characterized Cu, Ni, Co, V, B, Mo, Nb as organophile where as Pb, Cu, Ni, Mn, La, Ba, Y, Cr, Sr, Zn as inorganic fraction. Swaine (1992) adopted float and sink method to find out the organic and inorganic association of coal. Ghosh et al. (1987) studied trace element associated in the lithotypes of some selected Indian coals. Z. Klika (2000) adopted new concept for the calculation of trace element affinity between organic and inorganic parts of coal. Palmer and Lyons (1990) studied vitrinite concentration in coal and categorized organic and inorganic affinity. Robert et al. (1986) studied lignite samples and found organic and inorganic association of trace elements in lignite. He found Be, Sc, Cr, Y, Yb, V, Ni, Cu and Zn to be associated with organic matter.

5.2. Lateral variation of trace elements in coal seam - I at different mines

Occurrence of trace elements is very complex in nature. The same element even varies in the same seam at different locations. The seam I at Balanda OCP,
Talchir, UG, Deulbera UG and Nandira UG shows variable results. Fourteen trace elements such as Mn, Cr, Zn, Fe, Cd, Cu, Ni, Co, Na, Ca, K, Mg, Pb and Sn were analysed at different locations in seam I of the Talchir coalfield. The results of variation in seam I at different mines is reflected (fig-2.1 to 2.13) by block diagrams based on the results of table - 3.

The concentration of Mn at Balanda OCP is 144.8 ppm, at Talchir UG it is 501.7, at Deulbera it is 285 ppm and in Nandira it is 349.5 ppm. The Mn concentration is the highest at Talchir UG and lowest at Balanda OCP. The concentration of Cr at Balanda OCP is 317.2 ppm, Talchir UG it is 91.3 ppm, at Deulbera it is 110.7 ppm and at Nandira UG it is 327.6 ppm. The concentration is highest at Nandura UG and lowest at Talchir UG. The concentration of Zn at Balanda OCP is 91 ppm, it is 150.3 ppm at Talchir UG, at Deulbera UG it is 68.5 ppm and the lowest concentration is at Nandira UG that is 46.5 ppm. The concentration of Fe is the lowest at Balanda OCP than another underground mines. At Balanda OCP it is 1906 ppm, at Talchir UG it is 2480 ppm, at Deulbera UG it is 2504 ppm and at Nandira UG it is 2456.2 ppm. The concentration of Cd is the highest at Balanda OCP that is 2 ppm, it is the lowest at Nandira UG i.e. 1.2 ppm, at Deulbera UG it is 1.55 ppm and at Talchir UG it is 1.5 ppm. Cu concentration is also the lowest at Balanda OCP than the underground mines. At Balanda OCP it is 98.2 ppm, at Talchir UG it is the highest i.e. 208.3 ppm, at Deulba it is 159.7 ppm and at Nandira UG it is 147.5 ppm. Ni shows the highest concentration at Balanda OCP that is 394.4 ppm. It is the lowest at Talchir UG i.e. 169.6 ppm and at Nandira it is 345.4 ppm. Similarly, concentration of Co is the highest at Balanda OCP and the lowest at Nandira UG. At Balanda OCP it is 17.98 ppm, at Talchir UG it is 141.8 ppm at Deulbera UG it is 10.44 and at Nandira it is 9.6 ppm. Na concentration is also the highest at Balanda OCP i.e. 631.7 ppm, at Talcher UG it is 549.5 ppm, at Deulbera UG it is 625.8 ppm and at Nandira UG it is 586.8 ppm. The concentration of Ca is the lowest at Balanda OCP i.e. 97.1 ppm, at Talchir UG it is 136.1 ppm, at Deulbera it is 460.3 ppm and at Nandira it is 168.7 ppm. K is the lowest in concentration at Balanda OCP. It is the highest i.e. 561.2 ppm at Deulbera UG. At Talchir it is 538 ppm, at Balanda it is 440.2 ppm. And at Nandira it is 493 ppm.
ppm. Like K and Ca, Mg is lowest at Balanda OCP i.e. 159.8 ppm at Talchir UG it is 194.4 ppm, at Deulbera UG it is 218.6 ppm and at Nandira UG it is 188.9 ppm. The concentration of Pb at Balanda OCP is 31.6 ppm, at Talchir UG it is 26.5 ppm at Deulbera it is 30.6 and at Nandira UG it is 32.4 ppm. The concentration of Pb is the highest at Nandira UG and the lowest at Talchir UG. The concentration of Sn is not detected in seam I.

5.3 Lateral variation of trace elements in coal seam II at different mines

Representative coal samples of Seam – II were collected from Lingaraj OCP, Ananta OCP and Bharatpur OCP for trace element analysis. The results of variation is reflected (fig-3.1 to 3.13) by block diagrams based on the results of table – 4.

The results reveal that manganese concentration is very less i.e. 34.2 ppm at Lingaraj OCP, it is 106.49 ppm at Ananta OCP and at Bharatpur OCP it is 203.76 ppm. The concentration of Cr is 182.8 ppm at Lingaraj OCP, it is 170 ppm at Ananta OCP and is 138.3 ppm at Bharatpur OCP. Similarly, the concentration of Zn is the highest at Lingaraj OCP i.e. 148.1 ppm, it is 96.39 ppm at Ananta OCP and is 118.1 ppm at Bharatpur OCP. The concentration of Fe varies from 2042.6 to 2397.2 ppm. It is 2042.6 ppm at Lingaraj OCP, 2043 ppm at Ananta OCP and 2397.2 ppm at Bharatpur OCP. Cd is 3.6 ppm both at Lingaraj OCP and Ananta OCP but it is 1.5 at Bharatpur OCP. The concentration of Cu varies from 57.3 to 101.2 ppm, it is 87.8 ppm at Lingaraj OCP, 101.2 ppm at Ananta OCP and 57.3 at Bharatpur OCP. The concentration of Ni at Lingaraj OCP is 104 ppm, it is 160.19 ppm at Ananta OCP and at Bharatpur OCP it is 144.2 ppm. Co concentration varies from 5.28 to 12.1 ppm, it is 6.28 ppm at Bharatpur OCP, 12.1 ppm at Ananta OCP and 5.28 ppm at Lingaraj OCP. The concentration of Na at Lingaraj OCP is 658.1 ppm, at Ananta OCP 614.2 ppm and at Bharatpur OCP 627.2 ppm. Ca concentration is very less at Lingaraj OCP than concentration at Ananta and
Bharatpur OCP At Lingaraj OCP Ca concentration is 63.5 ppm, at Ananta OCP it is 266.8 ppm and at Bharatpur the concentration is the highest i.e. 1469 ppm. The concentration of K at Lingaraj OCP is 504.6 ppm, at Ananta OCP it is the highest of 612.1 ppm and at Bharatpur it is 541.5 ppm. Similarly, the Mg concentration at Lingaraj OCP is 154.3 ppm, at Ananta OCP it is 150.25 ppm and Bharatpur OCP it is 185.1 ppm. The concentration of Pb varies from 45.5 ppm to 92.7 ppm. It is 72.2 ppm at Lingaraj OCP, at Ananta OCP it is 92.7 ppm and at Bharatpur it is 45.5 ppm. The concentration of Sn is also not detected in seam II of these coal mines.

5.4 Lateral variation of Trace Elements in Coal seam - III of different Mines

Representative coal samples of seam III were collected from Lingaraj OCP, Ananta OCP and Bharatpur OCP for trace element analysis. The results of variation of trace elements are reflected (fig.4.1 to 4.13) by block diagrams based on the results of table – 5.

The results reveal that the concentration of Mg varies from 69.3 to 137.4 ppm. It is the lowest at Lingaraj OCP and the highest at Ananta OCP and at Bharatpur the concentration is 133.4 ppm. Na concentration at Lingaraj OCP is 632.4 ppm, at Ananta OCP it is 587.5 ppm and at Bharatpur OCP it is 627.1 ppm. Similarly, the Ca concentration at Lingaraj OCP is 214.4 ppm, at Ananta OCP it is 219.1 ppm and at Bharatpur it is 265.9 ppm. The concentration of Pb varies from 22.38 ppm at Ananta OCP to 52.55 ppm at Lingaraj OCP and it is 37.34 ppm at Bharatpur OCP. Mn is 22.4 ppm at Lingaraj OCP, it is 83.92 ppm at Ananta OCP and 60.3 ppm at Bharatpur OCP. The concentration of Cr varies from 87.5 ppm at Lingaraj OCP to 142.28 ppm at Bharatpur OCP and at Ananta OCP it is 88.36 ppm. Zn concentration is higher at Lingaraj OCP and Bharatpur OCP than the Ananta OCP. At Ananta OCP the concentration is 45.46 ppm, at Lingaraj OCP it is 141.8 ppm and at Bharatpur OCP it is 126.6 ppm. The concentration of Fe varies from 1728.9 to 2325 ppm. It is the highest at Bharatpur OCP and the lowest at Lingaraj OCP.
The concentration is 1906 ppm at Ananta OCP. The concentration of Cd is 1.6 ppm at Bharatpur OCP, 2.2 ppm at Ananta OCP, and 3.7 ppm at Lingaraj OCP. Similarly, the concentration of Cu varies from 58.46 to 65.1 ppm; it is 65.1 ppm at Lingaraj OCP, 58.46 ppm at Ananta OCP, and 59.76 ppm at Bharatpur OCP. The concentration of Ni at Lingaraj OCP is 72.2 ppm, at Ananta it is 81.9 ppm, and at Bharatpur OCP it is 149.7 ppm. Similarly, the concentration of Co varies from 3.8 to 9 ppm; it is 5.8 ppm at Ananta OCP, 3.8 ppm at Lingaraj OCP, and the highest of 9.0 ppm at Bharatpur OCP. The K concentration at Lingaraj OCP is 482.2 ppm, at Ananta it is 627.4 ppm, and at Bharatpur the concentration is 509.9 ppm.

5.5 Vertical variation of trace elements in different coal seams

Systematic representative samples of around hundred numbers were collected from Talchir UG, Deulbera UG, Nandira UG, Balanda OCP, Lingaraj OCP, Ananta OCP, and Bharatpur OCP, which covered the entire stratigraphic sequence of coal seams from Seam - I to Seam – VI. These seams belong to both Karharbari and Barakar Formations. The results of trace element concentration from Seam - I to Seam – VI is reflected (Fig-5.1 to 5.13) by block diagrams based on the results of table - 9.

The results reveal that Mn concentration varies from 15.5 to 320.2 ppm and the average is 119.1 ppm. There is no systematic trend of increase or decrease of manganese from Seam - I to Seam – VI. However, manganese is showing the highest concentration in the bottom Seam (Seam – I), i.e., 320.2 ppm and in lowest in Seam – IV, i.e., 15.5 ppm. Cr ranges from 64.2 to 211.7 ppm with an average of 116.5 ppm. It appears that Cr enrichment occurs towards bottom seam. Zn varies from 71.9 to 162.7 ppm with an average of 104.5 ppm. The concentration of Zn has no systematic trend of increase or decrease. The concentration of Fe ranges from 1832.5 to 2445.4 ppm with an average of 2164.5 ppm. It shows no relation with stratigraphy. The concentration of Cd varies from 1.56 to 4.6 ppm with an
Table 9  Seam wise vertical variation of Trace elements (in ppm) of the study area, Talchir Coal Field, Orissa

<table>
<thead>
<tr>
<th>Name of Seams</th>
<th>Ash %</th>
<th>Mn</th>
<th>Cr</th>
<th>Zn</th>
<th>Fe</th>
<th>Cd</th>
<th>Cu</th>
<th>Ni</th>
<th>Co</th>
<th>Na</th>
<th>Ca</th>
<th>K</th>
<th>Mg</th>
<th>Pb</th>
<th>Sn</th>
<th>Na/K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seam-VI</td>
<td>42</td>
<td>35</td>
<td>64</td>
<td>28</td>
<td>22</td>
<td>4</td>
<td>6</td>
<td>6</td>
<td>69</td>
<td>38</td>
<td>553</td>
<td>93</td>
<td>38</td>
<td>ND</td>
<td>1.25</td>
<td></td>
</tr>
<tr>
<td>Seam-V</td>
<td>42</td>
<td>173</td>
<td>79</td>
<td>162</td>
<td>24</td>
<td>4</td>
<td>1</td>
<td>62</td>
<td>6</td>
<td>50</td>
<td>590</td>
<td>180</td>
<td>19</td>
<td>ND</td>
<td>1.09</td>
<td></td>
</tr>
<tr>
<td>Seam-IV</td>
<td>38</td>
<td>15</td>
<td>74</td>
<td>26</td>
<td>18</td>
<td>3</td>
<td>1</td>
<td>64</td>
<td>58</td>
<td>40</td>
<td>423</td>
<td>81</td>
<td>10</td>
<td>ND</td>
<td>1.37</td>
<td></td>
</tr>
<tr>
<td>Seam-III</td>
<td>24.7</td>
<td>55</td>
<td>106</td>
<td>105</td>
<td>19</td>
<td>2</td>
<td>2</td>
<td>61</td>
<td>61</td>
<td>23</td>
<td>539</td>
<td>113</td>
<td>37</td>
<td>ND</td>
<td>1.1</td>
<td></td>
</tr>
<tr>
<td>Seam-II</td>
<td>24</td>
<td>115</td>
<td>164</td>
<td>121</td>
<td>21</td>
<td>2</td>
<td>1</td>
<td>82</td>
<td>61</td>
<td>23</td>
<td>552</td>
<td>163</td>
<td>70</td>
<td>ND</td>
<td>1.2</td>
<td></td>
</tr>
<tr>
<td>Seam-I</td>
<td>23</td>
<td>320</td>
<td>211</td>
<td>89</td>
<td>23</td>
<td>1</td>
<td>5</td>
<td>56</td>
<td>59</td>
<td>21</td>
<td>508</td>
<td>190</td>
<td>30</td>
<td>ND</td>
<td>1.17</td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>119</td>
<td>116</td>
<td>104</td>
<td>2164</td>
<td>9</td>
<td>3</td>
<td>1</td>
<td>111</td>
<td>57</td>
<td>52</td>
<td>137</td>
<td>34</td>
<td>2.9</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

54
average of 3.19 ppm. It is showing highest concentration in the top seam and lowest in the bottom seam. It also shows a systematic increase in concentration from bottom seam to top seam. The enrichment of Cu is highest at the bottom seam i.e., 153.4 ppm and lowest in Seam – IV i.e., 37.1 ppm with an average concentration of 74.1 ppm. The concentration of Ni is the highest in the bottom seam and is the lowest in the top seam. Like Cd, it also shows systematic change in concentration in relation to stratigraphy. The lowest concentration is 46.9 ppm and the highest is 262.8 ppm with an average of 111.2 ppm.

The concentration of Co varies from 2.58 to 12.2 ppm with an average of 5.79 ppm. It appears that Co enrichment increases towards bottom seam. Na varies from 580.9 to 697.3 ppm with an average of 628.9 ppm. It is highest at top seam and lowest at seam IV. The concentration of Ca varies from 40.8 to 599.7 ppm with an average of 197.5 ppm. The concentration is higher in bottom three seams than the top three. The concentration of K is approximately equal in all seams. It varies from 423.1 to 590.6 ppm with an average of 522.9 ppm. The concentration of Mg is the highest in the bottom seam and less in top seams. It varies from 81.8 to 190.4 ppm with an average concentration of 137.1 ppm. Pb varies from 10.8 to 70.1 ppm with an average of 34.38 ppm. It does not show any systematic trend of increase or decrease from seam I to seam VI. The concentration of Sn is not detected in any of the seams.

5.6 Trace element concentration at Balanda OCP

The concentration of fourteen trace elements of Balanda OCP(Comes under seam-I) is reflected in table 3 & figure 6.

The concentration of Mn is 144.8 ppm, Cr is 317.2 ppm, Zn 91 ppm, Fe 1906 ppm, Cd 2 ppm, Cu 98.2 ppm, Ni 394.4 ppm, Co 17.98 ppm, Na 631.7 ppm, Ca 97.1 ppm, K 440.2 ppm, Mg 159.8 ppm, Pb 316 ppm and the concentration of Sn is
not detected Here Fe shows the highest concentration and Cd shows the lowest concentration.

5.7 Trace element concentration at Talchir UG.

The concentration of trace elements of Talchir UG (Seam – I) is reflected in table 3 and figure 7.

The results show the concentration of Fe is the highest of 2480 ppm and Cd is the lowest of 1.5 ppm, and Mn concentration is 50.17 ppm, Cr 91.3 ppm, Zn 150.3 ppm, Cu 208.3 ppm, Ni 141.8 ppm, Co 10.79 ppm, Na 549.5 ppm, Ca 136.1 ppm, K 538 ppm, Mg 194.4 ppm, Pb 26.5 ppm, and Sn is not detected.

5.8 Trace element concentration at Nandira UG.

The concentration of different trace elements of Nandira UG (Seam – I) is reflected in table 3 and figure 8.

Here Mn is 349.5 ppm, Cr 327.6 ppm, Zn 46.5 ppm, Fe 2456.5 ppm, Cd 1.2 ppm, Cu 147.5 ppm, Ni 345.4 ppm, Co 9.6 ppm, Na 586.8 ppm, Ca 168.7 ppm, K 493 ppm, Mg 188.9 ppm, Pb 32.4 ppm, and Sn is not detected. Fe shows the highest concentration and Cd shows the lowest concentration.

5.9 Trace element concentration at Deulbera UG.

The concentration of different trace elements of Deulbera UG (Seam-I) is reflected in table 3 and figure 9.

Fe shows the highest concentration of 2504 ppm, and Cd shows the lowest concentration of 1.55 ppm. Other elements like Mn is 285 ppm, Cr 110.7 ppm, Zn 68.5 ppm, Cu 159.7 ppm, Ni 169.6 ppm, Co 10.44 ppm, Na 625.8 ppm, Ca 460.3 ppm, K 561.2 ppm, Mg 218.6 ppm, Pb 30.6 ppm, and Sn is not detected in the seam.
5.10 Trace element concentration at Ananta OCP.

The concentration of different trace elements of Ananta OCP (which contains Seam – II and III) is reflected in table 4 and 5 and figure 10. Mn is 106 49ppm in seam – II and 83 92ppm in seam – III. Similarly, Cr is 170 and 88 36ppm, Zn 96 39 and 45 46ppm, Fe 2043 and 1906ppm, Cd 3 6 and 2 2ppm, Cu 101 2 and 58 46ppm, Ni 160 2 and 81 9ppm, Co 12 1 and 5 8ppm, Na 614 2 and 587 5ppm, Ca 266 8 and 219 1ppm, K 612 1 and 627 4ppm, Mg 150 25 and 137 4ppm, Pb 92 7 and 22 38ppm.

The result shows that the concentration of all elements are higher in seam – II than seam – III except the concentration of K. The concentration of Sn is not detected in both the Seams.

5.11 Trace element concentration at Bharatpur OCP.

The concentration of different trace elements of Bharatpur OCP (which contains seam – II and III) is reflected in table 4 and 5 and figure 11.

The concentration of Mn in seam – II is 203 76ppm, and in seam- III it is 60 3 ppm, Cr is 138 3 and 142 3ppm, Zn 118 1 and 126 6ppm, Fe 2397 2 and 2325ppm, Cd 1 5 and 1 6ppm, Cu 57 3 and 59 76ppm, Ni 144 2 and 149 7ppm, Co 6 28 and 9ppm, Na 627 2 and 627 1ppm, Ca 1469 and 265 9ppm, K 541 5 and 509 9ppm, Mg 185 1 and 133 4ppm, Pb 45 5 and 37 34ppm and Sn is not detected in both the seams.

The results show that the concentration of Cr, Zn, Cd, Cu, Ni, Co are higher in concentration in seam – III than seam- II and other elements are just the reverse. The concentration of Ca shows a remarkable difference in both the seams.
5.12 Concentration of trace elements at Lingaraj OCP.

The concentration of different trace elements at Lingaraj OCP which contain seam-II to seam-VI is shown in table 4 to 8 and fig 12.

The result reveals that Mn concentration is the highest in seam-V i.e. 174 ppm and the lowest in seam-IV i.e. 15 5ppm. Similarly, the concentration of Cr is the highest in seam-II i.e. 182 8ppm and lowest in seam – IV i.e 64 2ppm. It shows a sequential order of decrease from seam – II to seam-VI. Zn shows the highest of 163ppm in seam – V and the lowest of 71 9 in seam – IV. Fe having the highest of 2445 4ppm in seam – IV and lowest of 1728 9ppm in seam – III. Cd shows the highest of 4 6ppm in the top seam and the lowest in the seam – IV that is 3 5ppm. Cu concentration is the highest in seam – II that is 87 8ppm and the lowest in seam – IV i.e. 37 1ppm. Ni concentration is the highest in bottom seam – i.e. 104ppm and lowest in the top seam i.e 46 9ppm. Co concentration is the highest in bottom seam i.e 5 28ppm and lowest in the seam – IV that is 2 58ppm. Na concentration is the highest at top seam i.e 697 3ppm and the lowest in seam IV i.e. 580 9ppm. Ca concentration is the highest of 214 4ppm in seam – III and the lowest of 40 8ppm in seam IV. K concentration is the highest in seam – V i.e. 590 6ppm and lowest of 423 1ppm in seam – IV. Mg concentration is the highest in seam – V that is 180ppm and the lowest of 63 3 in seam-III. Pb is the highest in bottom seam i.e 72 2ppm where as it is the lowest at seam – IV i.e. 10 8ppm and Sn is not detected in any seam of this mine.

5.13 General correlation of trace elements with ash percentage

Coal consists predominantly of organic material and inorganic mineral matter. Besides these, most coals contain measurable quantities of many metals (trace elements), which occur in quantities of only up to a range of about 1000...
ppm. They are additional constituents and some by replacement of essential elements in the crystal lattice of minerals associated with coal. The highly variable occurrence of trace elements in coal is probably due to the variation in source rocks and also the tectonic set up of the depositional basins. The trace elements which have inorganic affinity are generally found associated with coal ash. The ash content of the coal is supposed to be the proportionate representation of the inorganic matter.

The overall observation suggests that the elements in coal have diverse phases of origin. Some belong to organic origin and some belong to inorganic origin. In addition, the incorporation of some of these elements in inorganic constituents of coal and the formation of organometallic chelates are also influenced by the donor elements to which the metals are bonded (Zubovic, 1966). Because of this diverse phase of origin the intercorrelation coefficients between them are not very high.

5.14 Cluster Analysis and Multivariate Analysis

In the present study, an attempt has been made to correlate the coals of different mines on the basis of multivariate analysis. In addition, to know the organic and inorganic association of different elements in coal, the matrix correlation coefficient with percentage of ash was calculated which has been shown in table-10. The correlation with ash indicate that Mn, Fe, Cd, Na and Mg have positive correlation hence, may be treated as inorganic association. The other elements have got negative correlation with ash, hence may not be regarded to have inorganic association.

Swaine (1977) suggested that Mn exists exclusively in inorganic constituents of coal, probably together with carbonates, silicates or oxides. Similarly, Cd, Na and Mg belong to Chalcophile/Lithophile group of elements and are found in mineral matter. Therefore these elements may be considered to be inorganic association in
coal. Fe belongs to Siderophile group of elements and is present in sulphide phase i.e. as pyrite in coal.

The cluster analysis of these elements are shown by Dendogram (Fig-13) The cluster analysis result of these elements reveal that Na shows the closest relationship with ash. According to Bouska and Honek (1962), alumino-silicate minerals present in coal and its concentration in general was greater in coal seams than in the adjacent clay stone. This indicates that the over-burden or parting rocks (sandstone/shale) contain aluminosilicate minerals such as feldspar, mica etc which might have contributed the enrichment of Na in coal similarly Mn, Cr, and Fe which show close affinity to ash may have the inorganic source in coal. The cluster analysis further reveals that Cd and Ni have shown close affinity in cluster diagram but in matrix correlation they do not show any significant relation. Cd is showing a good positive relation with ash where as Ni shows negative relation with ash. This indicates that since some of the elements have organometallic affinity, Cd may have inorganic affinity while as Ni has got organic affinity. Co and Ni show very strong correlation coefficient. Similarly the element Co, Ca, K and Pb show fairly a good correlation. These elements might have been incorporated in the sulphide mineral phases. The mechanism of fixation of Pb appears to be different for most of the elements studied. It has a correlation with most of the elements. Hind (1912) was the first to report the presence of galena in certain coals. Chow and Earl (1972) suggested that Pb was incorporated into coal forming material prior to coalification, probably by circulating ground water.
Figure 2.1 to 2.13. Lateral variation of individual trace elements in different mines of Seam - 1

BOCP = Balanda Open Cast Project, TUG = Talchir Under Ground, DUG = Deulbera Under Ground, NUG = Nandira Under Ground

Numbers in Y-axis indicate concentration in ppm
Figure 2.1. to 2.13. Continued

**Figure 2.5** Cd

**Figure 2.6** Cu

**Figure 2.7** Ni

**Figure 2.8** Co

BOCP = Balanda Open Cast Project, TUG = Talchir Under Ground, DUG = Deulbera Under Ground, NUG = Nandira Under Ground

Numbers in Y-axis indicate concentration in ppm
Figure 2.9 Na

Figure 2.10 Ca

Figure 2.11 K

Figure 2.12 Mg

BOCP = Balanda Open Cast Project, TUG = Talchir Under Ground, DUG = Deulbera Under Ground, NUG = Nandira Under Ground

Numbers in Y-axis indicate concentration in ppm
Figure 2.1. to 2.13. Continued

Figure 2.13. Pb

BOCP = Balanda Open Cast Project, TUG = Talchir Under Ground, DUG = Deulbera Under Ground, NUG = Nandira Under Ground

Numbers in Y-axis indicate concentration in ppm
Figure 3.1. to 3.13. Lateral variation of individual trace elements in different Mines of Seam - II

Figure 3.1. Mn

Figure 3.2. Cr

Figure 3.3. Zn

Figure 3.4. Fe

LOCP = Lingaraj Open Cast Project, AOCP = Ananta Open Cast Project, BOCP = Bharatpur Open Cast Project

Numbers in Y-axis indicate concentration in ppm
Figure 3.8. Co

LOCP = Lingaraj Open Cast Project, AOCP = Ananta Open Cast Project, BOCP = Bharatpur Open Cast Project

Numbers in Y-axis indicate concentration in ppm.
LOCP = Lingaraj Open Cast Project, AOC = Ananta Open Cast Project, BOCP = Bharatpur Open Cast Project

Numbers in Y-axis indicate concentration in ppm
Figure 3.1. to 3.13. Continued

**Figure 3.13. Pb**

LOCP = Lingaraj Open Cast Project, AOCP = Ananta Open Cast Project, BOCP = Bharatpur Open Cast Project

Numbers in Y-axis indicate concentration in ppm
Figure 4.1. to 4.13. Lateral variation of individual trace elements in different mines of Seam - III

LOCP = Lingaraj Open Cast Project, AOCP = Ananta Open Cast Project, BOCP = Bharatpur Open Cast Project

Numbers in Y- axis indicate concentration in ppm
Figure 4.1. to 4.13. Continued

Figure 4.5. Cd

Figure 4.6. Cu

Figure 4.7. Ni

Figure 4.8. Co

LOCP = Lngaraj Open Cast Project, AOCP = Ananta Open Cast Project, BOCP = Bharatpur Open Cast Project
Numbers in Y-axis indicate concentration in ppm
Figure 4.1. to 4.13. Continued

LOCP = Lingaraj Open Cast Project, AOC = Ananta Open Cast Project, BOCP = Bharatpur Open Cast Project

Numbers on Y-axis indicate concentration in ppm.
Figure 4.1. to 4.13. Continued

**Figure 4.13. Pb**

![Bar graph showing Pb concentrations in ppm for LOCP, AOCP, and BOCP](image)

LOCP = Lingaraj Open Cast Project, AOCP = Ananta Open Cast Project, BOCP = Bharatpur Open Cast Project

Numbers in Y-axis indicate concentration in ppm
Figure 5.1 to 5.13. Vertical variation of individual trace elements in different seams of Talchir Coal Field Area

**Figure 5.1. Mn**

**Figure 5.2. Cr**

**Figure 5.3. Zn**

**Figure 5.4. Fe**

S - I = Seam I, S - II = Seam II, S - III = Seam III, S - IV = Seam IV, S - V = Seam V, S - VI = Seam VI

Numbers in Y-axis indicate concentration in ppm.
Figure 5.1 to 5.13. Continued

Figure 5.5. Cd

Figure 5.6. Cu

Figure 5.7. Ni

Figure 5.8. Co

S-I = Seam I, S-II = Seam II, S-III = Seam III, S-IV = Seam IV, S-V = Seam V, S-VI = Seam VI

Numbers in Y-axis indicate concentration in ppm
Figure 5.1. to 5.13. Continued

Figure 5.9. Na

Figure 5.10. Ca

Figure 5.11. K

Figure 5.12. Mg

S-I = Seam I, S-II = Seam II, S-III = Seam III, S-IV = Seam IV, S-V = Seam V, S-VI = Seam VI

Numbers in Y-axis indicate concentration in ppm
Figure 5.1. to 5.13. Continued

Figure 5.13. Pb


Numbers in Y-axis indicate concentration in ppm
Figure 6. Variation of different trace element at Balanda OCP
Figure 7. Variation of different trace elements at Talchir UG
Figure 8. Variation of different trace elements at Nandira UG
Figure 9. Variation of different trace elements at Deulbera UG
Figure 11. Variation of different trace elements at Bharatpur OCP (Seam - II & III)
Figure 12. Variation of different trace element at Lingaraj OCP (Seam - II to VI)

Trace Elements:
- Mn
- Cr
- Zn
- Fe
- Cd
- Cu
- Ni
- Co
- Na
- Ca
- K
- Mg
- Pb

Concentration in ppm

Trace Elements
Table No-10  Matrix correlation coefficient of ash with other elements The numbers in parentheses indicate the number of samples in which each of them were analysed

<table>
<thead>
<tr>
<th></th>
<th>Ash</th>
<th>Mn</th>
<th>Cr</th>
<th>Zn</th>
<th>Fe</th>
<th>Cd</th>
<th>Cu</th>
<th>Ni</th>
<th>Co</th>
<th>Na</th>
<th>Ca</th>
<th>K</th>
<th>Mg</th>
<th>Pb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ash</td>
<td>1.0</td>
<td>0.18</td>
<td>-0.77</td>
<td>-0.34</td>
<td>0.14</td>
<td>0.93</td>
<td>0.21</td>
<td>-0.77</td>
<td>0.33</td>
<td>-0.79</td>
<td>-0.37</td>
<td>0.41</td>
<td>-0.68</td>
<td></td>
</tr>
<tr>
<td>Mn</td>
<td></td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>Cr</td>
<td></td>
<td>-0.11</td>
<td>1.0</td>
<td>0.25</td>
<td>0.36</td>
<td>0.15</td>
<td>0.41</td>
<td>0.48</td>
<td>0.91</td>
<td>0.91</td>
<td>0.91</td>
<td>0.91</td>
<td>0.91</td>
<td></td>
</tr>
<tr>
<td>Zn</td>
<td></td>
<td>0.07</td>
<td>-0.87</td>
<td>0.26</td>
<td>0.33</td>
<td>-0.83</td>
<td>0.91</td>
<td>0.48</td>
<td>0.91</td>
<td>0.91</td>
<td>0.91</td>
<td>0.91</td>
<td>0.91</td>
<td></td>
</tr>
<tr>
<td>Fe</td>
<td></td>
<td>0.88</td>
<td>-0.02</td>
<td>0.15</td>
<td>0.41</td>
<td>0.91</td>
<td>0.41</td>
<td>0.48</td>
<td>0.91</td>
<td>0.91</td>
<td>0.91</td>
<td>0.91</td>
<td>0.91</td>
<td></td>
</tr>
<tr>
<td>Cd</td>
<td></td>
<td>0.27</td>
<td>-0.26</td>
<td>0.73</td>
<td>0.51</td>
<td>-0.22</td>
<td>0.15</td>
<td>0.48</td>
<td>0.91</td>
<td>0.91</td>
<td>0.91</td>
<td>0.91</td>
<td>0.91</td>
<td></td>
</tr>
<tr>
<td>Cu</td>
<td></td>
<td>0.15</td>
<td>0.24</td>
<td>0.26</td>
<td>-0.83</td>
<td>0.91</td>
<td>0.91</td>
<td>0.91</td>
<td>0.91</td>
<td>0.91</td>
<td>0.91</td>
<td>0.91</td>
<td>0.91</td>
<td></td>
</tr>
<tr>
<td>Ni</td>
<td></td>
<td>0.21</td>
<td>0.91</td>
<td>0.33</td>
<td>0.91</td>
<td>0.91</td>
<td>0.91</td>
<td>0.91</td>
<td>0.91</td>
<td>0.91</td>
<td>0.91</td>
<td>0.91</td>
<td>0.91</td>
<td></td>
</tr>
<tr>
<td>Co</td>
<td></td>
<td>0.40</td>
<td>0.78</td>
<td>0.48</td>
<td>0.70</td>
<td>0.22</td>
<td>0.22</td>
<td>0.22</td>
<td>0.22</td>
<td>0.22</td>
<td>0.22</td>
<td>0.22</td>
<td>0.22</td>
<td></td>
</tr>
<tr>
<td>Na</td>
<td></td>
<td>0.83</td>
<td>-0.46</td>
<td>0.34</td>
<td>0.73</td>
<td>0.51</td>
<td>0.22</td>
<td>0.22</td>
<td>0.22</td>
<td>0.22</td>
<td>0.22</td>
<td>0.22</td>
<td>0.22</td>
<td></td>
</tr>
<tr>
<td>Ca</td>
<td></td>
<td>0.57</td>
<td>0.62</td>
<td>0.54</td>
<td>0.47</td>
<td>0.67</td>
<td>0.67</td>
<td>0.67</td>
<td>0.67</td>
<td>0.67</td>
<td>0.67</td>
<td>0.67</td>
<td>0.67</td>
<td></td>
</tr>
<tr>
<td>K</td>
<td></td>
<td>0.59</td>
<td>0.39</td>
<td>0.39</td>
<td>0.22</td>
<td>0.22</td>
<td>0.22</td>
<td>0.22</td>
<td>0.22</td>
<td>0.22</td>
<td>0.22</td>
<td>0.22</td>
<td>0.22</td>
<td></td>
</tr>
<tr>
<td>Mg</td>
<td></td>
<td>0.64</td>
<td>0.44</td>
<td>0.88</td>
<td>0.35</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td>Pb</td>
<td></td>
<td>0.09</td>
<td>0.40</td>
<td>0.61</td>
<td>0.43</td>
<td>0.41</td>
<td>0.41</td>
<td>0.41</td>
<td>0.41</td>
<td>0.41</td>
<td>0.41</td>
<td>0.41</td>
<td>0.41</td>
<td></td>
</tr>
</tbody>
</table>
Fig 13  Dendogram based on linear correlation coefficients computed by weighted pair group