

高等学校规划教材

# 选矿工程专业英语

蔡 璋 匡亚莉 编

煤炭工业出版社

郑玉水

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### 内 容 提 要

本书比较系统地、全面地反映了选矿工程专业所涉及的专业面,内容包括煤质、破碎、筛分、重选、浮选和脱水共7章。各章对方法、原理及典型的设备等内容进行了介绍。为了便于自学,书中对全部难句、长句均作了语法注释。本着循序渐进的原则,各章前面一部分内容附有参考译文,后面部分在语法注释的下面附有译文。全书的最后附有总词汇表,以便查用。

本书是高等院校选矿工程专业及煤质班本科生的通用专业外语教材,并可作为选矿工程专业技术人员、专业教师和研究生学习专业外语的主要书籍。

### 高等学校规划教材 选矿工程专业英语

蔡 璋、匡亚莉 编

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## 前 言

“选矿工程专业英语”是一本包括英语原文、文中长句、难句语法注释及译文、部分内容附有译文的书籍。本书按照教学大纲编写，其目的是帮助学习过两年基础英语的学生学习专业外语，提高他们阅读英语专业文献的能力。

由于“专业英语”是由“基础英语”到自由阅读专业技术文献的过渡，其内容设置与“基础外语”不同，不以“课”为单位，而按专业内容设置“章”、“节”。全书分煤质、破碎、筛分、重介选、水介质分选、浮选和脱水共7章。各章后不设单词，所有词汇集中在全书最后，类似字典、词典。学习者要自己判断、正确选择词义。但词汇数量少、词义范围较窄、比查阅字典、词典容易，可作为过渡训练、培养能力。

每课时的内容可按各校、各届学生外语水平，由教师灵活选定，可多可少，适应性强。

本着循序渐进的原则，每章前面约三分之一的内容附有译文，对难句有语法注释。后面约三分之二的的内容仅对难句、长句有语法注释和译文，而且注释逐渐减少，有利于自学。

本书第一、五、六、七章由蔡璋编写，第二、三、四章由匡亚莉编写，全书由蔡璋主编和统校。

在本书编写过程中，曾得到王祖訥教授、张月薇副教授和关梦嫔副教授的帮助，在此向他们深表感谢。此外本书的出版，还有责任编辑、总编、出版社其他人员的辛勤劳动，在此向他们表示深切的谢意。

由于编者水平有限，书中缺点、错误在所难免，敬请指正。

编 者

1992年12月21日

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# **Chapter 1 Mineral Impurities in Coal, Chemical Analysis and Classification of Coal**

## **1.1 Mineral Impurities in Coal**

### **1.1.1 Chemical (Element) and Mineralogical(Species)Analyses**

Composition of the noncombustible fraction and the mode of distribution of the mineral species in coals are based on the results of chemical and mineralogical analyses. A prerequisite to the analyses is the removal of the combustible matter, and it is usually carried out by burning coal samples in a laboratory muffle furnace<sup>1</sup>. According to the ASTM Standard or the British Standard on coal analysis, the ashing procedure is carried out at comparatively high temperatures, above 900 K<sup>2</sup>. This method of ashing is widely used for routine analysis of nonvolatile<sup>3</sup> elements of coal minerals.

Classical methods of "wet" chemical analysis were the first to be used for coal-ash analysis<sup>4</sup>. These have been largely superseded by more rapid colorimetric methods, and by the spectrochemical methods<sup>5</sup>. Introduction of flame photometric, atomic absorption, x-ray fluorescence, and neutron activation techniques have speeded up the analytical procedures. Different analytical techniques available for the major constituent and trace-element analysis are described in the book edited by Babu<sup>6</sup>.

For mineralogical analysis, the optical microscope was the earliest tool used to identify different mineral species found in coal. Thiessen was the first to use petrographic thin-section techniques to identify different mineral species in coal<sup>7</sup>. Optical microscope techniques have been extensively used by researchers.

Development of the scanning electron microscope has greatly increased the scope of identification of sub-micron-size<sup>8</sup> mineral impurities in coal. Since the early 1970s, the electron microscope fitted with the energy dispersive analysis of x-rays (EDAX) has been used to identify different mineral species in U.S. coals<sup>9</sup>. Earlier, Dutcher et al. had used the electron probe microscope with some success to investigate the distribution of mineral impurities in different coal strata<sup>10</sup>. Finkelman and Stanton have used the scanning electron microscope to study the dispersion of mineral grains in polished blocks<sup>11</sup>.

Of the nonmicroscopic methods<sup>12</sup>, x-ray diffraction analysis has been most widely used, and Gumz et al. have given an excellent introduction to x-ray



analysis of coal minerals.

Differential thermal analysis(DTA)<sup>13</sup> has been used extensively to identify different mineral species in Australian coals. O' Gorman and Walker have used the DTA method as well as thermogravimetric analysis(TGA) and derivative thermogravimetric analysis (DTGA)<sup>14</sup> in their work on mineral matter in U.S. Rekus and Haberkorn (1966) have used the x-ray diffraction technique<sup>15</sup> to identify different coal mineral species in individual particles of coal, 150 to 250  $\mu\text{m}$  in size. They used the results to discuss the mode of dispersion of the identified mineral species in coal. A computer-controlled method using the scanning electron microscope with the x-ray fluorescence emission and energy dispersive analyzer attachment has been developed and used for the analysis of particulate minerals in coal<sup>16</sup>. A comprehensive treatise on analysis of coal, coal minerals, trace elements, coke, and combustion products has been compiled by a team of internationally known experts.

Usual methods of analysis of coal mineral matter rely on taking representative samples of the supply delivery, but more recently on-line techniques have been developed<sup>17</sup>. The most favored technique is that of spectrometry of gamma-ray emission resulting from neutron capture<sup>18</sup>. An encapsulated source of fast neutrons, such as californium-252<sup>19</sup>, is placed in a coal bed, and the neutron stream is slowed down by multiple collisions in a solid fuel. This produces a flux of thermal neutrons subsequently captured by the atoms of coal mineral elements in proportion to their neutron cross sections<sup>20</sup>. The neutron capture results in an emission of gamma rays with energies characteristic of each element. An on-line coal-ash monitor has been developed and has been extensively tested with satisfactory results<sup>21</sup>. Brown et al. have made a survey of the techniques which have been used to determine the moisture content of coal<sup>22</sup>. Three electromagnetic techniques were identified as promising for eventual on-line application; these are the capacitance, microwave attenuation, and nuclear magnetic resonance (NMR) techniques<sup>23</sup>.

#### 1.1.2 Coal Mineral Matter in Relation to the Geological Environment

The mode of occurrence and relative concentration of mineral impurities in different coal strata reflect the geological environment in which the fuel deposits were laid down<sup>24</sup>.

The surface skin of the earth's crust<sup>25</sup> consists chiefly of soils, sediments, and sedimentary rocks. Below the surface skin, the rocks are composed chiefly of quartz, feldspar, mica, and hornblende. Silicon (Si) combined with oxygen in the form of  $\text{SiO}_2$  is the most abundant element in the crust and rock strata known as the earth's sialic layer<sup>26</sup>. Sedimentary deposits and rocks, which are the main source of mineral impurities in coal, are made up chiefly from degraded sialic materials and carbonate precipitates<sup>27</sup>. Sandstone is a sedimentary rock com-

posed chiefly of quartz grains. Granite is another mineral species of high silica content. Shale, a mixture of sedimentary deposit and weathered rock, consists chiefly of clay minerals<sup>28</sup>. Basalt can have chemical composition similar to that of clays. Peridotite is a basic rock of high magnesium content. Limestone consists largely of calcium carbonate ( $\text{CaCO}_3$ ) formed from the shells of animals or by chemical precipitation from sea water<sup>29</sup>.

Mixtures of clay species and basaltic-type rock together with some sedimentary sandstone and carbonate sediment constitute a mineral matter that has the chemical composition similar to that of typical bituminous coal ashes<sup>30</sup>. This is illustrated by the results given in the first half of Table 1-1, showing representative ash compositions taken from over 100 sample analyses that covered a wide range of British bituminous coals<sup>31</sup>. The ash analysis results for a selection of U.S. bituminous coals are given in the second half of Table 1-1. The first two samples represent low- $\text{SiO}_2$  ashes in bituminous coals.

Samples 3, 4, and 5 cover the range of medium- $\text{SiO}_2$  ashes in large number of bituminous coals mined in Britain, the United States, and many other countries, and samples 6 and 7 are examples of high- $\text{SiO}_2$  ash.

The sub-bituminous coals and lignites can have a mineral matter either of

Table 1-1 Composition<sup>a</sup> of a selection of bituminous coal ashes

Coals	Low silica		Medium silica			High silica	
	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7
<b>British</b>							
$\text{SiO}_2$	29.6	35.1	40.8	45.3	50.4	55.5	59.2
$\text{Al}_2\text{O}_3$	19.8	20.3	19.4	25.5	24.7	30.0	26.7
$\text{Fe}_2\text{O}_3 + \text{FeO}$	12.7	24.8	8.0	8.0	5.3	2.6	4.3
$\text{CaO}$	24.5	7.2	19.9	11.6	8.1	3.5	1.6
$\text{MgO}$	5.4	7.4	5.1	3.1	3.3	0.4	0.3
$\text{Na}_2\text{O}$	0.9	0.3	0.9	0.9	1.5	1.3	1.6
$\text{K}_2\text{O}$	1.1	1.1	2.1	3.9	3.6	2.7	2.8
$\text{TiO}_2$	0.9	0.6	0.9	0.8	1.0	1.2	1.1
$\text{SO}_2$	4.4	2.6	2.2	1.1	2.3	0.9	0.8
<b>United States</b>							
$\text{SiO}_2$	25.6	37.0	41.2	46.6	49.0	55.1	59.5
$\text{Al}_2\text{O}_3$	21.0	17.8	32.0	27.8	32.6	23.9	26.7
$\text{Fe}_2\text{O}_3 + \text{FeO}$	20.5	23.3	14.4	17.8	3.7	2.2	4.2
$\text{CaO}$	15.8	5.6	1.8	1.7	3.4	7.3	2.3
$\text{MgO}$	0.7	1.2	1.1	0.6	0.9	0.4	0.7
$\text{Na}_2\text{O}$	2.0	1.8	0.7	0.4	0.4	0.3	0.8
$\text{K}_2\text{O}$	0.2	0.2	0.7	1.1	2.1	0.4	0.1
$\text{TiO}_2$	0.6	0.5	1.5	1.1	0.9	1.7	3.4
$\text{SO}_2$	10.9	10.9	3.6	0.6	3.9	6.8	1.8

<sup>a</sup>Given as weight percent of ash.

the clay type as in Table 1-1., or of entirely different as shown by examples in Table 1-2<sup>32</sup>.

Occasionally bituminous coals have mineral matter in an unusual composition where the clay minerals do not constitute the bulk of ash (samples 2, 3, and 4 in Table 1-2)<sup>33</sup>. Sample 1 is SiO<sub>2</sub>-rich<sup>34</sup> ash of lignite. Sample 2 is SiO<sub>2</sub>-rich ash of bituminous coal. Sample 3 is SiO<sub>2</sub>-rich ash of anthracite. The fourth sample is an iron oxide-rich ash of bituminous coal. For sample 5 we have calcium-rich ash of sub-bituminous coal. Sample 6 is calcium- and sodium-rich ash of lignite. Sample 7 is calcium-, magnesium-, and sodium-rich ash of sub-bituminous coal.

The above cursory review of the variability of mineral matter in different coals shows that the most abundant elements of the earth's crust—Si, Al, Fe, Ca, Mg, Na, K, and Ti, in combination with oxygen—also constitute the noncombustible fraction of solid fuels<sup>35</sup>. Relative concentrations of the impurity elements depend on local geological environment and on the age of the solid fuel deposits. Lignites and sub-bituminous coals are the first products of coalification processes of the original vegetable matter and these deposits lie usually close to the earth's surface. Consequently, the mineral matter in sub-bituminous solid fuels can vary over a wide range, and the impurity species reflect sharply the local mineralogical environment that existed during the period of initial formation of peat and lignite deposits<sup>36</sup>. By contrast<sup>37</sup>, the initial mineralogical regimes are less discernible in the case of bituminous coals. Usually the increase of coal rank from lignite via subbituminous to bituminous coal and anthracite has resulted in a gradual process of enrichment of clay mineral dispersions in fuel deposits<sup>38</sup>.

Table 1-2 Exceptionally high- and low-silica ashes (composition in weight percent)

Mineral	High-silica			Low-silica			
	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7
SiO <sub>2</sub>	80.0	73.8	68.5	17.5	7.2	19.0	1.8
Al <sub>2</sub> O <sub>3</sub>	6.0	21.6	20.8	9.2	9.4	12.0	5.9
Fe <sub>2</sub> O <sub>3</sub> + FeO	5.6	2.0	2.6	64.1	7.9	9.0	5.4
CaO	3.1	0.7	1.4	4.1	28.1	20.0	21.7
MgO	1.8	0.2	0.4	0.4	1.4	8.0	26.9
Na <sub>2</sub> O	1.3	0.1	0.6	0.3	2.9	8.0	13.5
K <sub>2</sub> O	0.4	0.2	0.1	1.0	ND <sup>a</sup>	0.3	0.3
TiO <sub>2</sub>	ND	1.2	3.6	0.4	0.5	0.5	0.2
SO <sub>3</sub>	ND	Nil	1.7	1.8	40.3	23.1	23.9

Tables 1-3 and 1-4 list mineral species that have been identified in different coal deposits.

Table 1-3 Silicate and oxide mineral species in coal

Species	Chemical formula	Specific <sup>a</sup> gravity (kgm <sup>-3</sup> )	Melting point (K)
Silica and silicates—common occurrence			
Quartz	SiO <sub>2</sub>	2650	1983
Kaolinite	Al <sub>2</sub> O <sub>3</sub> ·2SiO <sub>2</sub> ·2H <sub>2</sub> O		2083
Muscovite	K <sub>2</sub> O·3Al <sub>2</sub> O <sub>3</sub> ·6SiO <sub>2</sub> ·2H <sub>2</sub> O	2900	(Mullite)
Illite	As muscovite with Fe, Ca, and Fe		
Montmorillonite	(1-x)Al <sub>2</sub> O <sub>3</sub> ·x(MgO, Na <sub>2</sub> O)·4SiO <sub>2</sub> ·nH <sub>2</sub> O		
Chlorite	Al <sub>2</sub> O <sub>3</sub> ·5(FeO, MgO)·3.5SiO <sub>2</sub> ·7.5H <sub>2</sub> O		
Orthoclase	K <sub>2</sub> O·Al <sub>2</sub> O <sub>3</sub> ·6SiO <sub>2</sub>	2500	
Plagioclase	Na <sub>2</sub> O·Al <sub>2</sub> O <sub>3</sub> ·6SiO <sub>2</sub> —Albite CaO·Al <sub>2</sub> O <sub>3</sub> ·2SiO <sub>2</sub> —Anorthite		
Silicates—less common occurrence			
Augite	Al <sub>2</sub> O <sub>3</sub> ·Ca(Mg, Fe, Al, Ti)·0.2SiO <sub>2</sub>		
Amphibole	Augite + Na, F, P	3100	
Biotite	Al <sub>2</sub> O <sub>3</sub> ·6(MgO·FeO)·6SiO <sub>2</sub> ·4H <sub>2</sub> O	3100	
Granite	Al <sub>2</sub> O <sub>3</sub> ·3(CaO, MgO, FeO, MnO)·3SiO <sub>2</sub>		
Epidote	4CaO·3(Al, Fe)O <sub>3</sub> ·6SiO <sub>2</sub> ·H <sub>2</sub> O	3350	
Kyanite	Al <sub>2</sub> O <sub>3</sub> ·SiO <sub>2</sub>	3550	2083(Mullite)
Sanidine	K <sub>2</sub> O·Al <sub>2</sub> O <sub>3</sub> ·6SiO <sub>2</sub>	2570	
Staurolite①	Al <sub>2</sub> O <sub>3</sub> ·FeO·2SiO <sub>2</sub> ·H <sub>2</sub> O		
Tourmaline	Na(Fe, Mn) <sub>3</sub> ·3Al <sub>2</sub> O <sub>3</sub> ·6SiO <sub>2</sub> ·3BO·2H <sub>2</sub> O	3100	
Zircon	ZrO <sub>2</sub> ·SiO <sub>2</sub>	4500	2825
Oxides and hydrated oxides			
Rutile	TiO <sub>2</sub> <sup>b</sup>	4200	2100
Magnetite②	Fe <sub>3</sub> O <sub>4</sub>	5140	1865
Hematite	Fe <sub>2</sub> O <sub>3</sub>	5200	1840
Limonite	Fe <sub>2</sub> O <sub>3</sub> ·H <sub>2</sub> O	4300	675°
Diaspore	Al <sub>2</sub> O <sub>3</sub> ·H <sub>2</sub> O	3400	425°

<sup>a</sup>The specific gravity of silicate minerals is in the range of 2500 to 3500 kgm<sup>-3</sup>, it increases with Al<sub>2</sub>O<sub>3</sub>/SiO<sub>2</sub> ratio and decreases with H<sub>2</sub>O content. The silicates containing Na, K, Ca, Mg, and Fe do not have a definite melting point temperature.

<sup>b</sup>With the exception of rutile, the oxide minerals rarely occur in coal.

<sup>c</sup>Denotes loss of water.

### 1.1.3 Clay Minerals (Aluminosilicates) and silica (Quartz)

By far the most abundant noncombustible species in coal are those of aluminosilicate clay minerals. Together with quartz, they usually account for between 60 and 90 percent of the total mineral matter in coal. Most common species of clay minerals are muscovite-illites (potassium aluminosilicates), kaolinites (alumi-

编者注:

①原文错, 应为staurolite.

②原文错, 应为Magnetite.

nosilicates), and mixed layer illite-montmorillonites of variable composition. Rao and Gluskoter, in an investigation of 65 coals from the Illinois Basin, reported a mean value of 52 percent for clay in the mineral matter<sup>39</sup>. O'Gorman and Walker also found that the clay minerals constituted the greater part of mineral matter in the majority of U. S. coals. Barwood et al. have described a selective cation saturation method<sup>40</sup> for identifying different clay minerals in coal. The method, based on selective cation saturation with potassium and magnesium, has been shown to allow identification of several clay species in the low-temperature ash of coal<sup>41</sup>.

Much of the clay material dispersed in coal seams is made up of<sup>42</sup> clastic material brought in by water. It therefore follows that the coal deposits laid down in areas that were subject to periodic flooding usually contain a great deal of clay dispersion intimately mixed with the coal<sup>43</sup>. Dixon et al. have studied the distribution of mineral species in various coal strata.

Dixon et al. have listed potassium aluminosilicates as micas, whereas usually these are said to belong to muscovite-illite group of minerals<sup>44</sup>. Other minerals identified included pyrite, siderite, iron oxide, and rutile. The authors, after examining more than 50 seam sections from various localities in the coalfield<sup>45</sup>, have arrived at the following conclusions.

A. Quartz, kaolin, and mica are the principal silica-bearing minerals in all sections of the seam profiles, potassium aluminosilicates frequently being the more abundant species in all strata with the exception of the coal seam<sup>46</sup>.

B. Quartz is more abundant in the roof and floor strata<sup>47</sup> and least in the intraseam dirt and coal layers. The immediate roof layer is frequently rich in carbonate, and the floor material has high kaolin and mica content.

C. The highest kaolin concentrations (relative to the total mineral matter) occur in the coal and in some intraseam dirt bands; the kaolin-to-mica ratio is on average much higher for coal (between 5:1 and 10:1) than for the other strata<sup>48</sup>. For cannel and run-of-mine coal<sup>49</sup>, the average kaolin to mica ratio is respectively 1:2.5 and 1:1.5.

D. The nonsilicate minerals constitute from 20 to 90 percent of the mineral matter in the coal seam but are usually absent in the floor material<sup>50</sup>. Siderite may constitute up to 10 percent of mineral matter in the coal seam roof, where it frequently occurs in discrete bands or nodules.

Nelson classified quartz as<sup>51</sup> a mineral of minor importance, but his survey work was based on early studies of U.S. coal seams by Gauger et al. More recent analytical data show that the majority of U.S. coals have a quartz content between 1 and 20 percent of the total mineral matter, and there are some coal ashes that have over 30 percent of quartz<sup>52</sup>.

Quartz content of ashed coal residues can be determined by x-ray diffraction

Table 1-4 Carbonate, sulfide, sulfate, phosphate, and chloride minerals in coal

Species	Chemical formula	Specific gravity ( $\text{kgm}^{-3}$ )	Melting/decomposition temperature(K)
<b>Carbonates</b>			
Calcite	$\text{CaCO}_3$	2710	1200 <sup>b</sup>
Aragonite	$\text{CaCO}_3$	2710	1150 <sup>b</sup>
Dolomite	$\text{CaCO}_3 \cdot \text{MgCO}_3$	2850	1050 <sup>b</sup>
Ankerite	$\text{CaCO}_3 \cdot \text{FeCO}_3$		1000 <sup>b</sup>
Siderite	$\text{FeCO}_3$	3830	800 <sup>b</sup>
<b>Sulfides</b>			
Pyrite	$\text{FeS}_2$	5000	1075 <sup>b</sup>
Marcasite	$\text{FeS}_2$	4870	1075 <sup>b</sup>
Pyrrhotite	$\text{FeS}_x$	4600	1300
Chalcopyrite	$\text{CuFeS}$	4100	1300
Melnikovite	$\text{FeS}_2 + (\text{As}, \text{FeS}, \text{H}_2\text{O})$	~5000	1075 <sup>b</sup>
Galena	$\text{PbS}$	7500	1370
Mispickel	$\text{FeS}_2 \cdot \text{FeAs}_2$	~5000	1075 <sup>b</sup>
Sphalerite	$\text{ZnS}$		
<b>Sulfates</b>			
Barytes	$\text{BaSO}_4$	4500	1855
Gypsum	$\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$	2320	1725
Kieserite	$\text{MgSO}_4 \cdot \text{H}_2\text{O}$	2450	1395 <sup>b</sup>
Thenardite	$\text{Na}_2\text{SO}_4$	2680	1157
Mirabilite①	$\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$	1460	1157
Melanterite	$\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$	1900	755 <sup>b</sup>
Keramolite	$\text{Al}_2(\text{SO}_4)_3 \cdot 16\text{H}_2\text{O}$	1690	945 <sup>b</sup>
Jarosite	$\text{K}_2\text{SO}_4 \cdot x\text{Fe}_2(\text{SO}_4)_3$	2500	900 <sup>b</sup>
<b>Phosphates</b>			
Apatite	$\text{Ca}_5\text{F}(\text{PO}_4)_3$	3100	>1500
Evansite	$3\text{Al}_2\text{O}_3 \cdot \text{P}_2\text{O}_5 \cdot 18\text{H}_2\text{O}$	2560	>1775
<b>Chlorides</b>			
Halite	$\text{NaCl}$	2170	1074
Sylvite	$\text{KCl}$	1980	1043
Bischofite	$\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$	1570	987

<sup>a</sup> Calcite, dolomite, ankerite, siderite, pyrite, barytes, and apatite minerals occur frequently. Gypsum and other sulfates are found mainly in low-rank and weathered coals, other mineral species are rarely found.

<sup>b</sup> Denotes the decomposition temperature.

analysis, differential thermal analysis (DTA), and infrared absorption<sup>53</sup>.

When there are no facilities available for a mineralogical analysis for quartz its approximate value can be deduced from the chemical analysis of ash<sup>54</sup>.

Chemically analyzable or total silica,  $(\text{SiO}_2)_t$ , includes quartz, which is said to be "free" silica  $(\text{SiO}_2)_f$ , and "combined" silica  $(\text{SiO}_2)_c$ , when present with  $\text{Al}_2\text{O}_3$  and other oxides in clay minerals<sup>55</sup>. That is<sup>56</sup>:

编者注:

① 原文错, 应为Mirabilite.

$$(\text{SiO}_2)_t = (\text{SiO}_2)_q + (\text{SiO}_2)_c \quad (1-1)$$

Dixon et al have shown that the aluminosilicate clay fraction of coal, chiefly kaolinites and muscovite-illites, has  $\text{SiO}_2$  and  $\text{Al}_2\text{O}_3$  constituents in a weight ratio between 1-4 and 1-6 with an average value of 1.5; that is<sup>57</sup>,

$$(\text{SiO}_2)_c = 1.5(\text{Al}_2\text{O}_3) \quad (1-2)$$

The quartz content is thus given by:

$$(\text{SiO}_2)_q = (\text{SiO}_2)_t - 1.5(\text{Al}_2\text{O}_3) \quad (1-3)$$

where<sup>58</sup> the concentrations of quartz, total  $\text{SiO}_2$ , and  $\text{Al}_2\text{O}_3$  are given in weight percent of either ash or coal.

Equation (1-3) was derived from the results of the chemical and mineralogical analysis of British (bituminous) coal ashes, but it also gives useful estimates of the quartz content of coals mined in the United States<sup>59</sup>.

The x-ray analysis for some coal samples gave unrealistically high quartz values that are not compatible with moderately high alumina content<sup>60</sup>.

Equation 1-3 cannot be used to calculate the quartz content of subbituminous coals or lignites when those have a mineral matter with the  $\text{SiO}_2$  content below 30 percent<sup>61</sup>. A part of the aluminum in these fuels can be present as precipitates of humic acids<sup>62</sup>. Exceptionally high amounts of alumina, above 35 percent by weight, in some coal ashes may indicate that a part of the alumina is present as  $\text{Al}_2\text{O}_3 \cdot x\text{H}_2\text{O}$  (bauxite)<sup>63</sup>. In these cases the quartz contents calculated according to Eq.(3-3) would be low.

#### 1.1.4 Introduction and the Mode of Occurrence of Sulfur in Coal

Sulfur is a vital element for sustenance of plant life, and it is therefore not surprising to find a relative abundance of sulfur compounds in coal deposits and in associated mineral-matter strata<sup>64</sup>. The coal deposits laid down in Brackish marine areas are usually rich in ash, sulfur, and nitrogen. Periodic flooding in these areas reduced the originally high acidity of plant deposits by dilution, resulting in an enhanced environment for bacterial sulfur fixation<sup>65</sup>.

Neavel considered that iron sulfide (pyrites,  $\text{FeS}_2$ ) found in peat and coal deposits had been largely formed as the result of activity of anaerobic bacteria<sup>66</sup>. Sulfur originated from plant and animal protein (organic sulfur), or it was brought in by sea water in the form of sulfates. Iron originated from weathered silicate minerals, consequently, syngenetic pyrites deposits appear frequently in claybearing sediment.

Coals deposited in calcium-rich swamps also show a high degree of sulfidation. Calcareous basements or influx of calcium-rich waters effectively increased the pH of the aqueous environment, thus creating favorable conditions for a high rate of sulfur fixation<sup>67</sup>. An extreme example of this type of coal is that found in Greece, which contains 11 percent by weight of sulfur<sup>68</sup>.



By contrast, the peat deposits and subsequently formed coal deposits laid down in raised bogs of inland areas<sup>69</sup> are usually low both in ash (clay minerals) and in sulfur. In the absence of flooding, the acidity of peat water had remained high with a pH value between 3 and 5, and such an acidic medium did not sustain a high degree of sulfidation bacterial activity; the bulk of sulfur therefore was returned to the atmosphere in the form of  $H_2S$  and  $SO_2$ .<sup>70</sup> Coals laid down in those areas have a low sulfur content, around 0.5 percent by weight. Currently, such coals are in great demand for electricity generation because of the low level of  $SO_2$  emission and the low-sulfur fuels<sup>71</sup>. However, on a worldwide basis, occurrences of low-sulfur coals are comparatively rare, and the vast reserves of bituminous coals have a sulfur content between 1.0 and 4.5 percent<sup>72</sup>. For example, the average sulfur content of British coals is 1.6 percent, which may be taken as a typical figure for coals of medium sulfur content<sup>73</sup>.

Wandless concluded after his extensive study of the mode of distribution of sulfur in British coals that on average the coals contained 0.8 percent by weight organically compounded sulfur, and the remainder was present as pyrites ( $FeS_2$ )<sup>74</sup>. The amounts of sulfatic sulfur in British coals, as<sup>75</sup> in the majority of all bituminous coals, were negligible. Neavel arrived at a similar conclusion, that there was a relationship between the relative abundance of pyritic sulfur and that of organic sulfur.<sup>76</sup> Gluskoter and Simon reported a mean value of 1.56 for the ratio of pyritic to organic sulfur in 473 face-channel samples of Illinois coal<sup>77</sup>. Arguably the most thoroughly investigated high sulfur coals are those mined in Illinois, where the sulfide species constitute about 25 percent by weight of the total mineral matter, as discussed by Rao and Gluskoter<sup>78</sup>.

Pyrite and marcasite, both of an approximate chemical formula of  $FeS_2$ ,<sup>79</sup> are the principal pyritic minerals found in coal. Pyrrhotite ( $FeS_x$ ), chalcopyrite ( $CuFeS_2$ ), mispickel ( $FeS_2 \cdot FeFS_2$ ), galena ( $PbS$ ), and sphalerite ( $ZnS$ ) as listed in Table 3.5 are other sulfur-containing mineral species that have been identified in coal<sup>80</sup>. Microstructural dispersion of the pyritic mineral species in coal seams and clay sediment-strata has been studied in the scanning electron microscope<sup>81</sup>.

Freshly mined coals usually do not contain any significant quantity of sulfates, but a variety of iron sulfates will form when the sulfides are oxidized in air<sup>82</sup>. Rao et al. have identified a number of hydrated ferrous and ferric sulfates in weathered coals, but the amount of sulfates in coals is usually insufficient to make it worthwhile considering their behavior in coal-cleaning processes or in the boiler flame.

#### 1.1.5 Carbonate Inclusions in the First and Second Stages of Coalification

Carbonate minerals were incorporated in the first as well as in the second stage of coalification processes<sup>83</sup>. The species of the syngenetic (first stage) process

consists chiefly of siderite ( $\text{FeCO}_3$ ) and dolomite ( $\text{MgCO}_3 \cdot \text{CaCO}_3$ ). The carbonate products of the second stage of the coalification process are calcite ( $\text{CaCO}_3$ ) and ankerite ( $\text{MgCO}_3 \cdot \text{CaCO}_3 \cdot x\text{FeCO}_3$ ). Dixon et al. after studying a number of coal samples from the East Midlands coal fields, concluded that calcite and ankerite were the principal carbonate minerals present. The latter has a relatively constant composition, namely 54 percent by weight  $\text{CaCO}_3$ , 24 percent  $\text{MgCO}_3$ , 20 percent  $\text{FeCO}_3$ , and 2 percent  $\text{MnCO}_3$ <sup>84</sup>.

Siderite, ankerite, and calcite are commonly occurring carbonate minerals in Australian coals, as determined both by microscopic observations and by chemical analyses<sup>85</sup>. Rao and Gluskoter (1973) concluded, however, that the carbonate minerals in Illinois coals are distinctly different from those in British and Australian coals<sup>86</sup>. Calcite was the dominant carbonate mineral in Illinois coals, siderite and dolomite were observed in a few samples in trace amounts<sup>87</sup>, and ankerite was not detected. Unusually high amounts of carbonate minerals can occur in some coals, as for example in Oklahoma coals. In these coals the carbonate minerals, siderite and dolomite, were the main impurity constituents, with<sup>88</sup> small amounts of clay minerals, kaolinite, illite, and chlorite.

#### 1.1.6 The Origin and Mode of Occurrence of Chlorine in Coal

The origin and the distribution of chlorine in coal have been investigated by many researchers, particularly in Britain, since British coals show a large variation in their chlorine content<sup>89</sup>. Skipsey, after reviewing the statistical data on chlorine in coal accumulated by the National Coal Board (NCB) and the previously published data, concluded that the chlorine content of British low-rank coals varied from 0.05 to 1.0 percent depending on their geographic locality<sup>90</sup>. However, with high-rank coals of carbon contents in excess of 85 percent (dry ash-free basis) the chlorine content rarely exceeds 0.2 percent<sup>91</sup>.

Undoubtedly much of the chlorine found in British coals came from sea water, but its introduction into the fuel deposit cannot be correlated unequivocally with any specific episode in the coalification process<sup>92</sup>. Crumley and McCamley have suggested that the chlorine was derived from salt absorbed from the aqueous environment in which the coal vegetation grew<sup>93</sup>. According to Wandless, the entry of chlorine may have been by infiltration from the overlying Permo-Triassic rocks<sup>94</sup>. Daybell has stated that extensive borings in Britain have shown that there is usually a gradual increase in the chloride content of coal seams with increase in depth<sup>95</sup>. Any association of the chlorine distribution pattern with the overlying Permo-Triassic beds would be expected to result in the highest chlorine values occurring in seams adjacent to the salt-bearing beds<sup>96</sup>.

This apparent anomaly was explained by Gluskoter and Rees (1964), who postulated, after studying the chlorine distribution in coals of the Illinois basin,