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# DENSITY OF COALS FROM THE TELKWA COAL PROPERTY, NORTHWESTERN BRITISH COLUMBIA

## (93L/11)

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*KEYWORDS*: Coal geology, coal density, *in situ* moisture, porosity, Telkwa.

## INTRODUCTION

It is important, for mining feasibility studies, to be able to accurately convert *in situ* coal volumes to tonnages using coal densities. The density of coal of constant rank varies depending on the amount of included rock (mineral matter), water, and void porosity. Actual measurements of density often require adjustment because data are needed at different ash, water or porosity values. Data from the Telkwa Coal property are used to validate a density equation. The equation predicts density given per cent ash or, per cent ash given the density. It requires the following constants to be defined; density of dry zero-ash coal (DC), density of dry mineral matter (DMM), weight per cent water (TM), volume per cent void porosity (VP) and the ratio weight of mineral matter divided by weight of resultant ash (WTLOS). The equation (Equation 1, Table 5-6-1) has the form;

$$\mathrm{BD} = 100\times\mathrm{DC}\times\mathrm{DMM}/[\mathrm{DC}\times\mathrm{DMM}\times(\mathrm{TM}+\mathrm{VP})+\mathrm{MM}\times(\mathrm{DC}-\mathrm{DMM})+\mathrm{DMM}\times(100-\mathrm{TM})]:$$

MM is the weight of mineral matter, and is given by;

$$\mathrm{MM} = \mathrm{WTLOS}\times\text{per cent ash.}$$

**TABLE 5-6-1**
**DEVELOPMENT OF DENSITY EQUATIONS**

Specific gravity = mass/volume × density of water.
Bulk density = mass/volume (grams/cubic centimetre).
DC = apparent specific gravity of dry, zero-ash coal.
DMM = apparent specific gravity of dry, pure mineral matter.
TM = *mass of water in sample including inherent and surface* water.
MD = moisture difference.
ADM = mass of air dried moisture.
VP = volume of air or gas-filled voids.
BD = *in situ* specific gravity or bulk density.
MM = mass of mineral matter.
MC = mass of zero-ash coal.
WTLOS = mass mineral matter divided by mass of ash.

$$\mathrm{BD} = (\mathrm{MC}+\mathrm{MM}+\mathrm{TM})/(\mathrm{MC}/\mathrm{DC}+\mathrm{MM}/\mathrm{DMM}+\mathrm{TM}+\mathrm{VP})$$

$$\mathrm{MC}+\mathrm{MM}+\mathrm{TM} = 100\text{ grams}$$

$$\mathrm{DC}\times\mathrm{DMM} = \mathrm{K}$$

$$\mathrm{BD} = 100\times\mathrm{K}/(\mathrm{K}\times(\mathrm{TM}+\mathrm{VP})+\mathrm{MM}\times(\mathrm{DC}-\mathrm{DMM})+\mathrm{DMM}\times(100-\mathrm{TM})) \qquad \text{(Equation 1)}$$

$$\mathrm{BD} = 1/(\mathrm{A}+\mathrm{B}\times\mathrm{Ash}) \qquad \text{simplified form Equation 1}$$

$$\mathrm{MM} = 1.08\times\mathrm{Ash}+.55\times\mathrm{PY} \qquad \text{(Rees, 1966)}$$

$$\mathrm{PY} = \text{per cent pyrite}$$

$$\mathrm{MM} = \mathrm{WTLOS}\times\mathrm{Ash} \qquad \text{as described in text}$$

$$\mathrm{VP} = 100\times(1-\mathrm{BD}/\mathrm{ASG}) \qquad \text{(Equation 2)}$$

$$\mathrm{MD} = 100\times(\mathrm{ASG}-\mathrm{BD})/[\mathrm{BD}\times(\mathrm{ASG}-1)] \qquad \text{(Equation 3)}$$

$$\mathrm{A} = (\mathrm{VP}+\mathrm{TM})+(1-\mathrm{TM})/\mathrm{DC} \qquad \text{(Equation 4)}$$

$$\mathrm{B} = -(\mathrm{DMM}-\mathrm{DC})/(\mathrm{DMM}\times\mathrm{DC})\times\mathrm{WTLOS} \qquad \text{(Equation 5)}$$

$$\mathrm{TM} = (\mathrm{ADM}\times(100-\mathrm{ADM})+\mathrm{MD}\times100)/100 \qquad \text{(Equation 6)}$$

The Telkwa coal property is located in northwestern British Columbia, 15 kilometres south of Smithers. In the area, Cretaceous sediments of the Skeena Group contain a coal-bearing succession which includes ten seams over approximately 300 metres of section (Figure 5-6-1). Exploration on the property by Crows Nest Resources Limited (geological assessment reports submitted to B.C. Ministry of Energy, Mines and Petroleum Resources, 1981 to 1989) has culminated in a submission to the provincial government seeking approval to develop an open-pit coal mine on the property. The data discussed in this study were collected as part of the mining feasibility study for one of the proposed open pits which is located on the north side of the Telkwa River (Pit 7). One hundred and eighty seven samples of NQ diamond-drill core from Seams 2 to 8 (Figure 5-6-1), representing approximately 50 metres of section, were analyzed on an air-dried basis (ADB) for apparent specific gravity (ASG), per cent ash, per cent sulphur and per cent moisture. The apparent specific gravity was measured on 60-mesh sized particles, using ASTM procedure D167.

Previous discussions of coal density versus ash relationships have taken two general directions. Some fit mathematical curves to data sets of ash and density measurements (Ward, 1984). This approach lacks flexibility and requires a new set of sample analyses if rank or moisture content of coal change. Other papers take a more theoretical approach and develop equations which predict coal density using real variables such as per cent ash and per cent moisture (Smith, 1989). This paper takes the latter approach; Equation 1 was developed over a number of years while working in industry and is similar to, though less rigorous than that used by Smith.

## COAL DENSITY

A number of concepts require clarification before embarking on a discussion of the subtleties of coal density versus ash relationships. Analytical laboratories measure per cent ash in coal; a coal seam actually contains mineral matter. When ash is extracted by burning off the coal there is a weight loss experienced by the mineral matter as it is in part volatilized and converted to ash. The ratio, weight of mineral matter divided by weight of resultant ash, is referred to in this study as the "weight loss value" (WTLOS). Coal in the ground or in a stockpile may contain air or gas-filled fractures or spaces which make up a volume referred to in this study as "void porosity". Void porosity (VP) is a volume which is in addition to, and does not include "water-filled porosity". The water content of the coal (TM) is expressed as a weight per cent; some of the water is in fractures, some in small-scale porosity and some is associated with the microporosity. In rough terms, total moisture

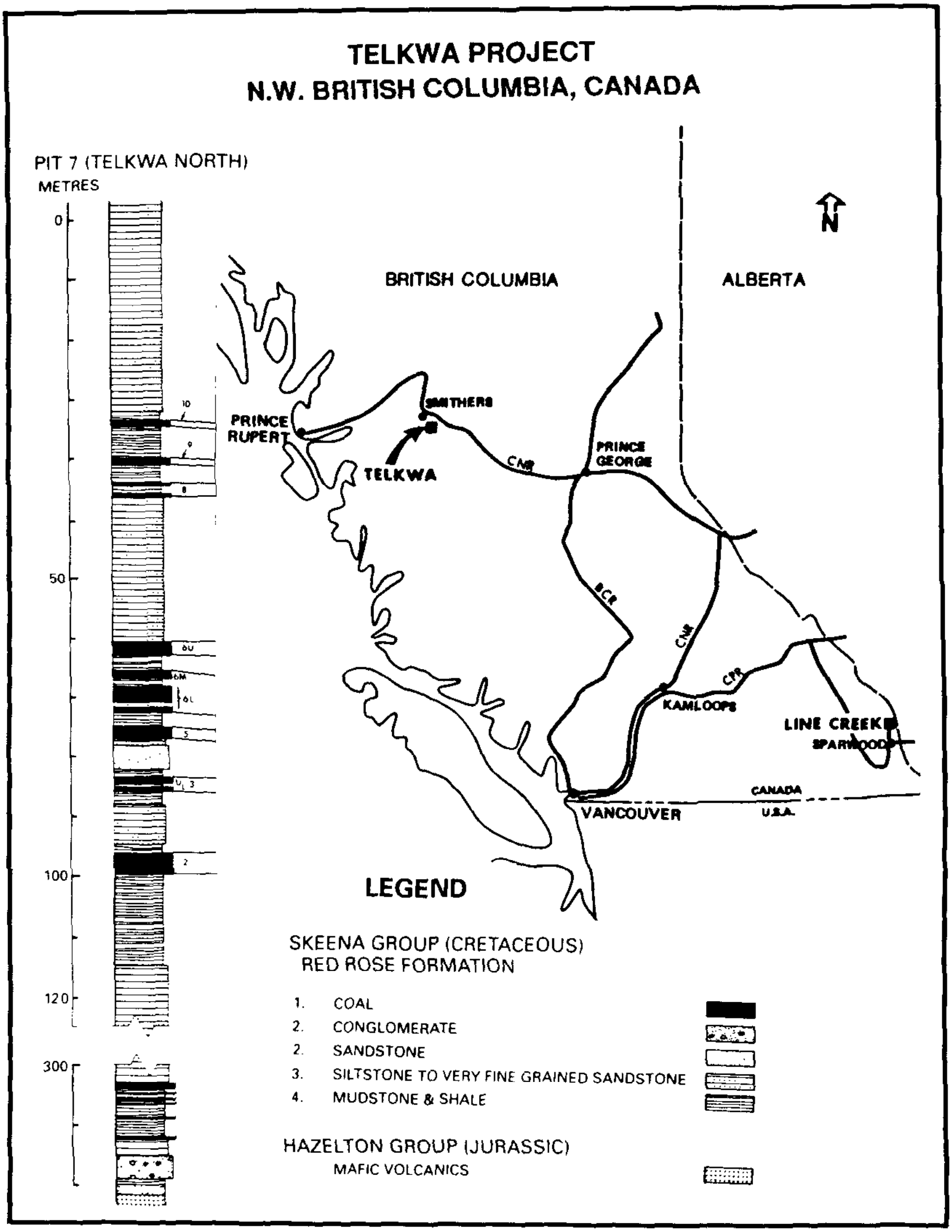

Figure 5-6-1. Telkwa project; location and stratigraphic section.

is equivalent to "*in situ* moisture", water in small-scale and microporosity is equivalent to as-received or equilibrium moisture and water in microporosity only is equivalent to air-dried or inherent moisture.

The true density of dry, zero-ash coal cannot, in reality, be measured. It is possible to remove all the water from coal but it is not possible to remove all the ash. It is also very difficult to measure true density corrected for microporosity (coal pores up to 200 A° units in size). The microporosity is filled with water, methane or other gases and density measurements which do not take microporosity into account will be lower than true density and should be referred to as "apparent density" or "apparent specific gravity" (ASG).

The terms density and specific gravity are often used interchangeably. Density is mass divided by volume often expressed as grams per cubic centimetre; the specific gravity of a substance is the ratio obtained by dividing its density by the density of water and is therefore dimensionless. In the rest of the text, general discussion may refer to densities, but all detailed discussion will refer to specific gravity, sometimes abbreviated to SG.

Measurements of apparent SG are usually made on samples with air-dried moisture and variable ash contents. Data are projected to give a values of apparent SG at zero per cent ash and moisture (DC) and specific gravity of the mineral matter at zero per cent void porosity and moisture (DMM).

It is important to differentiate between the concept of *in situ* SG or "bulk density" (BD) and particle apparent SG (ASG). Measurements of *in situ* SG incorporate open or water-filled fracture porosity. Measurements of apparent SG, utilizing 60-mesh sized grains, do not take into account fracture porosity and are normally higher than *in situ* SG measurements on the same coal. Romaniuk (1987) discusses the concepts of true, apparent and *in situ* SG. He also discusses the difficulties in making direct measurements of *in situ* SG and presents the limited amount of *in situ* SG data he could locate in the literature.

The *in situ* SG of a sample is usually less than the apparent specific gravity (ASG) on an air-dried basis (ADB). If this difference is because of the destruction of void porosity during preparation of the sample for ASG

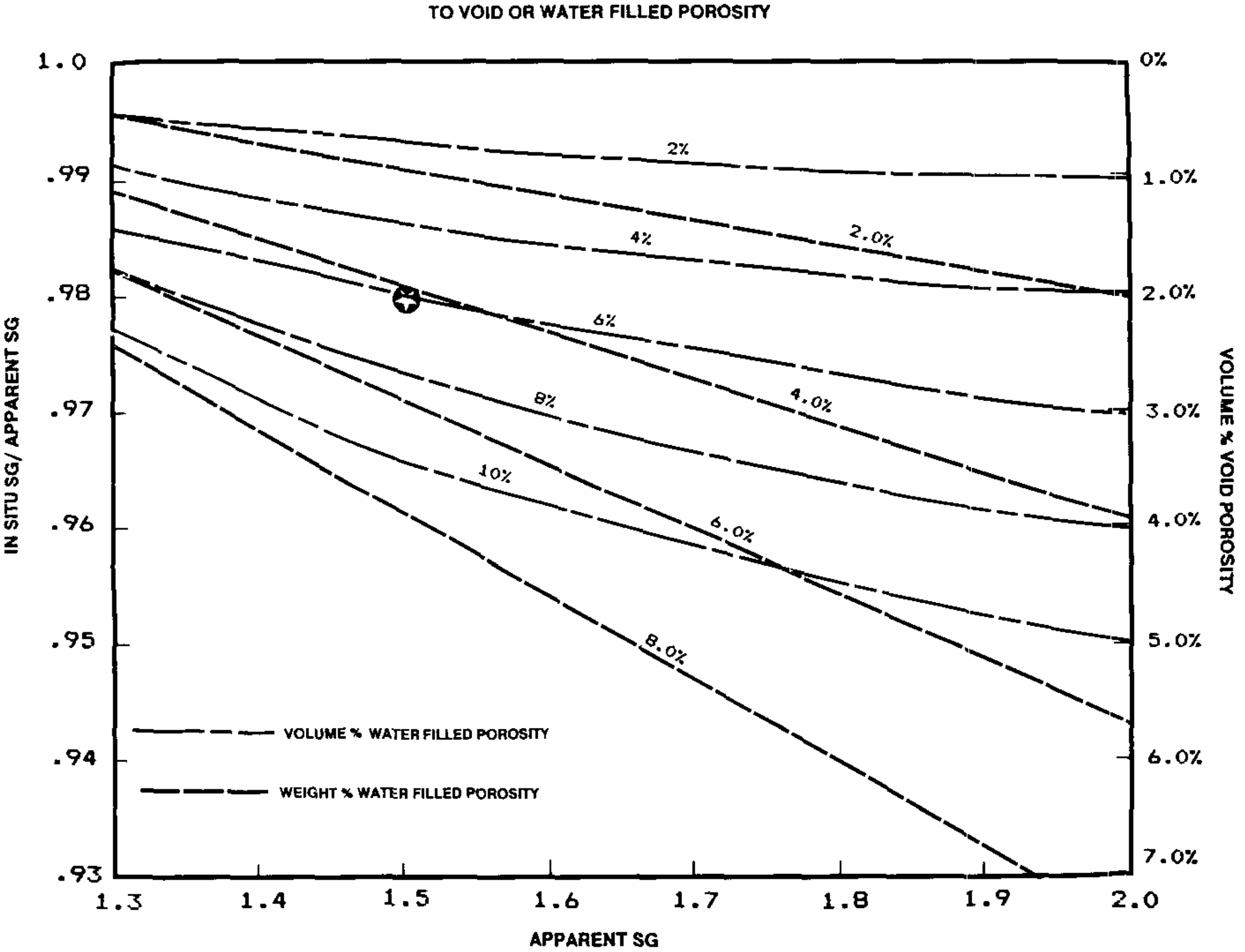

Figure 5-6-2. Relationship of *in situ* specific gravity and sample apparent specific gravity to air or water-filled porosity.

measurements then the per cent void porosity volume change is given by:

$100 \times (1-BD/ASG)$ (Equation 2, Table 5-6-1).

On the other hand, if the decrease is because of destruction of water-filled fracture porosity then the per cent porosity volume change is still given by Equation 2 and the change in weight per cent water (or water-filled volume) is given by:

$MD = 100 \times (ASG\text{-}BD)/[BD \times (ASG-1)]$.

(Equation 3, Table 5-6-1).

A plot of X axis = ASG, left Y axis = BD/ASG and right Y axis = void porosity (Figure 5-6-2) can be contoured using the two relationships above with iso-volume and iso-weight of water-filled porosity lines. An example point [X = 1.5 (ASG); left Y =.98 (BD/ASG = 1.47/1.5); Figure 5-6-2] predicts a void fracture porosity of 2 per cent (right Y axis) or a water-filled porosity volume of 6 per cent corresponding to 4 weight per cent water. The 6 per cent porosity volume and 4 per cent water content are in addition to the porosity or water values in the sample measured on an air-dried basis. Actual fracture porosity will probably be close to the 6 per cent by volume value, indicating close to 100 per cent saturation.

## DEVELOPMENT AND JUSTIFICATION OF THE DENSITY EQUATION

Equation 1 incorporates values of apparent specific gravity of dry zero-ash coal (DC); apparent specific gravity of dry mineral matter (DMM); volume of void porosity (VP) weight per cent of total water (TM), and a method of converting per cent ash to per cent mineral matter. Per cent ash can be converted to per cent mineral matter using the Parr Equation (Rees, 1966) or by using the value WTLOS. Equation 1 has the general form;

$BD = 1/[A+(B \times ash)]$,

where BD is *in situ* SG or bulk density. The values A and B are constant if per cent ash and BD are the only variables; in which case;

$A = (VP+TM)+(1\text{-}TM)/DC$ (Equation 4, Table 5-6-1)

$B = -(DMM-DC)/(DMM \times DC) \times WTLOS$

(Equation 5, Table 5-6-1).

Constant A provides a unique value for DC and constant B provides a set of paired DMM and WTLOS values.

**TABLE 5-6-2**
**APPARENT SPECIFIC GRAVITY ANALYSES, TELKWA PROPERTY**

| Seam | Data Count | ASG | Moisture ARB % | Moisture ADB % | Ash ADB % | Sulphur ADB % |
|---|---|---|---|---|---|---|
| 8 | 6 | 1.47 | 3.29 | 0.7 | 18.00 | 1.62 |
| 6 | 52 | 1.49 | 3.49 | 0.83 | 17.56 | 1.51 |
| 5 | 33 | 1.58 | 3.74 | 0.79 | 23.99 | 1.23 |
| 4 | 22 | 1.70 | 3.46 | 0.63 | 30.45 | 1.38 |
| 3 | 25 | 1.60 | 4.25 | 0.95 | 25.72 | 1.54 |
| 2 | 49 | 1.50 | 3.97 | 0.84 | 21.09 | 1.03 |
| Total | 187 | | | | | |
| Averages | | 1.547 | 3.75 | 0.81 | 22.2 | 1.33 |

Note: ASG apparent specific gravity measured on an ADB
ADB air-dried basis
ARB as-received basis
Seam averages are weighted based on sample size

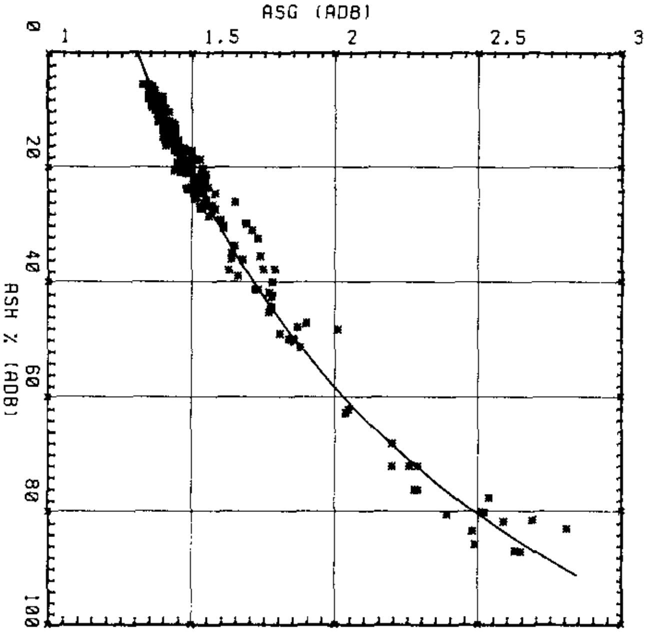

Figure 5-6-3. Telkwa data; apparent specific gravity versus per cent ash, both on an air-dried basis.

**TABLE 5-6-3**
**RESULTS OF CURVE FITTING TO TELKWA DENSITY DATA**

Equations fitted to all ash versus density data

| No. | Equation | r² |
|---|---|---|
| 1 | Y = 1/(A.(X + B)'2 + C) | .983 |
| 2 | Y = A.e'((X − B)/2) | .983 |
| 3 | Y = 1/(A + B.X) | .982 |
| 4 | Y = A.X'(B.X) | .982 |
| 5 | Y = A.B'X.X'C | .982 |
| 6 | Y = A(X/B)'C.c'(X/B) | .982 |
| 7 | Y = A + B.X + C.X'2 | .980 |
| 8 | Y = A.B'X | .980 |
| 9 | Y = A.e'(Ln(X) − B)'2/C) | .972 |
| 10 | Y = A + B.X + C/X | .971 |
| 11 | Y = A + B.X | .960 |

Constants from equation No. 3 Y = 1/(A + B.X)

| Data | Constant A | Constant B | r² | Clean-Coal Density DC |
|---|---|---|---|---|
| All Seams | .76230 | −.00450 | .982 | 1.315 |
| Seams 6 + 8 | .76376 | −.00463 | .975 | 1.313 |
| Seams 2 + 3 | .7597 | −.00439 | .981 | 1.320 |

Calculated paired values of DMM and WTLOS using Equations 4 and 5, Table 5-6-1 (VP=0% TM=0.8%)

| DMM | All Seams | Seams 6 + 8 | Seams 2 + 3 |
|---|---|---|---|
| 2.6 | 1.198 | 1.23 | 1.18 |
| 2.62 | 1.98 | 1.22 | 1.17 |
| 2.64 | 1.179 | 1.21 | 1.16 |
| 2.66 | 1.171 | 1.20 | 1.15 |
| 2.68 | 1.162 | 1.19 | 1.14(b) |
| 2.7 | 1.154 | 1.18 | 1.13 |
| 2.72 | 1.146(b) | 1.17 | 1.13 |
| 2.74 | 1.138 | 1.17 | 1.12 |
| 2.76 | 1.131 | 1.16(b) | 1.11 |
| 2.78 | 1.123 | 1.15 | 1.10 |
| 2.8 | 1.154 | 1.14 | 1.10 |

(b) = Best fit with plasma ashing data
Note: DMM density dry mineal matter
WTLOS (weight of mineral matter)/(weight of ash)

TABLE 5-6-4
PLASMA ASHING XRD AND REFLECTANCE DATA FOR FOUR TELKWA SAMPLES

| | Coal Samples | | | | Plasma-ashed Samples | | |
|---|---|---|---|---|---|---|---|
| Seam | $R_o$ Max % | Ash % | Mineral Matter% | WTLOS | Ash % | WTLOS high%-low% | Minerals |
| 6 | .963 | 26.2 | 30.26 | 1.155 | 85.92 | 1.164 | KQCDSP |
| 5 | .957 | 10.5 | 12.03 | 1.146 | 86.45 | 1.157 | QKDCPS |
| 3 | .901 | 27.0 | 30.08 | 1.114 | 86.44 | 1.157 | QKDCPS |
| 2 | .976 | 19.8 | 22.24 | 1.123 | 86.9 | 1.151 | KQPDCS |
| Average | | | | 1.135 | | 1.157 | |

**Mineral Data**

| Mineral | Code | Density g/cc | WTLOS | Weight Loss % of Mineral |
|---|---|---|---|---|
| Kaolinite | K | 2.63 | 1.162 | 14 |
| Quartz | Q | 2.65 | 1 | 0 |
| Calcite | C | 2.72-2.94 | 1.785 | 44 |
| Dolomite | D | 2.86-2.93 | 1.913 | 47.7 |
| Siderite | S | 3.5-3.96 | 1.613 | 38 |
| Pyrite | P | 4.95-5.03 | 1.5-1.67 | 33.4-40 |

Note: $R_o$ Max = reflectance of vitrinite in oil
WTLOS (weight mineral matter)/(weight ash)

The Telkwa data are plotted on Figure 5-6-3 and averaged in Table 5-6-2. Data in the plot of apparent specific gravity (ADB) versus per cent ash (ADB) (Figure 5-6-3) scatter along a curve rather than a straight line. A freeware program, CURVEFIT based on equations in Kolb (1984), fits 25 different equations to X versus Y data. Using regression analysis and $r^2$ values it assigns the best constants to each equation and ranks the equations in terms of their ability to fit curves through the data. The results of applying the CURVEFIT computer program to the Telkwa data are presented in Table 5-6-3. Equations are ranked based on $r^2$ values from the best ($r^2 = .983$) to a straight line ($r^2 = .960$). An equation of the form $Y = 1/[A + (B \times X)]$ which has the structure of Equation 1 is ranked third. Obviously Equation 1 has a structure which enables it to fit the Telkwa data well, which, to some extent, validates the theory and assumptions used to develop it. The constants A and B from Equation 3 (Table 5-6-3) provide a unique value of 1.315 for DC and a set of possible paired values for DMM and WTLOS (Table 5-6-4).

Generally, Equation 1 is used to generate data sets of apparent specific gravity (ASG) versus per cent ash at different void porosity volumes and weight per cent moisture contents. Data sets can be tabulated or plotted as curves; usually it is assumed that values DC, DMM and WTLOS remain constant for a single data set. In fact the density of the inherent mineral matter in coal seams is probably different from the density of rock splits that contribute to the per cent ash at high ash concentrations. The value DMM probably varies with the ash content. It is also dangerous to assume total moisture is constant over a range of ash concentrations. The inherent moisture in coal is unlikely to be the same as the inherent moisture in rock, nor is the fracture porosity likely to remain constant as the ash content of a seam varies from 10 to 50 per cent. Thus, in reality, *in situ* moisture content probably varies with ash content.

Computer programs were written to calculate the various specific gravity versus ash relationships and to plot the results. These programs and the CURVEFIT freeware program are available from the author on an informal basis.

## TELKWA COAL

### Apparent Specific Gravity of Coal and Mineral Matter

The curve generated using Equation 1 (Figure 5-6-3) represents the ASG versus ash relationship for Telkwa coals at ADB moisture averaging about 0.8 weight per cent (Table 5-6-2) and zero volume void porosity. Once values of DC, DMM and WTLOS are established, it is possible to vary the weight per cent water and volume void porosity in Equation 1 and develop a curve of *in situ* specific gravity (BD) versus ash (ADB) which can be used for *in situ* tonnage calculations. It is therefore important to confirm the accuracy of the value DC and to choose the most appropriate paired values of DMM and WTLOS.

The predicted value of apparent specific gravity for dry zero-ash coal (DC) for Telkwa coal is 1.315 (Table 5-6-4) which is reasonable, based on the rank of the coal (high volatile bituminous A) and agrees with density ranges suggested by Smith (1989). Clean coal density is rank dependent, higher rank seams lower in the stratigraphic section will have higher densities. To test if variations in the value DC are contributing to data scatter in Figure 5-6-3, data were divided into upper-seam data (Seams 6+8) and lower-seam data (Seams 2+3). The upper and lower seam data sets represent an average stratigraphic separation of 40 metres. The upper-seam data predict a DC value of 1.31 and the lower-seam data a value of 1.32 (Table 5-6-3). It is unlikely that this is a statistically significant difference, certainly it contributes very little to the data scattering on Figure 5-6-3.

The mean maximum reflectance of vitrinite in oil was measured on the four composite samples of Seams 6, 5, 3 and 2. Values range from .98 per cent to .9 per cent and average .95 per cent (Table 5-6-4) indicating a rank of high volatile bituminous A. Values do not correlate with stratigraphic position.

The values of DMM and WTLOS are higher for the upper seams than for the lower seams (Table 5-6-3). This implies that mineral matter associated with the upper seams is composed of heavier minerals which undergo a greater weight loss when ashed than minerals associated with the lower seams. Such minerals could be carbonates and pyrite. Data collected for an acid rock-drainage study (Norecol, 1990) indicated a net neutralizing potential of 35 and pyritic sulphur content 2.49 per cent for a composite Seam Six sample compared to 25 and 0.25 per cent for a composite Seam Two sample. The net neutralizing potential is usually proportional to the amount of carbonate in a sample.

## PLASMA ASHING AND X-RAY DEFRACTION RESULTS AND THE WTLOS VALUE

The four composite samples of raw coal from Seams 2, 3, 5 and 6 were ashed in a plasma furnace. Sample weights ranged from 9 to 12 grams. Samples were oxidized in an oxygen atmosphere at a pressure of less than 1 millimetre of mercury and a temperature of 50°C for four days. The resulting mineral matter consisted of fine, white to grey powder with no visible coal. One split of the mineral matter was used for X-ray defraction analysis and another split was ashed in the conventional manner at 850°C in air.

Data are presented in Table 5-6-4. The average WTLOS value calculated from the mineral matter after plasma ashing is 1.135. This value may be low because of the difficulty of recovering all the sample from the quartz boat used in the plasma furnace. The average WTLOS value obtained after conventional ashing of the mineral matter is 1.157, which may be high because of incomplete oxidation of carbon in the plasma furnace. The average WTLOS value obtained from both procedures is 1.145 which implies a DMM value of 2.72 for all the data (Table 5-6-3). The average WTLOS for the two upper-seam samples is 1.156 and 1.136 for the two lower-seam samples. These values are flagged in Table 5-6-3 and imply DMM values of 2.76 (upper seams) and 2.68 (lower seams).

The X-ray defraction analyses of the four samples identified a simple suite of minerals which are listed in order of abundance in Table 5-6-4. Also listed in Table 5-6-4 is the theoretical maximum weight loss experienced by each mineral if totally oxidized. Obviously mineral matter composed of quartz experiences no weight loss whereas mineral matter composed of carbonates may experience a weight loss of up to 50 per cent. All samples contain some carbonates, consequently DMM values greater than 2.67 are to be expected.

## IN SITU SPECIFIC GRAVITY AND MOISTURE OF TELKWA COALS

Down-hole sidewall geophysical logging, using a calibrated long-spaced density sond, can provide reasonably accurate values of *in situ* specific gravity of coal or rock. Generally it is difficult to establish a range of ash versus *in situ* specific gravity readings because of the resolution of the sond. *In situ* specific gravity values were read off Telkwa geophysical logs for thicker, cleaner seams where the interval could be matched to a sample interval and the thickness was greater than the limit of resolution of the sond. This provided a set of values for ash (ADB), ASG (ADB) and matching *in situ* specific gravity measurements. The data provide average values for the upper seams of 9.01 per cent ash, 1.382 (ASG) and 1.351 (BD) and for the lower seams of 11.25 per cent ash, 1.397 (ASG) and 1.369 (BD). In all, thirteen values from the upper seams were averaged and nine values from the lower seams.

The difference in weight of water between *in situ* samples and samples at ADB can be read from Figure 5-6-2 and is a measure of the water-filled fracture porosity. The difference can also be calculated using;

$$\text{MD} = 100\times(\text{ASG}-\text{BD})/[\text{BD}\times(\text{ASG}-1)]$$

(Equation 3, Table 5-6-1).

Total *in situ* moisture is given by;

$$\text{TM} = (\text{ADM}\times(100-\text{ADM})+\text{MD}\times100)/100$$

(Equation 6, Table 5-6-1);

where ADM = air-dried moisture, which in this case is 0.8 per cent. Using the average upper and lower seam data from above, the average *in situ* moisture for the upper and lower seams is 7 per cent and 6 per cent, respectively. Average equilibrium moisture for the seams is 3.4 per cent and average as-received moisture (Table 5-6-2) is 3.7 per cent. The moisture difference from an ARB of 3.7 per cent to an ADB moisture of 0.8 per cent is a measure of the small-scale water-filled porosity of coal fragments. The moisture difference from an *in situ* moisture of about 7 per cent to an ARB moisture of 3.7 per cent is a measure of the water-filled fracture porosity. A water-filled fracture porosity of about 3.5 per cent (upper seams) and 2.5 per cent (lower seams) is implied. Three per cent water by weight at 10 per cent ash corresponds to about 4 per cent volume for water-filled fractures; at higher ash contents, 3 per cent water by

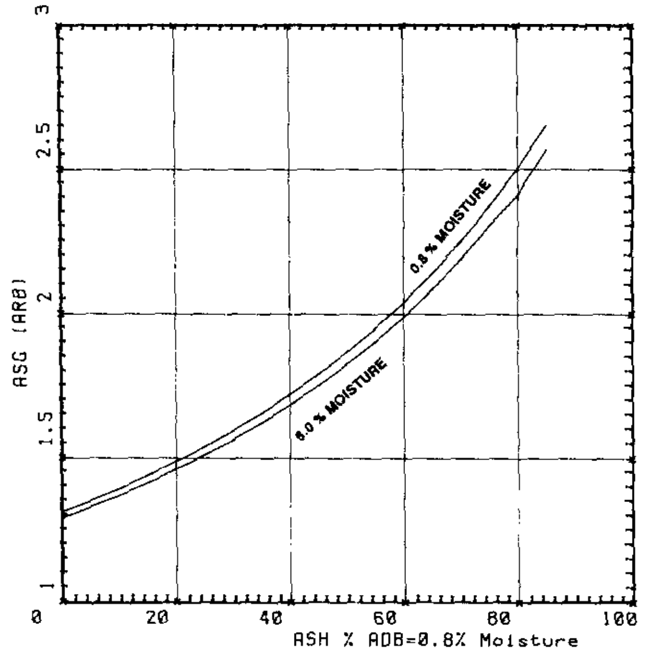

Figure 5-6-4. Apparent specific gravity at 6% and 0.8% moisture versus per cent ash at 0.8 % moisture.

**TABLE 5-6-5**
**APPPARENT SPECIFIC GRAVITY AND IN SITU DENSITY FOR TELKWA COALS**

| Ash %(ADB) | ASG (ADB) | BD (Case 1) 6% moisture | BD (Case 2) 6% moisture | BD (Case 3) 6% moisture |
|---|---|---|---|---|
| 5 | 1.35 | 1.32 | 1.32 | 1.33 |
| 10 | 1.38 | 1.36 | 1.36 | 1.36 |
| 15 | 1.42 | 1.40 | 1.39 | 1.40 |
| 20 | 1.47 | 1.44 | 1.43 | 1.44 |
| 25 | 1.51 | 1.48 | 1.47 | 1.49 |
| 30 | 1.56 | 1.53 | 1.52 | 1.53 |
| 35 | 1.61 | 1.58 | 1.56 | 1.58 |
| 40 | 1.66 | 1.63 | 1.61 | 1.64 |
| 45 | 1.72 | 1.68 | 1.66 | 1.70 |
| 50 | 1.78 | 1.74 | 1.71 | 1.76 |

ASG = apparent specific gravity
BD = In situ density
Case 1 WTLOS = 1.146 DMM = 2.72
Case 2 WTLOS = 1.20 DMM = 2.6
Case 3 WTLOS = 1.12 DMM = 2.8
*Note: All calculations at clean coal specific gravity(DC) = 1.315*

weight will correspond to a greater volume of water-filled fractures (Figure 5-6-2).

The average interburden rock *in situ* specific gravity read from the geophysical logs is 2.45; if a dry specific gravity of 2.67 for interburden rock is assumed, then this predicts an *in situ* moisture content for the rock of 5 per cent.

The estimate of *in situ* moisture of 6 to 7 per cent for the coal does not contradict equilibrium moisture data and rock density data. An apparent specific gravity (at 6 weight per cent moisture) versus per cent ash (ADB) curve is plotted on Figure 5-6-4 and for comparison the curve for ASG (at 0.8 weight per cent moisture) versus ash per cent (ADB) is also plotted. The same data are tabulated in Table 5-6-5.

*In situ* specific gravity versus per cent ash (ADB) relationships are essential for converting *in situ* volumes to tonnages. *In situ* coal tonnages represent the starting database for all mine feasibility studies; if *in situ* tonnages are not well defined then all subsequent analysis is suspect.

Once values of DC, DMM and WTLOS are established it is possible, using Equation 1, to construct *in situ* specific gravity versus ash ADB at a number of possible *in situ* moisture weight per cents for comparison purposes. It is also possible to construct curves which incorporate volume of void porosity for stockpile bulk densities.

It is important to know *in situ* weight of water in order to estimate "run-of-mine moisture". An *in situ* moisture content of 6 to 7 per cent for Telkwa coals probably translates into a "run-of-mine moisture" of about 8 per cent. If product coal were to be shipped at 10 per cent moisture then the company would in effect be selling 2 per cent water as coal.

## DISCUSSION

The proceeding discussion outlines a way of combining laboratory analyses, a density equation and geophysical log data to derive *in situ* specific gravity versus ash relationships. A number of potentially complicating factors have been ignored.

Equation 1 assumes that mineral matter density, and the value WTLOS, remain constant as per cent ash varies, which is not necessarily the case. Coal contains a background concentration of inherent ash which varies from 0 to 5 per cent. Inherent ash is derived from material that may be bound elementally with the organic material or exist as oxides dispersed within it. Ashing inherent ash will not result in a weight loss and may in fact result in a weight gain. The WTLOS value for low-ash samples may therefore approach 1 or be less than 1 (Gray, 1982). At intermediate ash concentrations the ash is probably derived from authogenic minerals such as carbonates and pyrite which will ensure high values for DMM and WTLOS. At high ash concentrations, the ash is dominated by interburden rock which is likely to have intermediate values of DMM and WTLOS.

Much of the data scatter at higher ash concentrations in Figure 5-6-3 is probably caused by variation in individual WTLOS values. Mineral matter composition varies from sample to sample, independently of variation in per cent mineral matter. It may be possible to reduce the scatter by using the simplest form of the Parr Equation (Table 5-6-1) to convert ash to mineral matter. This requires a pyritic sulphur analysis for each ash analysis. It should be realized that if a constant sulphur value is used then this forces the Parr Equation to predict higher WTLOS values at low ash contents, which is unrealistic. If the sulphur is in the mineral matter then the sulphur content of the coal sample will decrease as the per cent ash decreases. Data from a separate acid rock-drainage study at Telkwa (Norecol, 1990) established the relationship, per cent pyritic sulphur = 0.9935 × per cent total sulphur − 0.206, for Telkwa coals. Using this relationship, the Parr Equation and data from Table 5-6-3, average WTLOS values were calculated for each seam (Table 5-6-6); values average 1.11 which is distinctly lower than the measured values in Table 5-6-4. It appears that the simple version of the Parr Equation provides unreliable estimates of the WTLOS value for Telkwa coal.

The WTLOS value can be derived without resorting to the use of a plasma furnace. The relationship between volatile matter, dry mineral matter free basis (VM dmmf), and ash, and volatile matter (VM), as-received basis (ARB) and moisture content (TM) can be written as:

$$\text{VM dmmf} = \text{VM}/[1-\text{TM}-(\text{WTLOS}\times\text{ash})]-(\text{WTLOS}-1)\times\text{ash}.$$

On a plot of volatile matter versus ash the Y intercept is VM dmmf (1−TM) and the slope is WTLOS×(1−VM dmmf)−1. These equations can be solved for VM dmmf

**TABLE 5-6-6**
**CALCULATION OF WTLOS USING PARR EQUATION**

| Seam | Average Ash % | Average Total Sulphur % | Average Pyritic Sulphur % | WTLOS |
|---|---|---|---|---|
| 8 | 18 | 1.62 | 1.23 | 1.118 |
| 6 | 17.56 | 1.51 | 1.29 | 1.120 |
| 5 | 23.99 | 1.23 | 1.02 | 1.103 |
| 4 | 30.45 | 1.38 | 1.17 | 1.101 |
| 3 | 25.72 | 1.54 | 1.32 | 1.108 |
| 2 | 21.09 | 1.03 | 0.82 | 1.101 |

WTLOS = 1.08 ash + 0.55 Pyrite/Ash (Parr Equation)
Pyritic sulphur calculated using
Pyrite = .9935 × total sulphur − .206

and WTLOS. In practice, a good data set with a range in ash values is required. Normally volatile matter is measured on washed samples which have a limited range of ash contents, making it difficult to fit a line through the data. This approach assumes that the weight loss incurred by mineral matter during a volatile matter analysis is the same as the weight loss incurred during an ash analysis. The two analyses are performed under different conditions and the assumption is not always correct.

In most cases reasonable estimates of the DMM and WTLOS values will suffice for *in situ* specific gravity calculations because most studies are of coal with less than 40 per cent ash. Table 5-6-3 outlines a range of possible DMM, WTLOS pairs from 2.6, 1.198 to 2.8, 1.116. Table 5-6-6 illustrates the effect on *in situ* specific gravity calculations of choosing either of the two extremes. At 50 per cent ash results are 1.7 per cent low to 1.2 per cent high. Obviously, for ash concentrations less than 50 per cent DMM and WTLOS values can generally be estimated using previous experience without incurring large errors in the calculation of *in situ* specific gravity.

The apparent specific gravity of dry zero-ash coal (DC) at constant rank varies with changes in petrographic composition. Different macerals have different densities and microporosities. Coal with higher contents of fusinite and semifusinite have higher densities than vitrinite-rich coals. It is difficult to quantify the variation in DC caused by changes in petrographic composition but it is probably not significant.

## CONCLUSIONS

Equation 1 fits specific gravity measurements from the Telkwa property well. The combination of Equation 1, a set of apparent specific analyses on an air-dried basis and data from geophysical logs is sufficient to fully describe the *in situ* specific gravity or bulk density versus ash relationships required for mine planning. Equation 1 can generate *in situ* specific gravity versus ash curves at different *in situ* moistures for comparison purposes, and can also be used to predict stockpile bulk densities which incorporate a void porosity.

Coals in the Telkwa deposit have a clean coal apparent specific gravity of 1.31 to 1.32 on an ADB of about 0.8 per cent moisture. *In situ* moisture is approximately 6 per cent.

The WTLOS value for Telkwa coals is higher than is predicted by the Parr Equation and is influenced by the presence of carbonates in the mineral matter. In most cases it is not necessary to independently measure the values of WTLOS and DMM; reasonable estimates do not introduce large errors.

Reserve calculations and mining feasibility studies represent a sequence of calculation steps, like links in a chain, each of which has its own associated errors and possible bias. These errors and biases accumulate to effect the uncertainty and possible bias in the final conclusions. It seems that in many studies the unappreciated weak link in the chain is the conversion of volumes to tonnages. This note may help to ensure that the weak link is elsewhere in the chain, at a point less easy to quantify and more deserving of the notoriety.

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