Coal

Origin, occurrence, Classification, and Analysis

Fossil Fuels

Origin

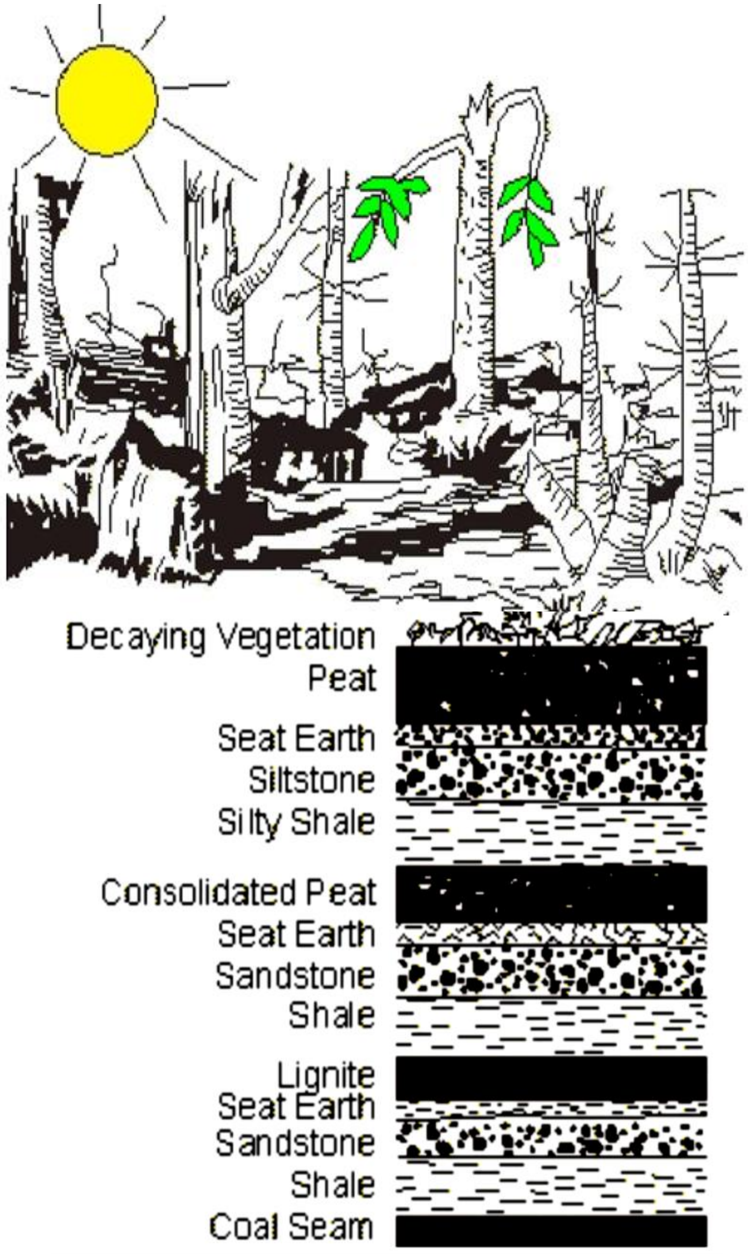
Fossil fuels were produced from fossilization process of carbohydrates.

In general,

Solar energy + CO_2 + H_2O $\longrightarrow$ Carbohydrate + O_2

This equation is known as the photosynthesis process which occurs in plants. Then,

$$\textbf{Carbohydrate} \xrightarrow{\text{Heat, high pressure,} -O_2} C_xH_y$$



Coal formation and factors

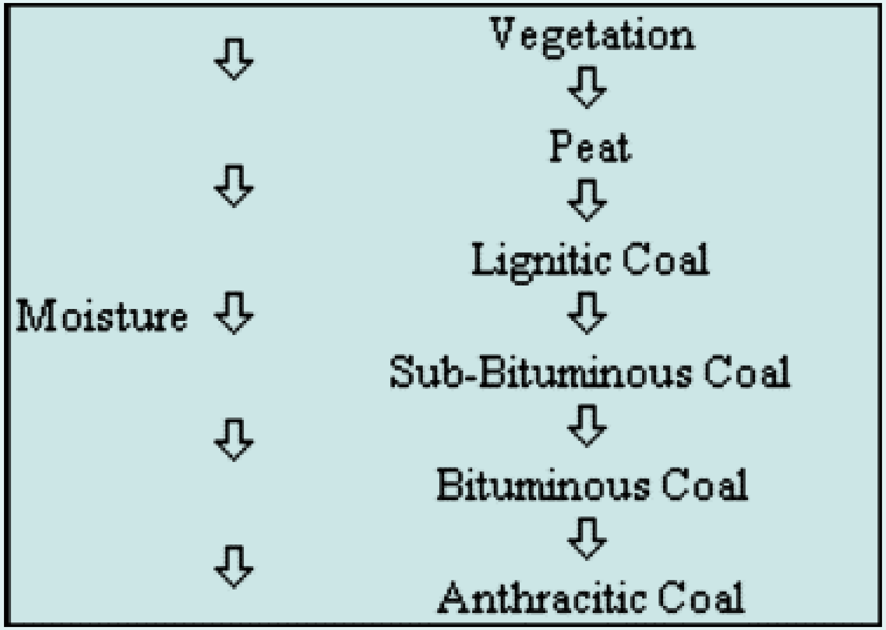
- Factors which greatly affected the content, makeup, quality, and rank of the coal were:
  - Temperature
  - Pressure
  - Time
  - Layering process
  - Fresh water/sea water
  - Swamp acidity
  - Types of plant debris
  - Types of sediment cover

Coal occurrence

- Sedimentary Rock
- Vegetable debriṣ
- Debriṣ were subjected to a complex series of chemical and physical changes during the course of many million of years.
- Genesis of coal {origin}

$$\text{Wood} \xrightarrow{\textbf{T, P, Bacteria}} \text{Coal}$$

Coal Rank

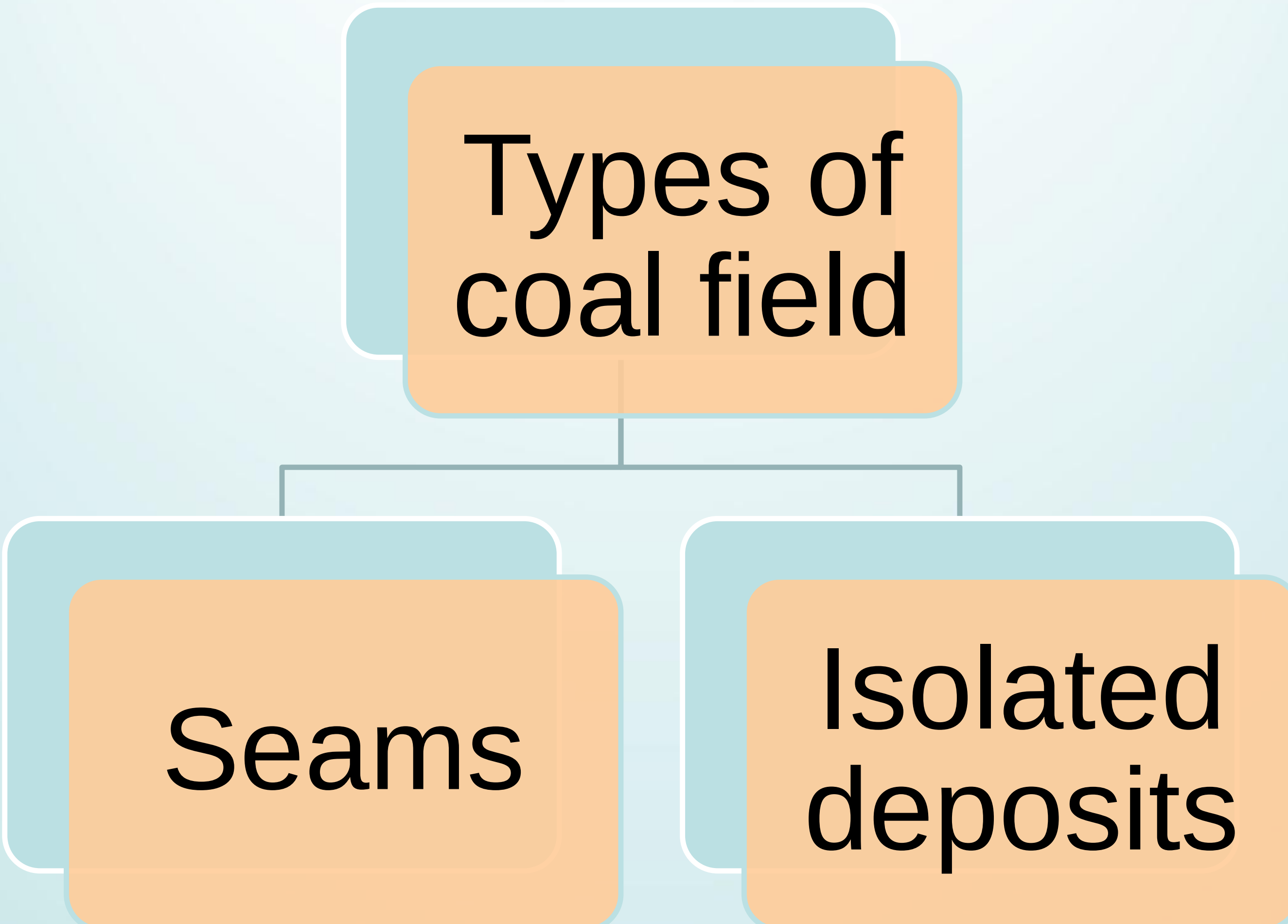


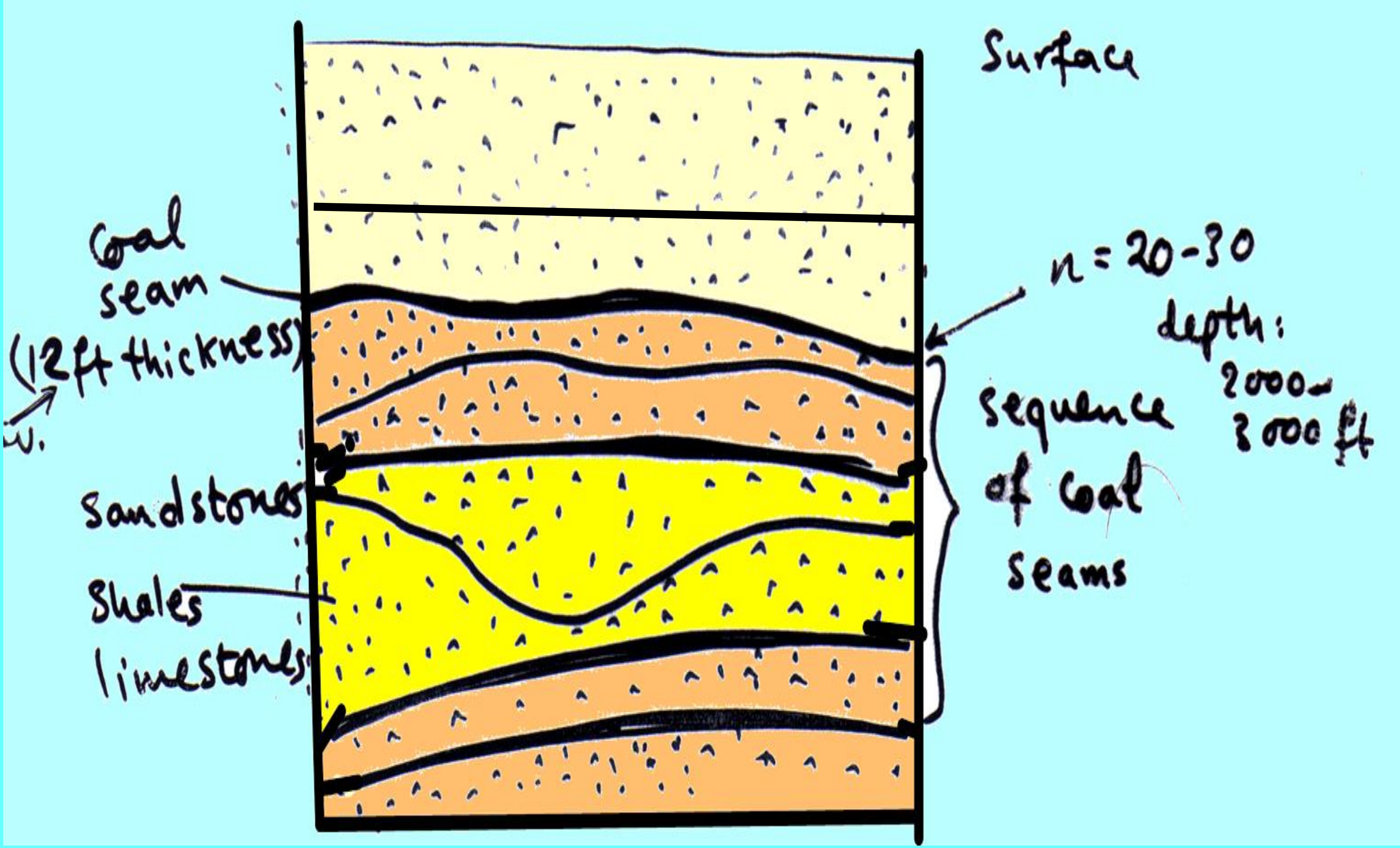
Moisture decreases, rank increases.

Rank increases, fixed carbon increases.

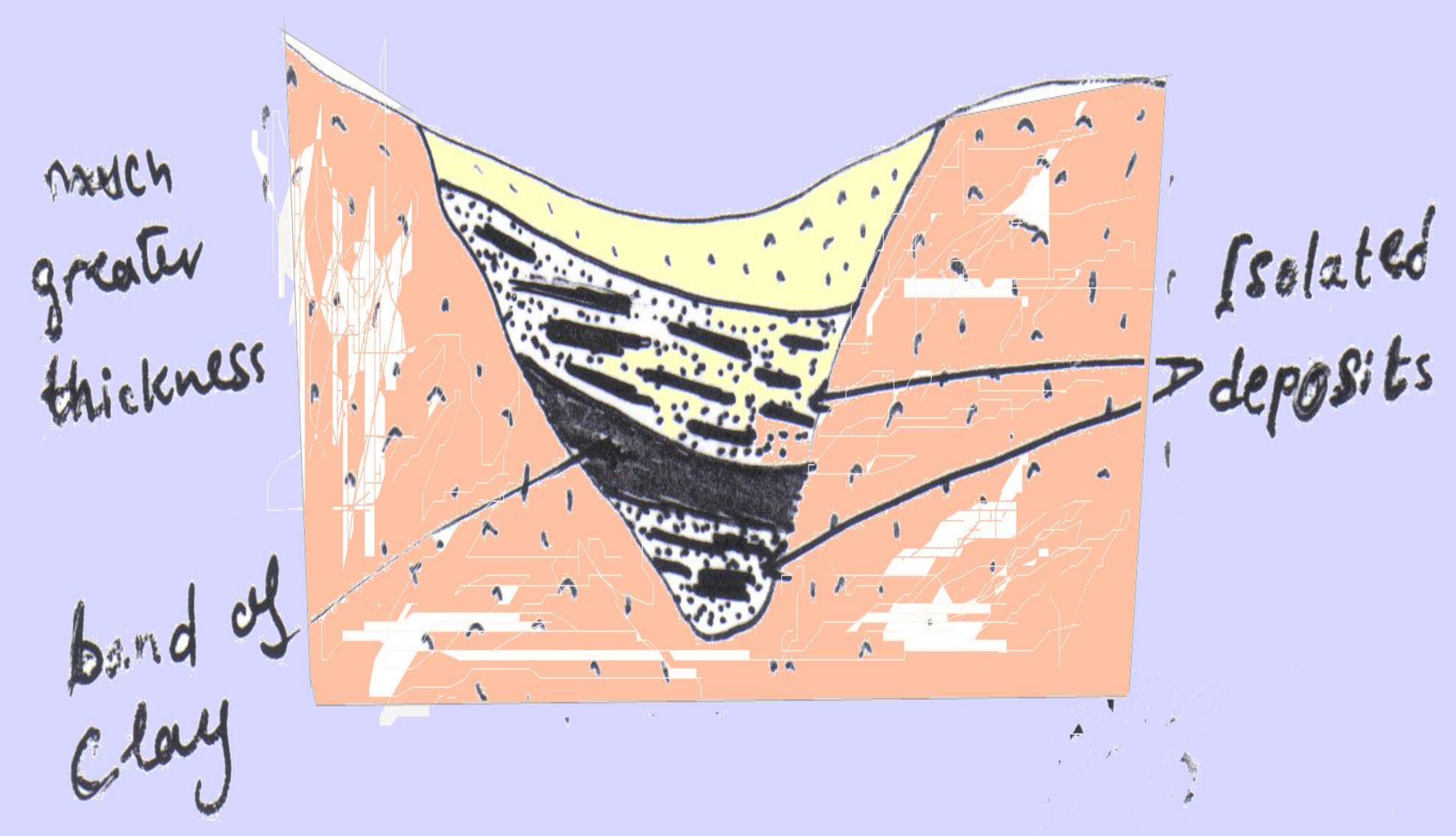
Rank increases, volatile matter decreases.

Rank increases, heating value increases


Types of coal field
Seams
Isolated deposits



(A) Seams of Coal



(B) Isolated deposits

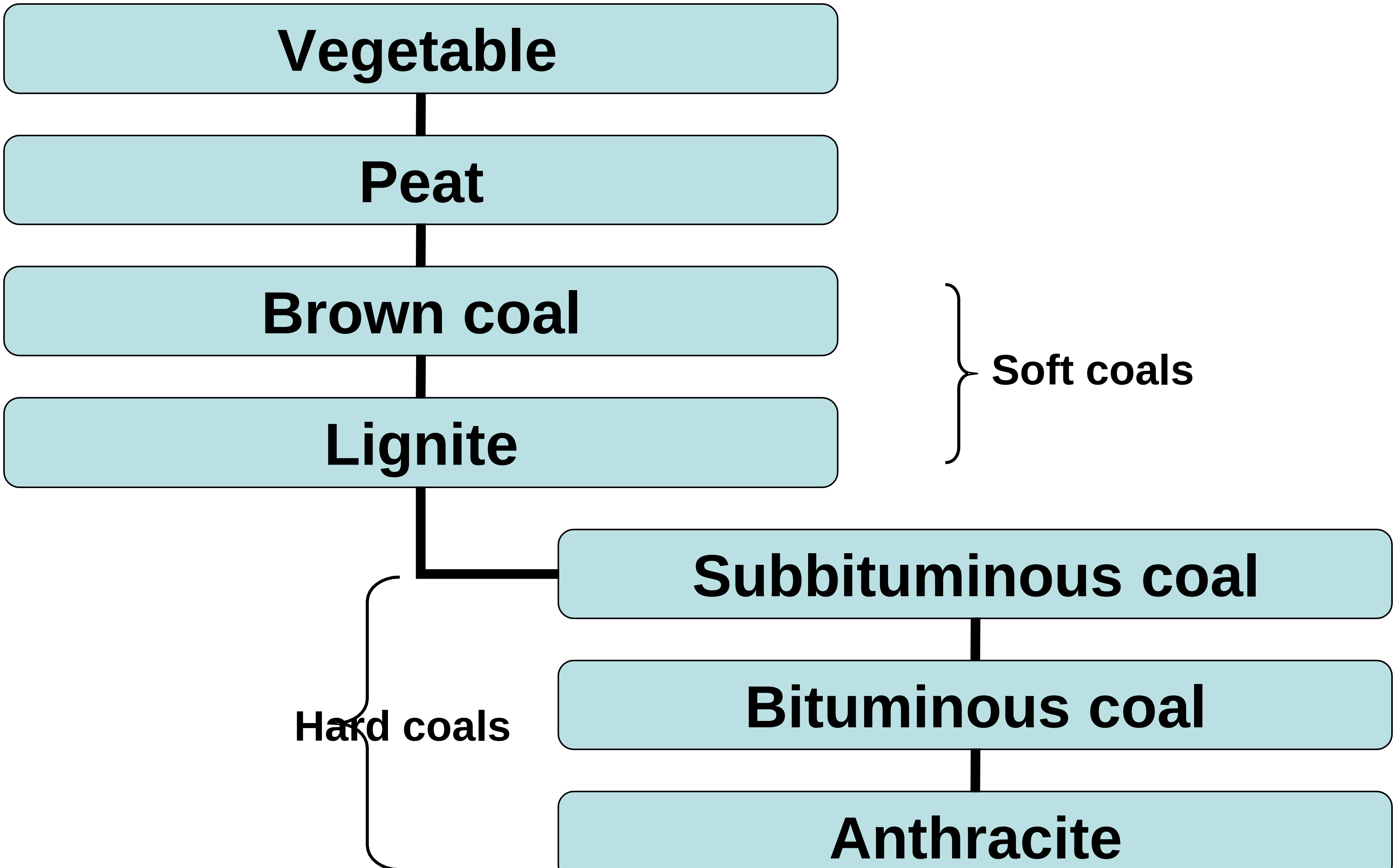
Sedimentary rock

Bituminous coal

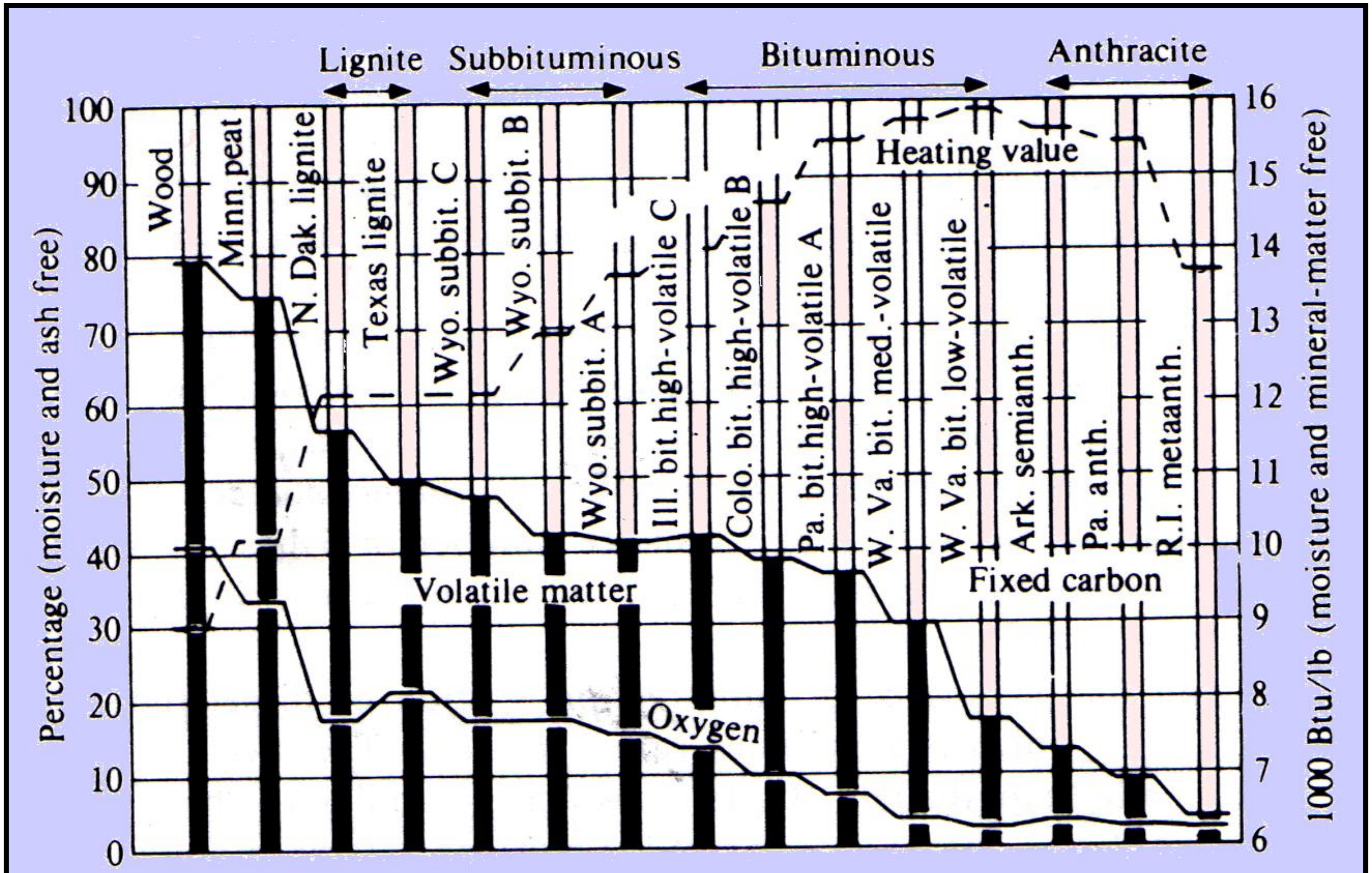
Lignite (brown coal)

Anthracite(hard coal)

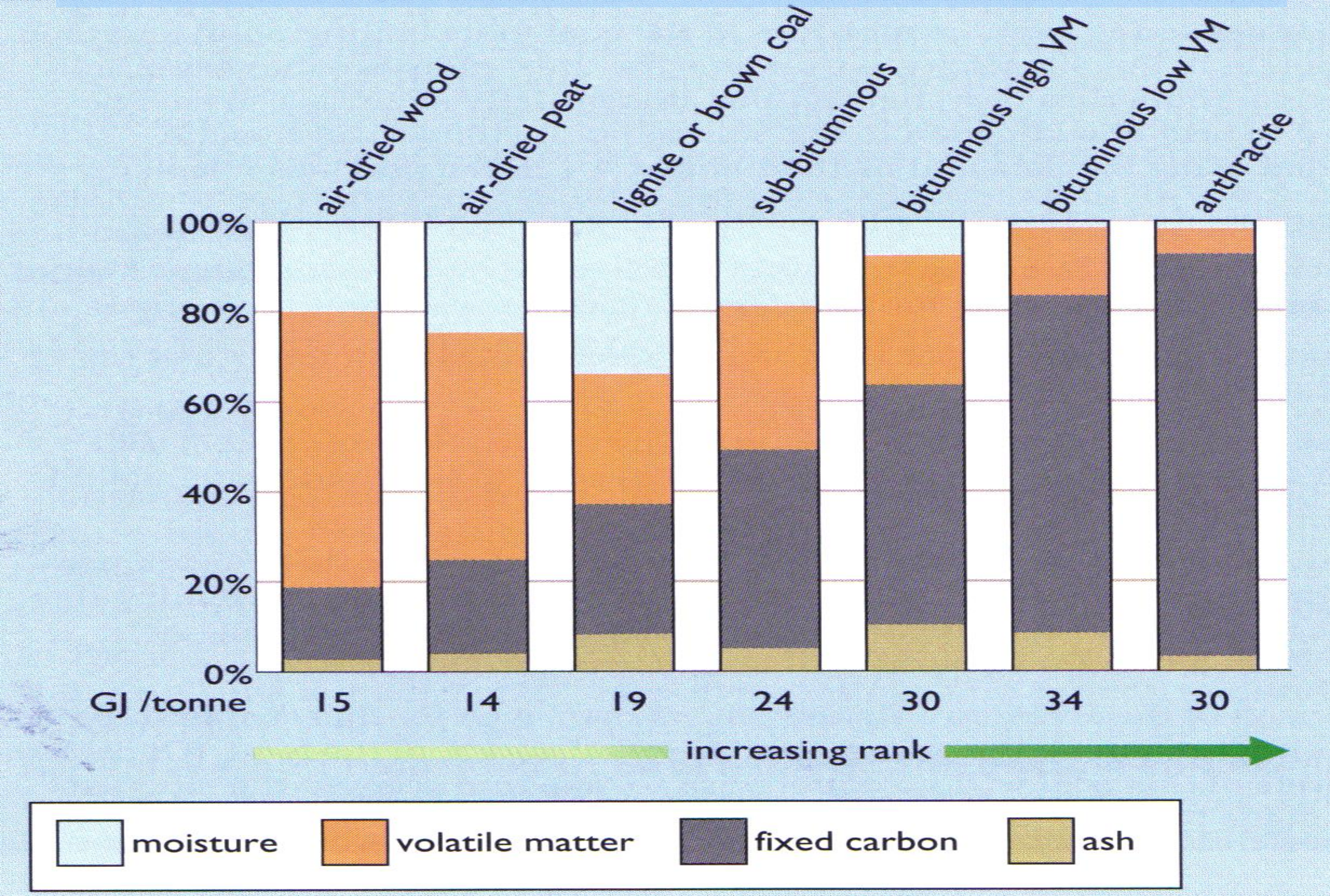
The process of coal formation takes several steps in the following order



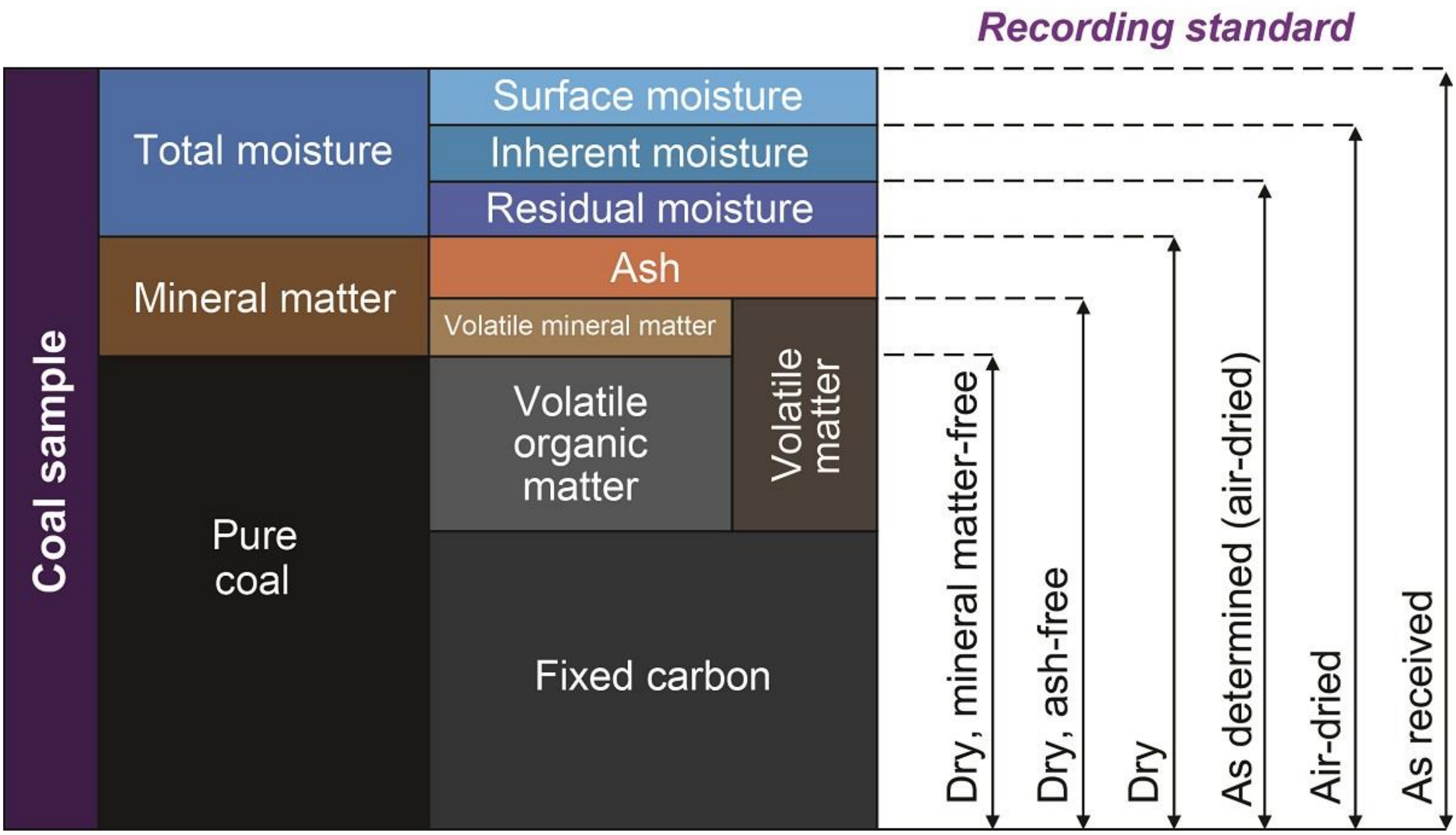
Variation of coal composition and properties with age



Proximate analysis of coal and other solid fuels



Basis for Coal Analysis



Notes

- As-determined (air-dried) basis: Usually denoted as “adm” or “ADM.” Even after air-drying, coal typically contains some moisture, which is referred to as residual moisture
- Dry basis: Data or results are calculated to a theoretical base as if there were no moisture in the coal sample. This basis is commonly used in testing laboratories because of issues related to measuring moisture. Usually denoted as “dry” or “DRY.”
- Moist, ash-free basis: Data or results are calculated to a theoretical base as if there were no ash, but there is moisture, in the coal sample. Usually denoted as “maf” or “MAF.”
- Moist, mineral-matter-free basis: For some low-rank coals, this basis is used to calculate calorific value. It uses a theoretical base as if there were no mineral matter, but includes the moisture content of the coal sample.

Mineral matter (weight %) = (1.08 x ash yield (weight %)) + (0.55 x total sulfur (weight %))

ASTM Coal Classification System ‘Definitions’

- **Percent, dry, mineral-matter-free fixed carbon = %dry, mm-free FC:**

$$\%\,\text{dry, mm-free FC} = \frac{(\text{FC} - 0.15\,\text{S})(100)}{1 - \text{M} - 1.08\text{A} - 0.55\text{S}} = \text{D, mm-f FC}$$

- **Moist, mineral-matter-free Btu content of coal, Btu/lb$_m$ = moist, mm-free Btu:**

$$\text{Moist, mm-free Btu} = \frac{\text{Btu} - 5000\text{S}}{1 - 1.08\text{A} - 0.55\text{S}} = \text{M, mm-f Btu}$$

Coal Classification
Class I

Class Group	Ranking parameter	Agglomerating character
Class I: Anthracitic coals		
Group 1. Metaanthracite	Dry, mm-free FC>98%	Nonagg.
Group 2. Anthracite	98%>D, mm-f FC>92%	Nonagg.
Group 3. Semianthracite	92%>D, mm-f FC>86%	Nonagg.

Class II

Class II: Bituminous coals

Group 1.	Low-volatile bituminous	86% > D, mm-f FC > 78%	Usually agg.
Group 2.	Medium-volatile bituminous	78% > D, mm-f FC > 69%	Usually agg.

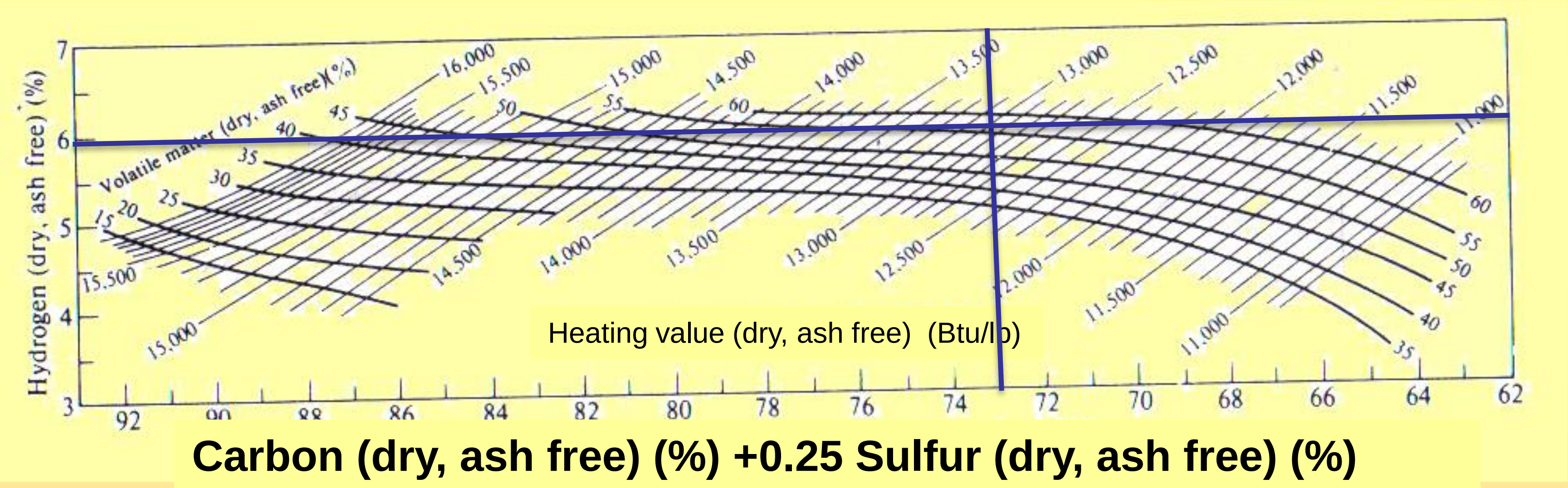
If dry, mm-free FC is less than 69%,
rank coal according to the moist, mm-free Btu value

Group 3.	High-volatile A bituminous	M, mm-f Btu > 14,000	Usually agg.
Group 4.	High-volatile B bituminous	13,000 < M, mm-f Btu < 14,000	Usually agg.
Group 5.	High-volatile C bituminous	11,500 < M, mm-f Btu < 13,000	Usually agg.
		10,500 < M, mm-f Btu < 11,500	Agg.

Class III and Class IV

Class III: Subbituminous coals		
Group 1. Subbituminous A	10,500 < M, mm-f Btu < 11,500	Nonagg.
Group 2. Subbituminous B	9,500 < M, mm-f Btu < 10,500	Nonagg.
Group 3. Subbituminous C	8,300 < M, mm-f Btu < 9,500	Nonagg.
Class IV: Lignitic coals		
Group 1. Lignite A	6300 < M, mm-f Btu < 8300	Nonagg.
Group 2. Lignite B	M, mm-f Btu < 6300 Btu/lbm	Nonagg.

Converting Proximate to Ultimate Analyses



Chemical Change with coal rank

Material	C,%	H_2,%	O_2,%
Wood	44	6	60
Peat	59	6	35
Lignite	71	5	24
subbituminous	74	5	21
Bituminous	84	5	11
Anthracite	94	3	3
Graphite	100	0	0

Coal Petrology
“appearance”

Major components

1. Vitrain: very bright constituents
2. Clarain: less bright constituents
3. Durain: dull constituents
4. Fusain: black constituents

The organic matter in coal is known as ‘Macerals’

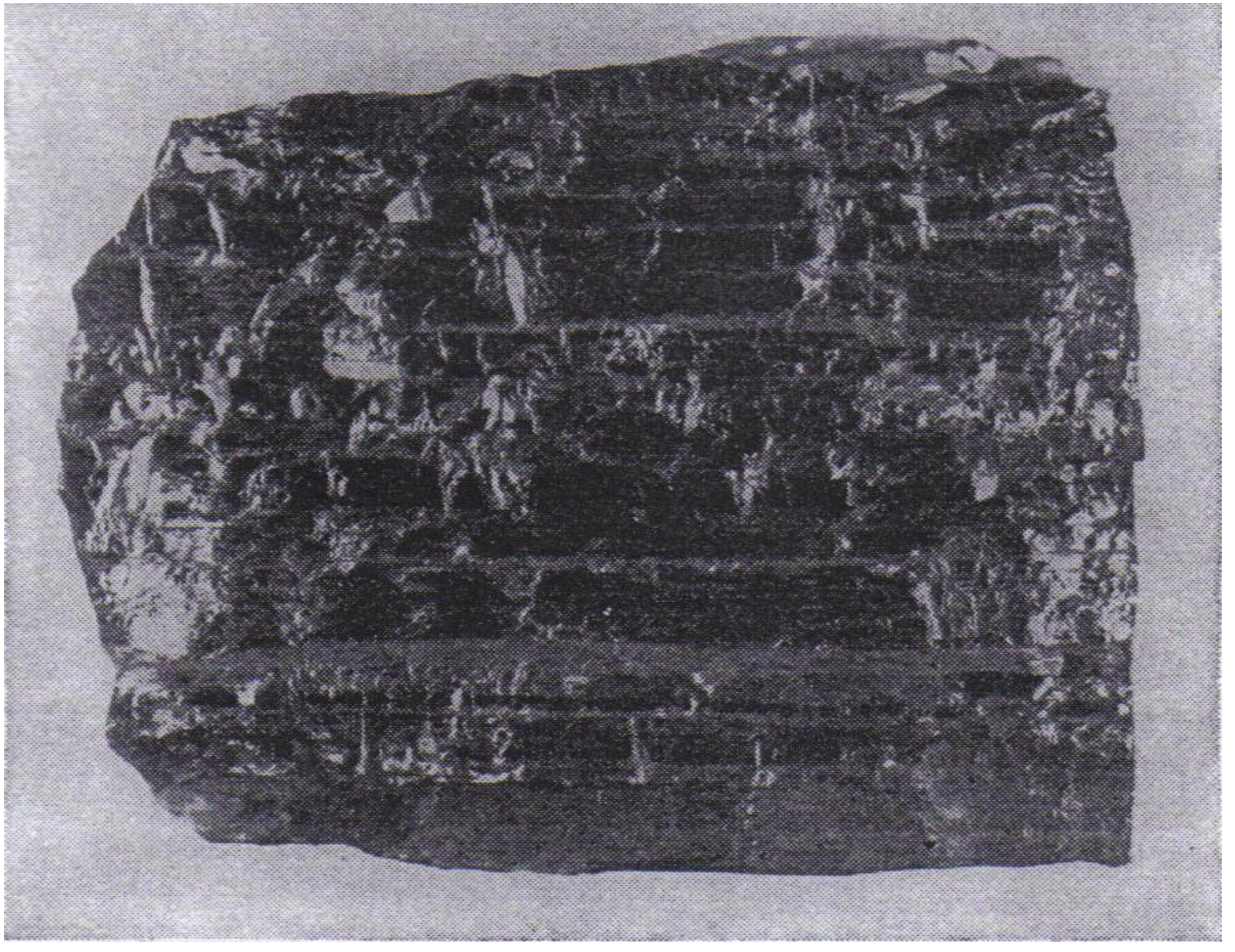
Macerals Distinguished by appearance

- **Vitrinite**
  - ➢Bright
  - ➢Derived from woody material and leaves.
- **Exinite**
  - ➢From spores, pollens, waxy plants, algae. Resins.
  - ➢ produce the highest yields of oil and gases and little chars.
- **inertinite**
  - ➢From oxidized plant material, oxidized resins and HC , and fungi.
  - ➢ produce little oil and mainly gases and chars.

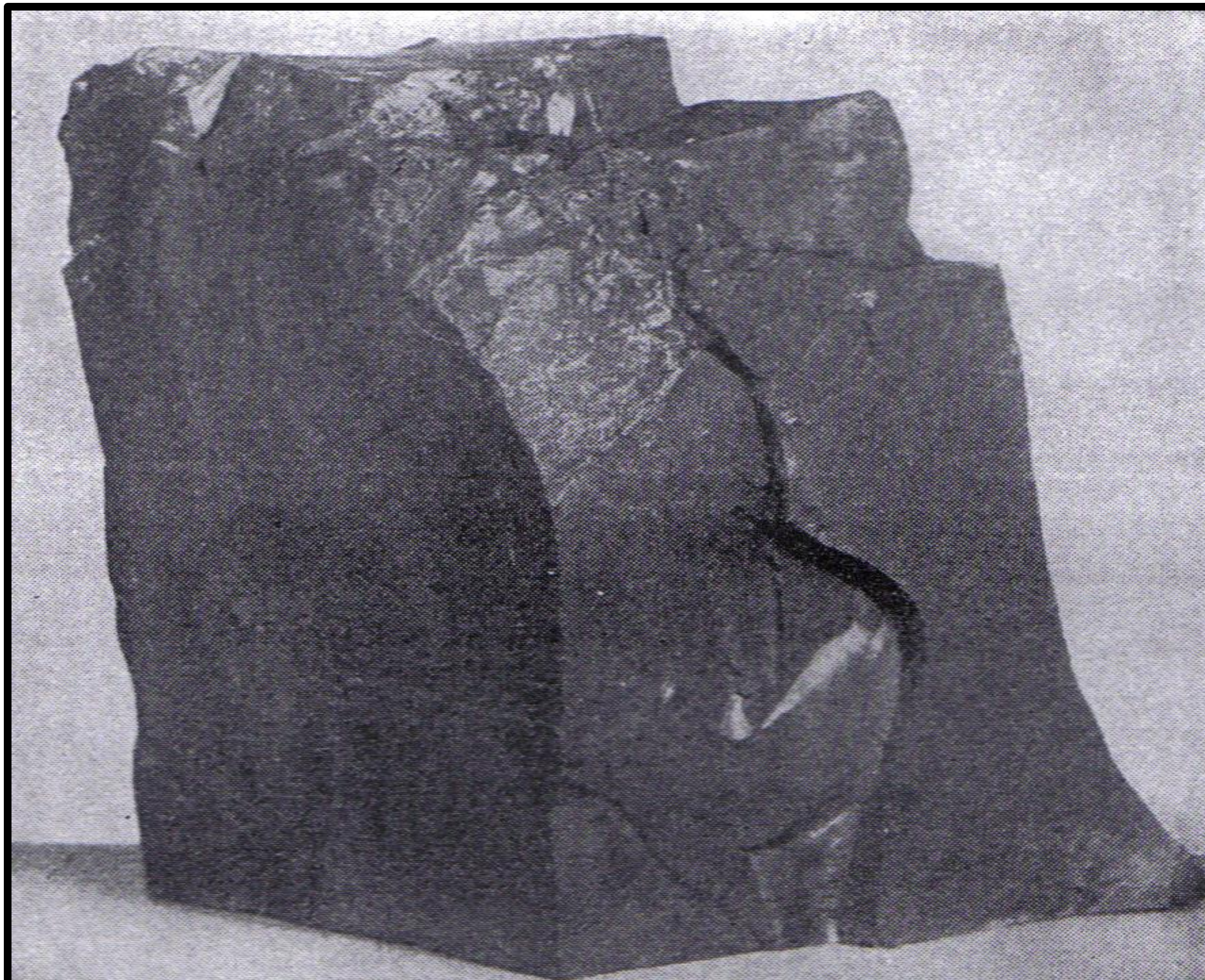
Coal as a fossil fuel

The picture shows a block of bright bituminous coal

The picture shows a block of bright, banded, bituminous coal.

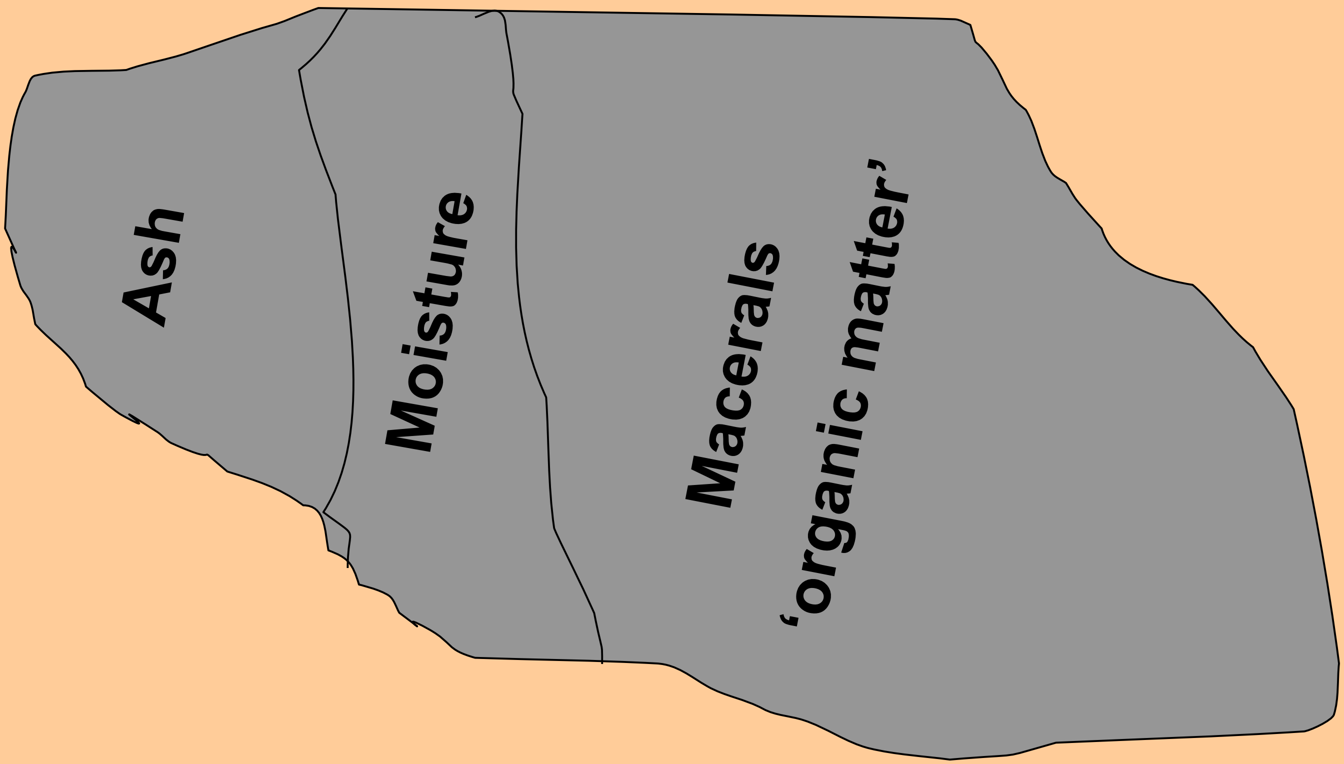


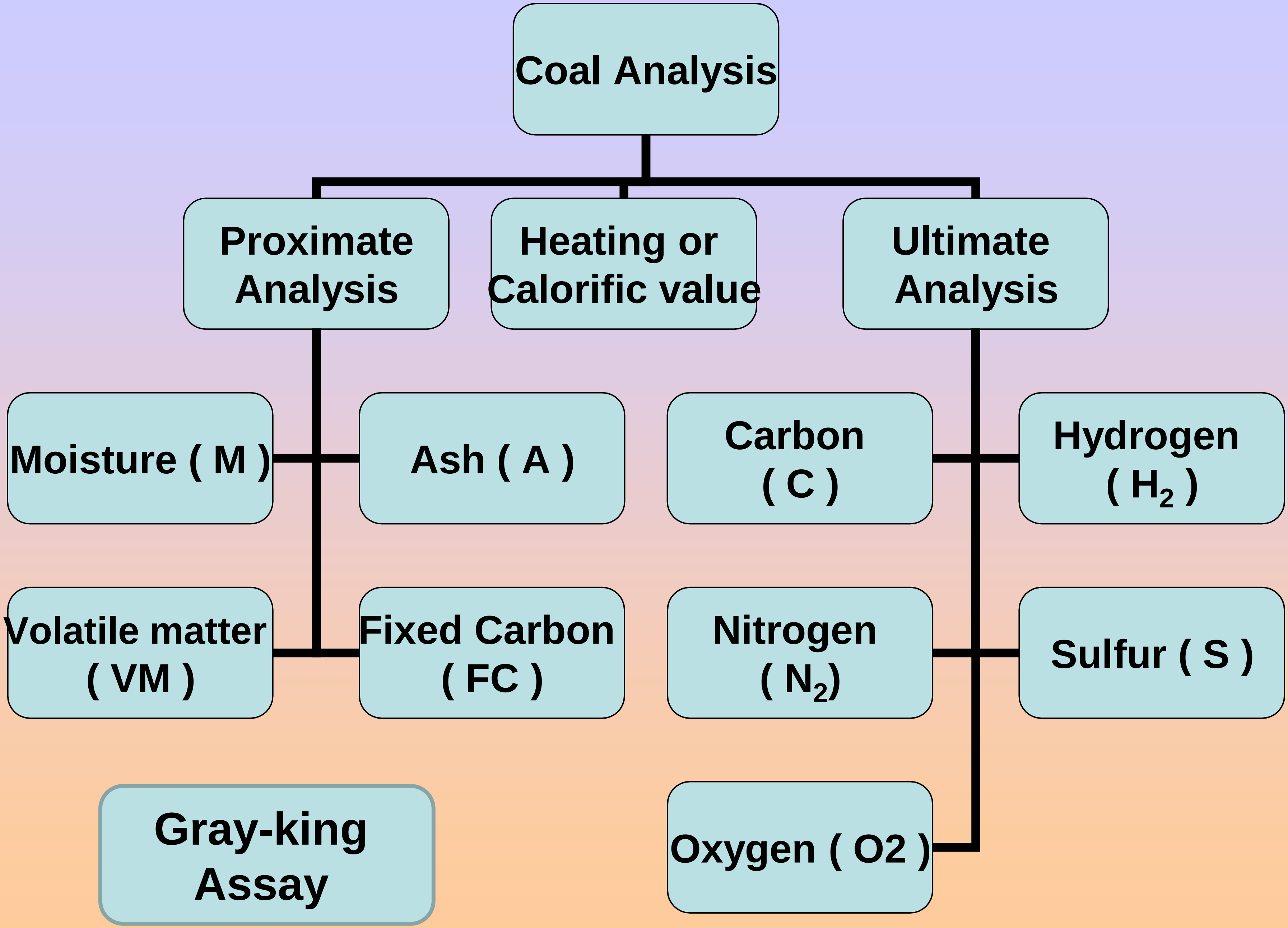
The non-banded coals are the cannel or bog-head types. The picture clearly shows a lump of cannel coal. It is uniform and compact in structure.



Summary

Rock of Coal





Coal Analysis
Proximate Analysis
Heating or Calorific value
Ultimate Analysis
Moisture (M)
Ash (A)
Carbon (C)
Hydrogen (H_2)
Volatile matter (VM)
Fixed Carbon (FC)
Nitrogen (N_2)
Sulfur (S)
Gray-king Assay
Oxygen (O2)

Higher (HHV) and lower (LHV) heating values of some common fuels at 25 °C

Fuel	HHV MJ/kg	HHV BTU/lb	HHV kJ/mol	LHV MJ/kg
Hydrogen	141.80	61,000	286	119.96
Methane	55.50	23,900	889	50.00
Ethane	51.90	22,400	1,560	47.62
Propane	50.35	21,700	2,220	46.35
Butane	49.50	20,900	2,877	45.75
Pentane	48.60	21,876	3,507	45.35
Paraffin wax	46.00	19,900		41.50
Kerosene	46.20	19,862		43.00
Diesel	44.80	19,300		43.4
Coal (anthracite)	32.50	14,000		
Coal (lignite - USA)	15.00	6,500		
Wood (MAF)	21.70	8,700		
Wood fuel	21.20	9,142		17.0
Peat (dry)	15.00	6,500		
Peat (damp)	6.00	2,500		

Coal Analysis and Properties

Proximate Analysis

Proximate analysis indicates the percentage by weight of the Fixed Carbon, Volatiles, Ash, and Moisture Content in coal.

Ultimate Analysis

The ultimate analysis indicates the various elemental chemical constituents such as Carbon, Hydrogen, Oxygen, Sulphur, etc. It is useful in determining the quantity of air required for combustion and the volume and composition of the combustion gases. This information is required for the calculation of flame temperature and the flue duct design etc.

Measurement of Moisture

- Determination of moisture is carried out by placing a sample (1-2g) of powdered raw coal of size 200-micron size in an uncovered crucible and it is placed in the oven kept at 105±2 °C along with the lid. Then the sample is cooled to room temperature and weighed again. The loss in weight represents moisture.
- M, wt% = (loss of weight/total weight) *100

Measurement of Volatile Matter

- Fresh sample (1-2g) of crushed coal is weighed, placed in a covered crucible, and heated in a furnace at 900 $\pm$ 15 ^{o}C for 7 min.
- Then, the sample is cooled and weighed. Loss of weight represents moisture and volatile matter.
- VM,% = (loss of weight/total weight)*100 – M

What is the remaining of the tested sample?

Measurement of Carbon and Ash

- The cover from the crucible used in the last test is removed and the crucible is heated over the Bunsen burner (800 ± 25 °C) until all the carbon is burned.
- The residue is weighed, which is the incombustible ash.
- The difference in weight from the previous weighing is the fixed carbon.
- In actual practice Fixed Carbon or FC derived by subtracting from 100 the value of moisture, volatile matter and ash.

Basis

- As received
- As mined
- As dry ash free
- As burned
- As moisture free

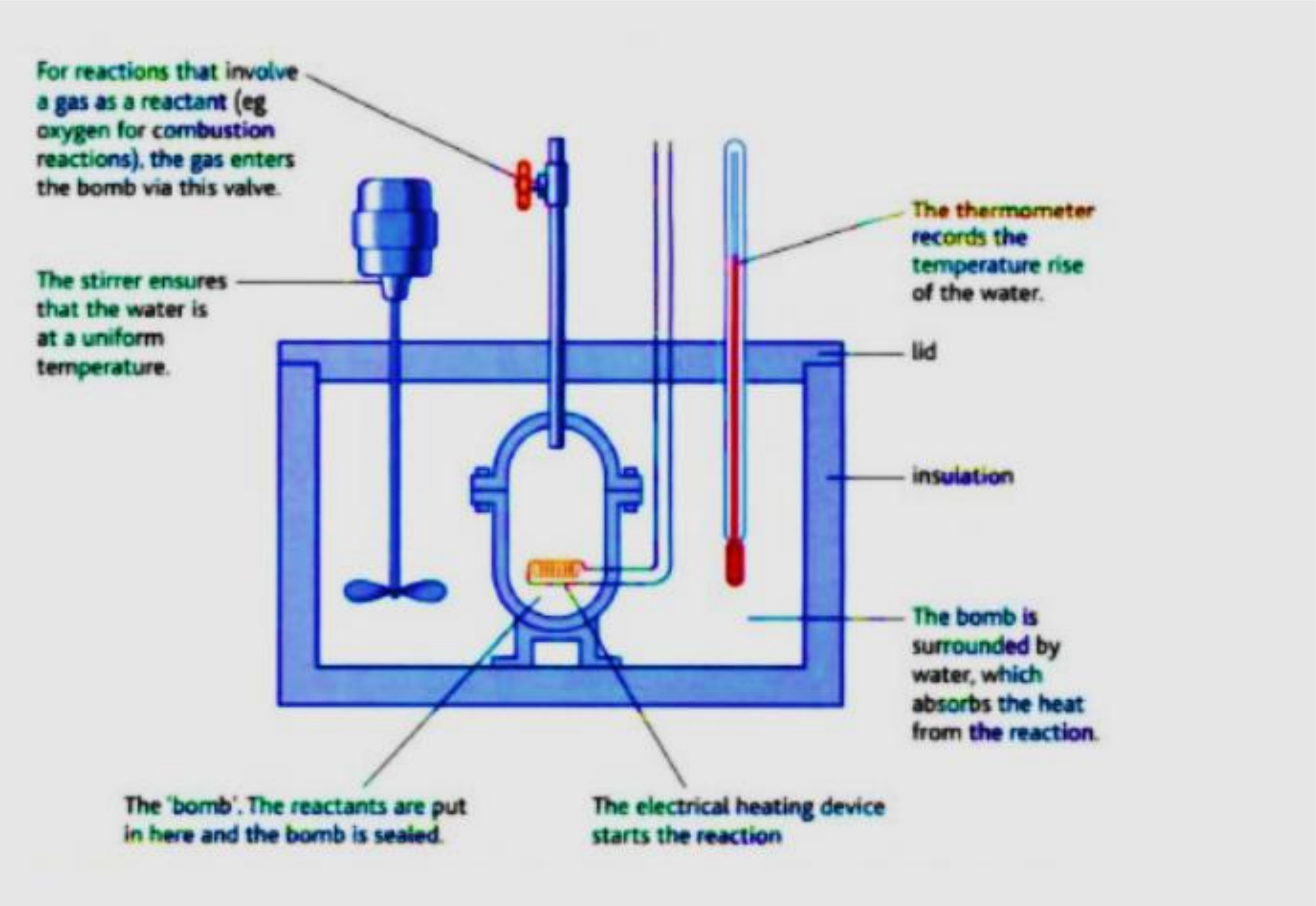
As-received mass fraction= [dry, ash free mass fraction][1-M-A]

As-received HHV= [dry, ash free HHV][1-M-A]

Heating value - Bomb Calorimeter

- **Bomb calorimeter** An apparatus primarily used for measuring heats of combustion. The reaction takes place in a closed space known as the calorimeter proper, in controlled thermal contact with its surroundings, the jacket, at constant temperature.

HHV determination using bomb calorimeter



Gross Calorific Value

- Calorific values as determined with the bomb calorimeter represent the heat produced by a unit weight of coal when completely oxidized, when the products of the combustion are cooled to room temperature.
- The calorific value as determined with the bomb calorimeter is called the gross calorific value (GCV) or the higher heating value (HHV).

Net Calorific value

- A lower value can be derived, which is the gross calorific value minus the latent heat of condensation at 15.5°C of all of the water involved. This is named the net calorific value (NCV) or Lowe heating value (LHV).

Dulong's Formula

$$HHV = 33{,}950\,C + 144{,}200\left(H_2 - \frac{O_2}{8}\right) + 9400\,S \qquad kJ/kg$$

All the values of C, H_2, O_2, and S are mass fractions.

The difference between the higher and lower heating values is approximated by the following equation which is applicable to any fuel on a mass basis:

$$HHV - LHV = 2400(M + 9\,H_2) \qquad kJ/kg$$

Where M, and H_2 are the as-burned moisture and hydrogen mass fraction of the fuel.

Example

Determine the as-received proximate and ultimate analyses, the estimated LHV from the listed higher values, the HHV as determined by Dulong's formula, and the ASTM classification (class and group) of Stark County, N.D., coal, with A = 8 percent, and M = 39 percent.

Typical coal analysis

States and counties	Moisture and ash-free values								As received	
	VM	FC	C	H_2	O_2	N_2	S	kJ/kg†	*M*	*A*
ALABAMA										
Jefferson, Tuscaloosa	27.7	72.3	88.1	5.2	4.2	1.7	0.8	36,340	2-5	3-10
Jefferson, Tuscaloosa	32.9	67.1	86.7	5.3	5.0	1.8	1.2	35,875	2-5	2-10
Jefferson, St. Clair	35.4	64.6	85.2	5.4	5.8	1.8	1.8	35,470	2-5	4-12
Walker, Bibb, Shelby	38.0	62.0	84.3	5.4	7.6	1.7	1.0	35,120	1-5	2-14
ARKANSAS										
Sebastian, Logan	19.0	81.0	89.3	4.4	2.0	1.8	2.5	36,040	2-4	6-12
Franklin, Johnson	16.1	83.9	89.4	4.2	2.1	1.8	2.5	35,935	2-4	6-12
COLORADO										
Las Animas	36.5	63.5	84.9	5.5	7.4	1.5	0.7	35,525	1-7	6-20
Huerfano, Gunnison, Garfield	40.7	59.3	80.6	5.5	11.6	1.6	0.7	35,575	3-10	3-12
Weld, Boulder	42.5	57.5	75.0	5.1	17.9	1.5	0.5	30,085	17-30	3-6
Routt, Fremont	43.0	57.0	76.6	5.2	16.0	1.3	0.9	31,515	10-18	3-10
El Paso	46.4	53.6	71.5	5.0	21.8	1.1	0.6	28,095	20-35	5-14
ILLINOIS										
Franklin, Williamson	39.1	60.9	81.3	5.3	9.8	1.7	1.9	33,725	8-12	8-12
Saline, Perry	39.6	60.4	80.6	5.4	10.3	1.7	2.0	33,770	6-11	7-12
Macoupin, Sangamon	46.3	53.7	77.5	5.4	10.2	1.4	5.5	32,970	12-16	8-16
Madison, St. Clair	46.7	53.3	77.0	5.4	10.6	1.3	5.7	32,865	9-16	11-20
INDIANA										
Sullivan, Greene	45.2	54.8	80.9	5.6	9.7	1.8	2.0	33,725	10-14	6-12
Vigo, Vermillion, Knox	48.0	52.0	79.6	5.6	8.8	1.5	4.5	33,750	6-12	7-12

Coal Analysis continue

States and counties	Moisture and ash-free values								As received	
	VM	FC	C	H_2	O_2	N_2	S	kJ/kg†	M	A
IOWA										
Appanoose, Polk, Lucas	47.9	52.1	77.0	5.5	9.7	1.5	6.3	33,155	13–19	7–15
KANSAS										
Cherokee, Crawford	39.5	60.5	83.0	5.4	6.1	1.5	4.0	34,955	2–8	9–12
Leavenworth	47.2	52.8	79.6	5.4	7.8	1.5	5.7	33,560	10–12	12–16
KENTUCKY										
Letcher, Pike	37.8	62.2	85.2	5.4	7.0	1.6	0.8	35,320	1–4	2–7
Harlan, Perry, Bell, Knox	40.2	59.8	83.5	5.6	7.9	1.9	1.1	34,785	2–6	2–8
Muhlenburg, Hopkins	44.7	55.3	80.3	5.4	8.6	1.7	4.0	33,595	4–10	5–12
Webster, Union, Butler	45.0	55.0	81.0	5.5	7.7	1.7	4.1	33,945	4–10	5–12
MARYLAND										
Alegheny, Garrett	18.2	81.8	89.3	4.7	2.7	1.7	1.6	33,400	2–4	6–14
MISSOURI										
Barton	38.0	62.0	83.0	5.5	5.1	1.4	5.0	35,165	5–7	8–13
Bates	42.3	57.7	81.0	5.5	7.5	1.5	4.5	34,190	7–12	11–15
Ray, Lafayette, Linn, Adair	46.3	53.7	78.6	5.6	9.3	1.3	5.2	33,315	11–16	7–15
Henry, Macon, Clay, Randolph	45.4	54.6	79.2	5.5	8.4	1.3	5.6	33,420	9–16	8–16
MONTANA										
Rosebud, Custer	44.4	55.6	71.7	4.4	22.0	1.1	0.8	27,980	27–30	3–15
Musselshell, Gallatin	42.8	57.2	78.5	5.4	13.6	1.4	1.1	32,365	4–14	6–30
Carbon, Fergus	40.6	59.4	76.0	5.1	14.2	1.4	3.3	31,025	8–24	8–18
Cascade	35.0	65.0	77.8	4.8	12.6	1.0	3.8	31,445	3–12	14–25
Valley	47.4	52.6	69.0	4.6	24.1	1.2	1.1	26,490	32–45	4–9
NEW MEXICO										
Colfax, Lincoln	43.1	56.9	82.6	5.7	9.3	1.5	0.9	34,560	2–5	9–17
McKinley	47.2	52.8	79.2	5.5	13.0	1.4	0.9	32,420	10–16	3–10
NORTH DAKOTA										
McLean, Morton, Stark	54.0	46.0	72.4	4.7	18.6	1.5	2.8	28,920	35–43	5–12
Williams, Ward	47.6	52.4	72.1	4.9	21.0	1.1	0.9	27,910	35–43	5–12
OHIO										
Belmont, Guernsey	46.0	54.0	80.3	5.6	8.0	1.5	4.6	34,120	3–6	9–16
Tuscarawas, Noble, Jackson	46.2	53.8	79.2	5.6	9.2	1.5	4.5	33,680	3–9	7–15
Athens, Perry, Meigs, Hocking	41.8	58.2	79.7	5.5	10.8	1.4	2.6	33,455	6–10	4–12
Jefferson, Guernsey	41.5	58.5	82.2	5.5	7.7	1.7	2.9	34,560	3–7	5–12
OKLAHOMA										
Pittsburgh, Latimer	40.0	60.0	84.0	5.5	7.4	2.0	1.1	34,990	2–10	4–8
Okmulgee, Tulsa	41.9	58.1	82.4	5.5	7.0	2.0	3.1	34,655	2–8	4–10
Coal	46.6	53.4	77.8	5.2	10.4	1.8	4.8	32,420	5–7	9–12
Haskell	23.6	76.4	89.1	4.8	3.2	1.9	1.0	36,165	2–4	3–8
LeFlore	18.2	81.8	90.4	4.6	2.2	1.9	0.9	36,190	1–3	6–12
PENNSYLVANIA										
Fayette	31.4	68.6	86.0	5.2	6.3	1.5	1.0	36,095	3–5	7–9
Fayette, Washington, Elk	37.8	62.2	84.8	5.5	5.7	1.6	2.4	35,525	2–4	6–13
Allegheny, Butler	39.6	60.4	83.7	5.5	7.1	1.7	2.0	35,050	2–5	4–13
Cambria, Center	24.6	75.4	88.2	5.1	3.4	1.4	1.9	36,320	1–5	5–12

Coal Analysis continue

States and counties	VM	FC	C	H_2	O_2	N_2	S	kJ/kg†	M	A
	Moisture and ash-free values								As received	
Somerset, Tioga	23.5	76.5	88.6	4.8	3.1	1.6	1.9	36,145	1-5	5-12
Westmoreland, Indiana	26.5	73.5	87.6	5.2	3.3	1.4	2.5	36,355	1-5	5-12
Westmoreland, Jefferson	35.4	64.6	85.0	5.4	5.8	1.7	2.1	35,550	2-4	7-15
Cambria, Bedford	19.8	80.2	89.4	4.8	2.4	1.5	1.9	36,435	1-6	5-12
Huntingdon, Somerset	17.1	82.9	90.3	4.6	2.3	1.4	1.4	36,715	1-6	5-12
Sullivan	10.6	89.4	91.6	3.8	2.5	1.2	0.9	35,925	3-4	10-15
Lackawanna, Luzerne	7.3	92.7	93.5	2.6	2.3	0.9	0.7	35,120	2-6	6-16
Schuylkill	2.0	98.0	93.9	2.1	2.3	0.8	0.9	34,585	2-3	8-13
TENNESSEE										
Campbell, Anderson	40.3	59.7	83.1	5.5	7.4	2.1	1.9	34,610	2-6	2-8
Claiborne, Overton, Scott	40.5	59.5	83.5	5.6	6.5	2.0	2.4	34,770	2-6	2-11
Morgan, Fentress, White	41.6	58.4	83.0	5.7	6.1	1.7	3.5	35,095	2-5	4-12
Marion, Hamilton	31.1	68.9	87.3	5.4	4.2	1.6	1.5	35,875	3-5	3-11
Rhea, Roane, Grundy	34.5	65.5	85.7	5.3	6.1	1.6	1.3	35,260	2-4	9-15
TEXAS										
Houston, Milam, Wood	53.3	46.7	72.8	5.3	19.3	1.4	1.2	29,550	29-37	6-13
UTAH										
Carbon, Emery, Grand	45.8	54.2	80.3	5.7	11.7	1.6	0.7	33,420	3-10	4-20
Summit, Uintah, Iron	45.3	54.7	76.2	5.4	13.7	1.2	3.5	31,490	5-17	3-13
VIRGINIA										
Wise, Russell	36.9	63.1	86.3	5.5	5.7	1.6	0.9	35,840	2-5	4-9
Tazewill	17.8	82.2	90.4	4.8	2.9	1.2	0.7	36,960	2-6	2-6
Lee, Scott	37.8	62.2	83.6	5.4	8.3	1.6	1.1	35,085	3-6	3-9
Dickenson, Buchanan, Henico	31.2	68.8	87.3	5.2	4.3	1.8	1.4	35,855	2-4	3-18
Montgomery	13.6	86.4	90.7	4.2	3.3	1.0	0.8	35,715	1-5	16-25

Coal Analysis continue

WASHINGTON										
Kittites, King	43.3	56.7	80.5	6.0	10.8	1.9	0.8	34,005	3-9	10-20
King, Pierce	39.4	60.6	82.5	5.9	8.6	2.0	1.0	34,655	2-6	8-20
Lewis, Thurston	49.3	50.7	71.7	5.8	19.5	1.3	1.7	29,305	16-30	6-23
King	44.8	55.2	76.6	5.7	15.1	1.8	0.8	31,865	7-18	5-16
Pierce	25.4	74.6	87.5	5.4	4.0	2.5	0.6	36,120	2-5	9-15
WEST VIRGINIA										
Logan, Fayette	36.2	63.8	86.3	5.5	5.4	1.7	1.1	35,680	1-3	4-8
McDowell, Fayette, Wyoming	17.7	82.3	90.4	4.8	2.7	1.3	0.8	36,540	2-4	3-6
Raleigh, Mercer, Fayette	18.5	81.5	90.1	4.8	3.0	1.4	0.7	36,560	2-4	3-6
Monongalia, Greenbriar	30.2	69.8	87.2	5.2	5.1	1.6	0.9	35,910	2-4	4-12
Preston, Fayette, Randolph	31.0	69.0	87.5	5.3	4.2	1.5	1.5	36,050	2-4	4-12
Marion, Kanawha, Harrison	40.9	59.1	83.9	5.6	7.4	1.6	1.5	35,075	2-4	4-10
WYOMING										
Sweetwater, Hot Springs	41.8	58.2	77.3	5.3	14.8	1.5	1.1	31,920	8-16	3-8
Sweetwater, Carbon	39.5	60.5	76.2	5.1	16.3	1.6	0.8	30,840	15-25	4-7
Lincoln, Uinta, Sweetwater	43.4	56.6	79.8	5.4	12.2	1.5	1.1	33,075	6-18	4-12
Sheridan, Campbell, Carbon	45.3	54.7	74.1	5.1	18.7	1.3	0.8	29,795	18-30	5-15
Albany, Converse, Freemont	45.1	54.9	73.6	5.2	18.8	1.3	1.1	29,610	17-27	4-15

Solution

Given: Stark County coal with $A = 0.08$ and $M = 0.39$. From App. E, the dry, ash-free proximate coal analysis gives:

$$VM = 54.0\% \qquad FC = 46.0\% \qquad S = 2.8\% \qquad HHV = 28{,}922 \text{ kJ/kg}$$

The dry, ash-free ultimate coal analysis gives:

$$C = 72.4\%, \qquad H_2 = 4.7\%, \qquad O_2 = 18.6\%, \qquad N_2 = 1.5\%, \qquad S = 2.8\%$$

To convert to an as-received coal basis, the correction factor or multiplier is $[1 - M - A] = [1.00 - 0.39 - 0.08] = 0.53$. The as-received proximate analysis becomes:

$$VM = 0.53 \times 54.0 = 28.6\% \qquad S = 0.53 \times 2.8 = 1.5\%$$

$$FC = 0.53 \times 46.0 = 24.4\%$$

$$M = 39.0\% \qquad HHV = 0.53 \times 28{,}922 = 15{,}329 \text{ kJ/kg}$$

$$A = 8.0\% \qquad = 0.43 \times 15{,}329 = 6591 \text{ Btu/lbm}$$

$$100.0\%$$

The as-received ultimate analysis becomes:

$$C = 0.53 \times 72.4 = 38.4\%$$

$$H_2 = 0.53 \times 4.7 = 2.5\%$$

$$O_2 = 0.53 \times 18.6 = 9.9\%$$

$$N_2 = 0.53 \times 1.5 = 0.8\%$$

$$S = 0.53 \times 2.8 = 1.5\%$$

$$M = 39.0\%$$

$$A = 8.0\%$$

$$\overline{100.1\%}$$

100.1%. (0.1% roundoff error)

$$HHV = 15{,}329 \text{ kJ/kg}$$

$$= 6591 \text{ Btu/lbm}$$

Lower heating value (*must* use as-received values):

$$LHV = HHV - 2400[M + 9H_2] = 15{,}329 - 2400[0.39 + 9(0.025)]$$

$$= 13{,}853 \text{ kJ/kg} = 5957 \text{ Btu/lbm}$$

Estimated HHV, using Dulong's formula:

$$HHV = 33{,}950C + 144{,}200\left[H_2 - \frac{O_2}{8}\right] + 9400S$$

$$= 33{,}950(0.384) + 144{,}200\left[0.025 - \frac{0.099}{8}\right] + 9400(0.015)$$

$$= 14{,}998 \text{ kJ/kg} = 6449 \text{ Btu/lbm}$$

Classification of the coal according to the ASTM method (*must* use the as-mined or bed-moisture values):

$$\text{Dry, Mm-free FC} = \frac{FC - 0.15S}{1 - M - 1.08A - 0.55S}$$

$$= \frac{0.244 - 0.15(0.015)}{1 - 0.39 - 1.08(0.08) - 0.55(0.015)}$$

$$= 0.469 = 46.9\%$$

Since this value is less than 69 percent, the coal cannot be classified according to the dry, mineral-matter-free value of fixed carbon. Thus:

Since this value is less than 69 percent, the coal cannot be classified according to the dry, mineral-matter-free value of fixed carbon. Thus:

$$\text{Moist Mm-free Btu} = \frac{\text{Btu} - 5000S}{1 - 1.08A - 0.55S}$$

$$= \frac{6591 - 5000(0.015)}{1 - 1.08(0.08) - 0.55(0.015)}$$

$$= 7197 \text{ Btu/lbm}$$

Since the moist, mineral-matter-free value of the higher heating value is between 6300 and 8300 Btu/lbm, this coal is ranked as a class IV, group 1 coal → lignite A.