Coal and Slag Characterization for Archaeologists
or "Coal and Slag Are Everywhere"

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In this workshop we will explore the analytical tools used in industry to characterizes and identify coal types. The presenter believes that in many cases this information can add clues for the archeological interpretation of a site. A main premise is that the type of coal deposited at a site can change over time as the coal supply for a region shifts. The types of coals shift over time due to many factors including reserve depletion, mining cost and perhaps most importantly, in the last 170+ years, as rail and water transportation developed. The less developed science of slag produced from combustion will also be covered.

Outline

   I.   What coal is
   II.   Short history of coal production
   III.   Changes in coal production over time
   IV.   Analytical Methods for coal characterization
   V.   Interpretation
   VI.   Slag characterization
   VII.   Future and data collection/retrieval

I.   What coal is

A. FOSSILIZED SWAMP
B. Had greenhouse gases, tremendous plant growth
C. Coalification process

      i. With time, pressure, temperature, usually caused by burial under rock and mountains

      ii. PEAT - Sable, hundreds to thousands of years old, think peat bogs and preservation of organic material

      iii. LIGNITE - Brown coal, high moisture

      iv. SUB-BITUMINOUS – Black, dull, friable, oxidizes easily

      v. BITUMINOUS – Black, shiny, hard to friable, banded unless cannel coal

      vi. ANTHRACITE – Black glass, conchoidal fractures

D. Geological impacts post formation, faulting, volcanic, dykes, water and water born minerals, fires, erosion…

II. Short history of coal production

A. Prehistory uses, found on surface, side of mountains, spontaneous combustion, natural combustion, scoria or red dog

B. Early civilizations, Chinese, Greeks 4th century BC used lignites

C. Primary uses in heating and smelting ores

D. Trading documented in 13th century England

E. Paris, France 1550's coal use was objectionable and smiths were banned from using or paid fine for use

F. By the 17th century many European cities were regulating use

G. The use of the steam engine and steam power greatly increased coal production, 1690+, English coal mines and water pumps

H. Brief timeline for US coal production

Brief US Coal History Timeline

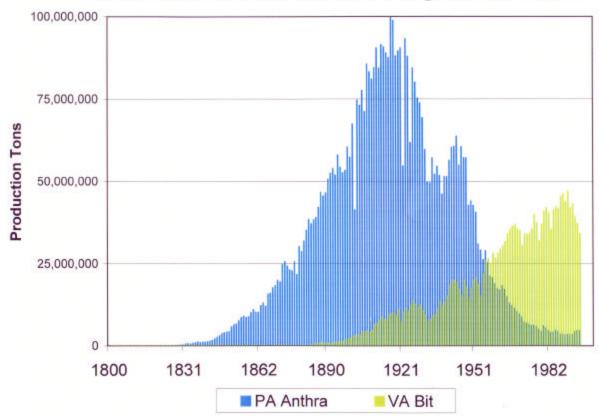|	
1643	Louis Jolliet and Father Jacques Marquette discover charbon de tierra (coal) on Illinois River
1748	First recorded coal production in Mankin, VA area
1762	Anthracite discovered in PA
1776	Coal used in shot and shell manufacturing during Revolutionary War
1787-9	First extensive mining at Richmond, VA for shipment to New York, Philadelphia and Boston
1790+	Anthracite mining begins in PA
1816	Baltimore, MD first city to light streets with coal gas
1817	Coal mining being conducted near St. Louis, MO
1818	Explosives first used in PA anthracite mines
1819	Mining begins in Meigs County, OH for shipment to Louisville, KY
1827	Mule power rail line installed in Mauch Chunk, PA for delivering coal to Lehigh River then to Philadelphia
1829	Delaware and Hudson Canal completed to bring Wyoming Valley anthracite to New York City
1830	Tom Thumb, first steam locomotive
1848	First coal miner's union formed in Schuylkill County, PA

1860	Mining in Camden, AR
1866	Strip mining started near Danville, IL
1869	Golden Spike, transcontinental railroad completed
1872	Strip mining in Kansas
1875	Coal replaces charcoal as major fuel for blast furnaces
1879	Coal mining in Utah

III. Changes in coal production over time

A. The historical record of coal production is well documented back to about 1880 and many records exist prior to 1880

B. Canal, barge, and river transportation of coal were use early on

C. Significant changes in production brought by railroad service moving into mountains

D. Mines open by railroads for fuel

E. Economics of coal force expensive mines to close if alternatives are available

F. Coal reserves are finite and production can be limited as reserves deplete

Figures 1 and 2 are derived from coal production records. There are significant differences in levels of production. Figure 1 compares production levels of two types of coals, Pennsylvania anthracite and Virginian bituminous. Figure 2 shows time of maximum production for individual counties.

Coal Production PA Anthracite, Virginia Bituminous

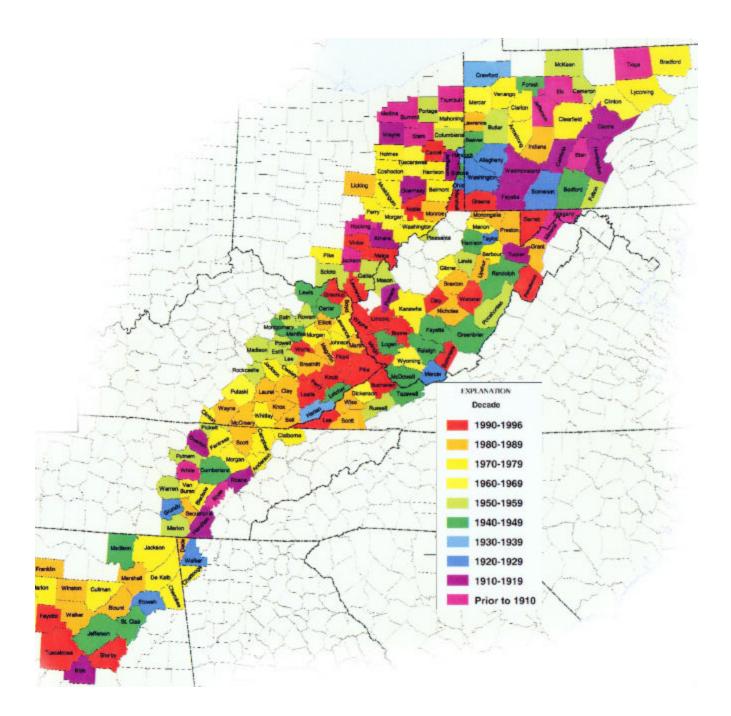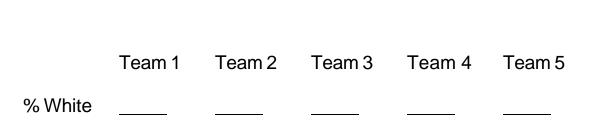Figure 1. Annual production levels for two different coal fields. USGS

Figure 2. Maximum coal production by decades and county
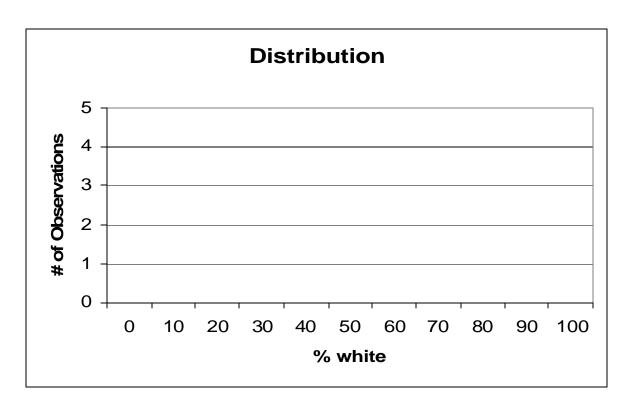By Robert C. Milici, USGS

IV. Coal Characterization

Coal is a combustible material; it will slowly oxidize in air at room temperature. The oxidizing of coal will alter its test results. It is best to consider coal oxidation in your sample. High ranks coals are more stable than low rank coals. Coals preserved under water or with limited exposure to air are preferred.

  A. Coal Sampling - Experiment

	Team 1	Team 2	Team 3	Team 4	Team 5
% White	____	____	____	____	____

Distribution

The actual Value of the percent white marbles is _____. How well did we do with limited sampling? How can we improve our results?

B. Sampling procedures

1. Should include description and classification of hand samples
2. Should include storage history and preservation methods
3. Should include retention of portions for further analyses
4. Retention and storage procedures to be developed and documented

C. **Should we use Statistical or Human discretion in sample preparation**

1. If samples are unique or recovered from specific location consider individual analyses

2. Are they same coal, if yes consider statistical

3. Use hand sample observations, (HSO) to sort types

4. Consider core hole in sample verses crushing sample

D. Sample Quantities

1. Standard industry samplings procedures require hundreds of pounds to be collected representing thousands of tons of material.

2. A one-inch square piece of coal contains approximately 25 grams of material.

3. Proximate and Ultimate analyses are destructive but require as little as 6 grams of material to conduct.

4. Ash chemistry material needs are inversely proportional to the amount of ash in the sample but will require a minimum of 5-10 grams of coal.

5. Coal petrology calls for 50 grams, maybe we can get away with 25 grams. Sample is preserved in epoxy

I'm a coal expert now!

Please describe the hand samples now and make educated guess as to what they are:

	Fracture	Luster	Banding	Friability	Coal Type
1.					
2.					
3.					
4.					
5.					
6.					
7.					
8.					
9.					
10.					
11.					
12.					
1a.					
13.					
14.					

D. Analytical Procedures

    1. Non-destructive
        a. Hand Sample Observations (HSO), classification of hand samples

Terms:

Fracture - conchoidal, angular, cubic, planer,

Luster – dull, shiny, glossy, color

Banding – brightness range, thickness

Friability – crumbles, chips, dusty, hard

        b. Petrology can be performed on polished sections of coal imbedded in epoxy, this will alter sample but will also preserve it.

    2. Destructive

        a. Proximate and Ultimate
        b. Ash chemistry

    3. New Methods

        a. Methods such as determining the salt water penetration or absorption rates may require new sampling, preparation, and preservation techniques to be developed.

COAL PETROGRAPHY

This section adapted from:
Kural, O. (1994): Coal, Istanbul Technical University, Istanbul. 494 pp.

Introduction

Coal is not a homogeneous substance but is composed of discrete entities. Coal petrography is the study of coal entities under microscope and its indications to various subjects, such as mode of origin and commercial processes of coal. The smallest constituents of coals are called macerals. Macerals are analogous to the minerals of inorganic rocks.

Coal

Coal is a compact, stratified mass of former plant debris consisting largely of lignocellulosic components often interspersed with inorganic clay, silt or sand. The plant parts, with the effects of heat, change their properties, becoming denser and danker. Since the constituents of coal become darker, it is essential to observe polished sections and to use reflected light microscopy in their study.

Petrography of Coal

Microscopic Constituents of Coals

Macerals and minerals are the microscopic constituents of coal. The term maceral describes the shape and the nature of the microscopically recognizable (organic) constituents of coal. A maceral is not crystalline but varies widely in its chemical composition and physical properties. The macerals are distinguished from one another microscopically on the basis of their differences in such properties as reflectance, color, morphology, size and hardness. To exclude any ambiguity in the definitions of different macerals, the ICCP has established standard roles for petrographic microscopy, which provide that the description of macerals and microlithotypes shall correspond to their appearance in reflected light using oil immersion objectives with 25x to 50x magnifications. Macerals take the suffix -inite, and microlithotypes take the suffix -ite

Macerals

Within the ICCP Handbook (1971), the macerals are defined as the microscopically recognizable individual constituents of coal. ISO standard 7404/1 explains macerals and the methods for their petrographical analysis. In the lignite and bituminous coalification stages, the macerals are classified in three groups: Vitrinite (Huminite in lignites), Liptinite (former Exinite) and Inertinite.

Each group includes a series of macerals that can be regarded as belonging together due to similar optical and chemical properties.
In coal of the same rank, vitrinite (or huminite) usually contains relatively more oxygen, the liptinite more hydrogen, and the inertinite more carbon. The volatile matter yield is relatively highest in the liptinite. With increasing coalification rank, the macerals change in their chemical, physical and technological properties. There is a distinct relationship between the reflectance of a maceral and its carbon or volatile matter yield. This means that the rank of a coal can be determined by its reflectance on a polished surface.

With increasing rank, the individual macerals become less different in reflectance, making it more difficult to differentiate between them under the microscope. When examining a polished surface of anthracite or a higher rank of organic material, special techniques are required to recognize the individual macerals.
Complementary methods of examination such as fluorescence microscopy or etching polished surfaces can help to reveal the normally hidden internal structures of the macerals and their chemical and physical properties. Shapes and structures, which are not recognizable by the normal microscopic examination of polished surfaces using oil immersion, are made visible in this way. The fluorescence properties of liptinite and vitrinite are rank dependent.

The three maceral groups in the lower ranks of coal exhibit different light absorption and, therefore, different light reflectance. To make the measurements more meaningful for the rank of coal, reflectance is always calibrated with standards like sapphires, artificial garnets, diamond.
Vitrinite (Huminite in Lignites) - This maceral group is the most abundant and important maceral group in coal. The low rank coal, being the less altered, exhibits a greater variety of macerals than higher rank coal. The

huminites are regarded as the precursors of the vitrinites. The huminite macerals are distinguished from each other primarily by their stage of preservation or decay and their degree of gelification, a process by which the humic (plant) matter passes through a soft plastic gel stage and takes on a swollen appearance. The degree of gelification has been shown to correlate with the performance of such industrial processes as crushing and briquetting, tar and char yields.

The vitrinite group of macerals is generally the most abundant maceral group occurring in the higher rank coal. The carboniferous coal of the Northern Hemisphere is usually rich in vitrinite. The reflectance of vitrinite is often used as a measure of rank due to its sensitivity to metamorphism and its gradual physical and chemical change when subjected to metamorphism. Compared with the liptinites and inertinites in coal of the same rank, the vitrinites (or huminites) have intermediate reflectance properties, hydrogen and carbon contents, and volatile matter yields.

V. Interpretation

So you are holding a coal analyses form with numbers on it, now what? You sent in a non-representative, improperly stored, contaminated, coal sample (or precious artifact maybe). The sample no longer exists because it has been destructively tested or at best entombed in epoxy. The world is seen through many eyes and we are just new at this.

    A. Rank determination - Proximate and Heating Value tests

        1. Local coal
        2. Potential sources
        3. Transportation routes
        4. Potential use
        5. Smokeless
        6. Coke

    B. Petrographic Results

        1. Rank
        2. Unique or distinguishing traits
        3. Match source

C. Chemical Testing

    1. Sulfur - match source
    2. Ash Chemistry - match slag
    3. Trace - maybe similar to ore and metal work

D. Coal Type Stratigraphy

    1. Did coal source change with time
    2. Marine use of coal
    3. Disturbances, man, weather…

VI. Slag Samples

A. Slags are produced by many processes

    1. Coal combustion
    2. Ore processing
    3. Glass manufacturing
    4. Volcanic lavas can all be classified as slags

B. Morphologies, chemistry and petrology allow for classification

    1. Metallic
    2. Amorphous
    3. Vesicular
    4. Sintered
    5. Many classification systems

C. Uses

    1. Max Temperature
    2. Slag stratigraphy
    3. Fly ash deposition
    4. Saline penetration
    5. Magnetic alignment
    6. Nice microphotographs