CLASSIFICATION OF COAL.

By M. S. Krishnan, *M.A., Ph.D., F.N.I., Geological Survey of India.*

Coal comprises a series of substances the classification of which has been attempted for many decades past. The need for some type of fairly widely acceptable classification has been felt for specifications in trade, for purposes of taxation and customs, and in legal disputes. This paper gives a short review of the numerous attempts which have been made in this direction.

Any acceptable scheme of classification should be scientific and systematic and should take into account the fundamental characters. It should be easily comprehensible and applicable. The criteria should be capable of quantitative measurements leaving nothing to mere opinions and personal factors. Even if applied for purely commercial purposes, it should be sufficiently systematised.

The earliest classification recognised the visual characters, agreeing broadly with the properties of combustion, *viz.*:—

Lignite or brown coal: Brown to black in colour, woody structure, high moisture.

Bituminous coal: Black, often banded; ignites fairly easily and burns with flame and smoke. Those which had a strong tendency to agglutinate on heating were called caking coal.

Anthracite: Black and lustrous and difficult to ignite; burns without flame.

Regnault was the first to use a chemical classification. He published a paper in 1837 in which he defined 5 groups on the basis of ultimate analysis (percentage of O+N).

	Per cent Mean (O+N)
Anthracite	2·62
Lean or short flame bituminous	4·47
Bituminous (smithy) coal	5·74
Long flame bituminous	8·89
Dry long flame	16·39

Hilt and others classified coal on the basis of volatile matter and coking property.

The late Prof. W. A. Bone modified the scheme of Regnault and published the revision in his well-known book on coal. This is reproduced in Table 1.

In a report printed in 1844, Walter R. Johnson listed the coals of the United States of America in the order of the ratio of the fixed carbon to the volatile matter, which was found to have a definite relationship to the heat evolved in burning as measured by the amount of water evaporated. The 'fuel ratio' had its origin then.

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TABLE 1.—*Regnault-Grüner—Bone Classificaiton.*

(Compositions given on ash-free basis.)

Genus.	Class.	Chief uses.	Percentage Composition. C	Percentage Composition. H	Percentage Composition. O+N+S	% Volatiles at 900°C.	% Fixed Carbon.	Character of Carbonaceous residue.
A Lignite	Non-caking	....	60 to 70	About 5·0	20 to 35	Above 45	Below 55	Non-coherent.
B Bituminous	(1) Non-caking, long flame.	Reverberatory furnaces.	75 to 80	4·5 to 5·5	15 to 20	40 to 45	55 to 60	Non-coherent.
	(2) Caking, long flame	Gas-making	80 to 85	About 5·6	10 to 15	32 to 40	60 to 68	Very porous coke.
	(3) Hard coking	Coke manufacture	84 to 89	5·0 to 5·6	5·5 to 11·0	26 to 32	68 to 74	Dense coke.
	(4) Hard coking short flame.	Coke manufacture and steam-raising.	88 to 90	4·5 to 5·5	5·5 to 6·5	18 to 26	74 to 82	Very dense coke.
BC Semi-bituminous	Non-caking short flame.	Steam raising	90 to 92	4·0 to 4·5	4·0 to 5·5	15 to 20	80 to 85	Weakly caking or non-coherent.
C Anthracitic and Anthracite	(1) Anthracitic non-caking.	Steam raising	92 to 94	3·0 to 4·5	3·0 to 4·5	8 to 15	85 to 92	Pulverulent.
	(2) Anthracites non-caking.	Domestic and central heating; Malting kilns.				Below 8	Above 92	

TABLE 2.—*Seyler's Classification.*

(All numbers represent percentages.)

	Anthracitic.	Carbonaceous.	Bituminous.			Lignitous.	
			Meta-	Ortho-	Para-	Meta-	Ortho-
Genus ..	C over 93·3	93·3 to 91·2	91·2 to 89·0	89·0 to 87·0	87·0 to 84·0	84 to 80	80 to 75
Per-bituminous	....	....	Per-Meta-Bituminous. Northern Steam Coals.	Per-Ortho-Bituminous. Cannels.	Per-Para-Bituminous.	Per-Lignitous	....
H over 5·8 ..	....	....	Over 5·7	Over 5·7	Over 5·8	Over 5·8	....
Vol. 30 to 44 ..	....	....	30 to 44	Seldom under 36	Seldom under 40	31 to 57	....
Bituminous ..	....	Pseudo-Bituminous	Meta-Bituminous. Welsh coking coals.	Ortho-Bituminous. Durham coking coals. Smithy and gas coals.	Para-Bituminous. Gas and coking and free-burning steam coals.	Lignitous	....
H 5·0 to 5·8 ..	....	....	....	....	5·0 to 5·8	4·7 to 5·8	....
Vol. 23 to 30 ..	....	....	....	....	30 to 40	31 to 57	....
Semi-Bituminous	....	Semi-Bituminous. Generally coking steam coals.	Sub-Meta-Bituminous. Continental coking coals.	Sub-Ortho-Bituminous. Westphalian coking coals.	Sub-Para-Bituminous.	Sub-Lignitous	....
H 4·5 to 5·0 ..	....	Over 4·45	4·5 to 4·9	4·5 to 5·0	5·0 and under	....	....
Vol. 16 to 23 ..	....	14 to 24	16 to 23	16 to 23	16 to 29	....	....
Carbonaceous ..	Semi-Anthracitic. Non-coking, dry steam coals.	Ortho-Carbonaceous. Welsh smokeless, slightly coking coals.	Pseudo-Carbonaceous. (Sub-Meta-Bituminous) steam coals.	Pseudo-Carbonaceous. (Sub-Ortho-Bituminous).	Pseudo-Carbonaceous. (Sub-Para-Bituminous).	Sub-Lignitous	....
H 4·0 to 4·5 ..	Over 4	4·2 to 4·5	3·7 to 4·5	Over 4·5	....	....	....
Vol. 10 to 16 ..	9 to 15	10 to 14	10 to 16	Over 16	....	....	....
Anthracitic ..	Ortho-Anthracite. True anthracites.	Pseudo-anthracite (Sub-Carbonaceous). Dry Steam coals. Bastard anthracites.	Pseudo-anthracitic (Sub-Meta-Bituminous).	Pseudo-anthracitic (Sub-Ortho-Bituminous).	Pseudo-anthracitic (Sub-Para-Bituminous).	....	....
H below 4·0 ..	Below 4·0	Below 4·2	Below 3·7	....	....	....	....
Vol. under 10 ..	5 to 9	Under 7·7	Under 10	....	....	....	....

P. Frazer (1887) used the fuel ratio on the lines followed by H. D. Rogers a few years previously. His divisions were:—

	Fuel ratio.
Dry anthracite	100—12
Semi anthracite	12— 8
Semi-bituminous	8— 5
Bituminous	5— 0

As this was based on Pennsylvania coals, no coals of lower rank than bituminous were considered.

C. A. Seyler, after an intensive study of South Wales coal, drew up a classification in 1901, in which he made use of ultimate analyses. The analyses were reduced to a 'pure coal' basis, *i.e.*, C, H, O and N making up 100. His investigations showed that the hydrogen content and volatile matter bore some relationship of the type:

$$H = a+b \log V.M. \text{ (both H and V.M. on pure coal basis).}$$

Coals with over 84 per cent C were grouped into three genera called anthracite, carbonaceous and bituminous. The bituminous coals were subdivided into three—meta-, ortho- and para-bituminous. Those with C 75–84 per cent were called lignitous. Those with over 84%C were regrouped into genera according to the percentage of hydrogen. When the oxygen was not high, the recurrence of hydrogen percentage in different groups produced coals with closely resembling characters. Seyler's classification is given in Table 2.

Marius R. Campbell, a great authority on coal in the United States Geological Survey, proposed a classification in 1904 based on the ratio of C to H, as shown in Table 3.

TABLE 3.

Class.		C : H ratio.
A.	Graphite	∝ to ?
B.	Anthracite	? to 30
C.	Anthracite	30 to 26
D.	Semi-anthracite	26 to 23
E.	Semi-bituminous	23 to 20
F.	Bituminous	20 to 17
G.	Bituminous	17 to 14·4
H.	Bituminous	14·4 to 12·5
I.	Bituminous	12·5 to 11·2
J.	Lignite	11·2 to 9·3
K.	Peat	9·3 to ?
L.	Wood	7·2

F. F. Grout in 1907 proposed a classification based on the percentage of fixed carbon in the dry, ash-free coal in the coals of higher rank, and the total carbon in those of lower rank. His scheme of 1909 was as follows:—

TABLE 4.

Class.	In dry ash-free coal.	
	% Fixed carbon.	% Total C.
Graphite	Over 99	....
Anthracite	Over 93	....
Semi-anthracite	83 to 93	....
Semi-bituminous	73 to 83	....
Bituminous	47 to 73	80 to 88
Sub-bituminous	47 to 73	73·6 to 80
Cannel	35 to 47	73·6 to 88
Lignite	30 to 55	65 to 73
Peat	Below 50	Below 65

In 1906 S. W. Parr drew up a new classification based on the ratio of volatile carbon to total carbon expressed as a percentage. The volatile carbon was the difference between the total carbon and the fixed carbon. (C−F.C. = V.C.) The basis of the classification was therefore $\frac{V.C.}{C} \times 100$. For lower rank coals the percentage of inert volatile matter was used and this, in the pure dry coal, was got by subtracting from 100 the percentages of C, S, ash, H_2O and available H, and multiplying the remainder by

$$\frac{100}{100-(\text{Ash}+\text{moisture})}.$$

In 1922, Parr published a revised classification making use of his 'unit coal', which was again revised in 1928. Parr's unit coal is pure coal. He used the following formulae:—

$$\text{Unit B.T.U.} = \frac{(\text{Indicated B.T.U.} - 50S) \times 100}{100-(1{\cdot}08\ \text{Ash}+0{\cdot}55S)}.$$

$$\text{Unit Volatile matter} = \frac{[\text{V.M. as determined} - (0{\cdot}08\ \text{Ash}+0{\cdot}4S)]10}{100-(1{\cdot}08\ \text{Ash}+0{\cdot}55S)}.$$

In Parr's scheme the percentage of unit volatile matter is useful in the higher rank coals whereas the unit calorific value (unit coal B.T.U.) is the characteristic property of the lower rank coals, which will be seen from Table 5.

TABLE 5.—*Parr's classification.*

Class.	% unit V.M.	Unit coal B.T.U.
Anthracite	0– 8	15,000–16,500
Semi-anthracite	8–12	15,000–16,500
Bituminous A	12–24	15,000–16,500
Bituminous B	25–50	15,000–16,500
Bituminous C	30–55	14,000–15,000
Bituminous D	35–60	12,500–14,000
Lignite	35–60	11,000–12,500
Peat	55–80	9,000–11,000

O. C. Ralston (1915) calculated a large number of ultimate analysis to the 'pure coal' basis so that C, H and O totalled up to 100. He plotted the percentages of these on triaxial co-ordinates and found that the coals separated on the graphs into some natural groups.

J. D. Fisher (1927) used two sets of trilinear co-ordinates. In one he plotted the constituents fixed carbon, volatile matter and moisture, based on the ash-free coal with moisture as mined. In the second were plotted C, H, O

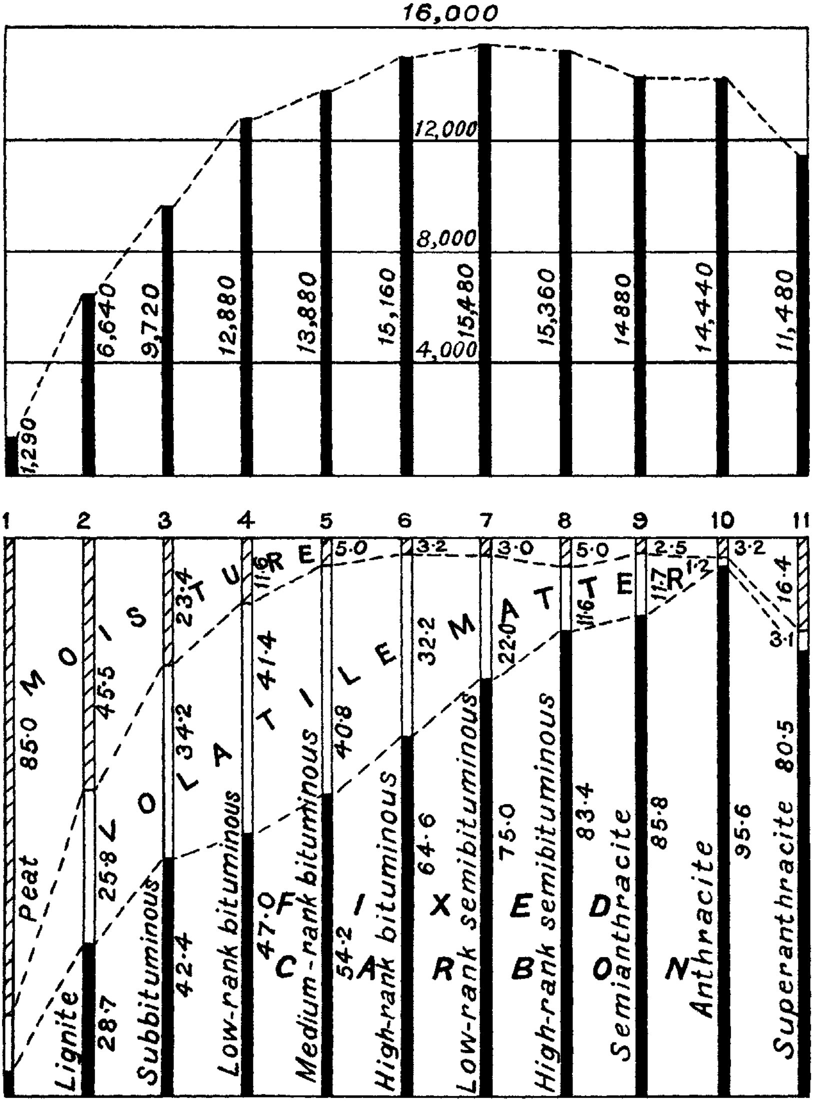

FIG. 1. *Upper diagram*: Calorific values of different ranks of coal.
Lower diagram: Composition of different ranks of coal on ash-free basis.
(After M. R. Campbell.)

which were also on the ash-free, moist coal. The approximate limits of the classes were shown in his diagrams by lines.

E. Stansfield (1925), in his investigation of coals of the Province of Alberta in Canada, found that moisture must be taken into account for a satisfactory classification. There is always some difference between the ash and the total mineral matter which must also be taken into account. The analyses were recast to a uniform 10 per cent ash (or 11 per cent mineral matter) which procedure was found to be more satisfactory than calculation to the hypothetical 'pure coal' basis.

M. R. Campbell has described the classification adopted by the U.S. Geological Survey in a paper presented before the International Bituminous Coal Conference at Pittsburgh in 1926. The details of this are shown in the following statement (Table 6) as well as in figure 1.

TABLE 6.—*U.S.G.S. Classification.*

Peat.—Contains approximately 85% moisture, 10·4% volatile matter, 4·6% fixed carbon; 1,290 B.T.U.

Lignite.—Brown, woody or composed of finely divided plant tissues, or amorphous and representing the first stage in the development of cannel. Contains 25 to 45% moisture; on drying shrinks and breaks up in an irregular manner; 6,000 to 7,500 B.T.U.

Sub-bituminous.—Black in colour; 12 to 25% moisture; slacks on exposure; 7,000 to 11,000 B.T.U.

Bituminous.—Slacks little on exposure; 11,000 to 15,000 B.T.U. Fuel ratio below 2·5; this class includes cannels, some of the best steam coals and the best gas and by-product coals.

Semi-bituminous.—Nearly smokeless, usually friable and slacks easily; 12,000 to 15,400 B.T.U. Fuel ratio 2·5 to 5.

Semi-anthracite.—Harder than bituminous; burns with a short yellow flame at first and then with a blue flame; fuel ratio 5 to 10.

Anthracite.—Hard, burns with a blue flame; does not soil the hands, difficult to ignite but burns without smoke. Fuel ratio over 10.

TABLE 7.

Grade.	Low Volatile.	High Volatile.
Selected	Up to 13% ash; over 7,000 cal.	Up to 11% ash; under 6% moisture; over 6,800 cal.
First	Up to 15% ash; over 6,500 cal.	Up to 13% ash; under 9% moisture; over 6,300 cal.
Second	Up to 18% ash; over 6,000 cal.	Up to 16% ash; under 10% moisture; over 6,000 cal.
Third	Inferior to the above.	

A simple classification is used by the Indian Coal Grading Board (Table 7) for coal intended for export. This has been in use for over a dozen years.

The latest scheme evolved in America is that tentatively adopted by the American Standards Association (A.S.T.M.). This recognises four broad classes: Anthracite, Bituminous, Sub-bituminous and Lignite. This scheme is shown in Table 8.

TABLE 8.—*Classification of coal by rank (A.S.T.M.).*

Class.	Group.	Fixed Carbon or B.T.U. on mineral matter free basis.	Physical property.
I. Anthracite..	1. Meta-anthracite	Dry F.C. 98% or more.	....
	2. Normal anthracite	Dry F.C. 92% or more up to 98%.	....
	3. Semi-anthracite	Dry F.C. 86 to 92%	Non-agglutinating [1].
II. Bituminous	1. Low volatile ..	Dry F.C. 77 to 86%	....
	2. Medium volatile	Dry F.C. 69 to 77%	....
	3. High volatile A	Dry F.C. less than 69%; moist B.T.U. 14,000 or more.	....
	4. High volatile B	Moist B.T.U. 13,000–14,000 [2].	....
	5. High volatile C	Moist B.T.U. 11,000–13,000 [2].	Either agglutinating or non-weathering.
III. Sub-bituminous	1. Sub-bituminous A	Moist B.T.U. 11,000–13,000 [2].	Both weathering and non-agglutinating.
	2. Sub-bituminous B	Moist B.T.U. 9,500–11,000 [2].	....
	3. Sub-bituminous C	Moist B.T.U. 8,300–9,500 [2].	....
IV. Lignite ..	1. Lignite ..	Moist B.T.U. less than 8,300.	Consolidated.
	2. Brown coal ..	Moist B.T.U. less than 8,300.	Unconsolidated.

[1] If agglutinating, classify under Low volatile bituminous.

[2] Coals having 69 per cent or more fixed carbon on the dry mineral matter free basis are to be classified according to F.C. regardless of B.T.U.

In the above classification the mineral matter is taken as 1·1 times the ash, which has been found to be a very good approximation to the truth. Coals having calorific value of 14,000 or over on the moist mineral matter free basis and those having 69 per cent or more of fixed carbon on the dry basis are classified according to fixed carbon. If the fixed carbon is less than 69 per cent on the dry basis, the classification is made on the moist B.T.U. In some semi-anthracites it happens that they are agglutinating, in which case they will be put under the low volatile bituminous group. The agglutinating test adopted is 500 grams of coal at a ratio of 15 parts of sand to 1 part of coal by the United States Bureau of Mines method.

The A.S.T.M. Committee recommended the following:—

$$\text{Dry mineral matter free basis} = \text{F.C.} \times \frac{100}{100-(\text{M}+1{\cdot}1\text{A}+0{\cdot}1\text{S})}.$$

$$\text{Moist mineral matter free basis} = \text{F.C.} \times \frac{100}{100-(1{\cdot}1\text{A}+0{\cdot}1\text{S})}.$$

For the weathering test, the United States Bureau of Mines test as described in the Report of Investigations No. 3055 (1930) is applied. In non-weathering coals the weathering index should not exceed 5%.

Seyler has very recently published a further elaborate discussion of classification on his pure coal basis and petrological constituents. Here he examines the proposition that coals of the same elementary composition are identical in all properties. Examining the relation between volatile matter and hydrogen, he proposes a law similar to Dulong's law ($V = a\text{H} - b\text{C} + \text{K}$). This is found to be applicable only to bright, non-anthracitic coals. He also finds that the composition of bright coal conforms to the rank. Emphasis is laid on coal petrography. Unfortunately, Seyler's classification requires elaborate calculations on the data of ultimate analysis especially if the coal contains appreciable quantities of 'dull coal' and is therefore highly artificial. Seyler however condemns the A.S.T.M. classification because it does not take into account the petrographical constituents, and adds—'In addition, the A.S.T.M. proposals, by the unfortunate step of introducing in different parts of the same classification a change from the dry to the moist mineral free basis, destroy all the simple correlations between elementary composition, volatile matter, petrological composition and properties which we have discussed in the paper'.

It will be noted that in Parr's scheme volatile matter and calorific value are used while in Seyler's the 'pure coal' is used. Both these systems ignore the existence of moisture as an integral part of the coal. The importance of moisture as an essential ingredient of the coal substance is now well recognised and X-ray study shows that at least in the lower rank coals it plays much the same rôle as volatile matter. Hence it would seem that moisture in coal as mined (or under standard conditions of storage and drying) should be determined and taken into account for the purpose of classification.

The methods of determining moisture are now far from satisfactory, whether in the raw coal as it comes out of the mine or in air-dried coal. In sampling, moisture from seepage should be carefully avoided and the coal should be immediately sealed air-tight and analysed as soon as possible. If the coal is stored, as is well known, moisture may be absorbed from the atmosphere or given up, according to conditions. Hence the question of the evaluation of this component should be studied intensively to arrive at a satisfactory method for the determination of that part of it which is inherent in the coal.

For coals of bituminous and lower ranks, the calorific value provides the best criterion for differentiation. The volatile matter shows only a small variation over a wide range and there is also much overlap. Similarly, the sum of volatile matter and moisture (and alternatively fixed carbon, which is simply the difference between 100 and the sum of volatiles and moisture in mineral matter free coal) fails. The calorific value is, in addition, of great importance for commercial purposes and can be readily determined.

The ultimate analysis of coal is particularly useful in studying the behaviour of coal of higher than bituminous rank, and has been used effectively by such authorities as Seyler and Ralston. It is not so valuable in the case of the lower ranks, for, as already mentioned, there is the difficulty about moisture which these authors have completely ignored.

For a classification to be of wide application, *i.e.* not only for one field but also over a whole country or even universally, the analytical procedure and the subsequent reduction of the results to a uniform basis should be standardised. In the evaluation of mineral matter Parr has used the factor 1·08 to multiply the ash percentage. Stansfield has shown that this factor varies between 1·05 and 1·20 for different Alberta coals in Canada and has advocated the use of the factor 1·1 as a satisfactory one, and the same factor has also been used by Tideswell and Wheeler and recently by the A.S.T.M.

If a standard method of adjustment is agreed upon for reduction to pure coal, comparison between different fields would be simplified. Such a procedure is necessary because the collection of representative samples of high purity for 'pure coal' determination is generally difficult.

REFERENCES.

[1] Bone, W. A.—Coal and its scientific uses (Chapter V), London, 1918, pp. 63–72.

[2] Campbell, M. R.—Report on the operation of coal testing plant of the U.S.G.S., 1904, pp. 156, 173. *Internat. Conf. Bitum. Coal at Pittsburgh*, 1926, Vol. 1, p. 5.

[3] Fieldner, A. C.—Classification of N. American coals. *Internat. Conf. Bitum. coal at Pittsburgh*, 1926, Vol. 1, pp. 632–661.

[4] Fisher, J. D.—Notes regarding coalification process. *Jour. Geol.*, 35, No. 7, p. 639, (1927).

[5] Frazer, P.—The Classification of Coal. *Trans. Amer. Inst. Min. Eng.*, 6, pp. 430–451, (1877).

[6] Grout, F. F.—Composition of coals. *Econ. Geol.*, 2, p. 225 (1907); 4, p. 646, (1909); 4, p. 653, (1909).

[7] Parr, S. W.—The classification of coal. *Jour. Amer. Chem. Soc.*, 28, p. 1425, (1906); *Jour. Ind. Eng. Chem.*, 14, p. 919, (1922); *Univ. Illinois Eng. Expt. Sta., Bull.* 180, (1928).

[8] Ralston, O. C.—Graphic studies in the ultimate analysis of coal. *U. S. Bur. Mines, Tech. Paper* 93.

9 Selvig, W. A., Ode, W. H., and Fieldner, A. C.—Classification of the coals of the U.S. according to fixed carbon and B.T.U. *Trans. Amer. Inst. Min. Eng.*, 108, pp. 188–197, (1934).

10 Seyler, C. A.—Chemical classification of coal. *Fuel in Science and Practice* 3, pp. 15, 41, 79, (1924); Petrology and classification of coal, *Op. cit.*, 17, pp. 177, 200, 235, (1938).

11 Stansfield, E.—A chemical survey of Alberta coals. *Trans. Can. Inst. Min. Met.*, 28, (1925).

12 Tideswell, F. V., and Wheeler, R. V.—Pure coal as a basis for classification. *Trans. Amer. Inst. Min. Eng.*, 76, pp. 200–214, (1928).