(*Reprinted from* MECHANICAL ENGINEERING *for March, 1938*)

FIG. 1 TWO BLOCKS OF BANDED COAL FROM SOUTHERN ILLINOIS
(The four components, clarain, durain, fusain, and vitrain, are indicated by the letters *C*, *D*, *F*, and *V*, respectively.)

ILLINOIS COALS

Constitution Important With Reference to Their Utilization

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ILLINOIS GEOLOGICAL SURVEY

MANY combustion problems of Illinois coals are related to the kind and quantity of bands in the coal beds and in the prepared coal. Such significant characteristics as ash content; fusion point of the ash; swelling, coking, and free-burning tendencies; friability; grindability; and Btu content are intimately related to the kind of bands making up the fuel. Importance may be attached to four distinct types of bands in Illinois coals in the order named; clarain, vitrain, fusain, and durain (Fig. 1). The glossy, finely laminated coal is clarain; the brilliant jet-black coal is vitrain; the dull laminated grayish coal, commonly known as splint, is durain. Fusain is the "mineral charcoal."

Relative proportions of the branded ingredients in No. 6 coal in Illinois are reasonably well-known but detailed information for the other workable coal beds is limited to a few mines. Clarain, however, is a predominant constituent in all coal beds of the state. Values obtained from measurements of the banded ingredients on polished surfaces of complete columns from the various coal beds are given in Table 1.

DESCRIPTION OF THE DIFFERENT COMPONENTS

The fusain content of No. 6 coal is highest on the western margin of the field and lowest toward the center and deeper parts of the basin. The clarain content is lowered appreciably by the presence of extraneous impurities and in two instances at least by the presence of durain. Vitrain shows a marked increase in quantity from the Belleville region in St. Clair County to Franklin County.

Proximate analyses of samples of vitrain, clarain, fusain, and durain in Table 2 show differences in the proximate values of the four ingredients which may exist in samples that were taken from the same mine. The two vitrain analyses are similar as are the two clarain analyses. Although the two fusain samples were collected in the mine on the same day and had identical preparation for analysis, they differ widely in moisture, ash, volatile matter, and Btu.

Fusain is the most porous of the coal components. Where ground water has access to it, the sample may contain considerably more moisture than the surrounding coal and ash-

TABLE 1 PERCENTAGES OF BANDED INGREDIENTS IN COLUMNAR SECTIONS OF COAL BEDS 2, 5, AND 6

(Each value represents an average of two determinations)

Coal bed	County	Banded coal ingredients: Vitrain	Clarain	Durain	Fusain	Banded impurities: Pyrite	Clay
2	Fulton	17.75	78.52	...	0.56	2.05	1.12
5	Saline	26.60	69.30	...	1.80	2.30	..
6	St. Clair	13.16	76.51	...	3.38	5.12	1.83
6	St. Clair	7.83	83.09	...	2.62	4.76	1.70
6	St. Clair	9.95	77.58	1.33	7.43	1.82	1.89
6	Montgomery	19.50	62.10	14.90	0.80	1.50	1.2
6	Washington	13.40	68.70	15.00	2.90	..	[a]
6	Randolph	14.76	75.88	...	4.77	..	4.59
6	Perry	19.00	69.90	2.60	4.50	..	4.00
6	Franklin	18.81	77.68	0.61	1.50	0.42	0.98
6	Franklin	22.70	72.40	1.60	2.30	0.10	0.90
6	Williamson	20.10	76.55	2.00	1.35	..	..

[a] 8-in. clay band removed in mining.

Presented at a meeting of the Chicago Section, Chicago, Ill., Oct. 19, 1937, of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

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forming mineral matter may be readily deposited from solution. In lenses closed to water, fusain usually has low ash and moisture. Volatile matter varies considerably but is usually much lower in fusain than in any of the other ingredients.

As vitrain was formed by coalification of the wood of the coal-forming plants, it is more homogeneous than coal formed from other parts of the plants. Because extraneous mineral matter has been excluded, an ash content of less than 1 per cent is not unusual.

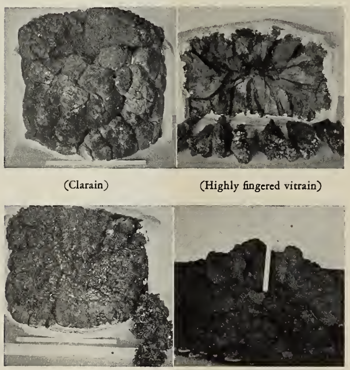
Clarain, formed from the coalified detrital materials of the coal swamp, such as leaves, twigs, bark, spores, and the like, has mingled with it the mineral matter that was present in the waters where the plant matter was deposited and usually has a considerably higher ash content than does vitrain. As the plant parts forming clarain are of a waxy or fatty nature, the volatile matter is usually higher than in vitrain.

Durain is of little significance in most Illinois coals, but when it occurs it may attain an importance out of proportion to its quantity because its "bony" appearance gives rise to the belief that it is essentially refuse. Frequently, however, the ash is low, and the durain has a much higher British thermal unit value than the other ingredients (Table 2). Practically without exception, durain has higher volatile matter than the coal with which it is associated. Like the clarain, it is formed from detrital materials but was probably formed during unusual conditions of deposition or by the preponderance of specific plant types.

TABLE 2 ANALYSES OF BANDED INGREDIENTS, COAL NO. 6, FRANKLIN COUNTY

Analysis number	Ingredient	Conditions	Moisture	Ash	Volatile matter	Fixed carbon	Sulphur: Sulphate	Sulphur: Pyritic	Sulphur: Organic	Sulphur: Total	Btu
C-510	Vitrain	a	8.87	0.87	35.60	54.66	0.00	0.18	0.49	0.67	13,010
		b	..	0.95	39.07	59.98	0.00	0.20	0.53	0.73	14,277
		c	..	..	39.44	60.56	0.00	0.20	0.54	0.74	14,415
		d	..	..	...	...	..	..	..	..	14,447
C-509	Vitrain	a	9.63	0.88	33.84	55.65	0.00	0.13	0.56	0.69	12,866
		b	..	0.97	37.45	61.58	0.00	0.15	0.61	0.76	14,237
		c	..	..	37.81	62.19	0.00	0.15	0.62	0.77	14,376
		d	..	..	...	...	..	..	..	..	14,411
C-503	Clarain	a	8.6	6.7	35.9	48.8	0.00	0.21	0.48	0.69	12,269
		b	..	7.3	39.2	53.5	0.00	0.23	0.52	0.75	13,426
		c	..	..	42.3	57.7	0.00	0.25	0.56	0.81	14,486
		d	..	..	...	...	..		..	..	14,600
C-504	Clarain	a	8.9	5.6	34.5	51.0	0.00	0.33	0.50	0.83	12,372
		b	..	6.1	37.9	56.0	0.00	0.36	0.55	0.91	13,582
		c	..	..	40.4	59.6	0.00	0.38	0.59	0.97	14,471
		d	..	..	...	...	..	..	..	..	14,569
C-505	Fusain	a	8.99	16.91	22.35	51.75	0.01	0.24	0.15	0.40	9,335
		b	..	18.58	24.56	56.86	0.01	0.26	0.17	0.44	10,257
		c	..	..	30.16	69.84	0.01	0.32	0.21	0.54	12,597
		d	..	..	...	...	..	..	..	..	12,844
C-506	Fusain	a	22.80	4.86	6.78	65.56	0.01	0.21	0.13	0.35	10,737
		b	..	6.29	8.78	84.93	0.01	0.27	0.17	0.45	13,908
		c	..	..	9.37	90.63	0.01	0.29	0.18	0.48	14,842
		d	..	..	...	...	..	..	..	..	14,937
C-1790	Durain	a	3.1	3.7	47.6	45.6	..	..	..	1.12	14,012
		b	..	3.8	49.1	47.1	..	..	..	1.16	14,460
		c	..	..	51.1	48.9	..	..	..	1.20	15,034
		d	..	..	...	...	..	..	..	..	14,630

[a] Moist bands as collected in the mine.
[b] Moisture-free.
[c] Moisture-and-ash-free.
[d] Unit coal Btu (dry, mineral-matter-free).



(Clarain) (Highly fingered vitrain)

(Weak granular durain) (Incoherent fusain after attempted coking)

FIG. 2 COKES MADE FROM THE FOUR INGREDIENTS

TABLE 3 ASH-SOFTENING TEMPERATURE OF COAL COMPONENTS, DEGREES FAHRENHEIT

	Mine A Illinois	Mine B Illinois	Mine C Illinois	Mine D Utah
Vitrain	1810	1906 1918 2084	2023 1927 2260	
Clarain	2130	2617	2073 2206	2131
Fusain	2270	2638	2565 2732 2349	
Durain	2540		2732	2440

Ash-softening temperatures of different ingredients from the same mine may be several hundred degrees apart. However, the data in Table 3 suggest the following order of increase in softening temperatures of ingredient ash; vitrain, clarain, fusain, and durain.

Ease with which the bands grind shows a wide difference. Durain is difficult to grind, clarain is less difficult, vitrain grinds easily, and fusain offers little resistance. These are important considerations where the coal is powdered before firing, and the cost of grinding must be considered.

Fig. 2 shows cokes made from the four ingredients. About 15 lb of each type of coal was sealed in separate metal containers and coked in a gas-fired furnace. A pipe leading from the top of each container permitted the escape of gas and tars. When the thermocouple at the center of each batch showed a temperature of 900 C, the coke was quenched. Vitrain (top right) showed the greatest expansion during coking but shrank and fingered badly when quenched. Clarain (top left) swelled considerably less and showed much less tendency to finger. Durain (lower left) had poor agglutinating qualities and the coal particles had practically no coherence. Fusain (lower right) gave off little gas and tars and was essentially in the same physical condition after firing as when it was charged. While fusain lacks positive swelling and agglutinating characteristics, it is useful in blocking up or reducing fingering in high-vitrain coal used for coking. The structure of the clarain, vitrain, and durain coke is best shown in the sections embedded in plaster of Paris (Fig. 3).

FIG. 3 SECTIONS OF COKE EMBEDDED IN PLASTER OF PARIS TO SHOW DIFFERENCES IN STRUCTURE

BEHAVIOR IN MINING, SCREENING, AND SHIPPING

Physical behavior of the coal components in mining, screening, and shipping is important. If blocks of coal are examined it becomes apparent that, on the majority of them, the surface parallel to the bedding plane is covered with fusain (Fig. 4). Fusain is structurally the weakest of the four coal components and is primarily responsible for degradation. Occasionally blocks will be seen with one or both surfaces parallel to the bedding plane covered by vitrain (Fig. 5). Vitrain is more resistant to breakage than fusain but is much weaker than clarain. It is the secondary cause of breakage in mining and preparation. Clarain, on the other hand, is closely knit together and stands up well under mechanical handling. When durain is present, it is the toughest and most resistant component. These breakage characteristics have considerable to do with the kind of coal that goes into the prepared sizes. Both vitrain and clarain can be found in the lump, and most of the surface will have a thin layer of fusain on them where the lumps have split along fusain layers. Most of the fusain has broken off, however, and will be found in the screenings or, if the coal is dedusted, in the dust.

The 3-to-2-in. egg coal may have some of the smaller vitrain bands but for the most part is clarain. No. 2 nut, 2 to $1^1/_4$ in., is even richer in clarain. In most coals, No. 3 nut, $1^1/_4$ to $^3/_4$ in., is 8 to 10 per cent higher in vitrain than the coal bed from which it was mined. Vitrain continues to concentrate below 48 mesh in most cases until the 100- or 200-mesh size is reached. Below this, fusain is usually highly concentrated.

Washing may play a considerable part in separating the ingredients. In the $-1^1/_4$-in. screenings from one mine, 58.9 per cent of the coal floats at 1.30 sp gr. This coal is 58.2 per cent vitrain, 40.0 per cent clarain, 1.1 per cent fusain, and 0.7 per cent middling refuse. The average vitrain content of the coal bed is only about 20 per cent. This vitrain is so highly concentrated in the fraction floating at 1.30 sp gr that, as previously indicated, vitrain decreases and clarain increases in the nut and larger sizes. A microscopic analysis of a washed $^3/_8$-in. to 48-mesh coal from an Illinois mine showed the composition given in Table 4 in comparison with the coal in the seam.

TABLE 4 COMPOSITION, BY PERCENTAGE, OF A WASHED ILLINOIS COAL AND THE SEAM FROM WHICH IT WAS MINED

	Washed	Coal bed
Vitrain	40.8	19.0
Clarain	51.9	69.9
Fusain	2.6	4.5
Refuse	4.7	6.6

COMBUSTION TESTS

The foregoing discussion of the effect of sizing and washing and the chemical characteristics and distribution of the banded ingredients gives a generalized view of the information collected for conducting studies of how these different sizes, and, consequently, different mixtures of ingredients burn. Much of the uneven burning in the stoker fuel bed can be attributed

FIG. 4 FUSAIN AS IT OCCURS ON THE SURFACE OF A BLOCK

(Breakage readily occurs at such surfaces and the broken fusain concentrates in the form of 100- to 200-mesh dust.)

to the highly swelling nature of vitrain which our studies have shown to be concentrated in the stoker sizes. Crushing egg and large nut sizes, which have a great proportion of relatively free-burning clarain, and mixing this crushed coal with the normal stoker sizes or marketing the product as a special stoker fuel may be desirable for some mines.

In view of the different responses of the ingredients to coking and with a general knowledge of their distribution in prepared sizes, a study was made of the combustion in a domestic underfeed stoker of two of these types of coal, which were from the same mine. The $^7/_{16}$-in. to 10-mesh coal normally loaded at the mine was separated at 1.30 sp gr and the float was recovered to give a high-vitrain fuel, 70 to 75 per cent. The coal high in clarain was made by crushing the 2-to-$1^1/_2$-in. nut produced by the mine to $-^7/_{16}$ in. and screening out the —10-mesh dust. Screen analyses of the two coals as burned are shown in Table 5.

TABLE 5 SCREEN ANALYSES OF STOKER TEST COALS

(Each sample riffled from 100 lb of coal)

Screen size[a]	A	B
$+^1/_2$ inch	0.9	2.1
$^1/_2$ to $^3/_8$ inch	13.4	10.4
$^3/_8$ inch to 3 mesh	10.2	11.4
3 to 4 mesh	25.7	30.5
4 to 6 mesh	23.3	19.7
6 to 8 mesh	15.7	12.7
8 to 10 mesh	7.1	10.1
10 to 20 mesh	2.7	2.4
20 to 48 mesh	0.5	0.4
minus 48 mesh	0.5	0.3

A 1.30 sp gr float from $^7/_{16}$ in. to 10 mesh coal produced at the mine.
B 2 to $1^1/_2$ in. coal crushed to $^7/_{16}$ in. and 10 mesh removed.

[a] Round-hole screens used on sizes above $^3/_8$ in. Tyler standard sieves used on sizes below $^3/_8$ in.

Excessive swelling and coke-tree formation accompanied initial stages of combustion of the coal high in vitrain, as shown at the extreme left of Fig. 6. "Blowholes" appeared around the base of the coke tree (left center) and were present throughout combustion. When the coke tree reached the top of the furnace, it broke apart, and large blowholes were in evidence for some minutes (right center). As fresh coal was fed in, a swollen, plastic mass filled the firebox (extreme right). A satisfactory fuel bed did not develop at any time, and the furnace capacity was considerably reduced.

The left portion of Fig. 7 illustrates the first stage in the combustion of the high-clarain fuel. No excessive swelling and coking occurred such as accompanied the burning of vitrain. The even burning during a late stage of the clarain fuel bed is shown at the right.

CONCLUSION

Banded coals of Illinois have three and sometimes four coal components which differ chemically and physically, frequently to such an extent that, should they be separated before market-

FIG. 5 LUMP OF ILLINOIS COAL THAT WAS BROKEN THROUGH A VITRAIN BAND

(Many small vitrain particles break free of the block and go into the small sizes when such breakage takes place. The lines in the background are spaced 2 in. apart.)

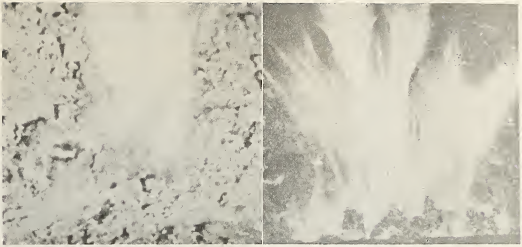


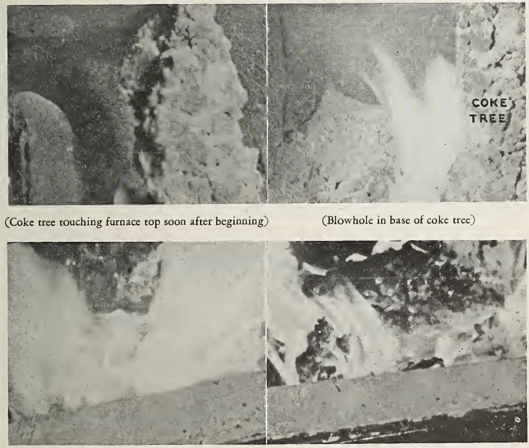
FIG. 7 COMBUSTION OF HIGH-CLARAIN FUEL

(Flame breaking through ash at start of combustion) (Uniform fire in later stage)

ing, the products would be regarded as distinctly different coals. Mining and preparation are responsible for a partial separation or segregation of the different types of coal now reaching the market. Friable vitrain and fusain are concentrated in the screenings and small prepared sizes, the latter reaching its highest concentration in the dust from dedusted coal. Clarain, and durain when present, comprise the greater part of the egg and nut sizes.

Of most immediate significance in the marketing and utilization of coals of this variety is the excessive swelling of vitrain and the relatively free-burning nature of clarain in an underfeed stoker. Screenings and the smaller stoker sizes, when high in vitrain, are likely to form coke trees and uneven fuel beds. Larger sizes, which are rich in clarain, when crushed to accommodate the small stoker, burn uniformly without excessive coking or swelling. In view of these combustion characteristics, it is sometimes advisable to crush and mix large coal with normal stoker sizes to obtain a fuel that burns uniformly.

Laboratory tests have brought out significant differences in the response of various types of coal to coking, in softening temperature of the ash, in grindability, and in proximate analysis. These data indicate that the banded coals here discussed lend themselves to a type of preparation that will yield fuels of a more uniform and desirable character.



(Coke tree touching furnace top soon after beginning) (Blowhole in base of coke tree)

(Close-up of blowhole in the fuel bed) (Plastic mass that filled firebox in later stage)

FIG. 6 STAGES IN THE COMBUSTION OF A COAL THAT IS HIGH IN VITRAIN