COAL-DUST EXPLOSION AT EXPERIMENTAL MINE.

By George S. Rice.

SELECTION OF MINE.

Soon after the investigation of the causes of mine explosions was authorized by Congress in 1908 the technologic branch of the United States Geological Survey, under whose charge it was placed, gave consideration to the establishment of an experimental mine where coal-dust tests could be made on a larger scale than was possible in a surface gallery. In 1910, when the mine-accidents work was transferred to the newly established Bureau of Mines, an allotment was made to establish an experimental mine. Attempts were made to find an abandoned mine which would be suitable, but none such was found. Following this, efforts were made to find a suitable location for opening a new mine. As the Pittsburg coal bed is one in which many serious disasters have occurred, it was thought best that the mine should be opened in this bed. Another consideration was that the mine must be isolated and in such a location that the concussive air waves started by an explosion would be deflected upwards, thus reducing the chance of shattering windowpanes in distant houses, a difficulty experienced at the English and the French dust-explosion stations.

It was also necessary that the mine should not produce a perceptible amount of methane so that coal-dust tests could be carried on without the complication of mine gas. On the other hand, it was important that natural gas be available for introduction through pipes into the mine for gas-explosion experiments and for combined gas and coal-dust tests.

It was also important that the mine be naturally dry so that experiments with dry coal dust would be possible. Complications and difficulties connected with shaft linings precluded a shaft mine, so that a mine on the outcrop was considered essential. The Bruceton location, which was finally selected, was one of the few available places that met all the requirements. The entries were started in December, 1910, and the work of development and of erecting the plant proceeded as rapidly as circumstances would allow.

LAYOUT OF MINE.

The mine consists of a pair of entries driven in the Pittsburg bed. These entries are nearly parallel with the "butt" joints of the coal and at right angles to the "faces"; in other words, the entries are what are termed "face" headings. The coal bed rises on a slight grade from the outcrop. A plan of the mine workings is shown in figure 2, and the mouth of the entries at the outcrop is shown in Plate I, *B*.

At the time of the experimental explosion of October 30, 1911, the main entry was 713 feet long and the airway 669 feet long, with three crosscuts between them. The entries extend in a southerly direction. The west one is called the main entry and is the chief explosion passage. The east entry is the airway. There is a small shaft on the east side of this entry, 62 feet from the mouth, for ventilation when driving entries.

A third passage, 198 feet long, enters the airway from the east at an angle of 55°. At the outer end there is a concrete section 20 feet long, covered with boards or plates weighted with sand bags, which serves as a large relief valve. Beyond this, and in line with it, there is a steel gallery (just back of two trees on right of foreground of Pl. II, *A*) 122 feet long, of which 20 feet at the mine end can be rolled to one side so that special experiments can be made in the isolated 102-foot section. This is nearly a duplicate of the gas and dust gallery at the Pittsburg station, except that the outer end is closed with a wooden stopping, and near this end there is a Y for fan connection. The installation of a powerful fan for making coal-dust experiments in high-velocity air currents is intended. This fan, which is now on hand, is reversible and has a rated capacity of 80,000 cubic feet of air per minute with a 2-inch water gage, and of 15,000 cubic feet of air per minute with a 6-inch water gage.

At the time of the test, on October 30, a small fan (capacity, 10,000 cubic feet per minute with a 1-inch water gage) driven by a gas engine was installed in an offset off the Y, near where the permanent fan will be erected. This small fan is for future use at the top of the air shaft, to act as an auxiliary fan for ventilating the mine when the large fan is not employed or is cut out by breakage resulting from an explosion.

The steel gallery is 6 feet 4 inches in diameter. The oblique heading between the external gallery and the airway is lined with reinforced concrete and is 6 feet 4 inches wide by 6 feet 4 inches high. The main entries are each 9 feet wide and from 6 to 7 feet high. The outer 169 feet of the main or explosion entry is lined with reinforced concrete; the internal dimensions are 8 feet wide and 7 feet 6 inches high. The airway at the junction of the slant or gallery entry and for a distance of 20 feet outby and 65 feet inby is similarly

A. VIEW OF SIDE HILL, SHOWING GALLERY ENTRANCE IN CENTER AND MAIN ENTRANCE IN BACKGROUND.

B. SIDE HILL OPPOSITE MINE, SHOWING CAR AND OTHER DÉBRIS THROWN BY THE EXPLOSION.

lined. At the junction the reinforcement, of $\frac{3}{4}$-inch square-rod arches and $\frac{1}{4}$-inch longitudinal rods, is supplemented by steel rails. Ordinary mine-car tracks are in each of the entries.

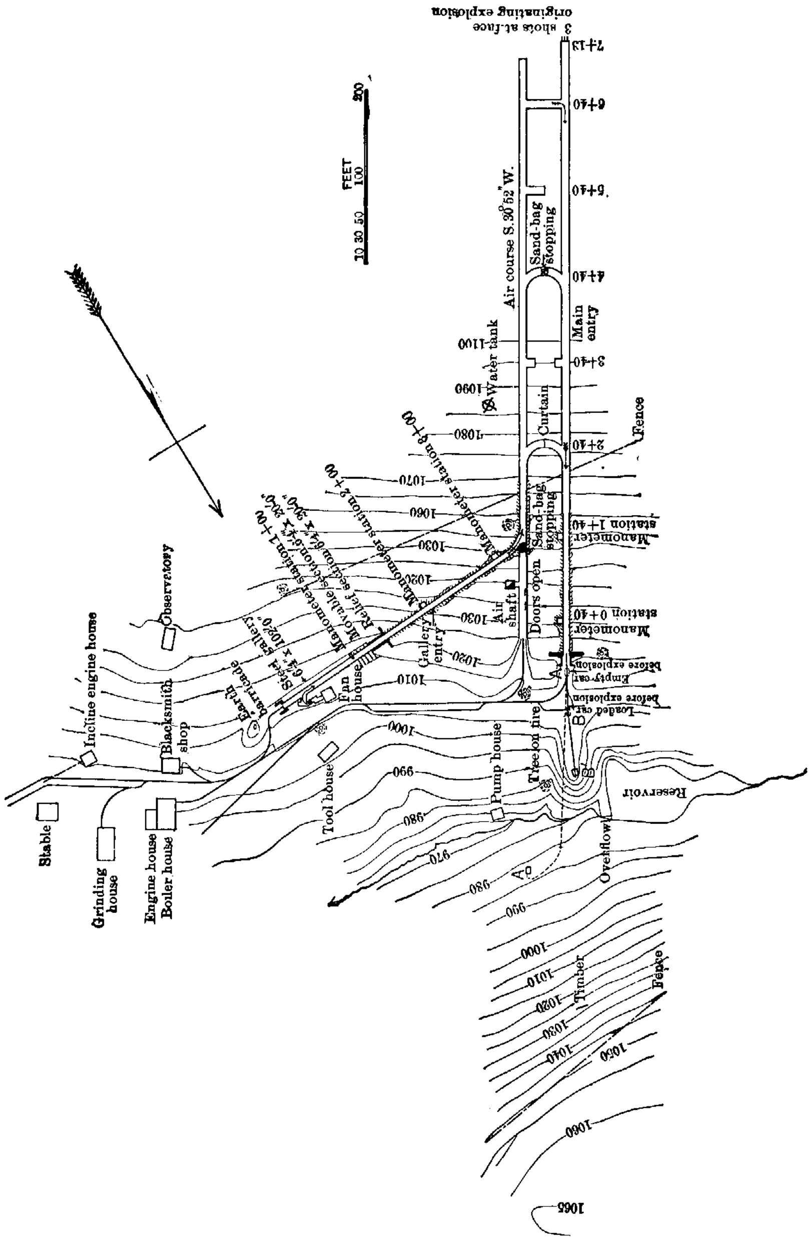


FIGURE 2.—Plan of experimental mine.

CHARACTER OF COAL BED.

The Pittsburg coal bed in this mine is 5 to 6 feet thick, above which there is a "draw slate" 6 inches to 2 feet thick. In places this "draw slate" contains many slips and has to be taken down.

Above the "draw slate" there is in places a top coal 1 to 2 feet thick, but more or less shaly. The next stratum above is shale. These are the normal conditions for the Pittsburg bed in the vicinity of the mine. The coal bed proper is free from continuous partings, except two small bands of shale 3 inches apart. The upper band is one-eighth to three-fourths inch thick, and the lower is one-fourth to one and one-fourth inches thick. These bands are a little below the middle of the bed. The faces and butts are strongly marked. The coal is somewhat soft, and in the process of mining a large proportion of finely broken coal is formed.

The average proximate analysis of the coal from three full-section face samples is as follows:

Analysis of coal from experimental mine.

Moisture	2.73
Volatile matter	36.03
Fixed carbon	54.98
Ash	6.26
	100.00
Sulphur	1.39

The dust used in the experiment of October 30 was not made by grinding the coal of this mine, as will be done in future experiments, but was made from coal from a mine in the Pittsburg bed, which has furnished the so-called standard dust of the Pittsburgh experiment station. Samples of the dust used showed that 98 per cent passed through a 100-mesh sieve. Its proximate analysis is as follows:

Analysis of coal dust.

Moisture	1.94
Volatile matter	35.11
Fixed carbon	57.73
Ash	5.22
	100.00
Sulphur	1.25

DISTRIBUTION OF THE COAL DUST.

As the floor of the entry is the natural floor with a ballasted track, it is not smoother than ordinary mine roadways. To save difficult cleaning, the old burned and unburned dust on the roadway is wet down or covered with damp clay. The fresh coal dust is placed on shelving which can be easily cleaned after each experiment. The permanent shelving will consist of 3 by 4 inch lumber, bolted along the concrete sections and, in the unlined coal sections, fastened to recessed props. The lumber is placed with the 3-inch face upwards so as to provide a 3-inch shelf. There will be five lines on either side (see fig. 3). This was essentially the arrangement on October 30, except that the shelving had been merely wired to the bolts in the concrete-lined area and in the unlined area had been fastened to temporary props. At a few points, as in the first crosscut, where the regular shelves had not been placed, some special cross shelves were used. No dust was used in the air course inby this crosscut. The

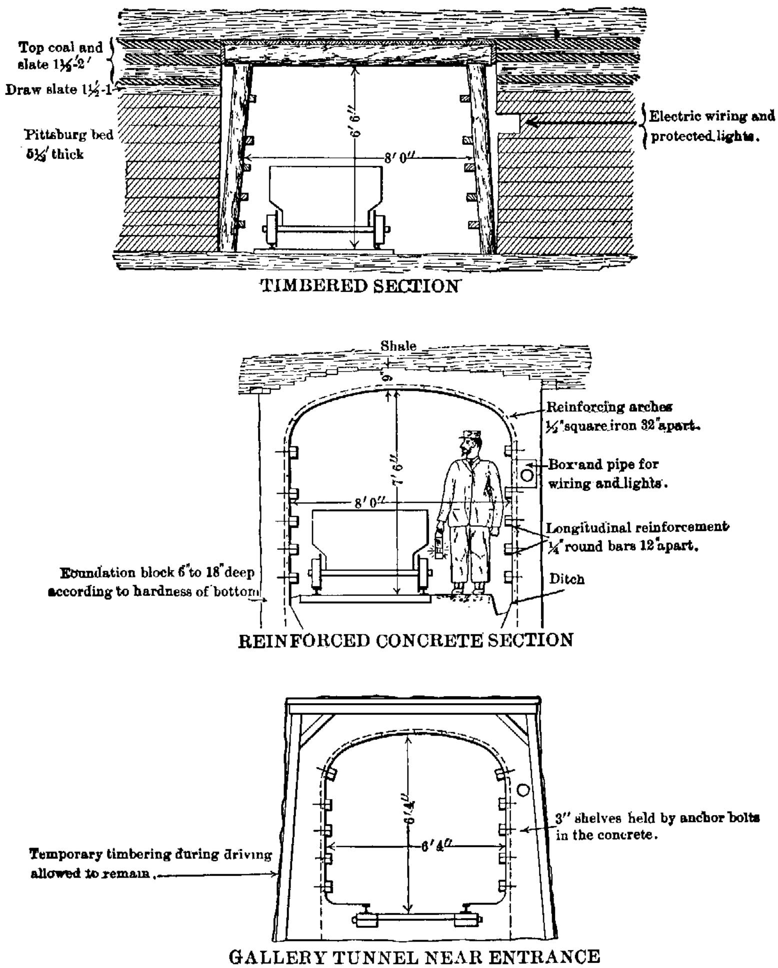


FIGURE 3.—Cross-sectional views of mine gallery, showing dust shelves.

air course outby the gallery junction was cut off by a heavy sand-bag stopping. In the main entry, 627 pounds of dust, equal to 0.88 pound per linear foot of entry, was placed on the shelving. The outby crosscut from the main entry to the airway, thence on this to the gallery entry and out the latter to and through the steel gallery, a total distance of 481 feet, was loaded with dust to the amount of 0.46

pound per linear foot, a total of 225 pounds of coal dust on that side. The entire quantity used in the explosion was, therefore, 852 pounds.

INSTRUMENT STATIONS.

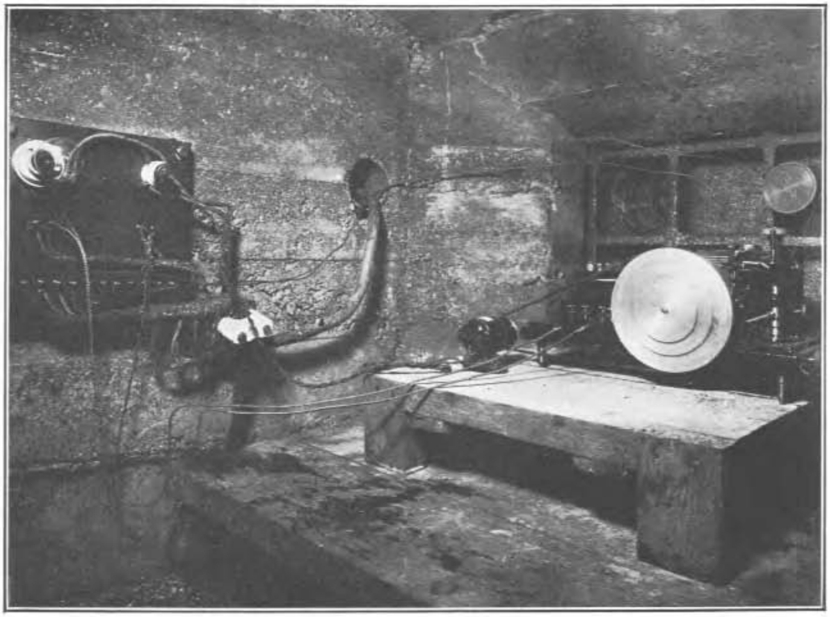
At the time of the test five instrument stations had been constructed—one attached to the external gallery, two in the gallery entry, and two in the main entry. These stations were erected for safely housing the recording manometers used to obtain pressure curves. They were also designed to house circuit breakers (both pressure and flame) for respective velocity records and automatic gas-sampling devices. The four mine stations are built in the rib and are lined with reinforced concrete. In the entry side there is a heavy-ribbed cast-steel plate, through which connections are made to the instruments (Pl. III, *A*). Entrance behind the instruments is obtained through an adjoining compartment, the doorway of which to the entry is guarded by a ribbed cast-steel door. The cast-steel cover and door are made to resist pressures of 600 pounds per square inch. The plate is permanently bolted in place and the door, after closing, is made tight by iron wedges.

The equipment at present includes circuit breakers and three manometers of the Altofts type. At the time of the experiment, only two manometers and two pressure circuit breakers could be used. The two manometers were placed in the main entry stations at 40 and 140 feet, respectively, from the mouth of the entry. The circuit breakers were also placed in these stations, and a small wire was placed where the first blown-out shot could break it and thus indicate the start of the explosion. The velocity records are automatically registered by instruments in the observatory on the hillside, from which point the shots are ignited by battery.

IGNITING SHOTS.

It had been planned that the persons who would see the exhibit would go to the mine by train, arriving about 2.30 p. m. After the mine had been examined, the test was to be made at about 3.45 p. m. Unfortunately, the train was delayed about an hour, so that the inspection of the mine by the 1,200 visitors was not completed until after 5 o'clock.

The intention was to ignite the coal dust by a single blown-out shot placed at the face of the main heading, as had been successfully done in a similar experiment on October 24. Two auxiliary holes, one on either rib, had been drilled for a second firing circuit in case of failure of the first shot. In the trial explosion of October 24, a single blown-out shot, charged with two pounds of black powder, started the explosion.



A. INTERIOR OF AN INSTRUMENT STATION, SHOWING MANOMETER AND PRESSURE CIRCUIT BREAKER.

B. JUNCTURE OF GALLERY ENTRY AND AIR COURSE, SHOWING BROKEN REINFORCED CONCRETE CORNER WITH CURTAIN AND WOOD IN THE CREVICES.

To cause each shot to blow out, there was drilled in the face a hole sufficiently large to receive a 1½-inch iron pipe, about 3 feet long, with an iron plug at the inner end. Some clay was tamped against the plug, and common black blasting powder was next inserted, with an electric detonator near the outer end. The charge was tamped hard with 4 inches of clay. The charged pipes were then placed in the respective holes so that the end of each pipe was flush with the mouth of the hole. Each hole was bored straight into the face, at 2 feet 10 inches above the floor.

The electric wires and lights which enabled the visitors to inspect the mine were removed, the shots prepared, and electric connections made. Tests of the firing lines, earlier in the day, had shown the lines intact. The lines, consisting of two separate circuits, in addition to a third circuit for velocity records, entered the mine in pipes placed behind the concrete lining. Beyond the lining the permanent arrangements had not been made, so the wires were laid in one corner of the air course, thence through the last crosscut to the face of the main entry.

On the first two trials the first shot, and later the second shot, failed to go off, owing to short circuits. It seems probable that the wires had been trampled upon and the insulation injured. Then an entirely new set of firing wires was brought into the mine and laid through the air course and last crosscut to the shots in the main heading. In view of previous mishaps, all shots were connected in parallel. When this arrangement was tried the ignition and the explosion followed at about 6.15 p. m.

In all 9¼ pounds of black powder was discharged in the shots on October 30. So far as the records showed, the effect on the inner part of the mine was no greater than on October 24, when a similar coal-dust explosion was started by a single shot with 2 pounds of black powder. Subsequent examination showed that the shots had all gone off, and each was essentially a blown-out shot; the pipe in each case had ruptured and the center shot had broken out some coal, making a crater about 18 inches deep (Pl. IV, *A*).

EFFECT OF THE EXPLOSION.

About one and one-half seconds after the circuit had been completed at the observatory, the explosion reached the open air. It burst forth with a roaring sound and vivid flames almost simultaneously from the several openings. The evening was rainy and dark, so that nothing but the sheets of flame could be observed. At the main entry the flame rose above the forest trees to a height variously estimated from 200 to 500 feet. Observers at the town of Library, 4 miles distant, saw the flames above the tops of the hills.

A limb of a tree was set on fire 153 feet from the mouth of the mine, and 46 feet above the level of the entry.

The sound of the explosion, while not sharp, carried a long distance. At Library windows were rattled. The explosion was heard at Carrick, 5 miles to the north, and at Monongahela City, 12 miles to the south.

A mine car containing several hundred pounds of gravel stood on a switch outside of the mine in line with the main entry and 40 feet from the mouth. Twenty-five feet beyond it there was a car loaded with 1¼ tons of coal. The gravel car, weighing about 2,000 pounds, was thrown over the top of the coal car, and landed 184 feet away on the opposite slope of the ravine that passes the foot of the dirt dump. It then bounded four times and landed 45 feet from where it first struck, making the total distance moved 229 feet (see Pl. II, *B*, and A–A′, fig. 2).

The loaded car, with the brakes set, was thrown along the track and derailed at the end of the dirt dump, 70 feet from where it had been standing (see B–B′, fig. 2). Pieces of timber were scattered over the hillside opposite, some of them higher than the level of the mine and nearly to the top of the hill. A 3 by 4 inch timber was thrown 413 feet from the mouth of the mine and landed on ground 18 feet higher. The flame that issued from the main entry was sustained for several seconds, so long that at distant points many persons whose attention was attracted by the sound were able to turn around and see the flame.

Sheets of flame burst out of all the doors in the steel gallery. The 20-foot relief valve at the mouth of the gallery entrance was thrown high in the air. It consisted of boards weighted with sand bags. The timber stopping closing the outer end of the gallery was blown out and broken into small fragments. The wooden casing and the connection to the fan, in spite of the relief valves and doors, were blown apart. Two windows in a near-by tool house were blown outward toward the gallery, presumably from the suction following the explosion. The heavy sandbag stopping, 6 to 8 feet thick, across the air course at the junction with the slant, was blown outward and the sandbags scattered to a point 50 feet outside the mine. Some of the bags of this stopping, by the inward reflex wave, were thrown 5 to 10 feet inby from their original position.

Owing to the wreckage of the fan casing and connection, ventilation could not be immediately restored, although a natural ventilation was established through the air shaft acting as an upcast. The repairs on the fan were made during the night and brattices erected in the crosscuts so that an inspection of the mine could be made on the following day.

EVIDENCE OF EXPLOSION IN THE MINE.

At the face of the main entry, where the shots were fired, it was found that fragments of some boards that had been laid on the floor to receive the coal dust had been drawn back into the crater made by the center shot (Pl. IV, *A*). This was due presumably to the gases rushing back to fill the vacuum caused by the blast. There was no evidence of great violence, except in the immediate vicinity of the shots, until the middle crosscut was reached.

SOOT FILAMENTS.

Between the face and the open crosscut 70 feet from the face there were threads of soot hanging from the roof and ribs (Pl. V, *A*). Evidently the threads or filaments came from the excess of carbonaceous matter in the atmosphere during the explosion, as they are frequently observed in quiet areas of mines in which explosions have occurred.

COKED DUST.

Although no dust had been placed along the inner crosscut, the flame from the main entry had branched through it, and thence into and outward along the air course. Crusts of coke were plastered on the rib near the roof at the inby corner of the air course and the crosscut (Pl. V, *B*). There was a small quantity of coked dust on a prop which stood at this corner.

Little trace of the explosion was found toward the face of the air course. Unused cross shelves were only slightly moved, and buckets, containing coal dust, standing at the face had not been disturbed. There were deposits of coke and coked dust on the west rib of the air course for 28 feet inby the last crosscut and for 14 feet outby. Smaller deposits were found on the east rib throughout this distance.

There was little coked dust in the main entry. The coke was found only as small isolated particles in the inner part of the entry and none at all was observed toward the outer end. The absence of a considerable amount of coked dust may be attributed to three causes: (1) There was practically no coarse dust, 98 per cent passing through a 100-mesh sieve, so that the dust which entered into the explosion was probably largely consumed, leaving only ash. (2) The violent movement of the gases along the main entry probably carried away what little coke might have been formed in that entry. (3) The roof and ribs were damp, and it has been observed in other mine explosions that coked dust does not tend to stick to a damp surface and that a relatively slow air movement, such as a reflex wave would give, is likely to sweep away detached particles.

EFFECT OF FLAME ON COAL RIBS.

In several places along the inner crosscut and along the air course outby the inner crosscut the ribs showed marked signs of blistering. The soot, which elsewhere coated everything, was absent in these places and evidently thin scales of coal had dropped off after the explosion, leaving rounded surfaces instead of the usual flat facings with square edges. (Pl. IV, *B*.)

VENTILATION.

The regular ventilation was carried on at the time of the explosion. There was about 9,000 cubic feet of air per minute entering the mine through the gallery and about 8,000 cubic feet passing through the open crosscut at the 640-foot station and returning in the main entry. The shots were, therefore, fired in a dead end, but the explosion encountered moving air at the first crosscut. The second crosscut contained a sandbag stopping 7 feet thick. The bulk of this stopping was blown toward the air course, but a considerable number of the bags had been thrown toward and into the main entry. It would appear that the first explosive wave coming out the main entry had overturned the stopping toward the air course and that the branch explosion coming out that passage a moment later had thrown a number of the loose bags back toward the main entry.

In the outer crosscut, there was only a canvas curtain stretched across to keep the air current from short-circuiting. The crosscut was loaded with 0.46 pound of coal dust per linear foot placed on temporary shelves. That branch of the explosion passing through this crosscut did not appear to have been violent, as light cross timbers placed in the air course just outby the crosscut had not been disturbed, although they had some burned dust sticking to them, and fragments of a curtain were slightly burned. Immediately beyond these timbers in the air course, the explosion appears to have suddenly increased in violence. Whether the increase of violence was due to enlargement of air space at the junction with the slant entry or to other cause is uncertain at this time. All the heavy shelves beyond this point were thrown down and some of them broken. The sandbag stopping across the air course was thrown outby, some of the bags going outside the mine, although a few bags were drawn inby, seemingly by the reflex air wave.

CONCRETE LINING BROKEN.

As in the explosion on October 24, the concrete arching was lifted. The concrete corner of the Y was broken by a horizontal fracture and the upper half lifted so that a stick and pieces of a curtain brattice were blown into the opening and held fast when the concrete settled back to its normal position (Pl. III, *B*).

OTHER EFFECTS OF EXPLOSION.

From the junction to the mouth of the concrete gallery there were continuous cracks along both springing lines of the arch, and at a point $22\frac{1}{2}$ feet from the mouth of this slant entry the lift was at least 12 inches, as shown by one of the $\frac{5}{8}$-inch reinforcing rods pulling out and subsequently doubling as the roof dropped back in place. (Pl. IV, *C*.) Other rods in this vicinity were pulled through the concrete. (Pl. V, *C*.) No upheaval due to the explosion was readily discernible on the surface, except where there had been a filling near the mouth of the gallery, where the cover was only 8 feet thick. This point was directly above the place where the concrete roof was lifted 12 inches.

The explosion rapidly increased in violence after passing the outby crosscut in the main entry, 470 feet from the origin of the explosion. Farther out the pressure lifted the reinforced concrete arching, breaking the concrete around the bars. At a point 50 feet from the mouth the arch was lifted and remained 11 inches above its former position. (Pl. VI, *A*.) There had been a roof fall at this point prior to putting in the concrete lining, and dry material had been packed into the hole. Cement subsequently pumped behind the lining may or may not have permeated the dry packing. Thus there may have been sufficient voids to permit some or all of the lift noted. The natural cover was 12 feet thick where the maximum displacement occurred. The cover did not show any break on the surface.

The effect of the explosion at the mouth of the main entry is shown in Plate I, *B*. The pieces of timber in the foreground are the shelves that were blown out of the mine at the time of the explosion. This illustration also shows the concrete construction at the mouth of the entry, which was heavily reinforced. The reinforcing bars of the concrete arch and sides of the entry are five-eighths inch square, which, together with $\frac{1}{4}$-inch round rods placed longitudinally, form a complete network of steel. This construction extends the entire length of the concreted portion of the entry.

INSTRUMENT RECORDS.

Unfortunately the circuit for the manometers had not been repaired at the time the new firing wires were brought in, so that the only records obtained were those for maximum pressure. The springs furnished with the instruments were for use up to a pressure of 30 pounds per square inch. The manometer at station 140 (140 feet from the portal) showed that the pressure was above 45 pounds,

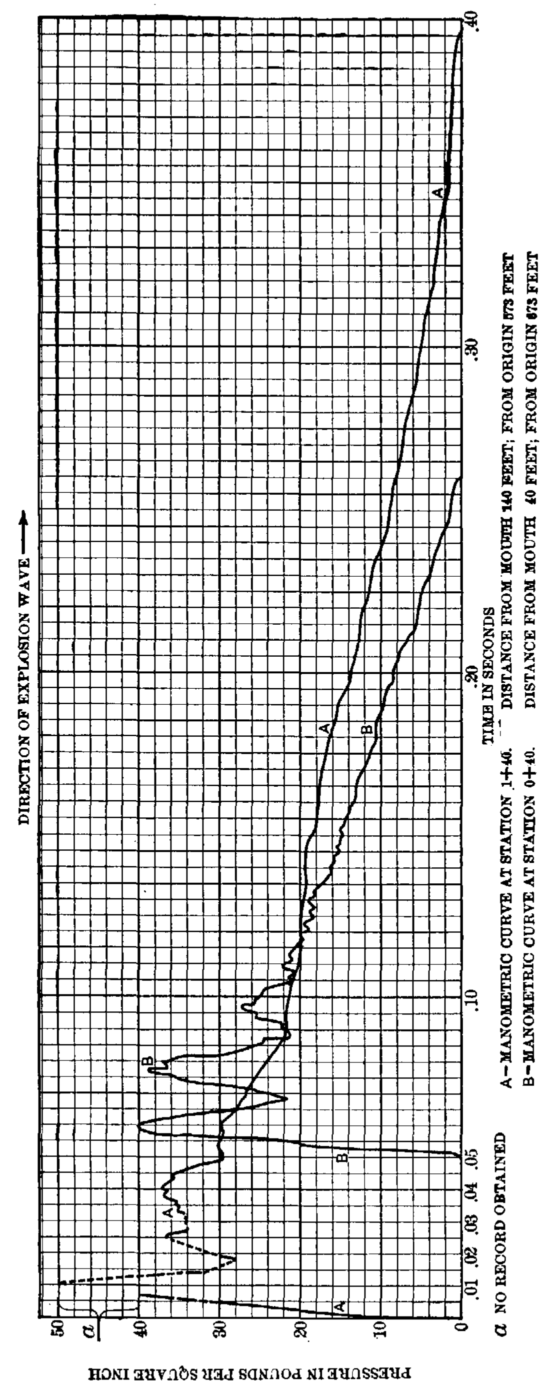
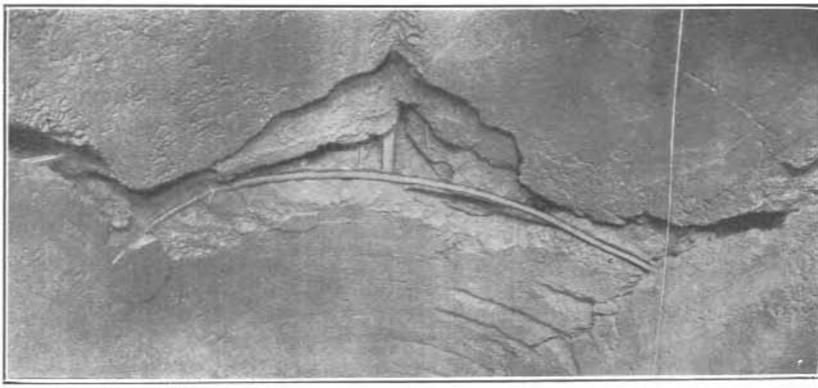


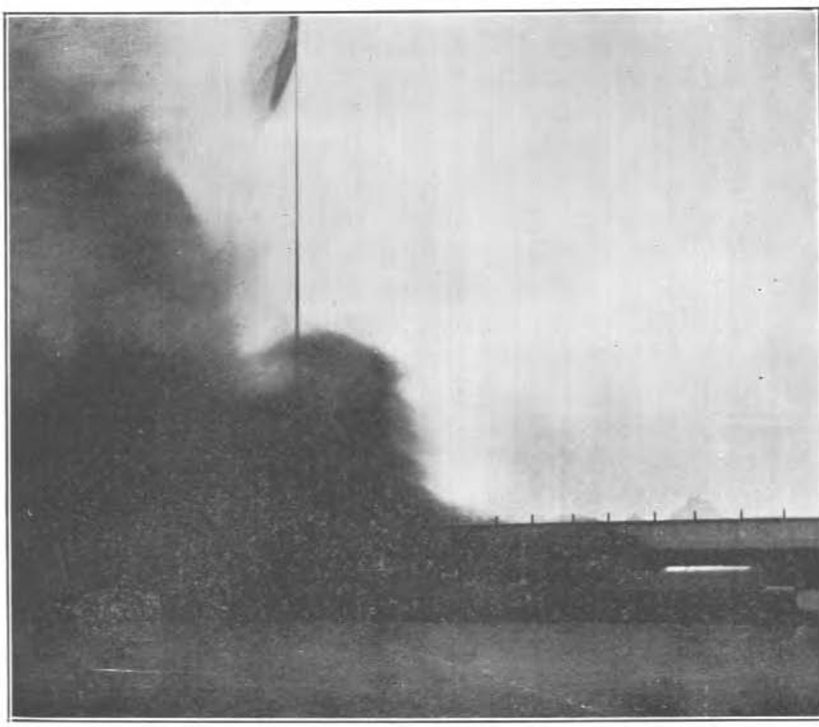
FIGURE 4.—Pressure curves obtained in coal-dust explosion on October 24, 1911, in experimental mine.

but how much higher is not known. The instrument at station 40 indicated a pressure of 44.8 pounds.

The actual pressure may be inferred from the records obtained on October 24, when the conditions were similar to those on October 30, except that only 500 pounds of coal dust was used in the main entry, and the outer 300 feet was not charged with coal dust. It is probable that there was nearly sufficient coal dust carried along by the advance wave to obtain approximately parallel records. A diagram showing the curves obtained by the two manometers is given in figure 4; both curves are platted with reference to the same time intervals. The circuit breakers showed that the explosion traversed the entry from the face to station 140 (573 feet) in 1.52 seconds, and between that and the next station (100 feet) in 0.0513



A. RUPTURE IN ROOF OF MAIN GALLERY, EXPERIMENTAL MINE.



B. COAL-DUST EXPLOSION IN STEEL GALLERY, FORBES FIELD.

second. Therefore, the average velocity of the first distance was 377 feet per second, and between the two stations was 1,948 feet per second. The latter velocity is greater than that reported in the first series of the Altofts experiments, though not so high as that reported in certain tests by Taffanel at the Liévin station.

It is the intention, when additional funds are allotted, to extend the main entry and air course and try more extensive explosions. When the wave movements of coal-dust explosions and the surrounding phenomena have become more thoroughly understood, the succeeding series of experiments will embrace tests of preventive means.

PERSONNEL.

The investigations at the experimental mine are in charge of G. S. Rice, chief mining engineer, assisted by L. M. Jones, mining engineer, and H. C. Howarth, mine foreman. J. K. Clement, physicist, assisted by W. L. Egy, assistant physicist, has charge of the velocity and pressure determinations.

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BY

HERBERT M. WILSON AND ALBERT H. FAY

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