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EXPERIMENTAL ADIT IN THE CHATTANOOGA SHALE

by

Andrew Brown

Unclassified by letter from J H Emme 3/20/56 of 2/29/56

March 1949

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EXPERIMENTAL ADIT IN THE CHATTANOOGA SHALE

by Andrew Brown

PURPOSE

Objectives of the adit in the Chattanooga shale were (1) large (10-15 ton) samples of fresh rock for large-scale laboratory tests, and (2) information on mining conditions.

(1) For more than a year before the adit was driven, extensive surface work was done on the Chattanooga in east-central Tennessee. Numerous outcrop samples, and cores from several drill holes, were taken and analyzed. As results indicated that large subsurface samples were desirable, plans were drawn for an adit 5 feet wide and not less than 100 nor more than 200 feet long, to be driven in the Top Black unit of the shale. A winze from the floor through the entire Upper Black, and possibly even lower, was contemplated, and provision was made for sampling the shale either as a unit or in benches not less than 1 foot in thickness at the discretion of the Government.

Between the first planning and the actual beginning of work the specifications were considerably simplified, and in their final form provided for an adit 100 feet long, 5 feet wide, and approximately 9 feet high, this being the estimated distance between the base of the Top Black Chattanooga and the base of the Fort Payne. The winze was eliminated, and the Top Black sampled as a unit.

(2) Though some stripping operations exist, the Chattanooga, so far as is known, has never been systematically mined underground. Therefore practically no information was available on methods of drilling and blasting it, how it would break when shot, and numerous

other factors such as roof and floor conditions and ventilation problems. The adit was, in short, designed as a laboratory or pilot-plant test preparatory to possible larger-scale mining.

LOCATION

The adit was driven N. 52° E. from the east side of a steep, narrow ravine running about S. 15° E. into Britch Creek, a short tributary of the Caney Fork river in eastern DeKalb County, Tennessee. The ravine drains through a culvert 14 feet below road level under old Tennessee Highway 26, now abandoned as a highway but used as a road to the Center Hill reservoir which now fills the Caney Fork bottom. The ravine afforded sufficient dumping space so that no mucking was necessary across the road. The spot is relatively isolated, though only half a mile east-southeast of the new Sligo bridge on Highway 26. Though off the main travelled routes, the site is easily accessible, Sparta being 16 miles east via Highway 26, Smithville 8 miles west.

The land on which operations were conducted is part of the Center Hill reservoir property owned by the U. S. Army Engineers. The adit is referred to in reports as the "Sligo adit", the name being that of the nearby bridge.

TOPOGRAPHY AND GEOLOGY

The topography in the vicinity of the adit is rugged and the slopes steep (see map, plate 1). The altitude of the upland is between 950 to 1000 feet; that of the original bed of the Caney Fork, about 540 feet. The normal pool level of the reservoir is 648 feet; flood level, 685 feet. The Chattanooga crops out on the slopes at an average altitude of about 800 feet for the top of the formation.

From water level to the base of the Chattanooga the exposed rocks are Ordovician limestones which, being of no interest to the adit operations, are not discussed further. The Chattanooga shale which, for the purposes of this report, includes the overlying Maury green shale, is in this region between 28 and 37 feet thick. It is of Devonian age except for the Nodule layer and the Maury, the former being classed as Devonian or Mississippian, the latter as Mississippian. Overlying the Chattanooga and extending to the top of the plateau is the Fort Payne cherty limestone of Mississippian age.

Chattanooga shale

On the basis of lithology and fossil content the Chattanooga has been divided into a number of well-defined units. These are given below, with thicknesses of each unit at four localities near the adit site: LC-10, the old highway cut 130 feet south of the adit; LC-102, a drill hole 1,500 feet north of LC-10; LC-55, a cut on new Highway 26 about 2,500 feet north-northwest of LC-10; and LC-4, a cut on a country road 1 mile north-northwest of LC-10. (see map, plate 1). As the core from LC-102 was not completely

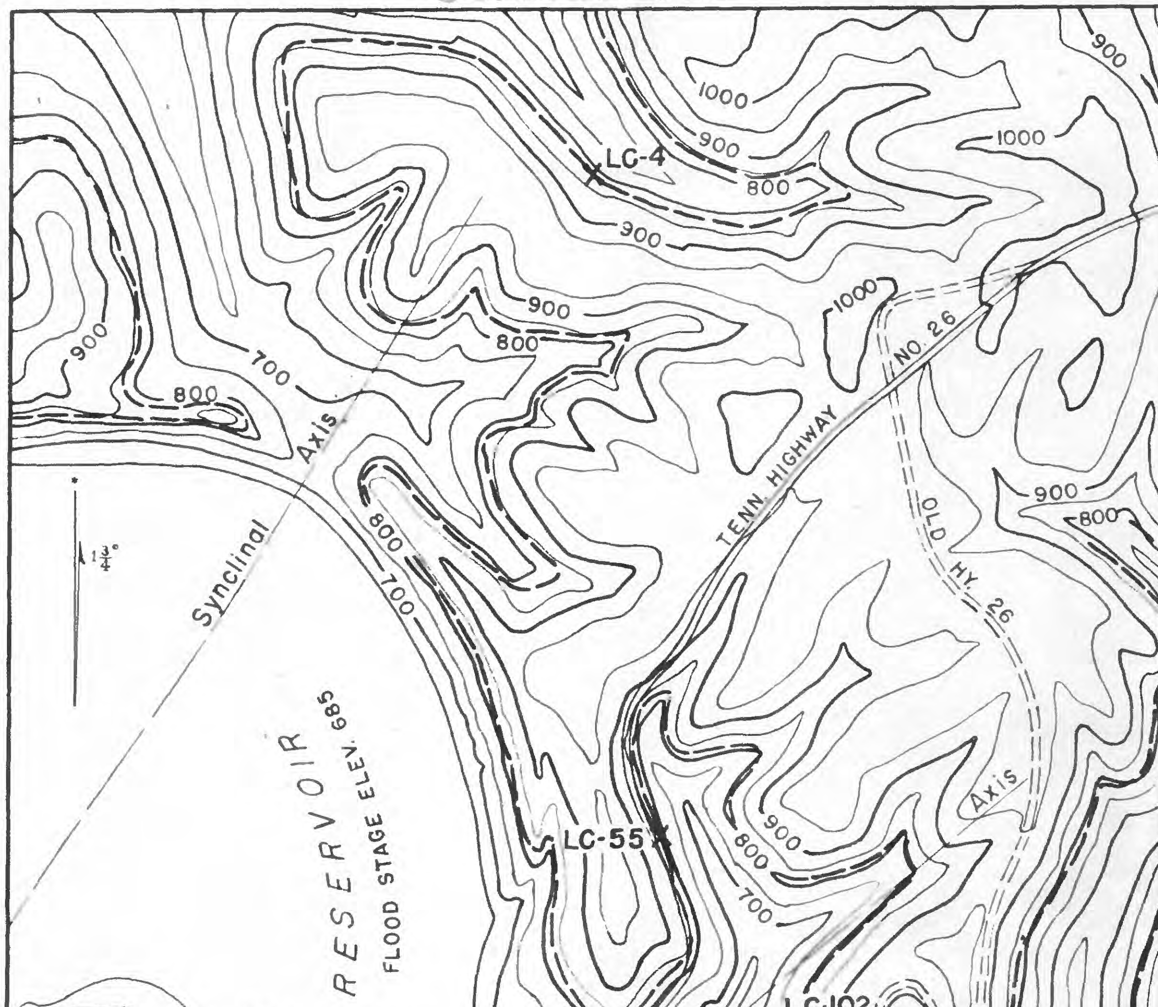

PLATE I

MAP SHOWING VICINITY OF SLIGO ADIT

DE KALB COUNTY TENNESSEE

— — — OUTCROP OF CHATTANOOGA SHALE

1000 500 0 1000 FEET

satisfactory, measurements in that hole, though reasonably accurate, are not as dependable as those from the surface outcrops.

Units of the Chattanooga shale

Unit	Thickness (feet) LC-10	LC-102	LC-55	LC-4	Description
Maury	2.06	2.0	1.8	2.07	Gray shale, weathering to green at outcrops, Usually referred to as "green shale" and so designated in this report. Mississippian age.
Nodule layer	.5	.25	.8	.3	Black shale containing phosphatic nodules. Devonian or Mississippian. Included in Top Black in geologic reports.
Top Black	7.2	5.85	6.8	7.69	Tough blocky black shale. Devonian.
Upper Silt	3.55	2.50	2.1	2.87	Alternating beds of black shale and gray silty shale. Distinct "varved" bed at base.
Middle Black	7.9	7.1	7.7	7.67	Black shale, thinner-bedded than Top Black but otherwise similar.
Middle Grey	9.7	10.36	8.5	9.77	Grey siltstone with a few beds of black shale in top and bottom parts. Bentonite bed in top foot.
Lower Black	4.6	5.74	5.7	6.77	Black shale, much like Middle Black.
Totals	35.51	33.8	33.4	37.14	

Though the adit was designed to obtain samples of the Top Black only, the apparent weakness of the Maury and the Nodule layer made it advisable to remove these units and to use the Fort Payne as a roof. From measurements at LC-10 it was estimated that this would require an opening 9 feet high. Actually the rocks removed were 1.75 feet of Maury, 0.5 foot of the Nodule layer, and 6.25 feet of Top Black, giving a total thickness of 8.5 feet. The floor is the uppermost gray bed of the Upper silt.

The Chattanooga as a whole maintains its 28- to 37-foot thickness with remarkable consistency over large areas, but the individual units vary somewhat from place to place. Normally, though not in the localities listed above, the lower Black shows the widest range. The Nodule layer is also irregular within small areas; but regionally it thickens toward the north and disappears a mile or two south of the adit site.

At weathered outcrops the shale appears thin-bedded and highly fissile, and breaks out in slabs averaging about an inch in thickness. At new exposures such as LC-55 the bedding is less apparent and the fissility is largely lacking; it must therefore be interpreted as a function of weathering. However, a number of persistent bedding planes were noted in the Top Black at LC-55, the most prominent being at 0.75, 1.33, 2.45, 2.8, 3.45, and 5.0 feet above the base of the unit. The same situation exists in the other subdivisions except that the beds are somewhat thinner.

In mining, the major bedding planes helped materially in breaking down the upper part of the unit after the bottom wedge had been shot out. The minor planes disappeared a few feet back of the outcrop and influenced the breaking slightly if at all. Thus the rock broke, not in slabs as might have been expected, but in irregular chunks like those from a massive formation.

Inflammability of the Chattanooga.—It has been stated in the literature that while the black shale will burn if thrown on a hot fire and may in some cases be lighted by a match, it will not support combustion. Experience at the adit site proves that this is not the case.

Facing work was completed Friday afternoon, December 31. A large amount of broken shale had been thrown from the cut into the ravine and a wood fire built on the loose rock. The fire was to all appearances extinguished before the workers left. Weather over the weekend was cold and clear with considerable wind; and when the site was visited Monday morning the loose shale was burning with little flame but much smoke, and was red-hot over considerable areas to depths of several feet. With the help of a heavy downpour which made it possible to divert water from the ravine into the burning rock, the fire was put out after a full day's hard work.

It was thought at the time that this fire was the only one of its kind known. It was learned later, however, that a pile of loose shale on a river bank in west Tennessee had previously caught fire, apparently from spontaneous combustion. It is evident that under certain conditions the shale will burn freely, and this characteristic should be taken into consideration in mining and handling it.

Fort Payne formation

The Fort Payne in the vicinity of the adit is a siliceous limestone containing at the outcrops, and apparently for considerable distances underground, many bands of chert (see photograph, fig. 1). The formation is distinctly bedded, the strata ranging in thickness from 0.3 foot to 2.7 feet. The immediate roof stratum of the adit is 0.5 foot thick.

At outcrops the Fort Payne is normally slumped and broken because of the weakness of the underlying Maury. It was thus necessary to cut back for a considerable distance in order to obtain a good roof for the adit.

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Fig. 1. View uphill from LC-10, showing bedding in the Fort Payne.

Fig. 2. Entrance to adit after completion of work, showing joints in the Chattanooga and Fort Payne.

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Fig. 1. View uphill from LC-10, showing bedding in the Fort Payne.

Fig. 2. Entrance to adit after completion of work, showing joints in the Chattanooga and Fort Payne.

Structure

The regional strike of the Chattanooga and of the underlying and overlying rocks is roughly northeast-southwest, with a dip to the southeast of approximately 30 feet to the mile. Locally, however, the picture is distorted by numerous small rolls, one of which places the adit on a reverse dip. At LC-10 the top of the Chattanooga stands at 800 feet above sea level; at LC-102, at 793 feet; at LC-55, at 820 feet, and at LC-4, at 830 feet. These elevations indicate that the small valley south of the new highway (see map, plate 1) follows the axis of a shallow syncline and this conclusion is corroborated by dips in the rocks exposed on the west side of the reservoir. This syncline, and a similar but deeper one to the northwest, are shown on the map.

The entire Chattanooga, but especially the Top Black, is cut by numerous and well-defined joints. Readings taken at LC-10 and other nearby localities while the adit plans were being made showed that the dominant joints follow roughly the northeast-southwest direction of the strike; that they are approximately vertical; and that they normally extend through the entire thickness of the unit. The minor joints form angles of from 30 to 60 degrees with the dominant set, do not as a rule extend through the unit, and dip at various angles. Neither the major nor the minor joints continue upward into the Nodule layer and the Maury. The former shows little evidence of any jointing; the latter contains numerous joints, but they follow courses different from those in the Top Black or the Fort Payne.

The direction of the adit was chosen to take advantage of the dominant joints, between two of which the facing cut was made.

The Fort Payne contains a number of prominent joints which in general follow the strike as does the dominant group in the Chattanooga. At the back of the facing cut a strong vertical joint transects the limestone about 2 feet inside the left wall, and another weaker joint is about a foot outside the right wall; these joints, and those in the Chattanooga, are shown in the photograph (fig. 2). As the left joint in the Fort Payne was deeply weathered and that on the right relatively tight, the adit was driven from the right side of the facing cut.

Anticipated mining conditions

Construction of the adit was essentially tunneling through flat beds and was not expected to present any unusual problems. It was thought that the floor and roof would be good; that the black shale would stand satisfactorily, but that the green might give trouble. It was therefore to be removed with the black, rather than left standing supported by timbers. To prevent contamination of the samples of black shale by the green, the latter was to be removed ahead of the former at sample intervals.

The narrow width of the adit made the use of a wedge system of drilling impracticable, and a "bottom round" of 12 holes in the black shale only was recommended, the depth of round being 5 feet. The green shale was not to be drilled and shot because it was thought that it would fall if the underlying black was removed. Charges necessary for proper breaking of the shale were to be determined by experiment.

Actual construction showed that the conclusions summarized above, which were included in the "Pertinent data" sent to prospective bidders, were essentially correct except that the green shale proved much stronger than anticipated and certain characteristics of the Nodule layer had not been taken into consideration. These differences led to a number of changes in the method of mining which will be discussed in later parts of this report.

PRELIMINARY WORK OF THE ADIT

Negotiations

The adit was driven for the Survey on a repay basis by the Construction and Maintenance Division of the Tennessee Valley Authority, under the immediate direction of Mr. Ed Tate, Engineer. For the Survey, the work was supervised by Andrew Brown, Mining Engineer. Operations began on December 20, 1948, and were completed February 8, 1949. One shift per day was worked during the preliminary phases. Beginning January 3, 1949, two shifts were employed. Drilling and blasting were done by a night shift consisting of a foreman who was also the powder man, two drillers, a helper, and a mechanic. Mucking and timbering were done by a day shift of a foreman, four laborers, and a mechanic.

The equipment used was excellent, and everything requested was readily made available. As no power lines are within easy reach, electrical current was furnished by two portable generators.

The advantages of the repay basis for experimental work, as compared with the usual type of contract, are many. When plans for the operation were drawn but little information was available on several important factors, such as the depth of rounds, the number and spacing of drill holes, the strength of charges, the amount of timbering required, and other items. Thus no contractor was in position to make an intelligent bid for the work. By working with the TVA it was possible to change the plans to meet the conditions, and to experiment constantly. Because of this, much more information was obtained than could have been the case under a fixed-sum contract; and because the indefiniteness of the specifications

would have forced a contractor to bid high, it is probable that the Government saved a considerable amount by use of the Authority's facilities. In this connection, it would be hard to praise too highly the cooperation received from all echelons of the contractor; everyone from the muckers to the supervising engineers assisted in completing the job efficiently, speedily, and safely.

Under Tennessee mining laws the adit is a Class I mine, the safest type as to material mined. In openings of this classification, no entry may be driven more than 90 feet without cross-cuts, using only fan and blowers for ventilation. The State Mine Inspector, however, has authority to extend the limit and did so in this case so that the adit could reach 100 feet. The Inspector, Mr. J. A. Welch, was most cooperative when consulted about the program.

Facing

The first cut for the face was made on the east side of the ravine, 130 feet north of the old highway. It was 10.5 feet wide and extended 12 feet back of the outcrop. Holes were drilled about 4 feet apart with a maximum depth of 10 feet, and the rock shot down. When mucking was completed it was found that the roof rock was badly broken, and the face was therefore taken back another 15 feet by the same method. Due to lack of experience in blasting the material the holes were overloaded and some undesirable shattering of the shale resulted. However, a good face 25 feet high was obtained 27 feet behind the original outcrop at floor level.

Approximately 130 cubic feet of material, mostly solid rock, was removed from the facing excavation and used to build a platform

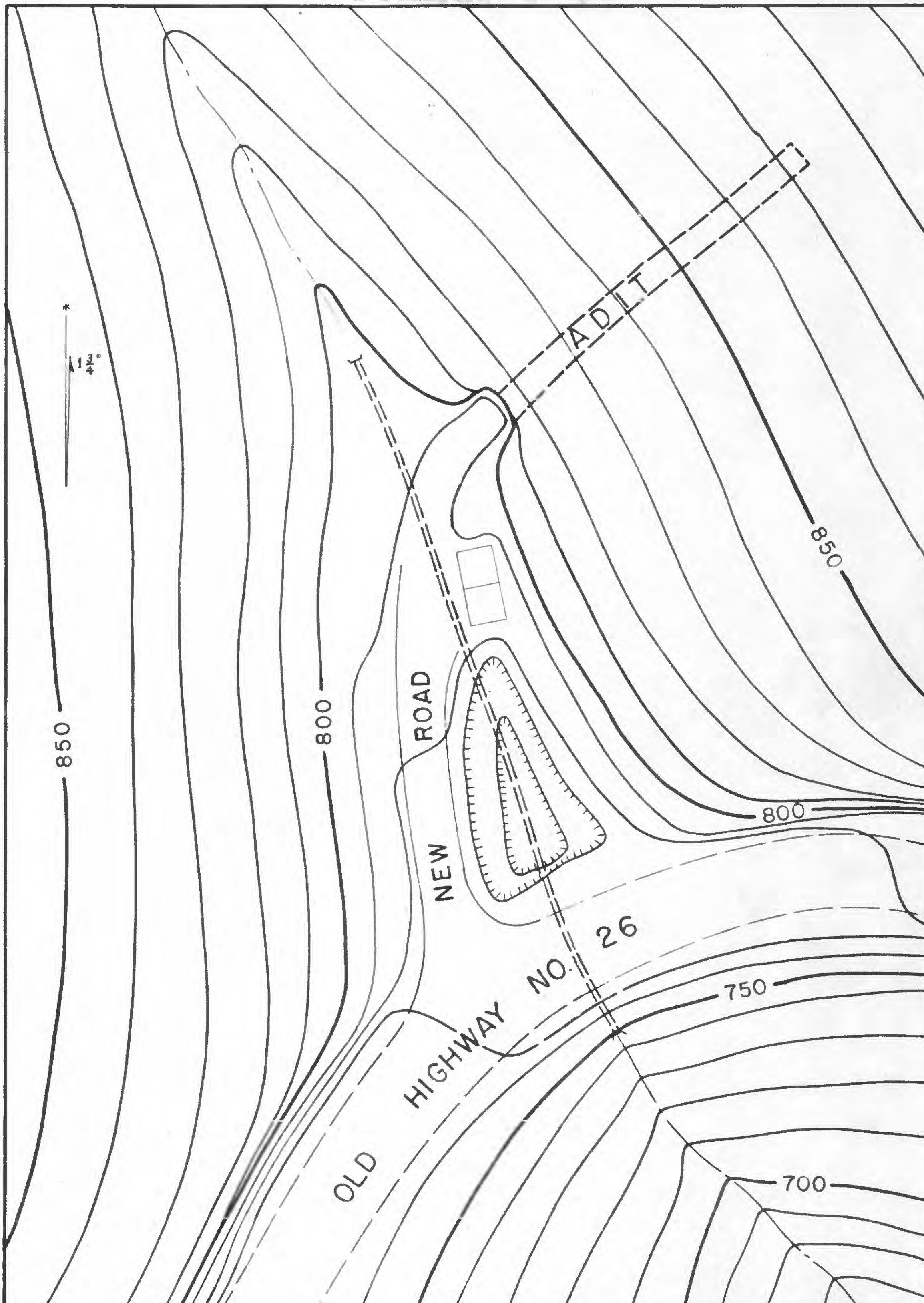

PLATE 2

MAP SHOWING IMMEDIATE VICINITY OF ADIT

50 0 50 FEET

for working space and ore bins (see photo, fig. 3) and to begin a road to the old highway which was later completed with material from the adit itself (see photo, fig. 4). The ravine was filled for a distance of 60 feet, drainage being maintained through a 15-inch corrugated iron culvert. As the highest part of the platform is about a foot higher than the adit floor, another culvert was installed to take care of drainage from that source. The immediate vicinity of the adit is shown on the map (plate 2).

Fig. 3. View of facing cut for adit, and one of the ore bins. Photograph taken January 24, 1949.

GENERAL DESCRIPTION OF ADIT

The adit was driven from the right side of the facing cut following the joint on that side, which persists for 25 feet underground. At that point it is broken by a cross-joint trending almost due north; this in turn is cut 30 feet from the portal by another longitudinal joint which forms the left wall of the adit for 42 feet. At 72 feet from the portal it is transected by a second cross-joint which trends S. 65° E. and is cut at 76 feet by a third longitudinal joint which forms the right wall to the full depth of the adit. Thus the opening as completed has a joint face as its right wall for the first 25 and the last 24 feet, and as its left wall for 42 of the middle 51 feet. For 8 feet (42 to 50) both walls are joint faces. The situation is shown on the Plan and Profile (plate 3), which also shows the timbering, the beds removed in each part of the opening, and the depths from which the large samples were taken.

All the longitudinal joints curve slightly; those on the right side to the left, that on the left side to the right. In addition, the joints curve back slightly where they meet the cross joints. As a result the adit is not straight; a line drawn N. 52° E. from the left side of the portal is at the center of the opening at 30 feet, within a foot of the right side at 52 feet, 2 feet from the right side at 80 feet, and in the right corner at 100 feet (plate 3).

The two cross joints mentioned above resemble the dominant longitudinal joints in that they are approximately vertical and extend through the entire Top Black. Numerous minor joints were encountered, cutting across the adit at various angles and usually sloping toward the front. Some of these caused considerable trouble in mining; if a hole was drilled a foot or so back of one of them,

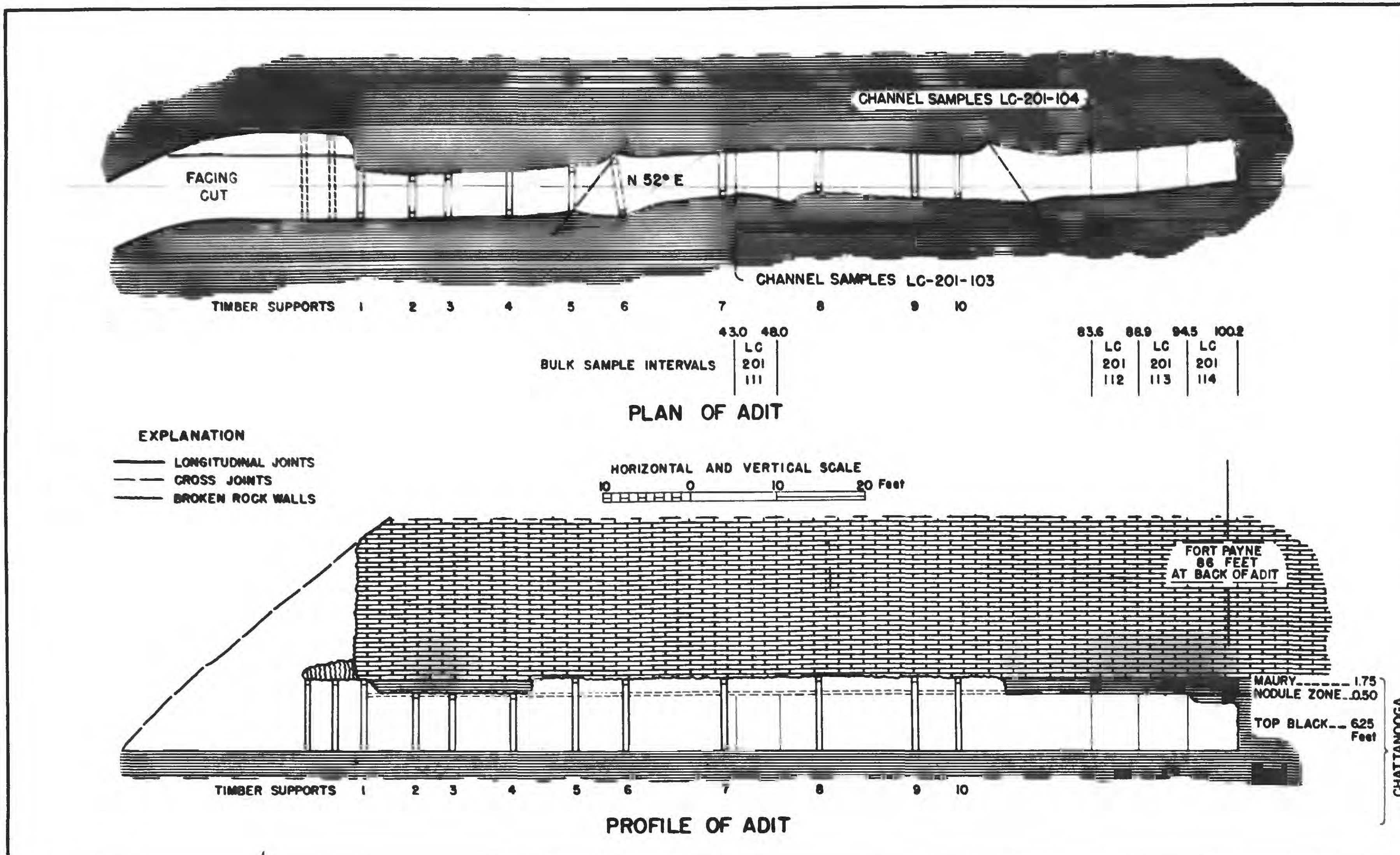

PLATE 3

PLAN AND PROFILE OF SLIGO ADIT, DE KALB COUNTY, TENNESSEE

the rock in front of the joint usually broke out, but that behind was little affected and had to be either re-shot or taken out with the paving breaker. These minor joints did not, so far as could be ascertained, extend throughout the entire unit, and none of them had any apparent influence on the dominant joints.

The joint system influenced the width of the adit, which for most of its length is from 5 to 5 1/2 feet wide. Where the main cross joints meet the longitudinal joints, the effect is considerable widening due to the rock breaking out of the angle. Thus the width at 30 feet is 7 1/2 feet, and at 72 feet 6 1/2 feet. In addition, divergence between joint faces increased the width from 5 feet at the 42-foot depth to 6 1/2 feet at 49. This additional width was responsible for the exceptionally large sample, LC-201-111, taken from 43 to 48 feet.

Bedding planes

Joint faces exposed in the adit show two prominent and persistent bedding planes, one 0.5 foot above the base of the Top Black, the other 0.65 foot below the top. Breaks less prominent, but strong enough to assist in bringing down the shale, are at 3.0 and 4.75 feet above the base. A number of minor bedding planes are visible, but they do not persist and apparently have little influence on fragmentation of the rock.

Casual inspection leads to the belief that the stronger bedding planes in the adit may be correlated with those at LC-55. However, the matter has not been studied sufficiently to justify a definite statement.

Adit walls

The walls of the adit, from the floor to the top of the Top Black, appear to be strong both on joint faces and in the rough shale. A few blocks may fall out of the rough walls after a few months, but this is doubtful as they were carefully scaled after each round. It is reasonable to expect that the black-shale part of the walls will stand for a long time without need of lagging or other protection.

The stability of the green shale is less certain. Shales much like the Maury give considerable trouble in many coal mines, and may be expected to fall in time. For this reason most of the roof supports rest either on the floor or on the top of the black shale; although in one support the crosspiece is set into a notch in the Maury for experimental purposes.

Nodule layer

The presence at the base of the nodule layer of a 1- to 2-inch bed of tough black shale, without nodules, was of great assistance in taking the large samples. The bed is separated from the Top Black by a quarter to half an inch of thin, weak beds, and from the Maury by about 4 inches of phosphatic nodules in a matrix of black shale. When it became apparent that the Maury could be removed ahead of the black shale only with great difficulty, an experimental round (no. 9) was blasted, in which the top row of holes was drilled horizontally 8 inches below the top of the Top Black, with the purpose of breaking down the black shale up to the strong bed in the nodule zone. Inspection at this point, and later in the back 16.3 feet of the adit, showed that this bed is uniform, apparently without joints and certainly not affected by the joints in the Top Black, and that it

makes a much stronger roof than its thickness and position would indicate. Therefore the last three rounds (63.6 to 100.2 feet) were shot under it and it was left standing without support for future study. It is worthy of mention that the blasts from the last two rounds did not appear to weaken it. It is not known whether this bed is persistent or is confined to the vicinity of the adit. If it does persist, it could be most useful in future operations.

ADIT-DRIVING OPERATIONS

Drilling

Equipment.—The major drilling equipment consisted of a Worthington compressor, a Gardner-Denver drifter, a jackhammer, a paving breaker, and a jumbo or "tunnel jack" with two columns and a bar. The width of the adit precluded the use of the columns and the bar alone, supported by notched timbers of varying heights for the different rows of holes (see photo, fig. 6) was used for all holes except the bottom row. The angles of the holes were fixed by wooden wedges laid on the drill steel and levelled. The bar was placed 3 feet behind the face to permit maximum travel of the drifter; and drill steel was changed every 2 feet, a necessity which slowed down the drilling and should be improved in future work.

Because of space limitations, the drifter was not used for the bottom row of holes, which were drilled with the jackhammer. Some loss in accuracy undoubtedly resulted, but in the later rounds in particular no bad results were noted.

Standard 4-way steel bits were used in early drilling, but did not give satisfactory footage and were replaced during the last half of the work by bits of tungsten carbide which were excellent in every respect.

Drilling pattern.—As stated previously, the basic drilling pattern was a standard "bottom round" designed to throw out a wedge at floor level and drop the higher beds. The plan suggested in the "Pertinent data" called for four rows of three holes each in the Top Black only, as it was thought that the Maury would fall of itself. A later provisional round (see plate 4) provided for five rows of four holes each, all in the Top Black. Horizontal spacing between holes

Fig. 5. Smoothing face with paving breaker, January 24, 1949.

Fig. 6. Face of adit at 58.5 feet, showing drifter, bar, and supports. White paint lines show locations of lines of holes. Note joint face on left. January 24, 1949.

was 16 inches, and it was expected that the rock would break about 6 inches from the outside holes. The bottom holes were 6 inches above the floor; the wedge holes 36 inches above the floor at the face, 12 inches at the back. The angle of the wedge was 25°, the depth of round, 5 feet.

When the prominent bedding planes exposed in the face were examined, it was decided that four rows in the black shale, rather than five, would be sufficient to break out the rock; the plan was therefore changed to that shown as Round 1 (plate 4). The wedge angle was unchanged, but the top row was drilled 2 inches below the Nodule layer, the first reliever halfway between the wedge and top rows. This pattern gave such good results in rounds 1 and 2 that the number of holes to the row was decreased in round 3 to three with 24-inch spacing. The wedge did not shoot out as well as expected, though this may have been due to errant drilling, a too-light charge, or a combination of both. For round 4, four holes to the row in the bottom and wedge rows, and three holes to the rows above, were used. As it had become obvious by this time that the green shale would not fall of itself, two angle holes were drilled into it. For all later rounds except rounds 9 and 10 where the green shale was taken out behind the black; and rounds 18, 19, and 20, where it and the nodule layer were left standing, the green and black shales were drilled and blasted together. It was found that angle holes in the Maury were not satisfactory, best results being obtained by three holes drilled horizontally 6 inches below the roof.

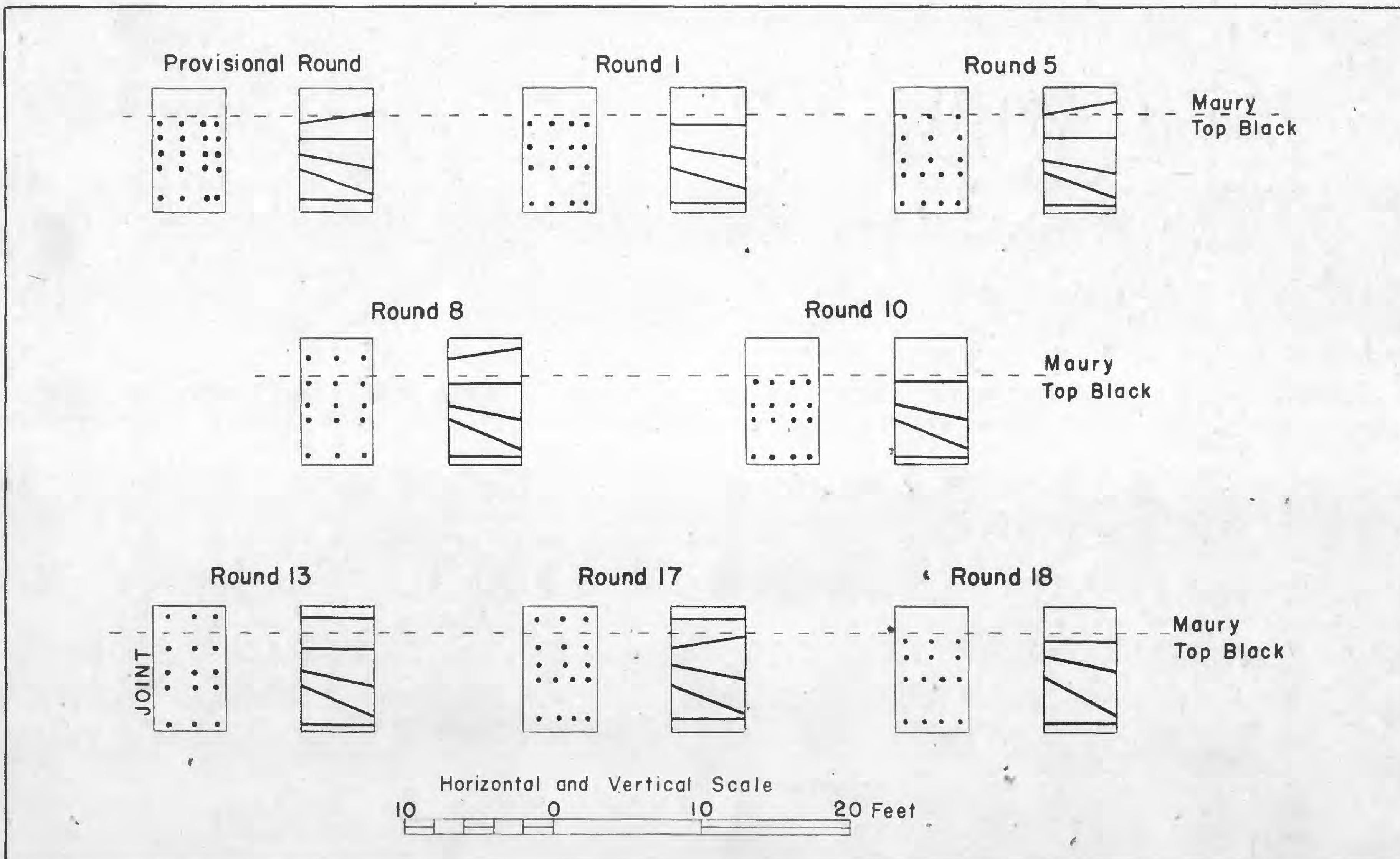

Plate 4

Front and Side Views of Hole Patterns in Sligo Adit

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The combination used for round 4 gave such good results that it was used thereafter except for the first sample shot (round 10), where four holes to the row were used throughout for better fragmentation; and under conditions such as those in round 13 where a joint on one side helped to break out the rock. Under such conditions the first line of holes was drilled 12 inches from the joint, spacing of the others being 21 inches.

Partly as an experiment, and partly to speed up work, the 5-foot depth of round was increased to 6 feet for rounds 9 and 11, and all later shots. This involved decreasing the angle of the wedge from 25° to 20°, which was not satisfactory. To correct this, and to speed drilling by eliminating two bar changes, the system shown in round 17 was devised. All holes except the top and bottom rows were drilled from one bar set-up and the wedge angle was brought back to 25°. Results were most gratifying, and the pattern was used thereafter with certain changes made necessary by the decision to leave the nodule layer and the green shale standing.

The change in the depth of round from 5 to 6 feet was not an unqualified success, indicating that the old rule that the depth of round should not exceed the narrow dimension of the opening is still a good one. The well-shot 5-foot rounds took out the full 5 feet, whereas none of the 6-foot rounds quite reached that depth. This is true despite the fact that the 6-foot rounds were, on the average, more accurately drilled, and blasted with better-balanced charges, than the shorter shots.

Speed of drilling.—The fastest drilling was 36 feet per hour, made with the jackhammer during one of the earlier rounds. This was something of a test run and was not typical. It also included no time for changing the bar, a time-consuming factor when the drifter was used.

Due to constant experimentation drilling speed figures for earlier rounds have little meaning beyond the fact that it ordinarily took from 6 to 8 hours to drill a round. Two later rounds which were fairly typical were rounds 13 and 17 (plate 4). Round 13 involved 15 holes, 93 feet of drilling, four changes in the bar setup, and three jackhammer holes. Total drilling time including changes was two or three minutes under 6 hours, giving a speed of 15.5 feet per hour. Round 17 involved 17 holes, 108 feet of drilling, but only two bar setups, and three jackhammer holes. Total time was 6 1/2 hours at a speed of 16.3 feet per hour.

Numerous observations were made of the actual cutting speed, ignoring bar changes and other delays, these show that the black shale was cut at the rate of about 30 feet per hour, the green at from 35 to 40 feet. The drillers were capable, and pushed the drills to reasonable capacity without "fighting" them. Considering the actual cutting speed, and the fact that the bar as used was cumbersome and hard to move and that the drill steel was changed every two feet, it appears likely that with a suitable jumbo setup the overall drilling speed could easily be raised to at least 20 feet per hour.

Bit footage.—One of the surprises of the work was the behavior of the standard 4-way steel bits, which drilled an average of only 2 feet. Although the teeth showed no signs of wear after this footage, the gauge was destroyed. Two tungsten carbide bits, a

chisel and a 4-way, were then brought in. The insert in the chisel bit broke after 48 feet; in addition, the bit was quite difficult to withdraw. The 4-way bit drilled 138 feet before breaking at the collar, at which time the gauge was unimpaired and the teeth still good. Tungsten carbide bits were therefore used exclusively for the remainder of the drilling. Footages are not available because the job was completed before any of the later bits reached the 138 feet obtained from the first.

Dust conditions.—To about 18 feet, dust from drilling operations was black and not too troublesome, though all men working in it were required to wear respirators. Beyond this point it was brown rather than black, extremely thick, and somewhat greasy. Even when aided by an air line from the compressor the fan did not move it adequately. A water jacket was accordingly attached to the drill, and for rounds 16 and 17 the dust was held to reasonable limits. Trouble then developed with the valve in the jacket, and the drillers preferred to complete the three remaining rounds without water rather than wait for repairs. Thus, water was used only enough to show that it should be used at all times.

A sample of the shale ground to minus 200-mesh was tested for explosibility by the U. S. Bureau of Mines laboratory at Pittsburgh. The complete report is given in the appendix and may be summarized by saying that "in the presence of open lights or other strong igniting sources, dust clouds of the shale can be ignited and mild explosions might result. Therefore normal precautions should be taken, such as prohibition of the striking of matches or smoking, and of the use of welding or similar equipment in locations where

the dust is dispersed in air."

No complete analyses of the shale are available, but one of the principal constituents is silica which, according to some reports, may comprise as much as 50 percent of the rock mass, of which 20 percent is microcrystalline quartz. Petrographic examination of the shale by the Health Branch laboratory of the Bureau of Mines indicates the following composition:

Constituent	Estimated percent
Quartz	30
Brown shale	45
Muscovite and sericite	10
Carbonate	2
Opaque	10
Unidentified	3

As the material contains about 30 percent free silica according to this analysis, and comparable amounts by other reports, wet drilling and handling methods are clearly indicated.

Blasting

Explosives used.--The only previous information available on the best type of explosive for black shale was that 45 percent semi-gelatin had been found most satisfactory in the shales of the Colorado plateau. When the contractors began work at Sligo, they brought only 60 percent gelatin and this was used for the preliminary work and for the first five rounds.

Electric detonators were used, with a system of delays utilizing no. 0 delays for the bottom and wedge row holes, no. 1's for the first reliever holes, no. 2's for the top holes in the black, and no. 5's for holes in the green. The use of the no. 5's instead of no. 3's was due merely to the fact that the 5's were readily available

whereas the 3's were not.

For the first two rounds, 36 sticks of 60 percent gelatin were used. Fragmentation was poor, with the extremes of many large boulders and much fine dust. Accordingly in round 3 the charge was reduced to 19 1/2 sticks, which proved entirely too light; fragmentation was poor, and the toe had to be re-shot. For the next two rounds the charge was increased to 25 sticks with only fair results, and it began to be apparent that reports that fast explosive "shot like a gun" out of the Chattanooga must have some basis in fact. Therefore, in round 6, 40 percent gelatin was substituted for the 60 percent and used in all later rounds. Rounds 7 and 8 were underloaded, but the 30 sticks used in the black only for round 9 (a test shot for sample round 10) gave good fragmentation and the round (a 6-foot one) was satisfactory in every respect except that it was a little short. In general, the same charge was used for later rounds except that the loading of the wedge and bottom holes was increased to 3 sticks. An exception was the second sample round (no. 16) where the first reliever holes were loaded with 3 sticks for better fragmentation. No improvement was noted and the practice was not continued.

As the weather during the adit-driving operations was unusually warm for the season, the dynamite was not adequately protected against the few sudden cold snaps. Only once was it actually frozen, on the night of February 1. Round 17, drilled that night, was not shot until the next day for that reason. But in a number of other rounds the explosive was apparently too cold for maximum efficiency. These rounds are listed in the table of data on drilling and blasting (see page 24).

DATA ON DRILLING AND BLASTING, ADIT IN CHATTANOOGA SHALE

Date 1949	Round no.	Depth drilled	Advance	From	To	Hole pattern a	Loading pattern b	No. of holes Bk	No. of holes Gn	No. of holes Tot	No. of sticks Bk	No. of sticks Gn	No. of sticks Tot	Remarks
1- 4	1	5.0	5.2	0.0	5.2	4 4 4 4 0	3 3 2 1 -	16	0	16	36	0	36	60% gelatin rounds 1 to 5. Rock broken by facing shots. See fig. 4. Took out Top Black and nodule zone.
1- 6	2	5.0	5.0	5.2	10.2	4 4 4 4 0	3 3 2 1 -	16	0	16	36	0	36	Took out Top Black and nodule zone. Shot too heavy; much dust and large pieces of rock.
1- 7	3	5.0	5.0	10.2	15.2	3 3 3 3 0	2 2 1⅓ 1 -	12	0	12	19½	0	19⅓	Took out Top Black and nodule zone. Underloaded; had to reshoot toe.
1-10	4	5.0	4.8	15.2	20.0	4 4 3 3 2	2 2 2 1 1	14	2	16	25	2	27	Rock much tougher and dust browner. Angle holes drilled in green, which fell from 19 feet back only.
1-11	5	5.0	5.5	20.0	25.5	4 4 3 3 2	2 2 2 1 1	14	2	16	25	2	27	Holes off line, poor shot. Face reshot, hence extra depth. See fig. 4.
1-12	6	5.0	3.2	25.5	28.7	3 3 3 3 3	2 2 2 2 1	12	3	15	24	3	27	60% gelatin in wedge holes, 40% in others. Holes off line, top holes entered roof. Misfire right side. Worst round.
1-13	7	5.0	4.5	28.7	33.2	3 3 3 3 3	2 2 2 2 1	12	3	15	24	3	27	40% gelatin in this and later rounds. Powder cold; toe had to be reshot.
1-14	8	5.0	4.8	33.2	38.0	3 3 3 3 3	2 3 2 2 2	12	3	15	25	6	31	Good round. Green shot fairly well from angle holes. See fig. 4.
1-17	9	6.0	5.0	38.0	43.0	4 4 4 4 0	2 2 2 1⅓ -	16	0	16	30	0	30	Test for sample, shot under hard bed in nodule zone. Good shot but short.
1-18	9A	6.0	5.0	38.0	43.0	0 0 0 0 3	- - - - 6	0	3	3	0	6	6	Took out green for sample shot.
1-19	10	5.0	5.0	43.0	48.0	4 4 4 4 0	2 2 2 1⅓ -	16	0	16	30	0	30	Sample LC-201-111 shot under hard bed in nodule zone. Good shot but widened to 6½ feet at 48 because of joint on right. See fig. 4.
1-20	10A	5.0	5.0	43.0	48.0	0 0 0 0 3	- - - - 6	0	3	3	0	6	6	Took down green after sample shot.
1-21	11	6.0	5.3	48.0	53.3	3 3 3 3 3	2 3 2 2 2	12	3	15	27	6	33	Struck bad set of joints; toe reshot.
1-24	12	6.0	5.2	53.3	58.5	4 4 3 3 3	2 3 2 2 2	14	3	17	32	6	38	Continued bad joints. Toe reshot.
1-25	13	6.0	5.5	58.5	64.0	3 3 3 3 3	3 3 2 2 2	12	3	15	30	6	36	Good round. Toe shot out well. See fig. 4.
1-26	14	6.0	2.5	64.0	66.5	3 3 3 3 3	3 3 2 2 2	12	3	15	30	6	36	Cold powder responsible for shortage.
1-27	15	6.0	5.5	66.5	72.0	3 3 3 3 3	3 3 2 2 2	12	3	15	30	6	36	Excellent round.
1-28	16	6.0	5.8	72.0	77.8	3 3 3 5 3c	3 3 2 2 2	14	3	17	34	6	40	Note 2 extra holes in Black; good round.
2- 1	17	6.0	5.8	77.8	83.6	4 4 3 3 3	3 3 2 2 2	14	3	17	36	6	42	Changed drilling plan; see fig. 4. Excellent round.
2- 3	18	6.0	5.3	83.6	88.9	4 4 3 3 0	3 3 3 2 -	14	0	14	39	0	39	Sample LC-201-112. Excellent shot.
2- 4	19	6.0	5.6	88.9	94.5	3 3 3 3 0	3 3 2 2 -	12	0	12	30	0	30	Sample LC-201-113. Hard bed in nodule zone left standing back of 83.6. Excellent round.
2- 7	20	6.0	5.7	94.5	100.2	3 3 3 3 0	3 3 2 2 -	12	0	12	30	0	30	Sample LC-201-114. Top holes drilled low to leave upper bed of Top Black standing (see fig.10) Bed stood but shattered badly; otherwise excellent round.

a Number of holes per horizontal row, from floor up. The figures can be understood from the plans given in figure 4.

b Number of sticks of dynamite per hole in each row, from the floor up.

c Third row originally drilled low; two holes added 0.5 foot above.

Fragmentation.—After the first few rounds fragmentation of the shale was satisfactory. The average diameter of the pieces was less than 6 inches, and few lumps larger than 1 foot in any dimension were broken out. The proportion of fines was not excessive. The rounds as shot down could have been handled by mechanical loaders with little or no preliminary breaking.

Rock broken per pound of explosive.—Overall figures based on the total tonnage of rock broken out and the total amount of explosive used do not have much meaning because of constant experimentation in the earlier phases of the work. Therefore only blasting done after the program was stabilized will be considered.

When the green and black shales were taken out together, the rock moved per round averaged about 255 cubic feet or about 9 1/2 yards. The number of holes per round was 15 or 17; the total footage of holes 93 to 108; and the number of sticks of 40 percent gelatin, 36 to 42 with an average of about 38. Thus a quarter of a yard was broken per stick, or 0.63 yard per pound of explosive. As the shale weighs about 140 pounds per cubic foot, about 1.2 tons of rock were broken per pound of powder.

Additional information on each round is given in the table of data on drilling and blasting.

Mucking

Though original plans contemplated machine mucking, no loader was available at the time work was started. Mucking was therefore done by a crew of four men, two of whom shoveled while two handled the wheelbarrows (see photos, figs. 7 and 8). The gray shale floor was smooth and easy to work from. The haul ranged from about 50 feet

Fig. 7. View at 58.5 feet showing mucking operations. January 24, 1949.

Fig. 8. Removing rock from adit, showing portal, fan, and tubing. January 24, 1949.

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at the beginning of the job to about 200 feet at the end, when the material was used to build a road to the old highway.

The day shift had no difficulty in clearing out each round and doing necessary timbering within their 8 hours. It would have been possible for the same crew to have moved 25 to 50 percent more rock than they did; in short, they could have cleared material from an adit 7 or 8 feet wide instead of 5 feet had that been necessary. This contrasts with the drilling shift, which was pushed on occasion to complete its drilling and shooting without overtime.

Ventilation

A 36-inch exhaust fan was used for ventilation (see photo, fig. 8). The tubing was 15-inch corrugated iron culvert material which happened to be readily available. Though not completely tight, it served fairly well. Beyond 40 feet, the fan was supplemented by an air line from the compressor to the face. With this combination ventilation was not a serious problem except when drilling was actually in progress. The difficulty of removing drilling dust has been discussed above.

Timbering

Although the specifications permitted the use of green or untreated timber for supports, it became apparent in the early stages of the work that more durable supports would be advisable in case future inspection and study of the adit were contemplated. Therefore all timbers actually used from the portal back were white oak crossties, 6 x 8 inches or 8 x 8 inches in size (see photo, fig. 9). Not only are such timbers stronger, but they were handled

Fig. 9. View of adit from portal, showing tubing for ventilation, and timbering. January 24, 1949.

Fig. 10. Back of adit, February 8, 1949. Note joint face on right, and bed in Top Black left standing in back. The roof is the hard bed in the nodule layer.

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more easily than round timbers could have been.

Timbering problems were not expected to be, and were not, serious. The opening being narrow and the roof as a whole solid, the adit contains more timbering than is actually needed except for the front 18 feet where the green shale was left in place, and at 63 and 66 feet, where the roof is weak because of penetration by drill holes. The rear 32 feet has no timbering whatever.

The adit contains, including the portal, 10 supports. Only three of these—nos. 2, 6, and the portal itself— are supported from the floor at both sides. Others are supported from the floor at one side, and from notches in the green shale or the nodule layer at the other side. In some cases blocks resting on the Top Black are used to raise the cross pieces (nos. 5, 8, and 10). Different beds were used deliberately for support, to give opportunities for observing their action under load. For each support three or four pairs of wedges were driven between the crosspiece and the roof, care being taken to leave them not much more than hand-tight.

The spacing and general plan of the timber supports is shown in the Plan and Profile (plate 3). They are listed below, distances being measured from the front of the portal to the front of the support.

Data on supports

Frame no.	Distance	Method of support: Right side	Method of support: Left side	Roof rock
1 (portal)	0	Floor	Floor	Fort Payne
2	5.4	Floor	Floor	Maury
3	10.4	Top Black; notch in nodule layer	Floor	Maury
4	17.4	Floor	Top Black; notch in nodule layer	Maury
5	24.3	Nodule layer; notch in Maury	Floor	Fort Payne
6	30.1	Floor	Floor	Fort Payne
7	41.0	Floor	Nodule layer; notch in green	Fort Payne
8	52.0	Floor	Maury; notch in top part of Maury	Fort Payne
9	63.5	Floor	Top Black; blocked up to roof	Fort Payne
10	68.0	Floor	Top Black, as (9)	Fort Payne

Floor supports were used normally on the side opposite the joints, no. 2 being the only exception; on the jointed side, support was on the Top Black or higher beds. As the sides of the adit opposite the joints are irregular, advantage was taken of depressions to place the posts with the idea both of saving room and of protecting the timbering from blast damage.

Drainage

As the adit is essentially level, drainage presented no serious problems. A ditch about 6 inches deep took care of all water back to the 40-foot mark, and its extension to the back would have drained all the water from the opening. This was not done because the decision to leave the last round shot down in the adit for future sampling purposes made additional ditching impracticable. Hence some water will stand in the back during wet seasons, but it should cause only slight inconvenience.

Sampling

The locality number of the adit, for sampling purposes, is LC-201. Large samples of about 12 to 17 tons of the Top Black were taken from four rounds, as follows:

Sample number	Location
LC-201-111	43-48 feet
LC-201-112	83.6-88.9 feet
LC-201-113	88.9-94.5 feet
LC-201-114	94.5-100.2 feet

Samples LC-201-111 and LC-201-112 were loaded from the adit into ore bins before being shipped on February 9 and 10, 1949. About 5 to 6 tons of -111 remains in the bin. Sample LC-201-113 was loaded directly from the adit and shipped February 11. The last sample, LC-201-114, was left inside for future availability, it being considered that it would be subject to less leaching there than in a bin.

Smaller samples were also taken from the adit, as follows:

LC-201-101, LC-201-102	20-pound grab samples from 43-48 foot round.
LC-201-105, LC-201-106	20-pound grab samples from 83.6-88.9 round.
LC-201-103	80-pound channel sample from right side of adit at 43 feet, split into four samples and shipped.
LC-201-104	60-pound channel sample from left side of adit at 84 feet, split into three samples and shipped.

Samples were also taken near the portal of the roof rock, the green shale, and the black shale. These were sent to Columbia University for strength tests. Each was about 6 x 12 inches and about 2 inches thick except for the roof sample, which included the entire 6-inch thickness of the immediate roof stratum.

The method of taking the large samples beneath the solid bed in the Nodule Layer has been discussed.

CONCLUSIONS AND RECOMMENDATIONS

Drilling

In the observations below, a width of opening of 5 feet, and depths of round of 5 or 6 feet, are assumed.

(1) Where no longitudinal joints are present, the rock breaks about 6 inches from the outside holes. Where such joints are present, the distance may be increased to 12 or 15 inches and probably farther. In such circumstances the force of the blast extends to the joint but not beyond it unless the hole penetrates that far.

(2) Best results are obtained by spacing the holes in the bottom and wedge rows not more than 21 inches apart. For higher holes 24-inch spacing is ample and this could probably be increased to 28 or 30 inches. The width of the adit prevented experimentation with the wider spacing.

(3) The green shale is much tougher than surface exposures would indicate. In particular, it lacks the strong bedding planes which help in bringing down the Chattanooga. Angle holes, used at times to avoid changes in the bar set-up, are not satisfactory; the shale was best brought down by three holes drilled horizontally 6 inches below the roof.

(4) The wedge angle should be not less than 25 degrees.

(5) The use of water in drilling should be mandatory, and until the dust hazard is definitely eliminated respirators should be worn by all personnel.

(6) Tungsten carbide or similar bits only should be used. Steel bits are not satisfactory because of rapid loss of gauge.

Blasting

(1) The only explosives used in the adit work were 60 percent and 40 percent gelatin dynamite. The former blew large holes in the rock rather than breaking it up properly; the latter gave good fragmentation under varying conditions of drilling and loading. Its use is therefore recommended pending further study of the best explosive for breaking the shale.

(2) Bottom and wedge holes should be loaded rather heavily. If this is done and the toe is thrown out properly, the higher beds can be dropped with relatively light charges provided a suitable system of delays is used. The charges actually used in the higher holes in the adit could probably have been reduced with no loss of efficiency.

Ventilation

The only major equipment which gave trouble was the fan and the tubing used for ventilation. The fan went out of commission on two occasions and the tubing, being abandoned culvert material, was not tight at the joints and reduced the pulling power of the fan. Some at least of the trouble with dust was chargeable to this combination. In future work the ventilation system should be given more attention than it received in the adit work.

Drainage

The black shale as a whole is tight and water does not seep into it appreciably. The floor of the adit is therefore relatively tight and holds most of the water that accumulates on it. Seepage from the roof was never serious, though the adit was driven in a wet season.

Because of the structure of the Chattanooga, it is almost certain

that any sizeable opening in the shale will encounter rolls which will make a certain amount of pumping necessary.

Roof conditions

The Fort Payne is not cavernous in the usual sense of the word, and weak roof areas due to solution cavities are most unlikely. The formation is, however, cut at the outcrops by numerous strong joints which under light cover may continue for long distances underground. Percolation through these joints might well result locally in a weak roof. Aside from this possibility, the Fort Payne in general makes a good roof except near the outcrops, where it is likely to be broken because of slumping of the underlying Maury. The behavior of the latter underground is at present only imperfectly known, but inspection of the adit in the future will give much useful information. The green shale shows many signs of being a poor roof rock.

South of the adit area the Fort Payne is locally separated from the Chattanooga by greenish crinoidal limestones ranging, where seen in the black shale investigations, from 10 to 37 feet thick. The beds in this member appear to be somewhat thicker than those in the Fort Payne, and the rock, though not cherty, is highly siliceous. This indicates that it is relatively strong physically, that solution cavities are not likely to be formed in it, and that it should therefore make a good roof for mining operations.

Selective mining

In all probability there will be little occasion for selective mining within any unit of the black shale. If, however, the mining or sampling of thinner beds should be found advisable, the bedded nature of the Chattanooga offers distinct advantages.

During one of the early rounds a row of holes was drilled 3 inches below a prominent bedding plane located about 8 inches below the top of the Top Black. The round was under-loaded and when it was shot, the top 8-inch bed stood although it was sufficiently shattered to be easily barred down. Little attention was paid to the occurrence at the time, but it was recalled later when the possibility of using this same bed as a roof stratum was under discussion. Accordingly in the last round in the adit, the top row of holes was drilled 6 inches below the strong bedding plane, each hole being loaded with two sticks of 40 percent gelatin. The bed again stood, as shown in the photograph (fig. 10). It was somewhat shattered; but its behavior suggests that had the holes been a little lower and the charges a little lighter, the shattering might have been avoided and the stratum would have made a serviceable roof. The greatest source of weakness would probably be, not damage from blasting, but the numerous joints which criss-cross all beds in the Top Black.

Experience with the top bed of the black shale indicates that after the bottom wedge has been taken out the shale may, by careful drilling and blasting, be brought down under any selected strong bedding plane. The best location for the holes is about 6 inches below the break; they should be drilled fairly close together, and charged lightly.

Of more potential value than the action of various beds in the Top Black is the behavior of the Nodule layer and the Maury. The hard bed in the Nodule layer has been discussed; it should be said further that in the vicinity of the adit, the Nodule layer will break cleanly from the Top Black when the holes are drilled anywhere from 3 to 8 inches below the strongly-marked contact between the two beds. This should be true whether or not the strong bed in the Nodule layer is present. The break between the Nodule layer and the Maury is not sharp and the contact is undulating, but even this situation should be handled fairly well. In rounds 1, 2, and 3, the top holes were drilled about an inch below the top of the Top Black. The entire Nodule layer fell, bringing down some, but not much, of the Maury. Had the rounds been farther underground, where the Maury is stronger, even less would probably have fallen. Some must always be expected, however, because of the irregularity of the contact and the tendency of the two units to interfinger.

Should mining be done more than a mile or two south of the adit site, where the Nodule layer is absent, the possibility of using the Maury as a permanent or temporary roof would become an important problem. In this area the contact between the Top Black and the Maury, wherever observed, is relatively sharp; and it should be possible by careful location of holes and regulation of charges to shoot the Top Black from beneath the Maury with little or no contamination from the latter.

Mining characteristics of other units of the black shale

As the adit was driven in the Top Black unit of the Chattanooga, all observations previously made refer to that member only. It is possible and even likely, however, that future mining will include beds other than the Top Black, and for that reason the probable mining characteristics of the lower units will be briefly discussed.

The four units below the Top Black, with their regional thickness and their thickness in the immediate vicinity of the adit, are given below.

Thickness of lower units of Chattanooga shale

Unit	Regional Thickness	Thickness Near Adit
Upper silt	2 feet	2.75 feet
Middle Black	8 feet	7.50 feet
Middle Gray	7 feet	9.50 feet
Lower Black	7 feet	5.75 feet

Lower Black.—In appearance and general characteristics this unit is much like the Top Black except that it is thinner-bedded. In analytical values it is only fair; and it is markedly irregular in thickness over small areas. In two drill-hole cores and at some outcrops the lower parts of the unit are seen to be faulted or otherwise disturbed. It is separated from the underlying Ordovician limestones by a thin (1/4 to 1-inch) bed of sandstone of no economic importance.

As its values are hardly high enough to justify mining as a separate unit, and as it is separated from the higher black beds by the comparatively barren Middle Gray, mining of the Lower Black in the future may be discounted heavily. Therefore but little need be said except that it should have much the same drilling and blasting

characteristics as the higher black beds, and that any opening in it would have a fairly good floor in limestone and a roof of doubtful strength in the Middle Gray siltstone.

Middle Gray.—At outcrops this unit is a monotonous succession of light-gray and darker-gray beds, with a number of 3- to 4-inch strata of black shale in the bottom and top thirds. It weathers readily, though not to the same extent as the Maury. Its characteristics underground have been studied only through drilling. It cuts somewhat faster when drilled than the black beds, but much more slowly than the Maury; it gives relatively solid cores showing the light- and dark-gray striping seen at the outcrops; and it does not separate readily along bedding planes as do most of the black units.

In some cores the general appearance of the Middle Gray is on casual inspection much like that of the Maury, but in most the two units are readily recognized even when removed from the adjacent beds by the fact that the Maury is usually disintegrated to some extent by the action of the drill water, whereas the Middle Gray is not affected. In one drill hole (LC-104) the Maury was recovered as a greenish clay; but even in the shallowest holes (the LC-108 series) the Middle Gray showed no evidence of any such alteration. A further method of differentiation is that the characteristic striping of the Middle Gray is not normally seen in the Maury which does, however, show some slight variations in color.

In future mining the Middle Gray would almost certainly be used as a roof or a floor, probably the latter. As a roof it may be expected to be considerably stronger than the Maury, though far from

an ideal rock. As a floor it should be soft enough to work on easily, but strong enough for any contemplated operation. It should break sharply from either the underlying or the overlying units.

Middle Black and Upper Silt.—For a number of compelling reasons, the logical mining unit in the Chattanooga includes the Top Black in which the adit was driven, the Upper Silt, and the Middle Black. Therefore these units will be considered together.

At weathered outcrops the Top Black is almost massive and normally juts out a foot or so beyond the Upper Silt, which in turn is usually cut back from the Middle Black; this gives an index of the relative resistance to weathering, and the probable relative strength, of the three beds. As to composition, the Middle Black, and the Black beds in the Upper Silt, contain values almost as high as those of the Top Black, while the relatively few and thin gray beds in the Upper Silt do not dilute these values to any important extent.

From a mining standpoint the most important difference between the Top Black and the underlying units is that the beds in the lower members are considerably thinner and are separated by stronger bedding planes. Though this has not been tested in actual mining, it is apparent from study of cores. In the best of these the Top Black is fairly solid whereas the Middle Black, and particularly the Upper Silt, are usually in the form of relatively thin disks because of separation along bedding planes. This thin bedding would probably make it somewhat easier to shoot out a bottom wedge than was the case in the Top Black; and it would certainly, if the cores can be relied upon, indicate that the beds above the wedge could be brought down with relatively fewer holes and lighter charges than were used in

the Top Black. As a result, less drilling and explosive would be required to bring out a ton of rock and costs would be correspondingly reduced.

The average height of an opening removing the Top Black, the Upper Silt, and the Middle Black would be about 17 feet in the vicinity of the adit. The advantages of working with this headroom are so obvious that they will not be discussed further. The roof would be the same as that of the adit, the Fort Payne; the floor would be the Middle Grey, which has been discussed from that angle. The walls should be strong; the few grey beds in the Upper Silt could hardly cause a weak zone, and the black beds should stand much as they do in the adit.

UNITED STATES
DEPARTMENT OF THE INTERIOR
Bureau of Mines

Explosives Branch
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REPORT ON INFLAMMABILITY TESTS OF OIL SHALE DUST SUBMITTED BY THE GEOLOGICAL SURVEY, U. S. DEPARTMENT OF THE INTERIOR

This report summarizes the results of laboratory tests made on dust prepared by pulverizing a sample of oil shale or siltstone, that was submitted by Mr. Andrew Brown, mining engineer, Geological Survey, U. S. Department of the Interior, Northington Campus, University, Alabama.

Mr. Brown reported that the sample is from the upper 7 feet of the Chattanooga shale and was taken from an adit in DeKalb County, near Sparta, Tennessee. Material from a nearby drill hole yielded about 10 gallons of oil to the ton upon destructive distillation of the kerogen content. The spent shale showed an ignition loss of 15 percent, ash content of 75 percent. The ash is thought to contain much finely-divided silica. Mr. Brown mentioned that in at least one instance a pile of loose shale was reported to have caught fire through spontaneous combustion.

Interest in the potential explosion hazard of the oil shale dust stems from the fact that drilling of the rock, unless water is used, is an extremely dusty operation. All laboratory tests were made on dust (Bureau of Mines No. 1510) of minus 200-mesh fineness (Tyler sieve scale) prepared from the rock samples by pulverizing. The apparatus and test procedure used in this work is described in Bureau of Mines Report of Investigations 3751.

The ignition temperature of a dust cloud in air was determined to be approximately 530° C. When a small undispersed layer of dust was heated for several minutes in the laboratory furnace, it glowed at the temperature of about 260° C. and flame was observed at 630° C.

The relative inflammability of the dust was determined to be 90 percent in the furnace test at 700° C. In other words, it was necessary to mix 90 percent inert dust (fuller's earth) with the shale dust, in order to prevent ignition when a small amount of the dust mixture was projected through the furnace. No ignition of dust clouds could be obtained by a high-voltage induction spark of approximately 20-watt power or by a 40-volt a.c., 7.5 ampere carbon arc.

Ignitions of dust clouds of the oil shale did result when a flame of 75 mg. of guncotton was used as the igniting source. When the ignitions were initiated in a closed laboratory test bomb, pressures of 15 to 20 p.s.i. were developed by dust clouds whose concentration ranged from 2.00 to 4.00 ounces per cubic foot. Rates of pressure rise during these ignitions were so small (approximately 100 p.s.i. per second) that the phenomena must be classed as rapid burning rather than explosions.

The test data show that in the presence of open lights or other strong igniting sources, dust clouds of the oil shale can be ignited and that mild explosions might result. To prevent ignitions, normal precautions should be taken, such as prohibition of the striking of matches or smoking, and of the use of welding and similar equipment in locations where the dust is dispersed in air.

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