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Calamity Hollow Mine Fire Project

(In Five Parts)

5. Excavation and Evaluation of the Fire Zone

By K. E. Soroka, R. F. Chaiken, L. E. Dalverny,
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PREFACE

More than 500 fires are now burning in abandoned coal waste banks and coal deposits in the United States. Once established, such fires can burn for decades, and extinguishing them by conventional methods such as surface sealing to exclude air, excavation to remove fuel, or flushing to cool the fire zone is usually difficult and always expensive. Burnout Control, a technique developed by the Bureau of Mines for the control of abandoned coal fires, involves the accelerated combustion of coal in place with total management of the heat and fumes produced. A burning waste bank or mine is placed under negative pressure relative to the atmosphere, and heat and combustion products are drawn from the combustion zone through an exhaust ventilation system. Heat produced appears as sensible heat in the exhaust, at temperatures as high as 1,000° C (1,832° F), and could be recovered for the production of steam, hot water, process heat, or electricity.

The Bureau's first held field demonstration of Burnout Control was at Calamity Hollow in Allegheny County, PA (near Pittsburgh). Calamity Hollow was the site of an underground mine in the 1900's and was surface mined in the 1940's. In the winter of 1961-62, a fire of undetermined origin was discovered in the exposed coal. In 1963, the Bureau constructed a trench barrier around the fire and a surface seal over the affected area. The fire was isolated but not completely extinguished. In 1979, when the Bureau began work on the Calamity Hollow Mine Fire Project to demonstrate controlled burnout, the fire was still smoldering on the hot side of the trench barrier. The project, which was begun in December 1979 and ended in July 1982, consisted of the design, construction, operation, and subsequent dismantling of a Burnout Control ventilation system.

This report is the fifth in a five-part series that describes the Calamity Hollow Mine Fire Project. The first report, part 1, describes the design and construction of the field installation. Part 2 will present the results of a continuous 4-month burnout operation. (Because part 2 involves the analysis of a substantial body of data, it will not be published until after publication of parts 1, 3, 4, and 5.) Part 3 describes the instrumentation used to control and monitor the progress of the burnout operation. Parts 4 and 5 deal with the closeout phase of the field demonstration. Part 4 describes the procedure used to quench the fire, and this part (part 5) describes the final excavation and backfilling of the heated zones.

The reports in this series document the Calamity Hollow controlled burnout demonstration which showed that (1) controlled in situ combustion is a feasible method for controlling underground fires in abandoned mines, (2) the resultant thermal exhaust output is sufficient for energy utilization, and (3) water injection-fume exhaustion is a potentially effective method for cooling large underground fire zones. Further investigations of both Burnout Control and the water-injection-fume exhaustion quenching procedure are planned.

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ILLUSTRATIONS

UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

°C	degree Celsius	kV·A	kilovolt ampere
°F	degree Fahrenheit	kW	kilowatt
ft	foot	mi	mile
gal/min	gallon per minute	MW	megawatt
h	hour	yd	yard
hp	horsepower	yd^3	cubic yard
in	inch		

CALAMITY HOLLOW MINE FIRE PROJECT

(In Five Parts)

5. Excavation and Evaluation of the Fire Zone

By K. E. Soroka,[1] R. F. Chaiken,[2] L. E. Dalverny,[3] and E. F. Divers[4]

ABSTRACT

The Bureau of Mines has demonstrated a new technological approach that utilizes controlled in situ combustion to bring fires in abandoned coal mines and waste banks under control. This new technology involves the accelerated combustion of "waste" coals in situ under controlled ventilation conditions, which allows for total management of the combustion products, including utilization of the heat produced. This concept could significantly lower the costs for reducing the environmental and public safety hazards associated with waste coal fires and lead to the conversion of a coal waste to a coal resource.

The Burnout Control technique was demonstrated at the site of an abandoned coal mine fire in Allegheny County, PA. Following a 4-month continuous operation of Burnout Control, a novel water injection-fume exhaustion technique was utilized to "rapidly" cool the underground heated zones, before the 1-1/2-acre fire site was excavated and backfilled.

Observations and interpretations made during excavation relative to fire propagation and quench efficiency are described. Pillar and entry layout, burn regions along entries, roof, and pillars, and degrees of coking of pillars were observed. Borehole temperatures greater than 200° C (392° F) correlated with observed burned and/or coked regions. Water injection-fume exhaustion lowered strata temperature to an average of 160° C (320° F) resulting in minimal gas outbursts and only two local instances of flaming combustion during excavation. The excavation analysis supports the effectiveness of both Burnout Control and water injection-fume exhaustion techniques for control of fires in abandoned coal mines.

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[3]Physicist.
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INTRODUCTION

The Calamity Hollow Mine Fire Project was conducted at the site of a shallow drift mine in the Pittsburgh coal seam that had been smoldering for more than 20 years. The mine was located in the Calamity Hollow area of Jefferson Borough, Allegheny County, PA (fig. 1). The mine was abandoned around the turn of the century, but a coal operator began surface mining in the late 1940's, leaving a highwall (approximately 60 ft high) with an exposed seam of coal at the base of a cliff. A fire of unknown origin began in the mine in the early 1960's. In 1963, the Bureau of Mines attempted to extinguish the fire by isolation techniques, utilizing a trench barrier of incombustible earth material and surface sealing (1).[5] The fire was isolated to within the 1.8-acre outcrop area enclosed by the trench barrier, but surface sealing failed to extinguish the entire fire. In 1979, when the site was visited, hot gases, steam, and smoke were being emitted from cracks and crevices in the surface. This site was chosen for the first field trial of Burnout Control. Following approximately 2 years of site preparation and facility construction (2), a continuous 4-month test was performed.

The Burnout Control technique utilizes an exhaust fan to create a partial vacuum that induces increased air flow into the fire zone(s) to accelerate burning while removing the heat and fumes at a central fan exhaust point. Figure 2 depicts the Burnout Control system constructed at Calamity Hollow. Figure 3 is an aerial view of the site to provide ease of reference from figure 2 to system components, such as the generator-fan assembly, dropout tank, and exhaust manifold, referred to throughout the excavation description.

Complete burnout of the originally estimated 17,000 tons of isolated combustible material (2), including coal and carbonaceous shale, at Calamity Hollow would have required 3 years of continuous burning. This was not possible owing to project funding and time constraints; however, the project afforded an opportunity to demonstrate the usefulness of the Burnout Control technique for 4 months. During the continuous burn operation, approximately 1,100 tons of combustibles were consumed to yield time-averaged values of 600° C (1,112° F) exhaust temperature and thermal output of approximately 3.1 MW (3). After the continuous-burnout phase, excavation of the fire zone allowed visual evaluation of the underground burning process and complete and permanent extinguishment of the fire.

Before excavation, a novel water-injection technique was used to cool the fire zone. With this technique, water was injected into as many as 50 boreholes while steam and heat were exhausted from the

[5]Underlined numbers in parentheses refer to items in the list of references at the end of this report.

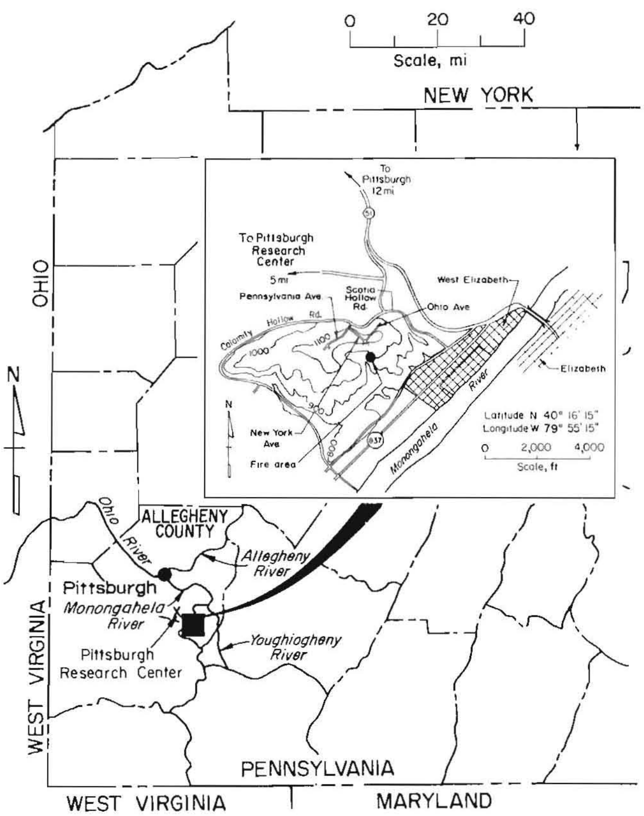

FIGURE 1. - Location of project area.

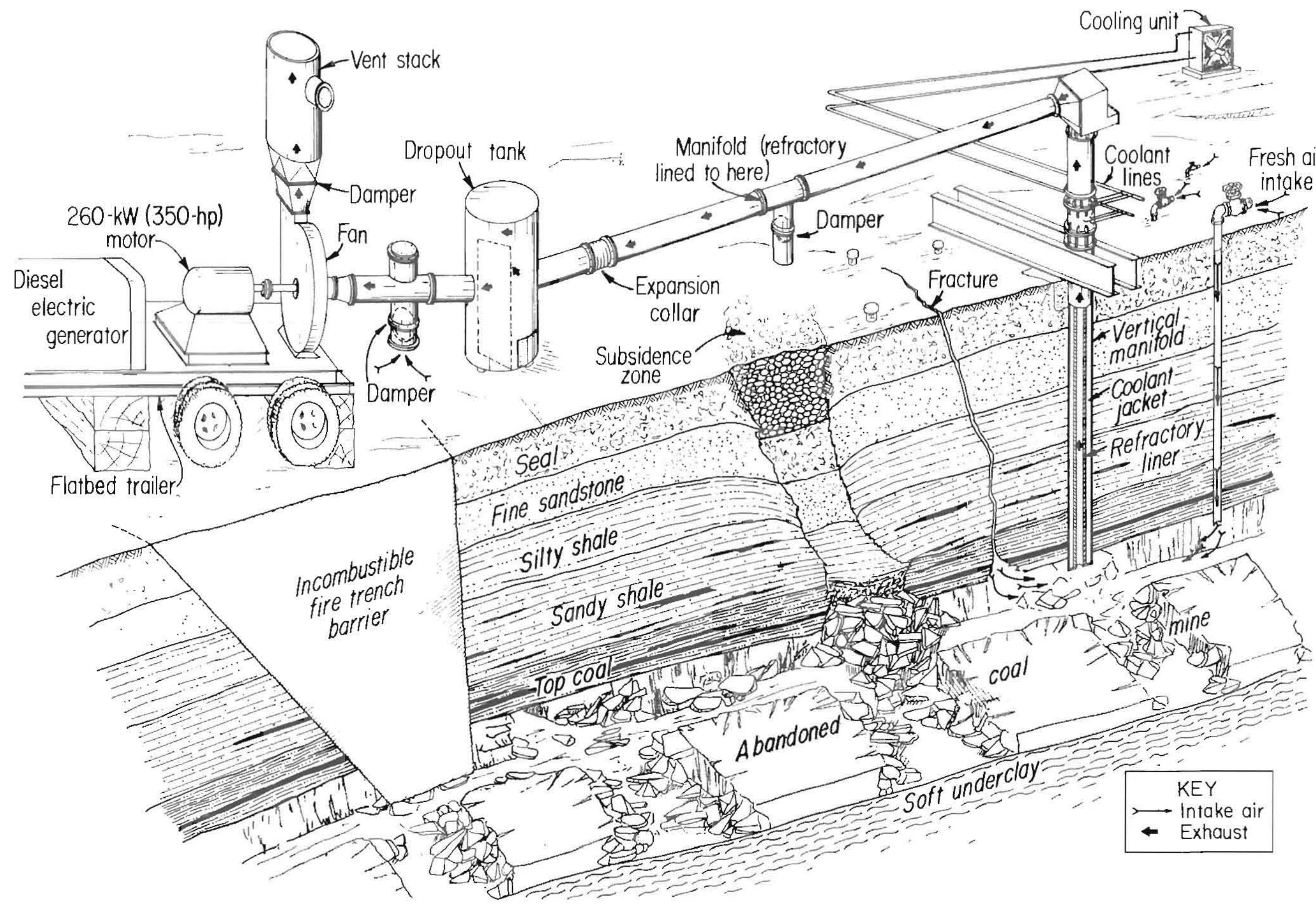

FIGURE 2. - Burnout Control system.

mine through the burnout ventilation system. After 30 days of water injection combined with fume exhaustion, the exhaust temperature was reduced to an average temperature of about 160° C (320° F) (4).

Exposure to view by digging away the overburden and excavating the fire zone (zone B, figure 4) began on June 3, 1982. The excavation provided an opportunity to evaluate (1) the extent and paths of combustion, (2) the effectiveness of the combustion process, especially on coal pillars and rider coal seams, (3) the extent of heating of the overlying strata, and (4) the effectiveness of the water injection-fume exhaustion quenching technique, and to ensure extinguishment of all remaining fire and complete restoration of the land.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the significant contributions by these persons to the success of the excavation portion of the field project: Joseph P. Slivon, Jr., and John R. Odoski, physical science technicians, Pittsburgh Research Center, Bureau of Mines, Pittsburgh, PA, provided technical and mechanical functions during excavation; they were assisted by Douglas P. Meyer, physical science aid, Bureau of Mines, Pittsburgh, PA. Roy Laverick, construction supervisor, headed the following group of operational personnel who maintained the continuous monitoring at the site during excavation: Timothy Fircak, Francis T. Kelly and Harold Smith, electromechanical technicians, Boeing Services International, Inc., Pittsburgh, PA.

FIGURE 3. - Aerial view of Calamity Hollow site.

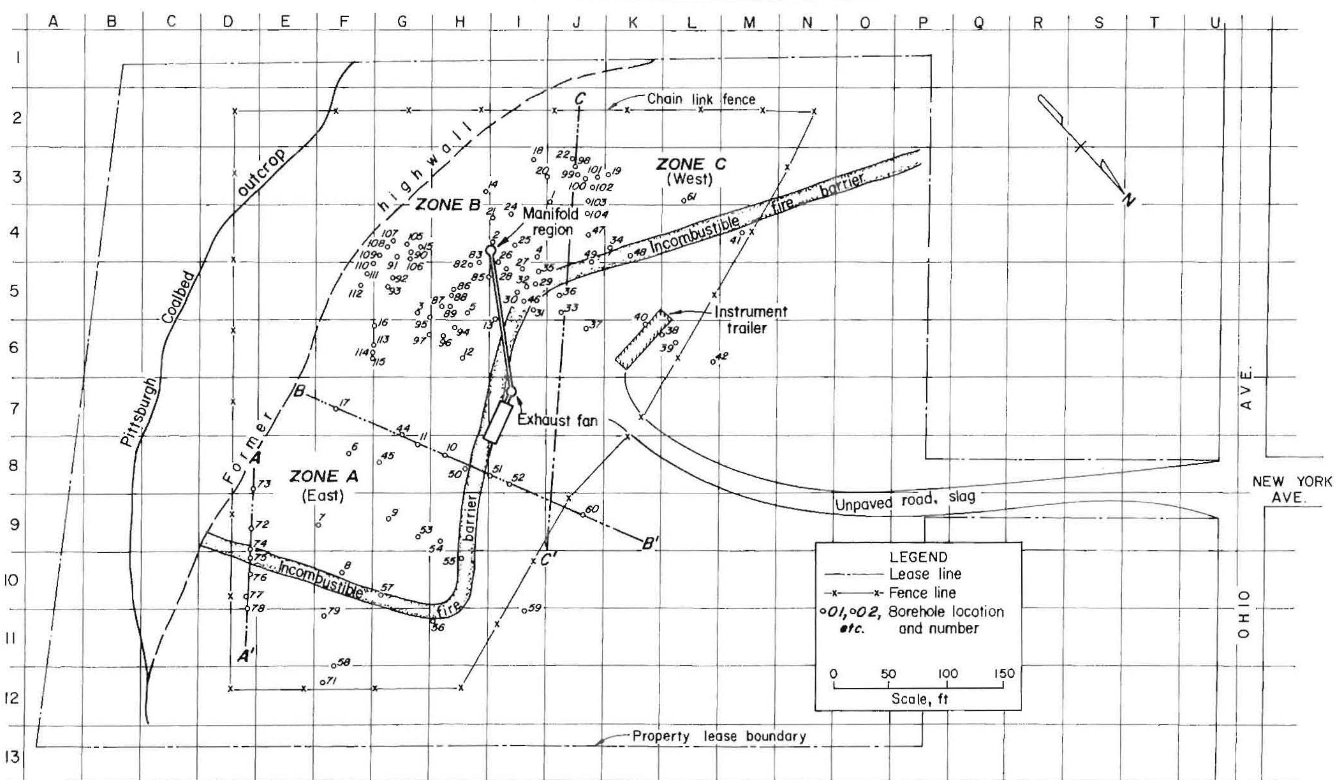

FIGURE 4. - Site plan.

EXCAVATION OF FIRE ZONE

In general, the strategy was to excavate zone B, the fire zone (fig. 4), from the surface to the gray underclay by excavating from the east side, around the former highwall, along the west side, and finally through the exhaust manifold region. To aid the interpretation of heat effects on strata throughout this report, the reader is referred to figure 5, which shows a generalized stratigraphic section of the Calamity Hollow site.

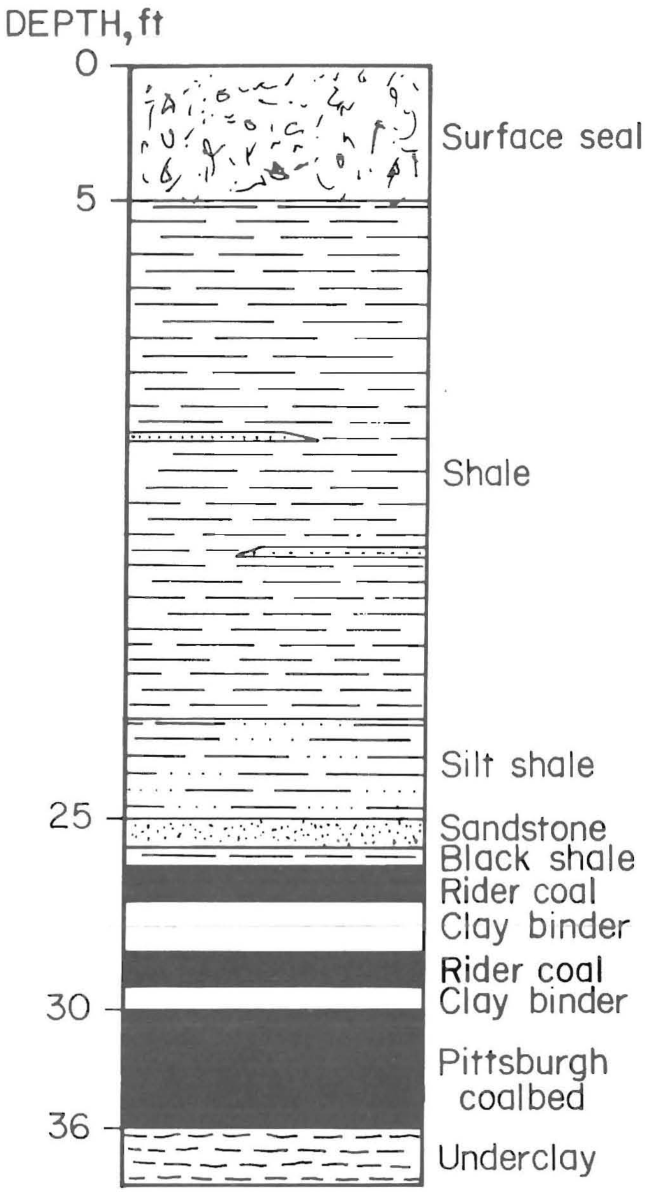

FIGURE 5. - Generalized stratigraphic section of site.

Under contract, an experienced crew excavated and backfilled approximately 70,000 yd^3 of material using the following equipment (with fully enclosed cabs):

1. 11-yd^3 front-end loader.
2. 6-yd^3 front-end loader.
3. 14-yd blade and parallel ripper dozer.
4. 20-ton truck.

This process included removal of an estimated 1,600 tons (1,460 yd^3) of unburned coal. Partially burned coal and coke (the amount of which could not be easily measured) was cooled by spreading on the ground and mixing with excavated overburden material to form part of the backfill. Total time for excavation, surface regrading, and seeding was 4-1/2 weeks.

Prior to the start of excavation, operating personnel were informed of the health and safety problems that have been encountered in the past while digging out underground mine fires, including toxic and explosive fumes, excessive heat and dust, ground caving, and highwall collapse (5-7). Surface caving also commonly results from underground fires. The level of danger increases as the exposed surface approaches the combustion zone (8-10). To help alleviate some of these potential dangers, it was decided to maintain the Burnout Control ventilation system for as long as possible in an effort to reduce emissions of dust, fumes, and steam as heated rock and carbonaceous material were exposed. The excavation strategy, with an appreciation for the possible dangers, was designed so that auxiliary water lines supplied water to cool the rubber tires of the excavation equipment, to reduce billowing of dry, heated dust in the air, and to prepare for any emergency requiring water; e.g., reignition of any carbonaceous material.

An indication of the possible dangers occurred during the first day of excavation when a large hole, 4 ft by 4 ft, opened under the rear wheel of the larger front-end loader exposing a dome-shaped vent. At 8 to 10 ft into this hole, the maximum temperature was only 30° C (86° F), which did not present any serious problems. Fortunately, there were no further incidents of this kind during the rest of the excavation.

During excavation, the exposed strata were examined continuously, ground temperatures were measured, and a photographic record was maintained. The color changes in the strata caused by the fire served as an approximate calibration of strata temperatures developed during burnout. To verify these temperature calibrations, a random sampling of rocks from an unaffected portion of the site was collected and exposed under controlled conditions to various predetermined temperatures ranging from 350° C to 950° C (662° to 1,742° F) for 12 h. Above 450° C, distinct color changes, ranging from shades of brown to shades of orange, were noted in all the sample regardless of their composition.

The first cut of the excavation, made on June 3, 1982, was wedge-shaped with one edge along a line passing through borehole 3 (G, 5), the point at the isolation trench barrier near the dropout tank, and the other edge along a line passing through borehole 17 (F, 7) (fig. 6). The first cut was initiated in the area that incorporated borehole 15 (G, 4) and the former highwall (fig. 6). As the surface layer (15 ft) was removed to expose brownish-red strata, water vapor rose indicating that heating had occurred.

Five days into the excavation, a fire was observed near borehole 12 (H, 6) in a portion of the seam originally assumed to be on the "cold" side of the excavation trench (fig. 6). This active fire along the eastern boundary of the cut was approximately 37 ft below the surface in an

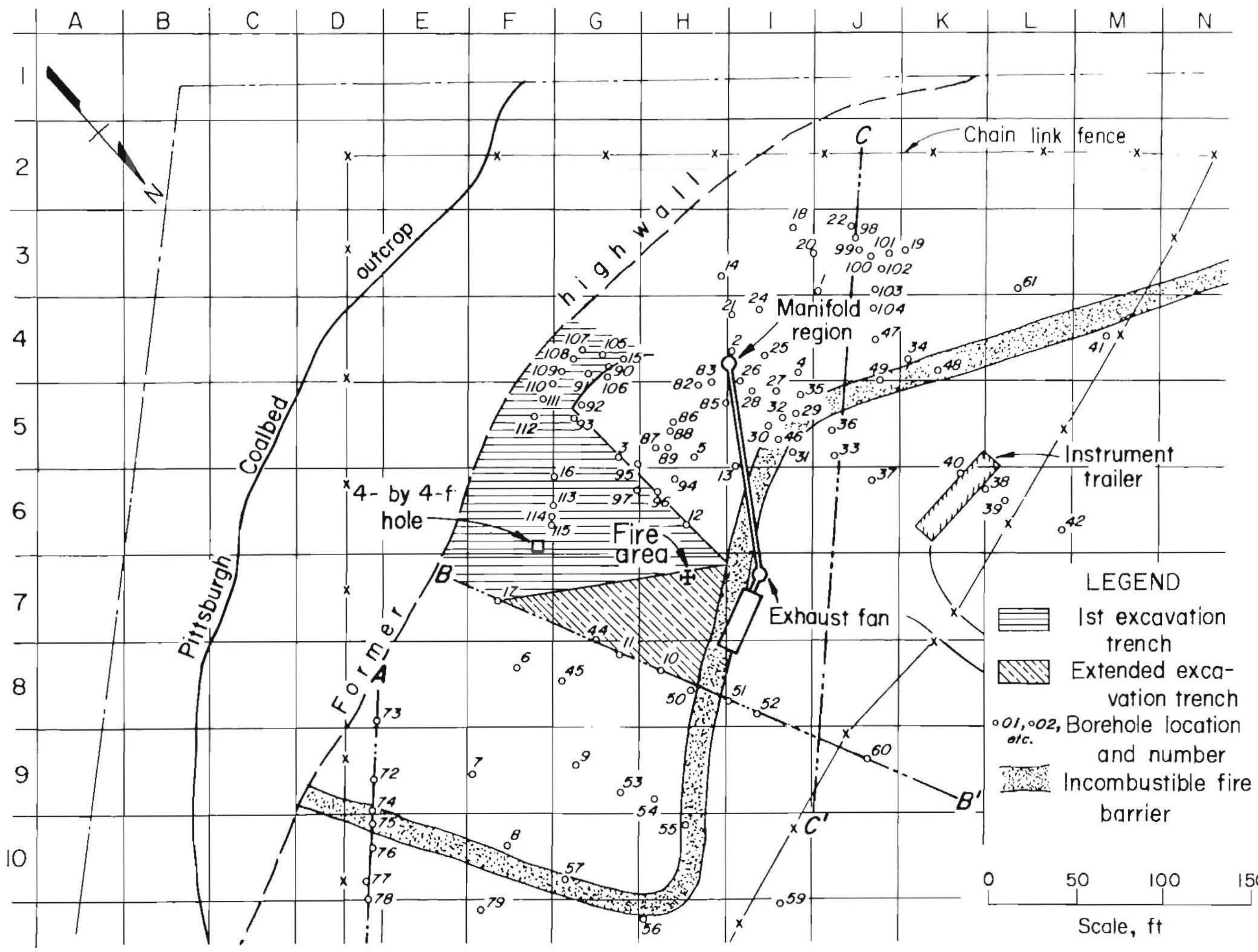

FIGURE 6. - Site plan showing first excavation trench.

area outside the borehole water-injection pattern of the quenching phase of the project. Water was used to extinguish the fire. Excavation was extended easterly, roughly along a line running between boreholes 10 (H, 8) and 17 (F, 7) to insure that all heated material was removed. From visual observations, the extended excavation established a definite cold boundary in the eastern direction. All the coal exposed along this new eastern boundary appeared "normally" rubblized and undisturbed by any heating.

The exposed cold eastern boundary strata appeared as normal brown earthern colors with rubblized coal in the rider and main coal seams. In contrast to the boundary, material exposed in the vicinity of boreholes 16 (G, 6), 12 (H, 6), and 113 to 115 (F-G, 6), while not uniform, showed large burned regions in rider coal seams, tops and sides of pillars, and partial, varying degrees of pillar coking. Figure 7 shows a section of a pillar from the general location of boreholes 113 to 115 (F-G, 6). The strata associated with these burned regions were red and orange with streaks of white, which appeared to be ash residue. However, even in these burned areas, the bottom 2 to 3 ft of the 5 to 7 ft high main coal seam appeared unaffected by heat.

On June 11, the excavation had progressed to the point of removing overburden along the original isolation trench barrier below the generator (fig. 8). As the removal proceeded, a large crack appeared in the ground under the generator assembly, and water-saturated material in the barrier collapsed when undercut. The region was excavated as near to the base of the isolation trench barrier and underclay as was possible without collapsing the surface installation. No burning was detected, and we concluded that the entire northeastern region of the burn zone had been isolated and would present no further threat of reignition. Figure 8 also shows the location of several coal pillars that appeared to have been affected by heat; i.e., color had changed to shades of red and white in the rider coal seams, and to gray and silver in the top 2 to 3 ft of the coal pillars. The exposed pillars, evaluated by the contractor to be recoverable coal were removed from the site.

On June 14, a second cut was initiated to excavate the region along the exhaust manifold which included boreholes 14 (H, 3), 21 (I, 4), and 2 (I, 4), shown in figure 9. The strata, in all shades of orange and red in the vicinity of the exhaust manifold, were very warm, dry, and highly fractured. Although no temperatures were recorded, puddled water was observed to boil in this area. When the manifold was exposed, the subsurface fractures were seen connecting to the surface fractures that had been observed during the burnout operation. Figure 10 shows the exposed exhaust manifold. Figure 11 shows the nearly straight wall along the manifold with the uppermost rider coal seam exhibiting the most color changes. Shades of orange, red, and white are contrasted to earthen shades (browns) above and below the rider seams, showing a line of combustion along these seams to the base of the exhaust manifold. Figure 12 provides a view of the base of the manifold positioned a few feet above the rider seam. During the burnout, clinkers, which are stony matter fused together at temperatures probably in excess of 1,200° C (2,192° F), formed at the base of the manifold. Figure 13 shows several clinkers removed from the area directly below the manifold (fig. 12).

As the strata were removed along the former highwall, old timbers and iron rails were observed. The excavation equipment disrupted most of the details of the original railroad layout in the mine.

The ventilation system was disassembled as the third excavation trench was dug (fig. 14). Excavation of this area provided the same observations as the first two areas: Rider coal seams were burned with red dog appearing above and below each rider coal seam, some areas of white ash were apparent, pillars were burned along the edges, and entries were caved showing small voids in the strata. Actual fire movement was not traceable, but the presence of fire was evident through

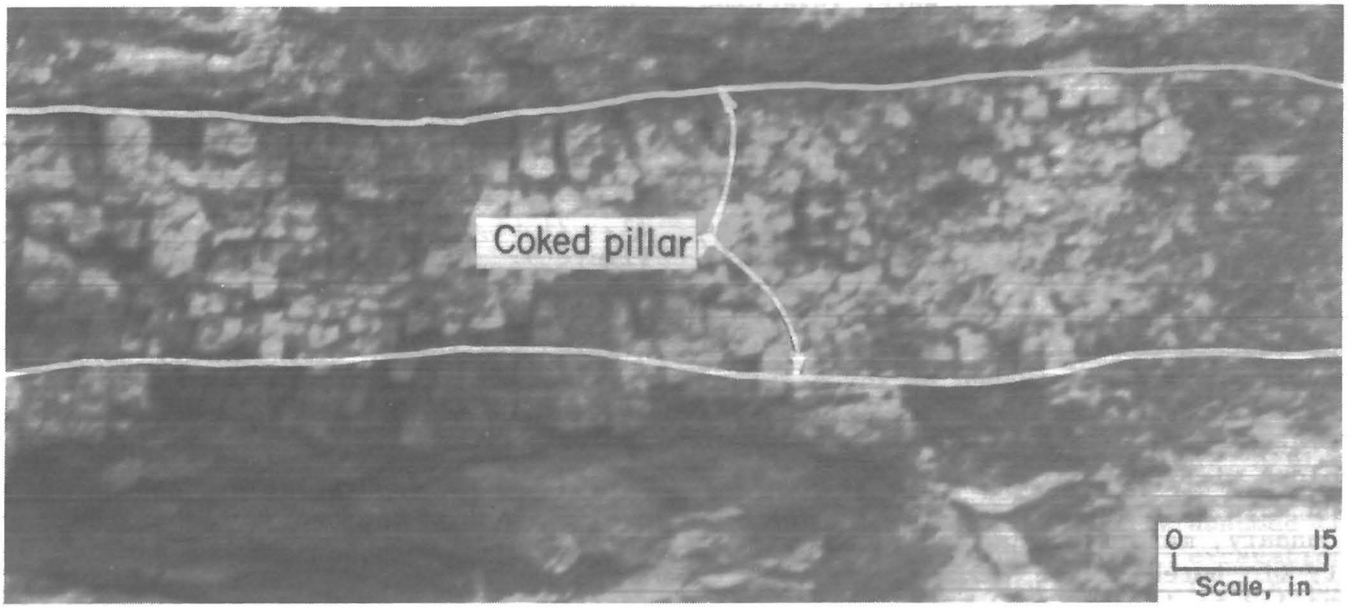

FIGURE 7. - Heat-affected pillar and rider seams.

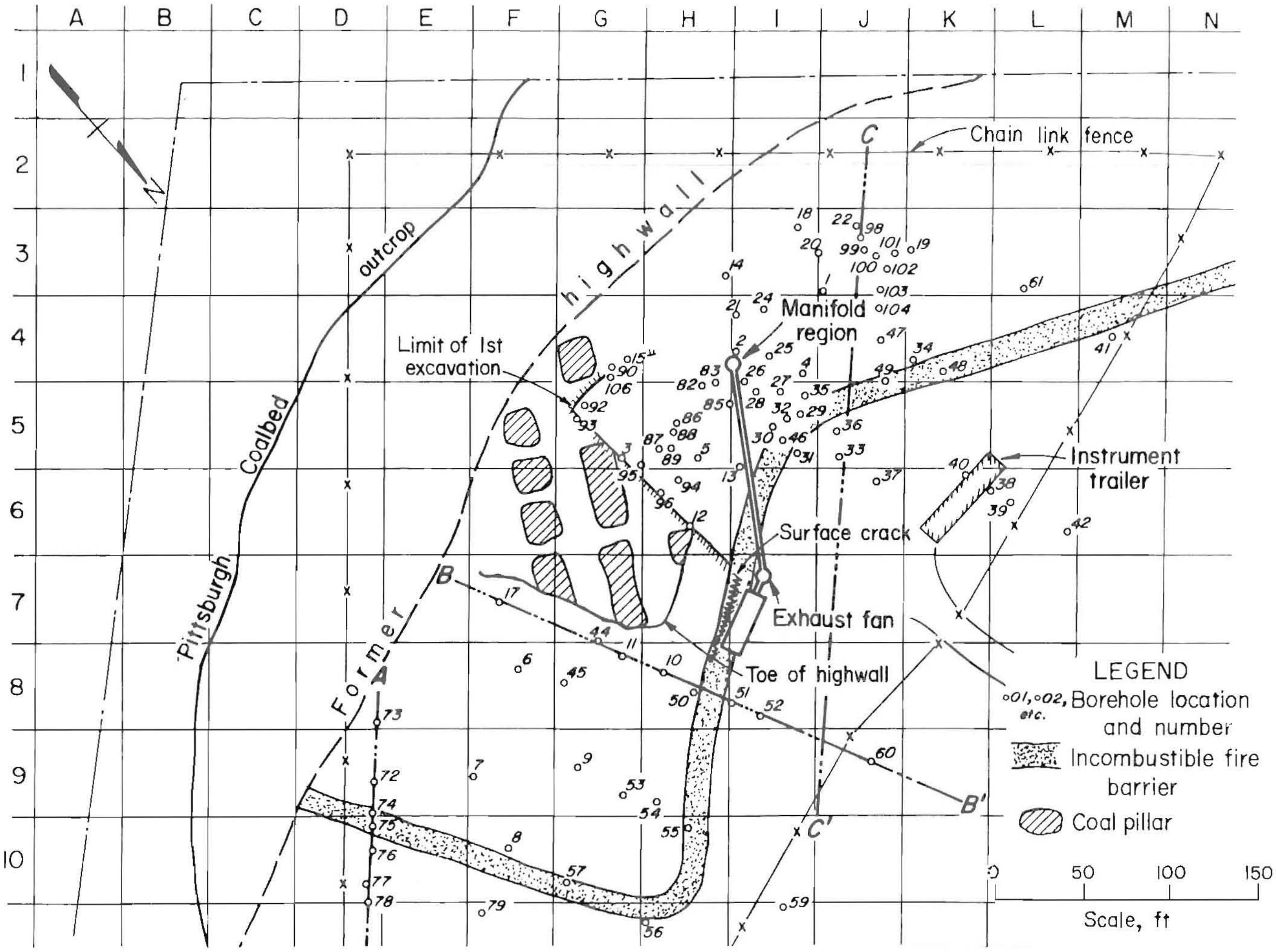

FIGURE 8. - Coal pillar orientation to incombustible fire barrier.

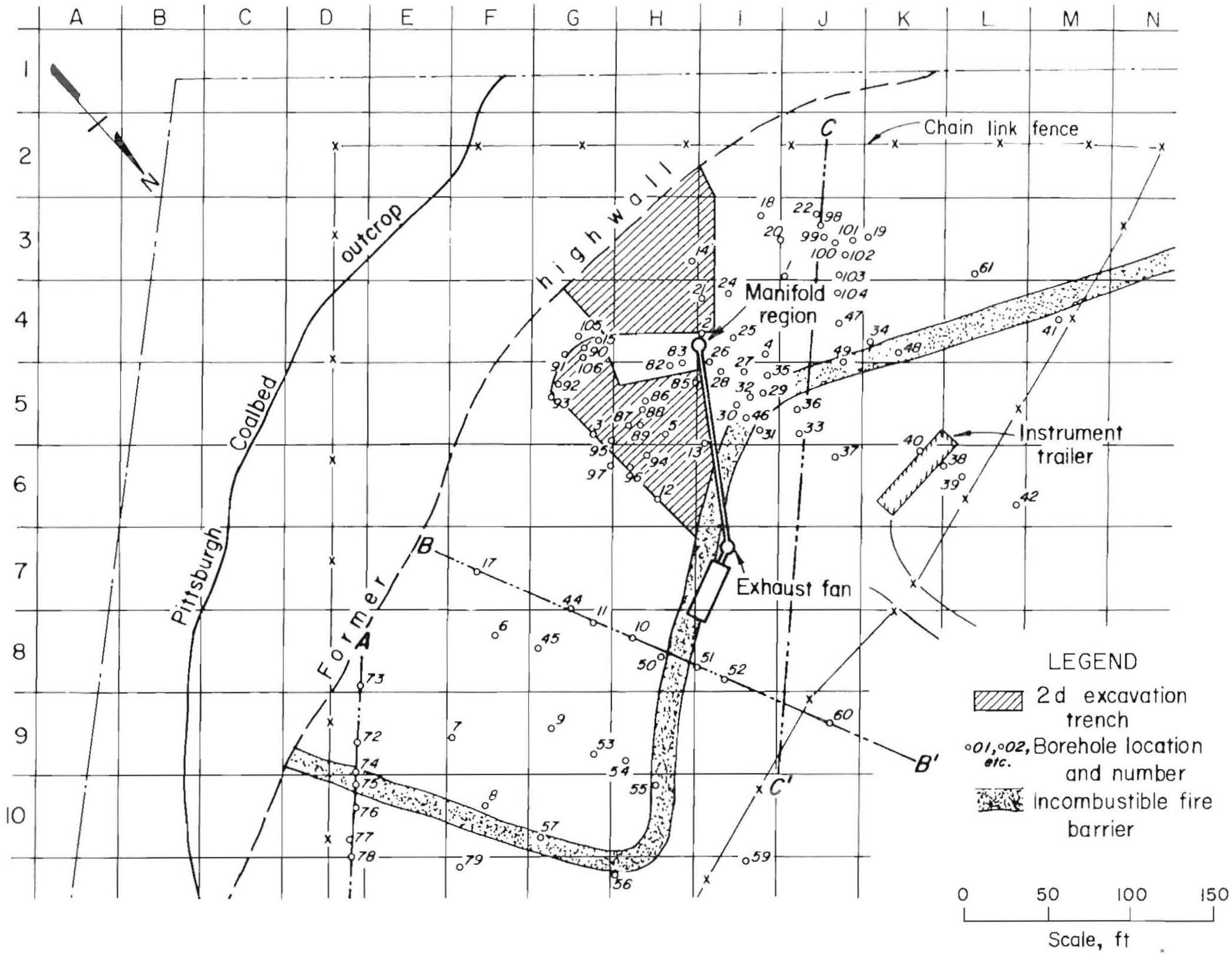

FIGURE 9. - Site plan showing second excavation trench.

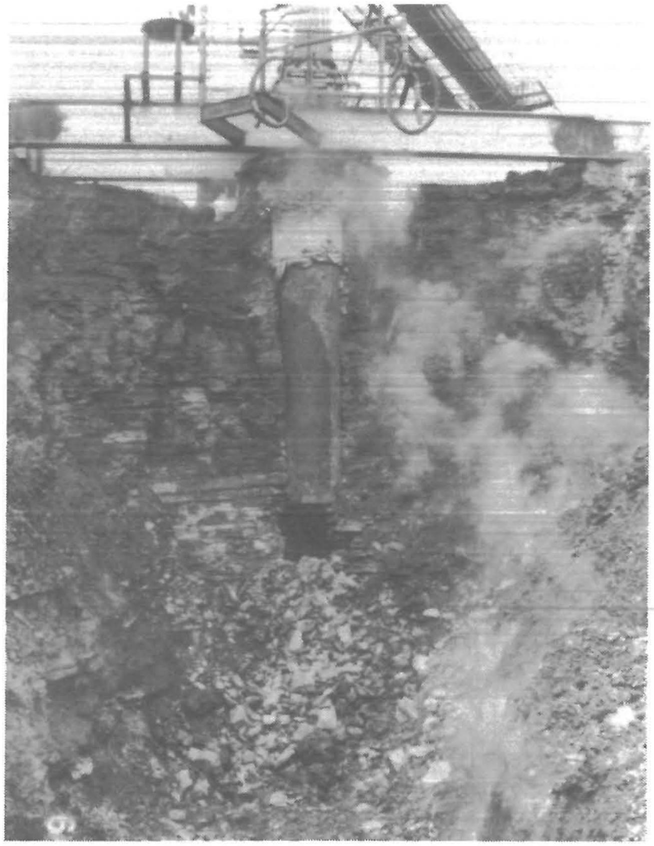

FIGURE 10. - Exposed exhaust manifold.

measured strata temperatures. After removing 25 to 30 ft of overburden in the area, including boreholes numbered in the eighties (H, 5), the temperature measured approximately 200° C (392° F). Excavation exposed a pillar devolatilized to within 1 ft of its base. The pillar was located below boreholes 94, 96, 95, and 87 (G-H, 6) (fig. 6). The temperatures measured in all these boreholes were greater than 200° C (392° F) at the termination of the burnout.

In the fourth excavation area, the incombustible fire barrier that isolated the fire zone from the "cold" side of the mine was very moist with a temperature of 50° C (122° F). On the fire-zone side of the barrier, the temperature in the underclay at the base of the barrier was 36.8° C (98.2° F). All observations supported the conclusion that fire had not breached the original incombustible fire barrier.

As the final trench was excavated toward the western field, a fire was discovered near borehole 19 (K, 3) (fig. 15). Flames, visible through voids in the strata, were quenched with water.

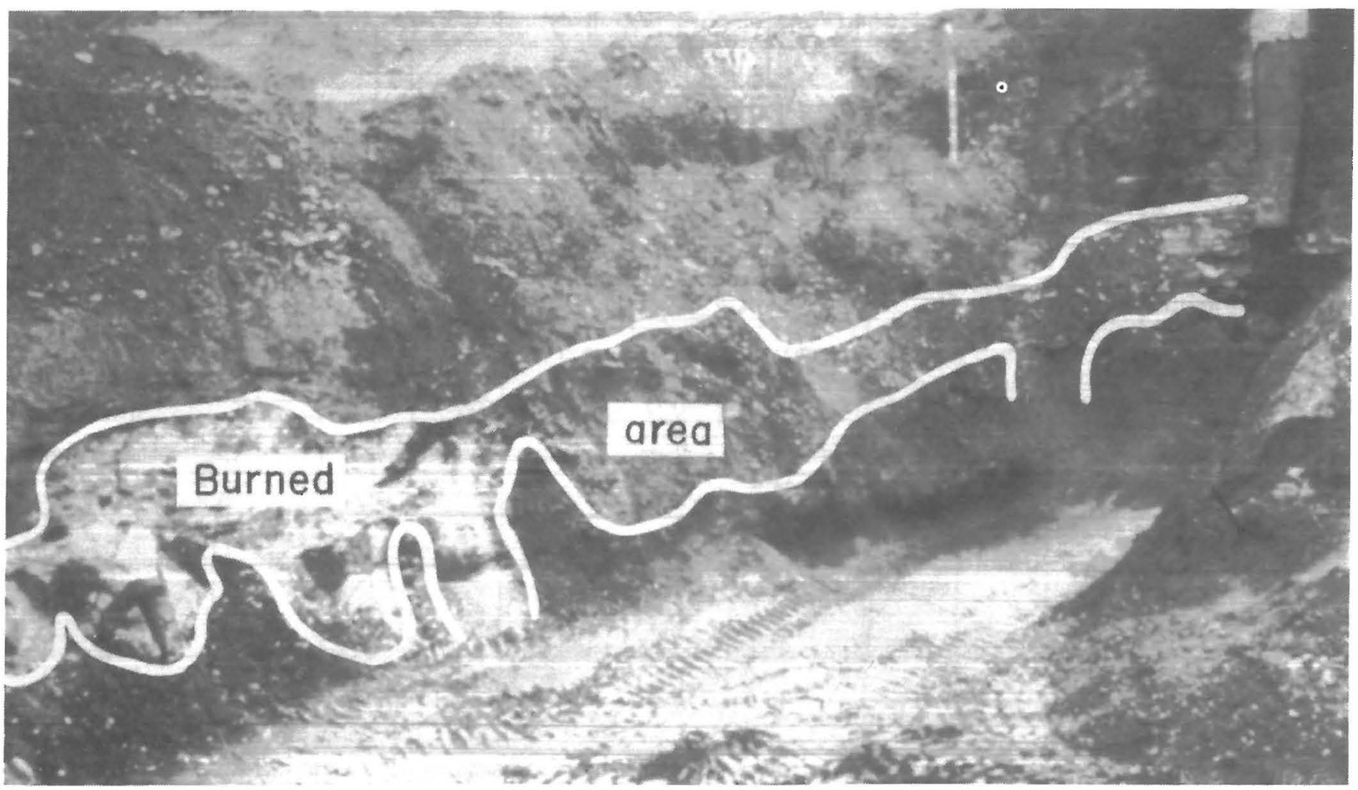

FIGURE 11. - Rider coal seams showing combustion line along seams to base of exhaust manifold.

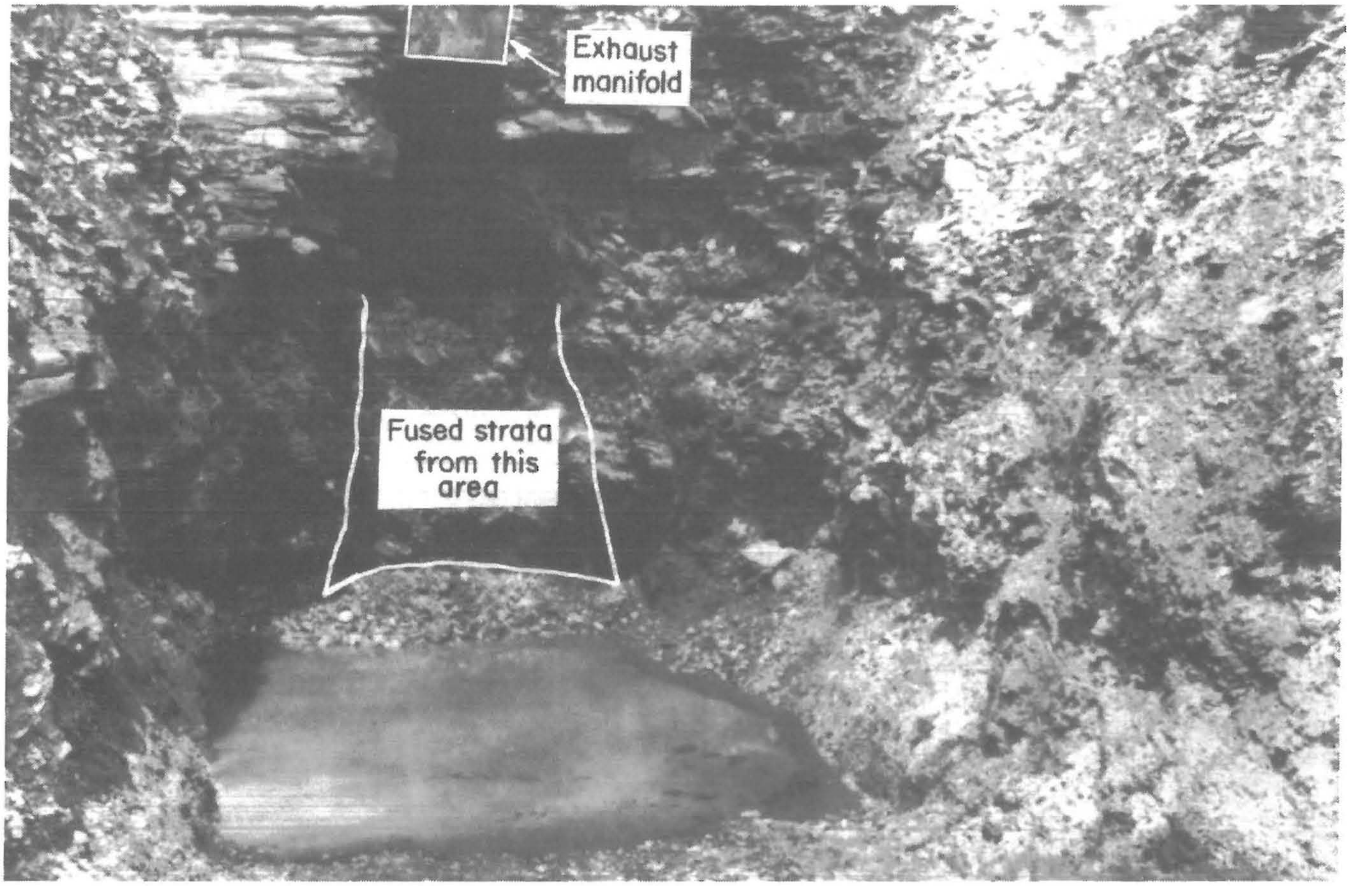

FIGURE 12. - Exhaust manifold.

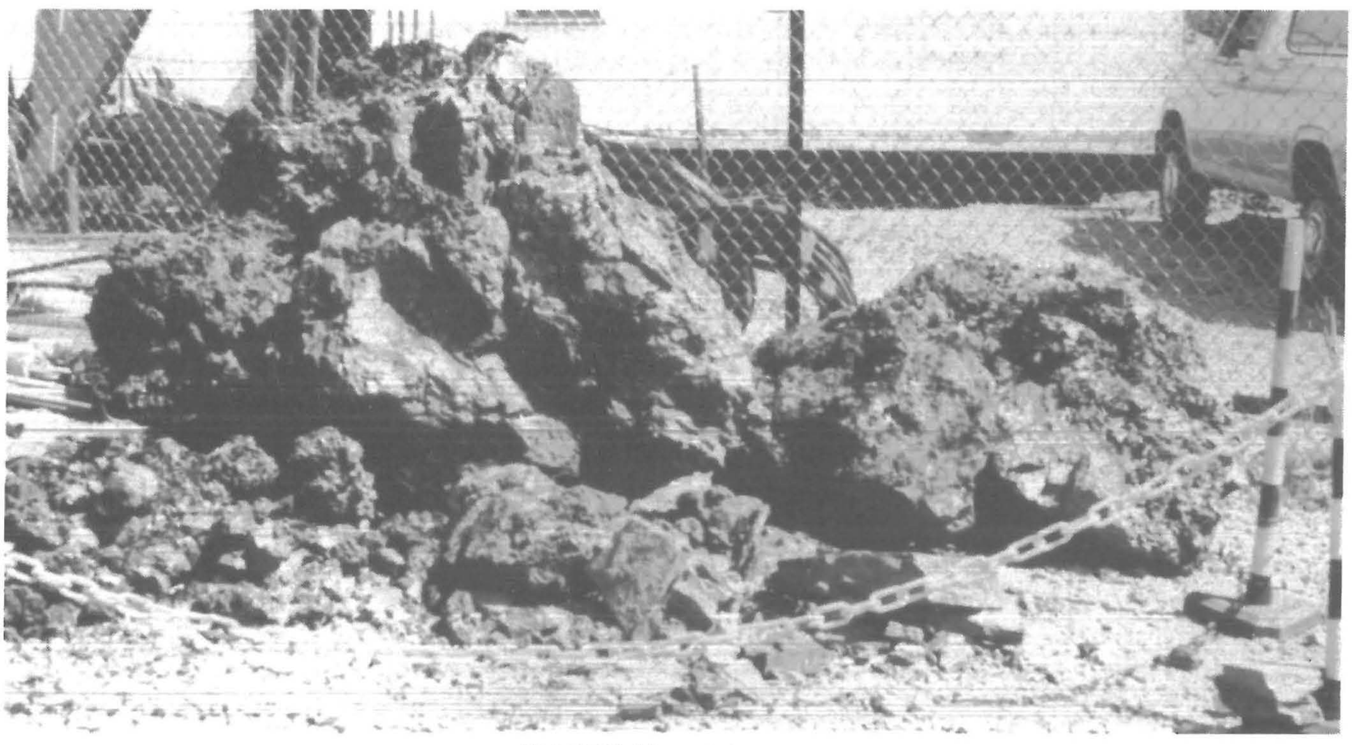

FIGURE 13. - Clinkers.

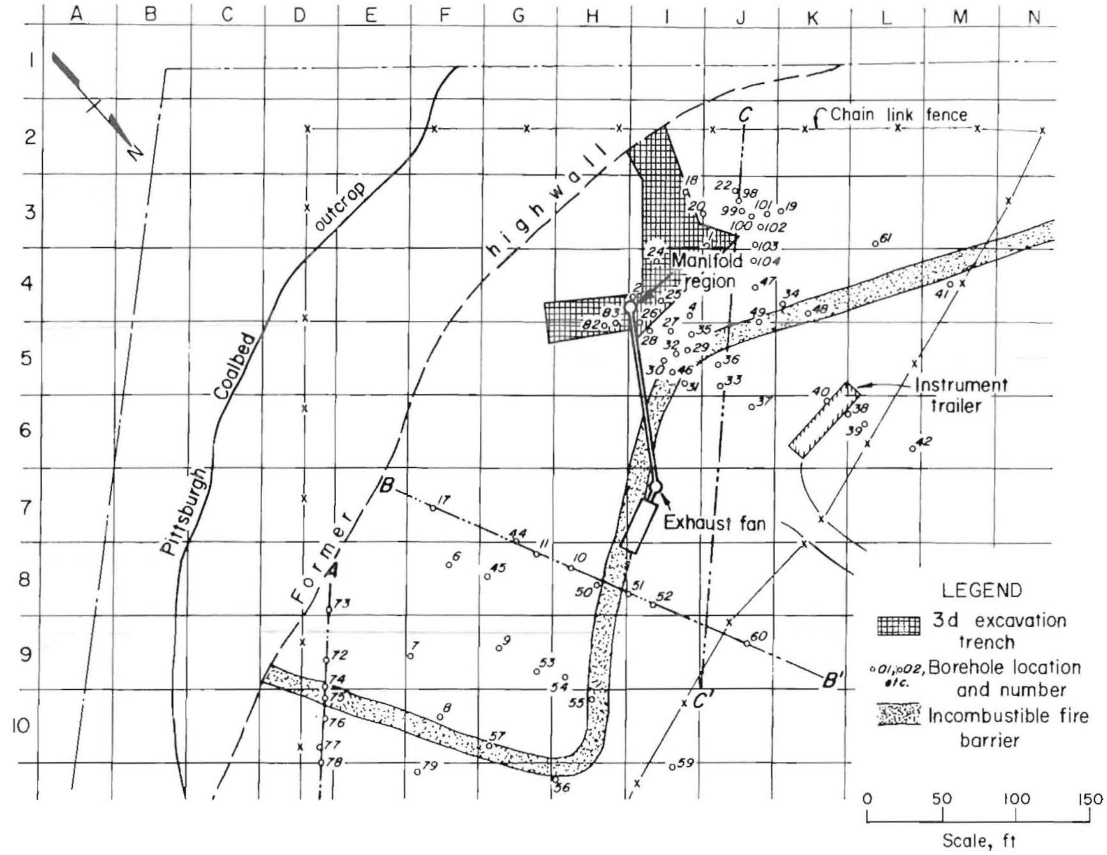

FIGURE 14. - Site plan showing third excavation trench.

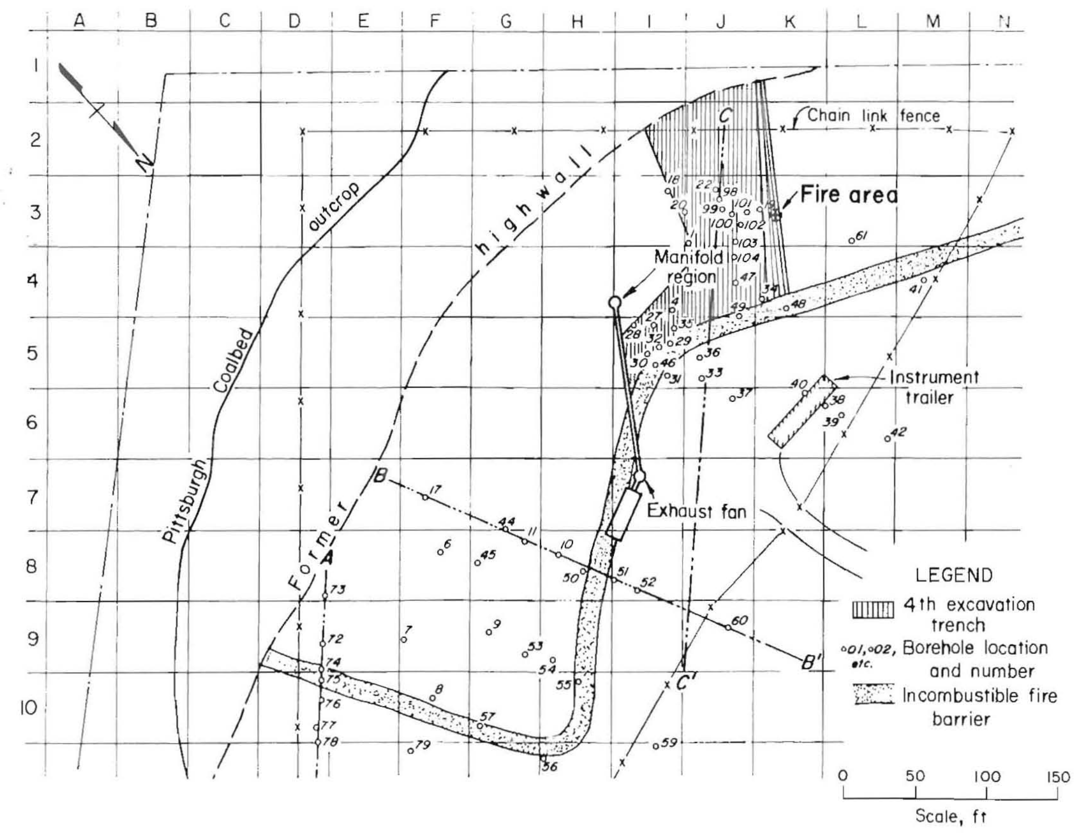

FIGURE 15. - Site plan showing fourth excavation trench.

This burning area was also beyond the perimeter of water penetration from the quenching phase of the project. Continued excavation at this site exposed a pillar that appeared to be thoroughly coked. The temperature of the removed rubble was greater than 258° C (496° F), indicating relatively recent combustion.

The fourth excavation trench exposed (1) areas of red dog with average strata temperatures of 160° C (320° F), (2) areas of strata with colors ranging from light orange to bright red, (3) areas of partial coking resulting from exposure to a range of temperatures, (4) areas of ash streaks throughout the burned rider seams, and (5) intact solid coal pillars. On June 7, the extended western excavation boundary exposed a burned coal pillar on the west wall near the outcrop, but the measured temperature in the burned area was only 25° C (77° F) with the ambient air temperature recorded as 31° C (88° F). The low temperatures and lack of combustion odors indicated that fire had occurred in this area years ago and that enough time had elapsed for the residual heat to have completely dissipated. It was evident that no active fire remained on site. The backfilling was then completed with recontouring and grass seeding. Figure 16 is a view of the site several months after completion of this project.

To summarize, the fire zone was excavated to the depth of the underclay from the B-B' line along the former highwall on one side and incombustible fire barrier on the other to approximately 40 ft west of the C-C' line (fig. 6). Throughout the fire zone, exposed strata showed coloration changes to within 10 ft above the seam, especially above caved areas as a result of exposure to heating, combustion of carbonaceous material, and varying degrees of pillar coking. The fire propagated along collapsed entries, roof coal, rider coal seams, and pillar edges.

FIGURE 16. - Site several months after termination of project.

EVALUATION OF SYSTEM COMPONENTS

VENTILATION SYSTEM

Dismantling the Burnout Control system offered a good opportunity to evaluate how various components and probes survived exposure to extreme temperatures and corrosive combustion products such as moisture and sulfur dioxide. The assembled components of the ventilation system are shown in figure 17. The reader is referred to part 1 (2) and part 3 (11) of this report series for detailed descriptions of the components.

In general, except for the fan and refractory lined T-section, the disassembled ventilation system showed only minor wear for the time used. Viewing photographs of the installed and dismantled components, it would be difficult to determine which photographs represent the postburnout operation components. The refractory lining of the exhaust manifold was completely intact when removed. The only change was that a 4-in insulation rim was missing from the base of the manifold (fig. 18); however, determination of the time of the loss--at installation, during operation, or on removal--could not be made. A section of the refractory lining of the gate valve and elbow combination was lost during the operation, probably as a result of the numerous actions of heating (expansion) and cooling (contraction) and opening and closing of the gate valve, but the valve was otherwise devoid of apparent operational damage. The afterburner extension showed only discoloration of the refractory brick and slight rusting of the external surface of the pipe.

The flanged T-section was most affected by the operation. The combined flow of ambient air, hot moist gas and water spray resulted in attrition of the refractory brick lining of the T-section abutting the unlined duct (fig. 19).

The stainless steel expansion bellows underwent no apparent damage from fully expanding in compensation to shifting as a result of subsidence under the manifold support beams. The expected subsidence effect was controlled through addition of support beams to eliminate tilt in the exhaust manifold. The dropout tank that collected particulate matter and liquids developed pin holes in its base. The liquid contents were acidic (pH 2 to 3) and resulted in corrosion of the steel base plate. The fan blades were flaked with rust and missing several balancing weights. These components were purchased by the Bureau as "second-hand" items (2) and not specifically designed for exposure to corrosive gases and liquids.

With the exception of the fan blades and the T-section, damage to the Burnout Control ventilation system was minimal. This is particularly noteworthy because the system was subjected to internal temperatures of 0° C to 1,000° C (32° F to 1,832° F) and to external temperatures of -30° C to 30° C (-20° F to 100° F); also, it was exposed to gases that contained varying concentrations of sulfur dioxide, hydrogen sulfide, oxides of nitrogen, carbon monoxide, carbon dioxide, oxygen, nitrogen, and hydrocarbons C_1 through C_5.

INSTRUMENTATION

Figure 20 shows the location of the seven major instrumented monitoring stations on the burnout ventilation assembly. The measurements at the various stations were based on the required information for process control and for air pollutant analysis. Instrumentation included gas-sampling probes and gas-transport tubing to the instrument trailer; thermocouples cased in either alumina thermowells or stainless steel thermowells; and two types of flow-monitoring probes, which were Annubar[6] concentric-tube probes and bidirectional flow probes.

Figure 21 shows several probes removed from stations 1 and 2. The thermowells (*A* and *D*) and gas-sampling probe (*B*) changed color from the heat exposure and accumulated residue but were not damaged. The bidirectional probe assembly (*C*) also

[6]Reference to specific products does not imply endorsement by the Bureau of Mines.

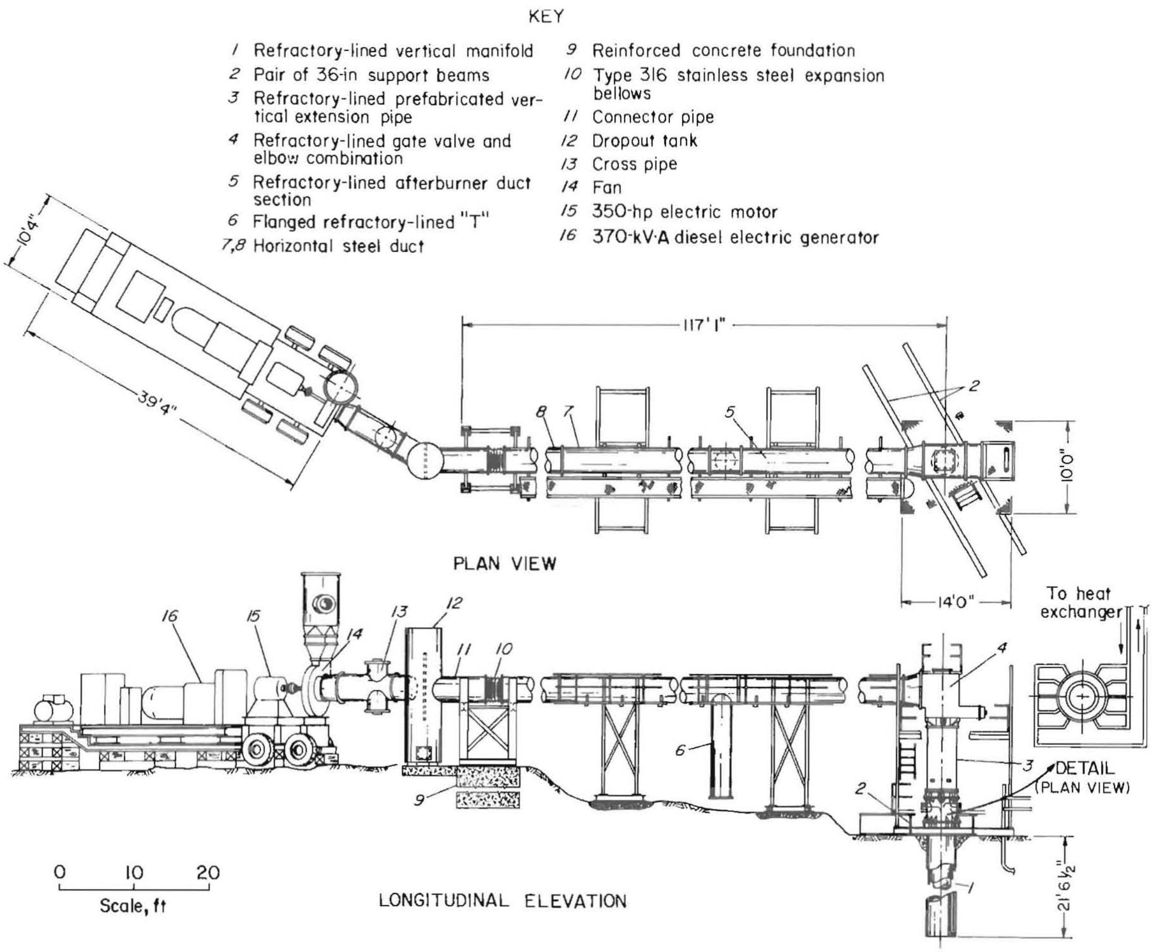

FIGURE 17. - Burnout unit assembly.

FIGURE 18. - Disassembled exhaust manifold.

FIGURE 19. - Attrition of refractory lining in T-section of air inlet.

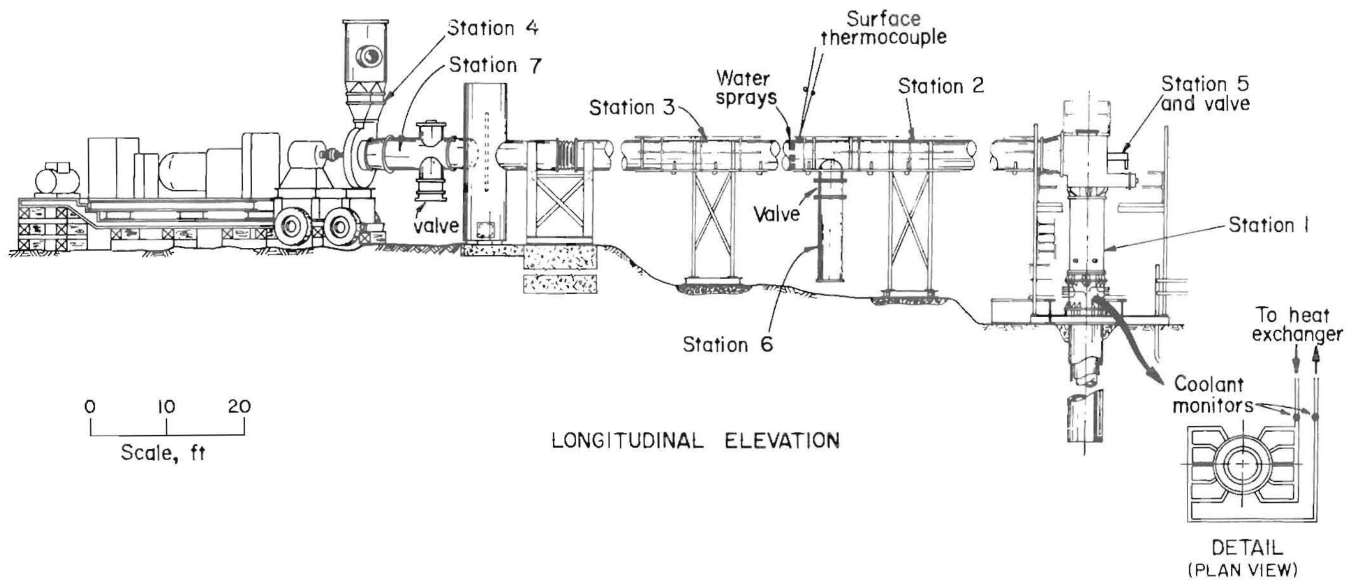

FIGURE 20. - Instrument station locations.

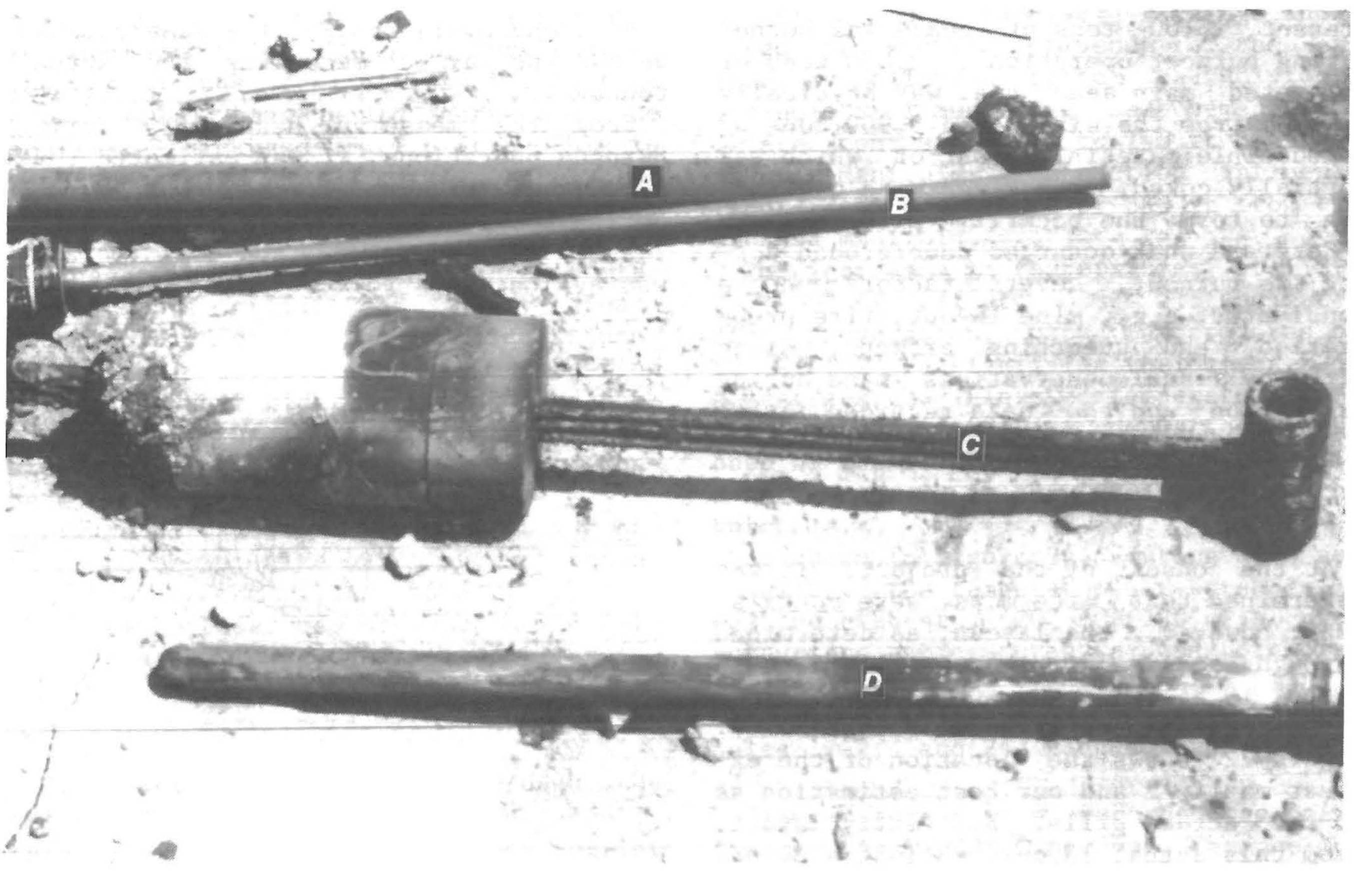

FIGURE 21. - Instrumentation probes from stations 1 and 2. *A*, Thermowell from station 1; *B*, gas-sampling probe; *C*, bidirectional probe; *D*, thermowell from station 2.

accumulated residue, which created partial blocking and corrosion of the stainless steel tubing; however, it continued to function satisfactorily. Overall, the monitoring probes removed from all stations had changed in color, attritioned (possibly from solid particles, water droplets, and/or flowing hot, moist gases), and were covered in greenish-black residue, but all probes functioned throughout the 4-month continuous burnout operation. Minimal damage occurred to the instrumentation-monitoring probes.

DISCUSSION

Physical evidence exposed through excavation showed combustion through the mine for a distance of 120 ft on one side and 140 ft on the other side of the exhaust manifold, essentially through rider coal seams and collapsed entries. Approximately 1 acre, estimated originally to contain 9,200 tons[7] of combustible material (2) was excavated (5,500 tons main seam coal plus 3,700 tons of rider seam coal). Of the 9,200 tons originally present, 1,100 tons of coal was burned during burnout operations, 2,000 tons of excavated main seam coal was physically removed from the site, and 5,900 tons of combustible material, most of which was partially coked, was mixed with overburden to form the backfill material. To understand what occurred underground during the burnout, several factors must be considered, e.g., mine layout, fire propagation, and quenching effects, along with the visual observations made during excavation and the data recorded during the 4-month operation.

MINE LAYOUT

At the onset of the project, it was determined that mine maps were nonexistent; however, the layout, as determined through excavation, showed pillars to be 14 to 19 ft wide and 50 to 55 ft long with entries approximately 19 ft wide. Figure 22 shows the location of the exhaust manifold and our best estimation as to the actual pillar and entry layout. From this actual layout, estimates of the coal, burned and intact, are calculated. The excavation revealed average pillar dimensions of 53 ft by 17 ft by 5 ft, implying 180 tons of coal per pillar. The average entry width was 19 ft, so the area per pillar plus entry was 2,600 ft^2 (53 ft + 19 ft) × (17 ft + 19 ft). There are 17 pillars per acre, which yields 3,000 tons of coal per acre or 5,500 tons for 1.8 acres. The original estimate of main coal seam for the 1.8 acres was 10,000 tons (2), or two times the current estimated excavated main coal seam. The original rider coal seam estimates of 6,660 tons would remain the same because we had no way of measuring the actual tonnage.

From the measured heat flow during burnout operations, it was estimated that 1,100 tons of combustibles was burned during the operation (3). Assuming that 1 acre was excavated, the coal balance was evaluated as follows:

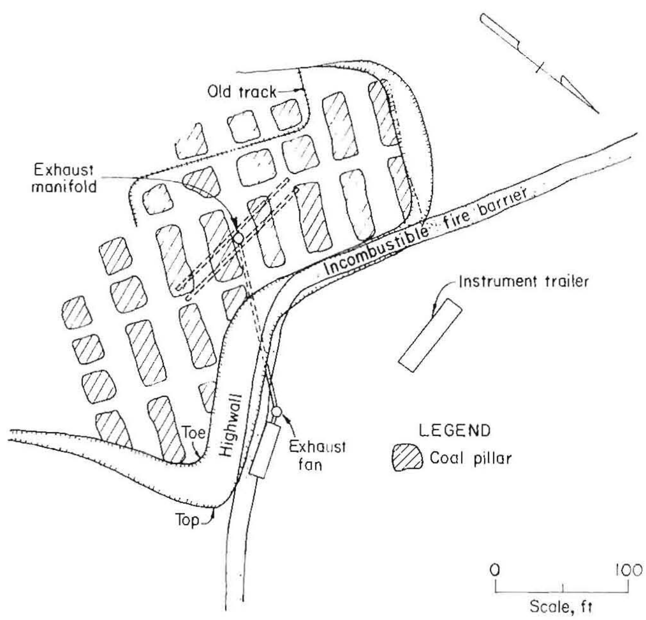

FIGURE 22. - Inferred location of mine pillars and entries.

[7]Material quantity values used throughout the discussion are approximate.

Original coal estimates:	3,000	tons main seam coal
	+	
	3,700	tons rider seam coal
Total:	6,700	tons combustibles (including carbonaceous shale)
Accounted coal estimates:	2,000	tons main seam coal removed
	+	
	1,100	tons combustibles burned during operation
Total:	3,100	tons total accounted
Total unaccounted combustibles:	3,600	tons

If the 1,100 tons of coal burned were primarily rider seam coal, there would be 3,000 tons of main seam (i.e., pillar) coal and 2,600 tons of rider seam coal remaining. However, only 2,000 tons of main seam coal were removed by the contractor indicating that 1,000 tons of coal pillars were considered too heat affected to warrant their recovery as usable coal. If all the heat-affected pillar coal were distributed uniformly along the tops of the coal pillars in the fire zone, 1,000 tons would correspond to a pillar thickness of 1.6 ft. This is consistent with the observations of heat affects in the upper 2 to 3 ft of many pillars.

Excavation revealed the actual mine layout, and pillar and entry dimensions enabled coal tonnage calculations. The visual observations of combustion throughout the rider seam coal and top-edge burning of main-seam coal pillars are consistent with the calculated tonnage of excavated coal.

Figure 23 shows an overlay of the entire borehole site plan over a reconstruction of the pillar and entry layout, which were based on borehole drill data and the mapped excavated solid pillars.

FIRE PROPAGATION

Propagation of the fire through the collapsed entries, along roof coal, through rider coal seams and on pillar edges was determined through actual observations of heating effects combined with recorded burnout operation parameters.

Excavation showed where underground combustion occurred, but not necessarily when it occurred. In order to determine how the fire propagated, it was necessary to evaluate the recorded monitored borehole temperature and pressure data obtained during the burnout operations. The temperatures defined the direction of fire propagation and lateral extent of the fire, and the pressure readings indicated the suction influence of the exhaust ventilation system on individual boreholes. Temperature measurements indicated combustion 120 to 140 ft from the exhaust manifold with suction influence recorded at a distance of 300 ft from the exhaust manifold.

The increases in temperature, from 25° to >200° C[8] (77° to >392° F) indicated fire propagation, with temperatures of 50° C (122° F) signifying the presence of a heat source. Elevated temperature does not explicitly indicate combustion at the base of the borehole, only that there is a heat source in the vicinity of the borehole.

As shown in figure 24, during site assessment, the temperature at borehole 14 was the highest, 420° C (780° F), with subsurface temperatures around boreholes 20 and 21 ranging from 148° to 155° C (298° to 311° F). Temperatures for boreholes 1, 2, and 24 ranged from 58° to

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[8]Temperatures were recorded as being greater than 200° C because the thermocouple was rapidly removed from the borehole to prevent damage to the thermocouple wires when the digital temperature indicator approached 200° C.

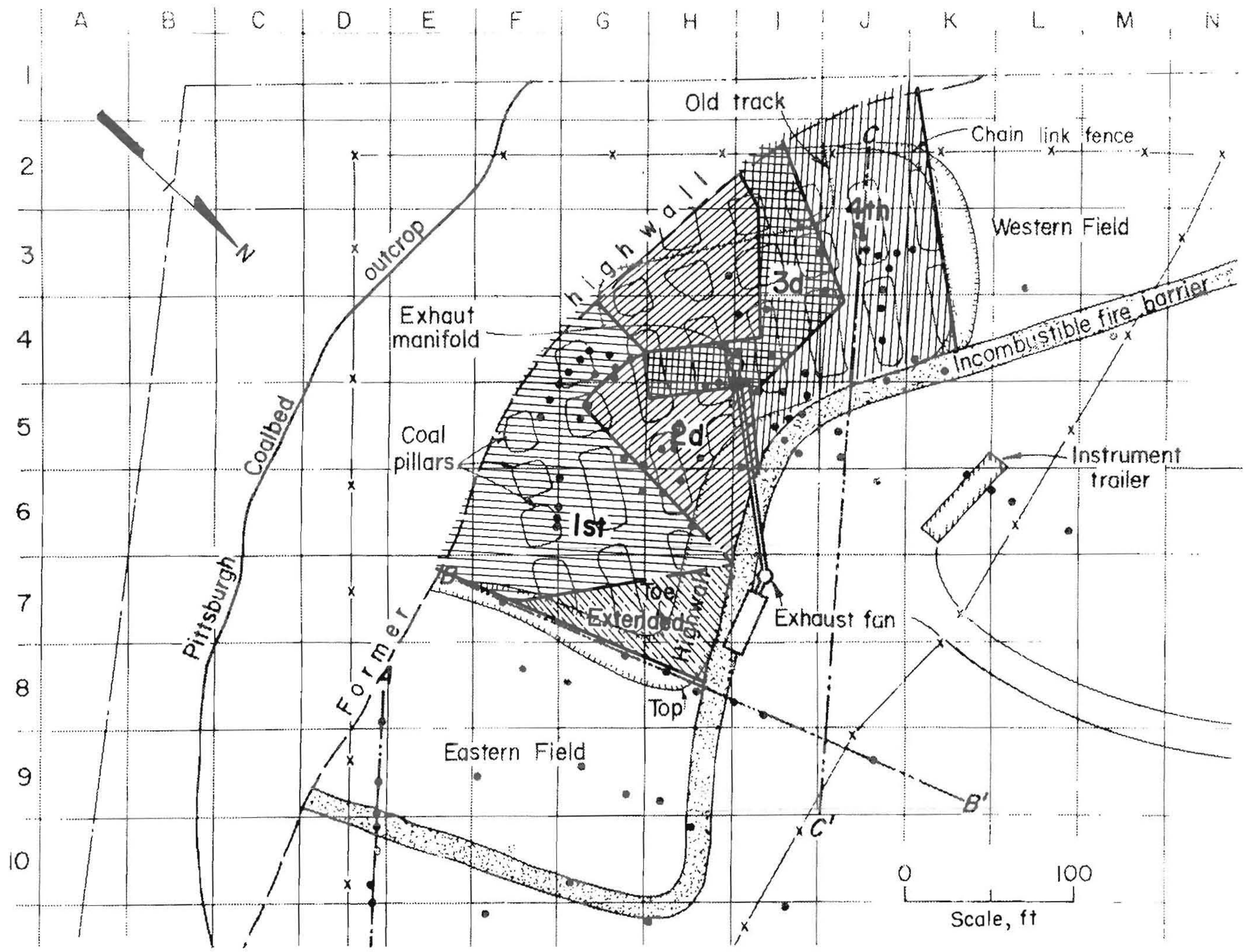

FIGURE 23. - Pillar and entry locations overlaid on borehole site plan.

69° C (136° to 156° F) indicating a nearby heat source; temperatures for the remaining boreholes were recorded as less than 30° C (86° F). The exhaust manifold was installed near borehole 2 where temperature measurements indicated that the coal seam was warm (approximately 58° C (136° F)) and demonstrated communication with a higher temperature zone, borehole 14, about 70 ft away (2). The concept was that by exhausting gases near borehole 2, the fire zone would intensify.

The 4-month continuous operation began on January 4, 1982. Figure 25 shows the borehole temperatures recorded 5 days later. The temperature at borehole 14 had decreased to 151° C (304° F), but the temperature near the exhaust manifold increased to >200° C (>329° F). In early February, ignited charcoal was poured into boreholes in the areas of boreholes 3, 5, and 15 in order to extend the fire zone easterly to create a more uniform fire zone around the exhaust manifold.

On May 1, 1982, before quenching, temperatures greater than 200° C (392° F) existed from borehole 99 in the western field to borehole 16 in the eastern field (fig. 26). The progression of increased temperatures throughout the mine during the 4 months provides data supporting the acceleration of combustion as controlled by the burnout ventilation system.

Excavation showed interesting effects from the differences in the lengths of the borehole casings. Boreholes were opened during the operation to provide air to accelerate the fire. The average diameter of the boreholes was 4 in with depths ranging from 24 to 44 ft. The

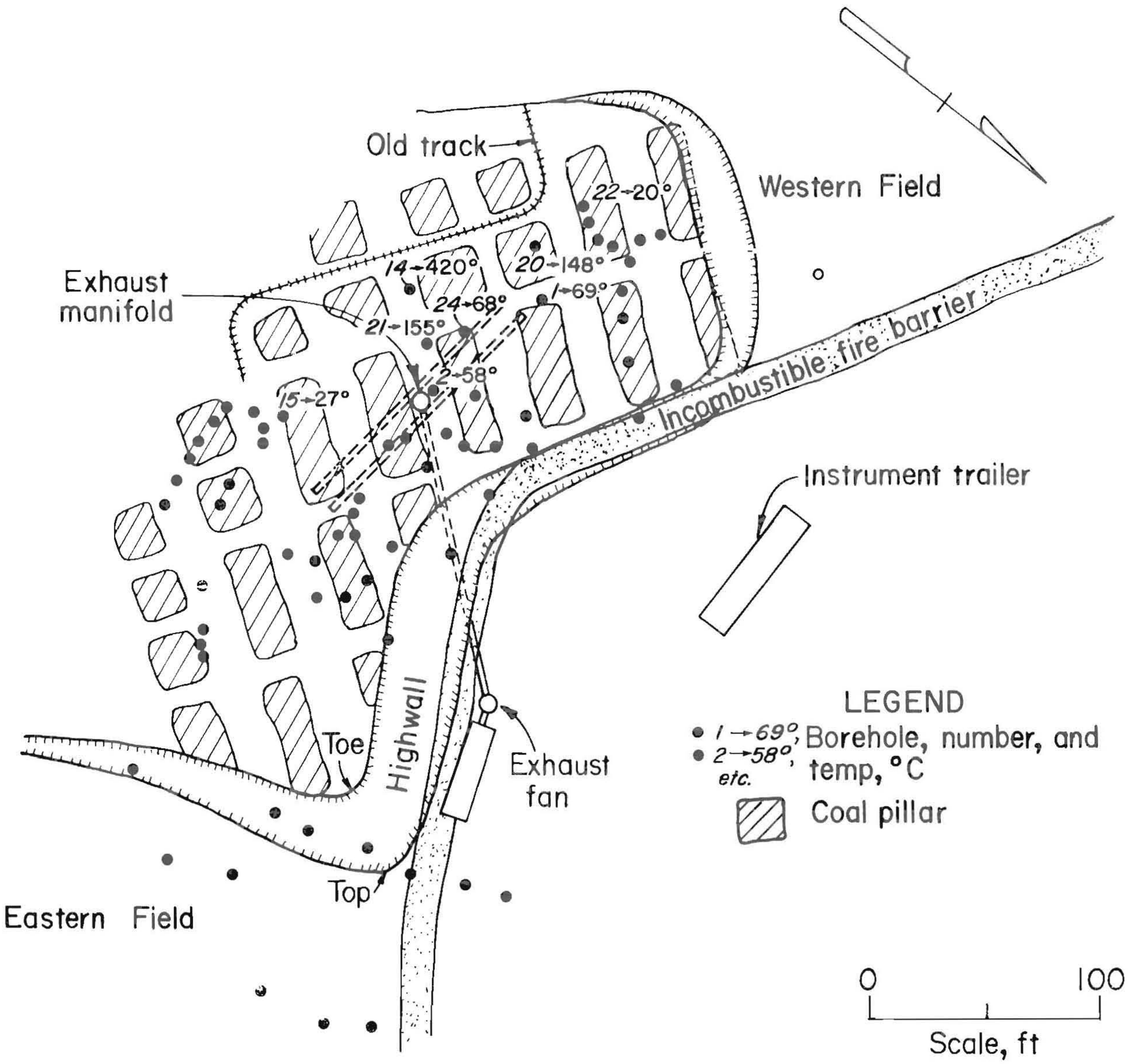

FIGURE 24. - Borehole temperatures on March 1, 1980.

placement of new boreholes during operations was based on best judgment using areas of subsidence, surface cracking, and venting of fumes and/or smoke (when the fan was off) as indicators of combustion. Boreholes 1 through 47, drilled before start of the burnout, were cased 20 ft from the surface, so as much as 24 ft of the hole was uncased in some of the boreholes. The boreholes were subject to shifting of the strata below the casing, sinking of the casing below the surface, and/or filling-in of the uncased portion of the borehole by loosened strata; any occurrences would influence the borehole permeability, possibly restricting air intake for influencing fire propagation in the mine. However, boreholes 82 through 115, which were drilled during the operation, were cased from the ground surface to a few feet above the main coal seam. The area excavated at these boreholes showed more intense color changes such as brilliant oranges to deep crimson shades with white ash streaks to within 10 ft above the main coal seam. The coal pillars beneath these boreholes appeared brilliant silver, devolatilized, and coked to within 1 to 2 ft of the bottom of the pillars. A more efficient

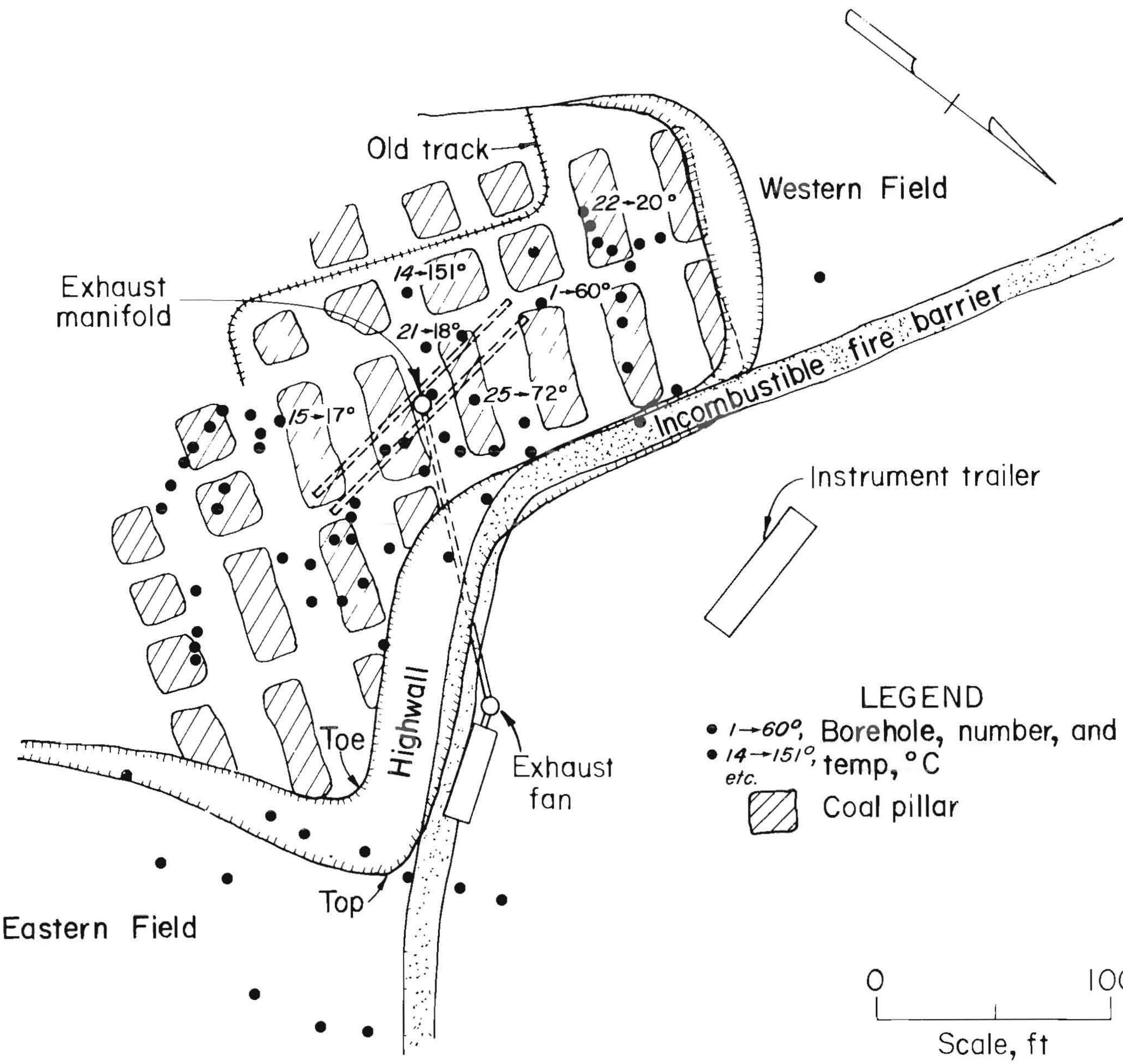

FIGURE 25. - Borehole temperatures on January 9, 1982.

combustion and more intense strata heating appeared in these regions, suggesting that if burnout had continued for a longer time, these pillars may have been completely burned.

The physical evidence at boreholes 82 through 115 suggested better burnout than at boreholes 1 through 47. This could have been the result of longer casings providing better air flow to the main seam coal.

The appearance of coked pillars during excavation indicates high-temperature heating of the pillars either during burnout operations or during quenching operations. Coke is formed by pyrolysis of bituminous coal when it is heated. The coal initially converts to a fluidic devolatizing state and begins to expand and form char as the volatiles are driven out and the temperature increases (12). Exothermal and endothermal effects can be observed in the pyrolysis of Pittsburgh seam coal in the temperature range 350° to 550° C (662° to 1,022° F), as the coal undergoes extensive structural and chemical changes: softening to the metaplast, plastic layer state, degasification,

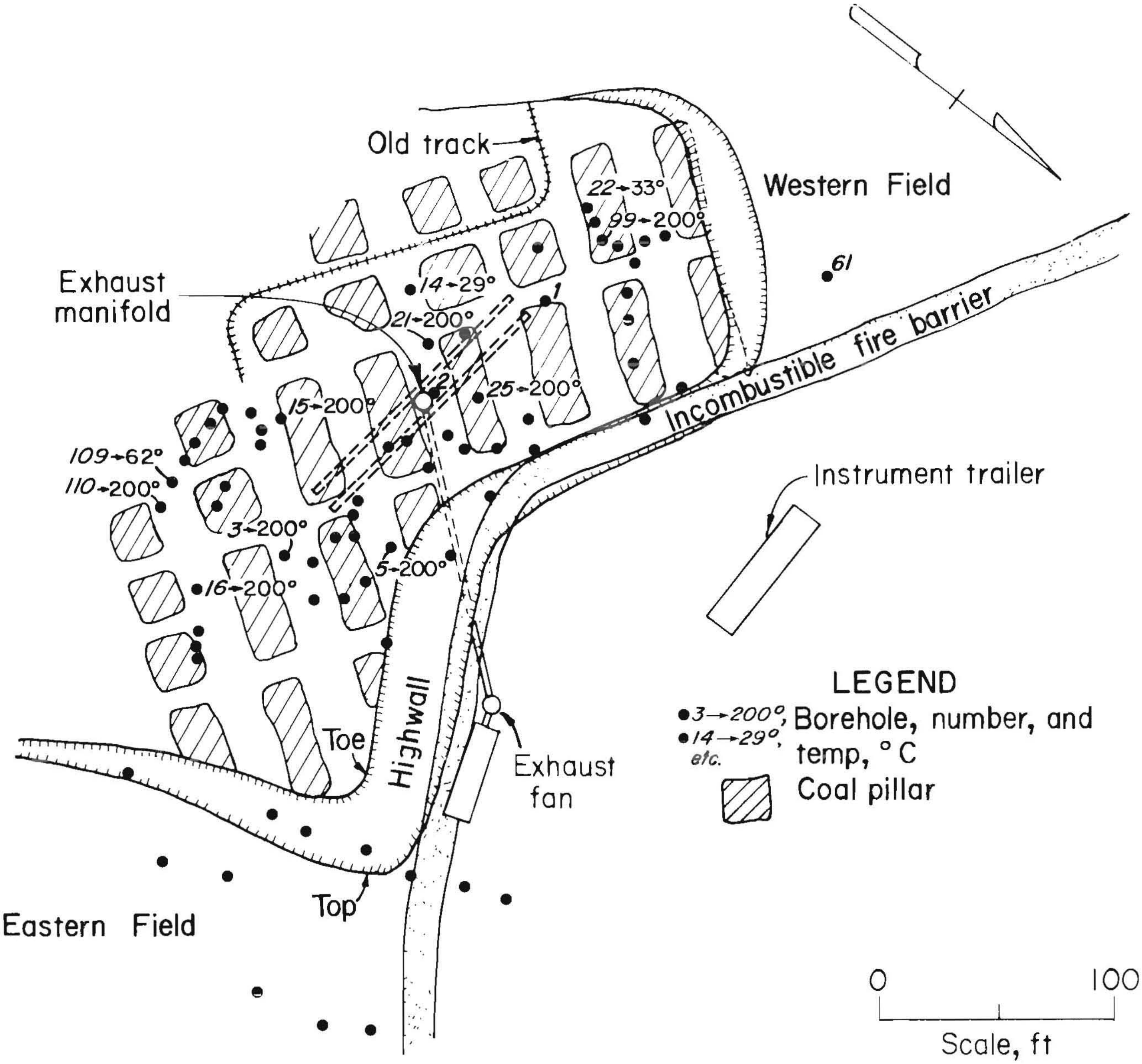

FIGURE 26. - Borehole temperatures on May 1, 1982.

recondensation, and solidification (13). Polymerization of the gas or liquid state to form coke is a very highly exothermic reaction (14). Thus, portions of a pillar at elevated temperature could continue the heating reaction to form coke, even after the external heat source has been removed and while other portions of the pillar are cooling. Therefore, coking in the fire zone could have occurred during the burnout operation or the quenching operation. Although there is no way to determine exactly when coking took place, the appearance of coke during excavation indicates that combustion would have continued if the operation was not terminated.

VENTILATION SYSTEM

In general, ventilation and instrumentation components of the Burnout Control system had been designed or chosen for function and durability with the 4-month continuous operation providing a test of these design parameters. As previously described, the disassembled system except for the fan and T-section showed minor wear for the time used.

One area of erosion was the air inlet T-section (figs. 17, 19) where attrition was caused by the combined effects of hot gases, cool air, and cold water spray flowing through this section. Redesign of the water spray coolant system could include a fluid-cooled duct with internal horizontal and vertical baffles to provide better mixing of the hot gases and cold air.

QUENCHING EFFECT ON HEATED ZONES

Injection of water, at a rate of 1 to 2 gal/min per borehole, while exhausting hot fumes through the ventilation system is the basis of the water injection-fume exhaustion system. By reducing the temperature of the strata and exhaust gases through the conversion of water to steam while excluding the intake of fresh air, the fire was extinguished. The strata cooled as the cooler gases and/or air flowed through it, thereby transferring heat to the atmosphere via the exhaust ventilation system.

At the beginning of the quenching phase, underground temperatures throughout zone B measured >200° C (>392° F) indicating extensive heating in the coal seam. The excavation exposed varied degrees of coking of pillars and color changes from heat exposure of the strata to approximately 10 ft above the rider coal seams. Visual estimates of these burned areas support the data analysis described in part 4 of this series (4) that approximately 20,000 tons of strata (rock and coal) was heated to a height of about 10 ft above the coal seam. Water injection-fume exhaustion reduced the strata temperatures recorded during excavation to approximately 160° C (320° F). Overall, this technique resulted in cooling of all the strata in the region of water injection. A detailed description and data analysis of the quenching technique is presented in part 4.

Two local burning areas discovered during excavation were observed as flickering flames through voids in the strata. The fires were not observed immediately upon exposure during the excavation. Ideal conditions for spontaneous combustion (heat, fuel, and air) existed in those regions and ignition or reignition occurred. The burning areas were outside the perimeter of the water injection boreholes. Although complete extinguishment of the Calamity Hollow mine fire was not achieved by the water injection-fume exhaustion technique because of too short a water injection time period, the exhaust gases and strata temperatures were reduced enough to provide for safe excavation of the site.

SUMMARY

The Calamity Hollow Mine Fire Project demonstrated the techniques of Burnout Control and water injection-fume exhaustion. During the 4-month continuous burnout operation, approximately 1,100 tons of combustibles was consumed to yield time-averaged values of exhaust temperature and thermal output of approximately 600° C (1,112° F) and 3.1 MW, respectively. After completion of the continuous burnout phase and before excavation, water injection-fume exhaustion was used to cool the fire zone. A 30-day application of the water injection-fume exhaustion technique resulted in 70% reduction in exhaust temperatures with strata temperature cooled to an average 160° C (320° F).

The excavation provided the opportunity to evaluate these techniques. The fire propagated 120 to 140 ft from the exhaust manifold, and paths of combustion were identified to be through roof coal, pillars, and collapsed entries. Combustion of the rider coal seams and carbonaceous material was more complete than was the burning of pillars, which occurred primarily on edges and top 1 to 3 ft of the pillars. Several extensively coked pillars were exposed, but it could not be determined whether the coking occurred during the burnout or during the

quenching phase. The coking indicated extensive pillar heating, and ostensibly combustion of pillars would eventually occur if air were supplied over a sufficiently long time. Through observation of strata color changes, the extent of strata heating was determined to be within 10 ft above the rider coal seam.

Excavation ensured complete extinguishment of all remaining fire and the land was completely restored. The results of the excavation analysis confirm the effectiveness of both Burnout Control and water injection-fume exhaustion for control of fires in abandoned coal mines.

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