UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF MINES

District F

FINAL REPORT OF MAJOR MINE INRUSH OF HOT GASES AND STEAM DISASTER

SHERWOOD MINE
INLAND STEEL COMPANY
IRON RIVER, IRON COUNTY, MICHIGAN

June 1, 1959

By

James Westfield, Assistant Director, Health and Safety
John A. Johnson, Chief, Division of Safety
Allen D. Look, District Supervisor, District F
R. O. Pynnonen, Supervising Mining Health and Safety Engineer

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INTRODUCTION

An inrush of hot gases and steam at the Sherwood mine, Inland Steel Company, Iron River, Iron County, Michigan at 9:05 a.m., June 1, 1959 caused the deaths of six men. Four men were killed instantly, a fifth man died that evening, and a sixth man died five days later; all from extensive second and third degree burns and inhalation of hot gases. Six additional men were hospitalized with severe burns, and 28 other men, underground at the time, escaped injury. Except for one conflicting statement, all of the men underground at the time reported no evidence of sulfur dioxide gas in the rush of hot gases that entered the underground workings.

GENERAL INFORMATION

The Sherwood mine is located in the village of Mineral Hills on the Menominee Iron Range approximately 1-1/2 miles north of the city of Iron River. Inland Steel Company opened the mine in 1940 and has operated it continuously since that time. Operating levels were the 1200, 1300, 1400, and the 1425.

Ore was shipped on the Chicago Northwestern Railway Company line to the port of Escanaba on Lake Michigan for lake shipment to the company's Indiana Harbor plant.

Names and addresses of company officials are:

Joseph L. Block, Chairman of Board, Chicago, Illinois
John Smith, President, Chicago, Illinois
R. D. Satterly, Gen. Manager, Ore Mines, Ishpeming, Mich
Phillip D. Pearson, Manager, Ore Mines, Ishpeming, Mich.
R. W. Edwards, Superintendent, Iron River, Michigan
E. C. Leonard, Safety Director, Ishpeming, Michigan
R. C. Silas, Safety Engineer, Ishpeming, Michigan

A total of 88 men was employed at the mine, 56 of whom were underground workers. Mechanics and electricians were classed as surface employees, but their duties often required underground work. The mine was operated two shifts a day, five days a week. Production in 1958 totalled 475,000 tons of ore.

The Sherwood mine was bounded on the east by the abandoned Spies-Virgil mine. The Cleveland-Cliffs Iron Company closed the mine in July, 1955. The operating Wauseca mine of The M. A. Hanna Company was located on the western boundary of the Sherwood mine.

The Sherwood mine was served by a main hoisting shaft to the 1200 level and a 15-degree incline from the 1200 level to the 1425 level. A 48-inch-diameter ventilation shaft bottomed on the 400 level. Most of the present production was from stopes between the 1200 and 1425 levels. There was one stope under development above the 1200 level.

Direct-shipping hematite ore containing small quantities of limonite and goethite was mined from irregular, and highly-folded ore bodies having an east-west trend and dipping to the north. The footwall of the formation contained black, pyritic-carbonaceous slates. Oxidation of the iron sulfides, whenever these slates were exposed, was a constant spontaneous-combustion fire hazard at all mines on the Menominee Range.

A black slate in the jasper-iron formation hanging-wall also contained iron sulphides, but was not conducive to spontaneous ignition on oxidation, probably because of high chert content.

The black slates were subject to spontaneous combustion whenever they were exposed to air. Once heat is generated by oxidation of the pyrites, the process becomes self-perpetuating until the supply of oxygen is cut off and all reserve oxygen in the area is completely consumed. Flaming is seldom if ever present in these fires, but the combustion process can produce extremely high temperatures in large masses of material. Attempts to extinguish many of these fires with water streams have not been entirely successful.

Fires from the oxidation of the black slates have been a common occurrence at all mines in the district. It was a general practice to leave a 4- to 6-foot thickness of ore on the footwall-side of a stope to prevent oxidation and to

introduce fill material into completed stopes through boreholes from surface. Abandoned levels were usually sealed with concrete bulkheads.

Company officials reported that the last fire at the Sherwood mine occurred in No. 8 stope more than 10 years ago. Reportedly, no indication of an active fire had been noted since that time.

Bureau of Mines' records show that a fire occurred from oxidation of the black footwall slates in the Sherwood mine on August 4, 1947. Black slates had been exposed during mining operations in No. 2 stope above the 1000 level. When caved slate sloughed into the mills, a vertical longitudinal pillar was left, and the portion of the stope north of the pillar was mined. A fire was discovered shortly before the pillar was to be mined. The fire area was sealed, and approximately 80,000 tons of mineable ore was lost. No men were killed or injured by this fire.

Three men were burned to death on June 1, 1952 at the Davidson mine, operated by Pickands Mather & Company, when a blasting operation to drop a floor pillar forced hot gases and dust into the working areas. This operation was carried out when all other men were out of the mine. Fuses of sufficient length to permit the men to reach the shaft were used in this blast, but contrary to orders, the men remained near the blast area with the probable intention of visiting the blasting site to determine the success or failure of the operation. The Davidson mine, now exhausted, was located approximately 1/2 mile northwest of the Sherwood mine. The possibility of an explosion of black slate dust as a cause of this accident was not discounted.

In July 1955, a cave-in to surface over a stoped area in the abandoned Spies-Virgil mine resulted in an inflow of water to the Sherwood mine. Water from the abandoned mine entered the Sherwood mine through an incline connecting the 8th level of the Spies-Virgil mine and the Sherwood mine 1200 level. Water rose to 10 feet above the 1200 level in the Sherwood mine before sufficient pumping capacity was installed in both the Sherwood and Spies shafts. This inrush did not result in any fatalities or injuries.

MINING METHODS, CONDITIONS, AND EQUIPMENT

Mining Method:

Ore was mined by a sublevel stoping method with re-

treating benches towards a pillar or a wall of the ore body. Main levels were driven on 200-foot vertical intervals with mining sublevels at approximately 35-foot intervals.

Stope development was started from the bottom with the development of transfer drifts at an elevation of approximately 4 feet above the main level. Raises were driven and connected by a grizzly or scraping sublevel, 25 feet above the transfer drift. Mill sublevels were developed 25 to 30 feet above the grizzly sublevel. Raises were carried to the upper main level, and mining sublevels, at 30-to 35-foot intervals, were driven before the actual development of the stope was started. The exact limits of the ore body were determined by extending the mining sublevels until the footwall or hangingwall was encountered.

A stope raise near either the footwall or hangingwall, depending on the direction of retreat selected for the particular stope, was opened, starting from the bottom mining sublevel and progressing upwards to the top mining sublevel. This opening was then widened by benching from each of the sublevels until the full width of the stope was reached. Benches, which were curved during the development of the stope, were squared after full width was reached so that the benches were at approximately right angles with the line of retreat. Depending on the thickness of the ore body, the retreat was carried to a pillar or the opposite wall of the ore body.

A 50- to 60-foot thick floor pillar was left between the top of the stope and the bottom of upper stopes. The vertical pillars between stopes varied in thickness but averaged 40 feet.

Explosives:

High explosives were detonated by cap and safety fuse during production operations and by electrical detonators in wet development work in main drifts only.

Gelex No. 1, 1-1/4- by 8-inch, 60-percent dynamite was used in development and slicing; "stope" holes and "uppers" were blasted with Gelex No. 2, 2- by 16-inch, 45-percent dynamite; and "block holing" was done with Gelex No. 1, 7/8- by 8-inch, 60-percent dynamite.

Ventilation:

The mine was ventilated through a 48-inch-diameter ventilation shaft bottoming on the 400 level. A 50,000 c.f.m. capacity fan on that level forced air through a ventilation raise to the 800 level. A concrete bulkhead prevented air from entering the abandoned stoping area. Air travelled through a short raise to an open stope between the 800 and 1000 level and then through several raises to the 1000 level. Most of the air then travelled down an air raise to an overpass above the 1200 level. A 30,000 c.f.m. booster fan forced the air to the 1200 level where a wooden brattice prevented eastward movement of the air.

Air travelled west on the 1200 level, down raises and through the mining sublevels of the operating stopes to the 1400 and 1425 levels. The air was exhausted eastward on these levels to the incline, up the incline to the 1200 level exhausting through the main hoisting shaft.

The east side of the mine was ventilated by a split of air from the 1000 level, through stopes and raises to the 1200 level. A booster fan on the 1200 level forced air through working places below the 1200 level. Some air exhausted from the 1300 level to the incline.

Transportation:

All underground ore transportation on the 1200, 1300 and 1400 levels was by conveyor belts. The 30- and 36-inch wide transfer belts were loaded from chutes equipped with pneumatic gates. The transfer belts discharged on the level belt which carried the ore to the incline. A 36-inch wide belt carried the ore up the incline to the 1200 level and discharged into a storage pocket. Skips were loaded from measuring pockets below the storage pocket.

Electricity:

Electricity was furnished as 23,000-volts alternating current by the Wisconsin-Michigan Power Company. A surface substation provided a 2,300-volt alternating current circuit and a converter provided a 250-volt direct current circuit for transmission underground. Transformers underground provided the required voltages for illumination and operation of equipment.

The mine pumps and main fan were powered from the 2,300-volt circuit. A trolley circuit on the 1200 level carried 250-volt direct current. The 20-, 25- and 30-horsepower tuggers and the incline hoist were powered by 440-volt alternating current. Lighting underground was from a 220-volt alternating current circuit. Individual pieces of equipment were protected against overload by fuses, and breakers protected the main circuits.

Illumination and Smoking:

Main levels, shaft stations, and pump rooms were illuminated by incandescent lights from a 220-volt alternating current circuit. The explosives-storage magazine was wired in conduit with explosion-proof fixtures. All underground employees were provided with portable electric cap lamps. Smoking was permitted in the mine except at designated locations such as explosives-storage rooms, and shaft stations. Signs prohibiting smoking were posted at these locations.

Drainage:

The mine was relatively dry; a total of 8,625,000 gallons of water was pumped from the mine during the month of April. Sumps were located on the 400, 1200 and 1425 levels. Water drained along ditches in the main drifts to collect in the sumps.

A 150 g.p.m. pump on the 1425 level pumped water to the sump on the 1200 level. Three pumps, one rated at 127 g.p.m., a second rated at 159 g.p.m., and a third pump rated at 424 g.p.m. pumped water directly from the 1200 level to surface. A 150-g.p.m. pump on the 400 level also pumped directly to surface.

Mine Rescue:

The company maintained a well-equipped mine rescue station at the mine. The station was located in a room off the concrete-lined tunnel connecting the mine office and wash house with the shaft. Six McCaa 2-hour self-contained oxygen breathing apparatus, two Chemox apparatus, and five Universal gas masks were maintained at the station. Well-equipped mine rescue stations were maintained by two other companies within a 5-mile radius of the Sherwood mine. Equipment from these companies was made available. A total of 17 men had received Bureau of Mines' training in mine rescue. The last training was completed on April 8, 1959.

STORY OF DISASTER AND RECOVERY OPERATIONS

Activities of Bureau of Mines Personnel:

The Bureau of Mines learned of the accident at 2 p.m. in a telephone call from the Duluth office of another mining company. Mr. Allen D. Look, district supervisor, immediately contacted E. Leonard, safety director, Inland Steel Company at the Sherwood mine, to offer the services of Bureau of Mines' personnel and equipment. Mr. Leonard requested the Bureau of Mines' services on a "standby" basis.

R. O. Pynnonen, supervising mining health and safety engineer, arrived in Iron River and contacted Mr. Leonard and R. Silas, company safety engineer at 7 p.m., June 1. Allen D. Look, district supervisor, arrived at 8:30 p.m. that same evening. James Westfield, assistant director, and John A. Johnson chief, Division of Safety, Washington, D. C., were at the scene during the periods June 4 - 8 and June 15 - 17.

Mining health and safety engineers Joseph B. Stepan and H. L. Schell and safety representative L. J. Zaverl assisted with the investigation at various times during the weeks following the disaster.

All rescue operations and removal of the bodies had been completed before the arrival of Bureau of Mines' personnel. Bureau employees assisted with the investigation of the accident; participated in conferences with company officials regarding recovery operations, and collected dust, slate, and air samples.

Mine Conditions Prior to the Accident:

Stopes 6, 2, and 8 going easterly from the Wauseca property line above the 1000 level had been mined and the level sealed with a concrete block bulkhead. Stopes 24, 22, 20, and 18 between the 1200 and 1000 level had also been mined. Present production from the west side of the mine came from stopes 1408, 1406, 1404, 1402, and 1400. Mining operations were being conducted in Nos. 1400, 1402, 1404, and 1406 stopes. Operations in No. 1408 had been completed, but ore was still being drawn from this stope.

Bureau of Mines' records show that a fire occurred in No. 2 stope on August 4, 1947. Company officials reported that a fire also occurred in the adjacent No. 8 stope (See figure 3), at a later date. This fire area was sealed by erecting

concrete bulkheads with provisions for sampling the atmosphere behind the seals. Sometime later these seals were relocated, but no sampling pipes were installed in the new seals. As a result there was no provision for sampling the sealed area. Both company officials and employees reported there was no indication of combustion detected in the ventilation current of the mine prior to the disaster. Reino Anderson, Iron County Mine Inspector, had observed no indication of fire during his regular inspections of the Sherwood mine.

Later a churn-drill hole was sunk from surface to the top of No. 2 stope, a distance of approximately 600 feet. The 160 feet of hole to ledge was 42 inches in diameter and cased. Below ledge, the hole was 30 inches in diameter and uncased. Pit-run fill material was introduced into the stope through the borehole. Sometime later, a raise was driven from the top mining sublevel in the pillar between No. 2 and No. 6 stopes which intersected the borehole and permitted the introduction of fill material into No. 6 stope. Fill material was obtained from a pit located approximately over the upper west side stopes. Surface subsidence in the pit area resulted in the loss of the borehole early in 1956, and no fill material had been introduced since that time. The subsidence formed a depression in the floor of the pit collecting rainfall which seeped into the cover over the west-side stopes. However, mine pumping totals had shown no abnormal increases during the spring months.

Company officials reported that No. 2 and No. 6 stopes had been completely filled before the borehole was lost. It was also reported that the pillar between stopes 22 and 24 had been mined, and that the resulting large opening was at least partially filled with material admitted from the stopes above. Also, stopes 18 and 20 had filled with caved material. Stope No. 16 was reported empty.

STORY OF DISASTER

Normal mining operations were resumed with the start of the "day shift" at 7:30 a.m., Monday, June 1. The mine had been idle since the completion of the afternoon shift at 1:30 a.m., Saturday, May 30. Sometime after 8 a.m., Jack Johnson, shift boss, after first stopping and talking with miners from No. 1406 and No. 1408 stopes, met the two miners who had been scraping from No. 1404 stope. The miners reported they could hear their stope "running". Johnson and one of the miners climbed to the scraping sublevel from where they could hear the stope "running like a river". Johnson immediately

called the miners out of No. 1406, No. 1408 and then No. 1402 stope and a crew working in a contract off the 1425 level. It was immediately after warning this crew that the first "pressure" was felt affecting the men's ears. Johnson reported a "terrific wind" and heavy dust going up the incline towards the shaft. The shift boss and four or five other men climbed to the 1200 level by way of No. 1403 ladder road, but when they opened the door covering the raise at the 1220 sublevel, a blast of heat forced them to return to the 1425 level. These men later climbed up the incline to the 1200 level where they found the air hot, but visibility improved.

In the meantime, the men from the 1400 level west stopes had congregated near the intersection of 1400 and the incline. Several of the men reported they had to hold on to timbers to prevent being blown east along the drift. Two men who attempted to climb to the 1200 level by way of 1402 ladder road, turned back when they felt hot water dropping on them. These men returned to the 1400 level and later climbed up the incline to the 1200 level and reached the cage.

W. Johnson, mine captain, had visited the miners in No. 1403 and No. 1405 stopes on the east side of the mine and was on his way to a third contract on the 1425 level when the wind and dust reached him. Believing conditions would be better in No. 1405 stope, he started that way, but could not find the manway because of the large amount of dust in the air. After conditions improved, the mine captain returned to a point near the incline where several other men had congregated. These men climbed the incline and found lamps, belts, hard hats, and clothing strewn along the way. The men were able to get on the cage upon reaching the 1200 level.

Several men working below the 1200 level on the east side managed to climb up to the 1200 level northeast drift. These men travelled the drift towards the shaft, but upon reaching the main drift, they found this drift "full of steam" and too hot to enter. The men gathered near the tool shed, and after some time, they heard a report over the teletalk saying the cage was at the plat and that men should get on the cage.

Other men who had climbed the incline and had taken refuge by lying on the floor of the station beneath the head pulley of the incline belt, also caught the cage after an announcement over the teletalk.

Of the four men who were killed instantly, three men were installing a tugger in the main drift near the intersection of the west and southeast drifts. The fourth man, the "powder man" was working in a small crosscut off the main drift containing the explosives- and detonator-storage magazines. A fifth man who died in the hospital that same day had been working in No. 1404 stope below the 1200 level and suffered burns after he ran up the incline to the shaft. He was found on the floor of the cage by the first man to escape. The sixth man who died 5 days after the accident had been cleaning the pan line in the incline near the 1300 level with another man. The seriously burned man was found near the southwest corner of the shaft.

Rescue and Recovery Operations:

The first rescue crew entered the mine at 10:15 a.m., approximately one hour after the occurrence of the disaster. Air temperatures were still high, but oxygen breathing apparatus was unnecessary. No odor of sulfur dioxide gas was detected at any time by the rescue crews. The last of the bodies was taken to surface at approximately 11 a.m.

After determining that the bulkheads above the 1200 level were intact, the main fan, which had stopped during the inrush, was restarted. Rescue crews spent the remainder of the afternoon checking bulkheads and searching for fires. The main fan was operated only when crews were in the mine and was shut down during the night.

Rescue and investigative operations were conducted with no assurance that a second inrush of hot gases and steam would not occur. Company officials requested, and Bureau representatives agreed, that the number of investigators underground at any time should be limited. In a conference attended by company officials, a representative of the Michigan Department of Health, the County Mine Inspector, and Bureau of Mines' representatives, company officials reported a decision to seal the entire west section of the mine before the resumption of mining operations. Local union officials were also notified. This decision to seal was made after sulphur dioxide gas was detected in No. 1404 scraping sublevel.

Concrete block seals on the 1425, 1400 and 1200 levels were completed to a 4-foot thickness by June 12. Standard 8- by 8- by 16-inch concrete blocks were laid with the long dimension of the blocks in one layer at right angles with the long

dimension in the succeeding layer. Hitches were cut in the sides, back, and bottom, and two rows of holes, approximately 18 inches apart, were drilled in the hitch around the circumference. Drill steel was inserted in the holes with two to three feet of steel projecting out of the hole to lock the seals. Mortar was placed in the holes in the blocks and drill steel was placed vertically in the holes to add further strength to the seals. No. 6-gauge wire reinforcing with No. 8-gauge wire crossbars at 16-inch intervals was placed between alternate layers of blocks. The seals were completed to a 10-foot thickness on July 3. Sampling pipes for testing the atmosphere behind the seals were installed in each bulkhead.

Concrete bulkheads on the 800 and 1000 levels, and 920 sublevel were strengthened to a total thickness of about 5 feet. This work was completed on July 13.

Production operations were resumed on the east side of the mine on June 16.

INVESTIGATION OF CAUSE OF DISASTER

Concurrent but separate investigations of the disaster were made by the Iron County mine inspector; Division of Occupational Health, Michigan Department of Health; the investigating committee appointed by the Governor of Michigan; and the United States Bureau of Mines.

The Bureau of Mines investigation consisted of a careful examination of the underground workings on the west side of the mine to determine the intensity and direction of forces and to search for evidence of flame, sampling and analysis of the atmosphere in both operating and sealed areas, and sampling and analysis of the pyritic-carbonaceous footwall slates and dust accumulations. A surface-subsidence area in the fill pit over the west-side stopes was also examined. Visits were made to the adjacent Wauseca mine operated by The M. A. Hanna Company. Hot vapors entering the Wauseca mine through cracks in the boundary pillar separating the two mines and the exhaust air from stope-fill boreholes in the Wauseca mine east fill pit were sampled and analyzed.

Interviews were held with company officials from both mines, several of the injured men, and the two attending physicians.

Separate investigations were conducted by the following:

Iron County Mine Inspection Department

R. Anderson — Iron County Mine Inspector

Division of Occupational Health, Michigan Department of Health

J. D. McKichan — District Engineer

Governor's Investigating Committee

W. Been, Head, Department of Mining Engineering, Michigan College of Mining and Technology, Houghton, Michigan — Chairman

J. Powell, District Representative, United Steel Workers of America, Negaunee, Michigan — Member

F. Werther, Assistant to the General Manager, Pickands Mather & Co., Duluth, Minn. — Member

United States Bureau of Mines

James Westfield	Assistant Director--Health and Safety
John A. Johnson	Chief, Division of Safety
Allen D. Look	Supervisor, District F
R. O. Pynnonen	Supervising Mining Health and Safety Engineer
Joseph B. Stepan	Mining Health and Safety Engineer

Other members of the Bureau of Mines who assisted during the investigation were mining health and safety engineer Harry L. Schell and safety representatives L. J. Zaverl and A. Schrader.

Flame:

No evidence of flame was found in any of the accessible workings in the mine. All of the victims suffered third degree burns, but none of the clothing or hair showed signs of scorching. Except for one man who had head cuts, none of the victims showed marked violence. The bodies were found on the 1200 level, and the other men who suffered burns received them on or near this level.

It was evident that most of the heat vented into the 1200 level west drift, travelled east to the main drift, and then north on the main drift to the shaft. Timbers and board stoppings in the west drift and the belt and insulation on light wires and power cables in the main drift showed no evidence of flame. Empty cardboard explosives containers, piled on a bench at the intersection of the main drift and stub drift to the explosives-storage magazine, were not scorched. From statements of officials and employees at the mine, reports of their activities during the disaster, and opinions of attending physicians it is estimated the duration of flow of steam and hot gases was approximately 5 to 15 minutes.

Forces:

All of the evidence indicated forces of mild intensity. Several wooden ventilation brattices, that were demolished, were of such construction that relatively low air pressures would have resulted in their destruction. The forces were insufficient to dislodge supporting timbers, lighting and trolley wires, and steel doors over raises. Forces had moved a manway ladder and bent water pipes on the 1220-foot sublevel.

The greatest forces appeared to travel from a point in the 1200 level west drift near the top of No. 1404 stope. Evidence was conflicting at this point regarding the direction of travel in No. 20 stope transfer sublevel and in the dog drift above No. 1404 stope on the opposite side of the west drift (see figure 1). There was some evidence that forces travelled west from this point in the west drift, but the greatest forces travelled east towards the main drift.

A ventilation brattice in the west drift, approximately 75 feet west of the main drift, was blown east against the conveyor-belt support structure in the main drift. The boards from the brattice, fine dirt, and several rolls of tugger cable which had been stored in the west drift, were jammed against the belt structure and formed a dam which backed up water in the drift.

Forces travelled only a short distance south on the south drift; most of the forces travelled north towards the shaft. A wooden brattice in the southeast drift directly opposite the west drift was blown eastward. The forces dissipated rapidly as they travelled northward on the main drift. Light bulbs near the intersection of the south, southeast, and west drifts were broken, but bulbs in the main drift starting at a point approximately 200 feet north of the intersection were undamaged. All surfaces in the area were

heavily coated with a fine-grained black mud permitting an easy determination of the direction of forces, even in areas of very low velocities.

Evidence of mild forces were found 20 feet below the 1200 level in a ventilation drift connecting the top mining sublevels to Nos. 1402, 1404, 1406, and 1408 stopes. Streamlining of fine black dust on the floor of the drift and the bent ends of wire used to support piping, indicated forces entered this area from No. 1404 stope and travelled south to the ventilation drift. Forces travelled both east and west on the ventilation drift and north on each of the dog drifts to Nos. 1402, 1406, and 1408 stopes, (see figure 2). A sample of the fine dust that covered all surfaces in the sublevel was taken from a 4-inch thick layer on the floor in No. 1402 stope dog drift.

Forces reaching the 1400 and 1425 levels had dissipated in the stopes. A few light bulbs were broken, but tools leaning against the sides of the drifts, clothing hung on nails, and other loose material apparently were not moved.

Workings on the east side of the mine, with the exception of the ventilation bulkhead in the southeast drift immediately east of the main drift, showed no evidence of forces. Reportedly, two miners drilling on the mill sub of No. 1405 stope, approximately 250 feet east of the main-south drift, were unaware of the events that had occurred. When pressure in the compressed air lines was lost, the miners waited for some time before proceeding to the shaft station where they met the first mine rescue crew to enter the mine.

Single-thickness, concrete block bulkheads on the 800 and 1000 levels and a similar bulkhead on the 920 sublevel were undamaged by the forces. These undamaged bulkheads and the fact that forces could have vented into the adjacent Wauseca mine through existing cracks in the boundary pillar and possibly through cracks to surface, indicated that steam pressure did not exist prior to the disaster.

Air, dust, and slate samples:

Vacuum bottle air samples were collected at several points in the Sherwood mine and in the boundary pillar area, of the adjacent Wauseca mine of The M. A. Hanna Company.

Hot gases and vapors from the Sherwood mine upper stopes were entering the Wauseca mine through cracks in the pillar on the 162-foot sublevel above the 9th level. Correlation of elevations in the two mines, placed the 162-foot sublevel approximately 12 feet above the 1000 level of the Sherwood mine, and the cracks in the pillar opposite the lower portion of No. 6 stope.

Vacuum bottle air samples were also collected of exhaust air at the collars of boreholes in the Wauseca mine sand-fill pit. A tabulation of the analyses of the air samples is appended.

Samples of a fine, black, talc-like dust deposited on the floor of the ventilation drift below the 1200 level, and a fine, but gritty, black dust deposited on the floor of the 1425 level were collected for analyses. Samples were also collected of a fine-grained black mud deposited on light wires and bulbs on the 1200 level, and a yellowish, crystalline material from No. 1404 mill sub and a similar substance deposited around leaks in the bulkhead on the 1000 level. Samples of the footwall slates were also analyzed. Tabulations of the analyses are appended.

Summary of Evidence:

Examination of the stopes above the 1000 and 1200 levels was impossible because the areas were inaccessible. Because it was at first believed that a floor pillar above the operating stopes had collapsed and that a large run of fill material had forced the hot gases into the working sections, initial efforts in the investigation were directed towards locating the remnants of the pillar. No evidence of the collapse of a large pillar or extensive run of fill material was found at the bottom of stopes 1402, 1404, 1406 south, and 1408, each of these stopes being practically empty. A rib pillar in No. 1406 stope divided it into north and south sections; the north section was reported as containing ore to a point above the first mining sublevel and possibly higher.

Some fill material, which included sand and rounded boulders, was found on the belt and in a chute in the transfer drift and scraping sublevel below No. 1404 stope; however, the back of the stope was examined from the top mining sublevel, and except for a breakthrough into a small drift above the stope, the floor pillar appeared intact. The amount of fill material found was insufficient to account for any great pressures.

It was known that the pillar between No. 1406 and No. 1404 stopes had caved previously and that No. 24 and No. 22 stopes above had fill material in them (see figure 3). Nos. 18 and 20 stopes, were at least partially filled with caved material and No. 16 stope was reported empty. Above the 1000 level, Nos. 6 and 2 stopes contained fill material.

Company officials reported that, previous to the disaster, caving had occurred from the back of No. 1406 stope north which was the floor pillar under No. 22 stope (see figure 5). It is believed that, at the time of the disaster, this caving broke into No. 22 stope, fill material entered No. 1406 stope north and rolled down the pile and through the break in the pillar into No. 1404 stope and down the mill to the transfer drift where fill material was found. It is further believed that the amount of fill material in these two stopes was sufficient to account for the sound of running material noted by the miners on the 1400 level and cause the initial rush of air.

Analyses of air samples showed that no methane or hydrogen was present, and that the possibility of an explosion of combustible gases as a cause of the disaster was improbable. The presence of carbon monoxide in the samples was definite indication of a recent fire if not an active fire at the time of sampling.

An inter-office memorandum by the ventilation engineer of The M. A. Hanna Company dated March 27, 1958 reported the presence of a temperature of 130°, carbon monoxide concentrations, and low oxygen in vapors emitting from cracks in the boundary pillar. Sherwood mine officials had visited the boundary pillar area in the Wauseca mine. Unfortunately they were unaware of the report and no high temperatures or other indication of fire was observed. Regular inspections of the Wauseca mine had been made by Reino Anderson, Iron County Mine Inspector, since January 1959. No evidence of fire was observed during his inspections.

Explosibility tests were made on three dust samples; sample No. 59-11-G collected on the ventilation drift below the 1200 level, sample No. 59-12-G collected on the 1425 level from an accumulation about 2 feet in depth on the floor of the drift, and sample No. 59-19-G that had been deposited as a mud on power cables near the intersection of the main and west drifts on the 1200 level. The dust from two samples of the

footwall slates, sample Nos. 59-16-G and 59-17-G, that were crushed in the laboratory were also tested.

The tests showed that none of the samples collected as dusts presented an explosion hazard when tested in air at concentrations up to 8 oz./ cu. ft. in the presence of high-voltage induction sparks, a heated coil, or the flame from a 75-mg. tuft of guncotton. Samples of the crushed slates, however, ignited when dust clouds were passed through an experimental furnace at a temperature of 630° C. (1,166°F.). Ignitions occurred when sample No. 59-12-G was tested in oxygen at 950° C. (1,742° F.) and higher temperatures; no ignitions were noted when sample No. 59-11-G was tested under these conditions.

The ultimate analyses of dust samples Nos. 59-11-G, 59-12-G, and 59-19-G do not give definite support to the theory that these dusts were the products of combustion. Lowered carbon and sulfur contents, when compared with the analyses of the footwall slates (samples No. 59-16-G and No. 59-17-G) could be the result of contamination by fill material with low sulfur and carbon content. The percentage of ash in the samples also does not support the theory that the three dusts were products of combustion.

Cause of Disaster:

During the investigation considerable information was received from company officials and employees, State and County officials, and others. This information, with facts gained during the recovery operations, and some pure conjecture leads to the concensus of the Bureau of Mines' investigators that the following factors combined to cause the disaster:

1. Spontaneous combustion of the black slates in the mined-out area above the 1200 level, more probably above the 1000 level, had resulted in the formation of a mass of highly heated material.

2. Water, probably surface runoff into the subsidence area, had entered into the fill material and collected at some point above the heated material. This is purely conjectural.

3. There was a partial collapse of the weakened floor pillar over No. 1406 north stope.

4. There was a considerable run of fill material into No. 1406 north stope that filled the stope at least to the breakthrough in the pillar between Nos. 1404 and 1406 stopes. Fill material then ran into No. 1404 stope.

5. The run of fill material caused a shift in the fill and caved materials in the upper stopes which allowed water to come in contact with the hot material and form steam.

6. Most of the resulting hot gases and steam vented out on the 1200 level west drift and reached the shaft through the main drift.

RECOMMENDATIONS

The following recommendations are offered to prevent a similar occurrence:

1. A positive procedure should be established to insure that each mined-out stope will be back filled immediately on completion.

2. Back fill material should be of suitable porosity to allow drainage.

3. Fire areas in abandoned stopes should be sealed with substantial bulkheads, and pipes for sampling the atmosphere behind the seals should be installed.

4. Fire seals should be patrolled at regular intervals; temperature readings and air samples should be taken and recorded. These records should be open for inspection by authorized persons.

5. Consideration should be given to scheduling regular meetings between company officials operating mines with common property lines for an exchange of pertinent information regarding mining activities near the line.

ACKNOWLEDGMENT

The courtesies and cooperation extended by the officials of the Sherwood mine and Inland Steel Company in providing information and assisting with the investigation is gratefully acknowledged. Acknowledgment is also made to officials of

The M. A. Hanna Company; R. Anderson, Iron County mine inspector; J. D. McKichan, district engineer, Michigan Department of Health; and W. Been, J. Powell, and F. Werther, members of the Governor's Investigating Committee, for their assistance during the investigation.

Respectfully submitted,

/s/ J. Westfield

J. WESTFIELD
Assistant Director--Health & Safety

/s/ J. A. Johnson

J. A. JOHNSON
Chief, Division of Safety

/s/ A. D. Look

A. D. LOOK
District Supervisor, District F

/s/ R. O. Pynnonen

R. O. PYNNONEN
Supervising Mining Health and Safety Engineer, District F

APPROVED BY:

/s/ Marling J. Ankeny

MARLING J. ANKENY
Director

Table 1. - Analyses of Air Samples - 800 Level

Date	Bottle No.	Analysis - As Received O_2	CO	CO_2	CH_4	N_2	Analysis - Air Free CO	CO_2	Press.
6/17/59	S-8860	10.07	0.005	3.65	0.00	86.28	0.01	7.0	≠
6/17/59	S-8861	10.14	.005	3.62	.00	86.24	.01	7.0	≠
6/18/59	O-6085	10.45	.010	3.39	.00	86.15	.02	6.8	≠
6/19/59	A-101	16.46	.000	1.49	.00	82.05	.00	7.0	≠
6/23/59	R-191	13.34	.005	2.44	.00	84.22	.01	6.7	≠
6/29/59	O-6902	18.34	.000	.85	.00	80.81	.00	6.9	-
6/30/59	O-6900	18.35	.000	.82	.00	80.83	.00	6.7	-
7/7/59	S-5397	17.05	.000	1.19	.00	81.76	.00	6.4	-
7/8/59	S-5400	17.99	.000	.94	.00	81.07	.00	6.7	-
7/14/59	S-5611	15.33	.000	1.81	.00	82.86	.00	6.8	-
7/22/59	S-5243	12.26	-.005	2.78	.00	84.96	-.01	6.7	-

Table 2. - Analyses of Air Samples - 1000 Level Bulkhead

Date	Bottle No.	Analysis - As Received					Analysis - Air Free		Press.
		O_2	CO	CO_2	CH_4	N_2	CO	CO_2	
6/16/59	R-60	13.66	0.01	1.93	0.00	84.40	0.029	5.6	-
6/16/59	R-76	13.68	.01	1.87	.00	84.40	.029	5.4	-
6/17/59	S-8398	17.41	.01	.98	.00	81.60	.060	5.8	-
6/17/59	S-433	16.67	.01	1.18	.00	82.14	.050	5.8	-
6/18/59	S-6092	14.36	.01	1.85	.00	83.78	.032	5.9	-
6/19/59	R-1	15.40	.01	1.52	.00	83.07	.038	5.8	-
6/23/59	R-190	13.99	.01	1.78	.00	84.22	.030	5.4	-
6/29/59	0-6126	13.94	-.01	1.70	.00	84.35	-.030	5.1	-
6/30/59	0-6122	13.73	-.01	1.69	.00	84.57	-.029	4.9	-
7/7/59	S-5420	7.61	.01	3.00	.00	89.38	.015	4.7	-
7/8/59	S-5413	14.97	-.005	1.35	.00	83.68	-.018	4.7	-
7/22/59	S-5605	8.17	-.010	2.90	.00	88.92	-.016	4.8	-

Table 3. - Analyses of Air Samples - 162-Foot Sublevel, Wauseca Mine

Date	Bottle No.	Analysis - As Received					Analysis - Air Free		Press.
		O_2	CO	CO_2	CH_4	N_2	CO	CO_2	
6/6/59	154	18.83	-0.005	0.67	0.00	80.50	-0.050	6.7	/
6/6/59	155	18.75	- .005	0.71	0.00	80.54	- .050	6.8	/
6/6/59	R-83	15.63	- .010	1.60	0.00	82.76	- .040	6.3	/
6/6/59	R-79	15.71	- .010	1.57	0.00	82.71	- .040	6.3	/
6/10/59	S-8864	14.90	- .010	1.59	0.00	83.50	- .035	5.5	/
6/10/59	S-8865	14.95	- .010	1.58	0.00	83.46	- .035	5.5	/
6/11/59	S-8890	15.16	- .010	1.44	0.00	83.39	- .036	5.2	/
6/11/59	S-8891	14.40	- .010	1.57	0.00	84.02	- .032	5.0	/
6/12/59	S-8638	20.75	.000	0.15	0.00	79.10	--	--	-

Table 4. - Victims of Inrush of Hot Gases and Steam, Sherwood Mine
Inland Steel Company

Name	Age	Marital Status	No. Dependents	Occupation	Experience in Mines
Anderson, Carl R.	40	Married	7	Maintenance Man	11 yrs., 6 mos.
Groop, Howard	31	Married	3	Miner	6 months
Johnson, Einar	59	Married	1	Miner	17 yrs., 4 mos.
Shaver, Talcott	22	Married	2	Belt Attendant	8 months
Wester, Ingvar	51	Single	1	Powderman	17 yrs., 1 mo.
Zucal, August	50	Single	0	Maintenance Man	18 yrs., 8 mos.

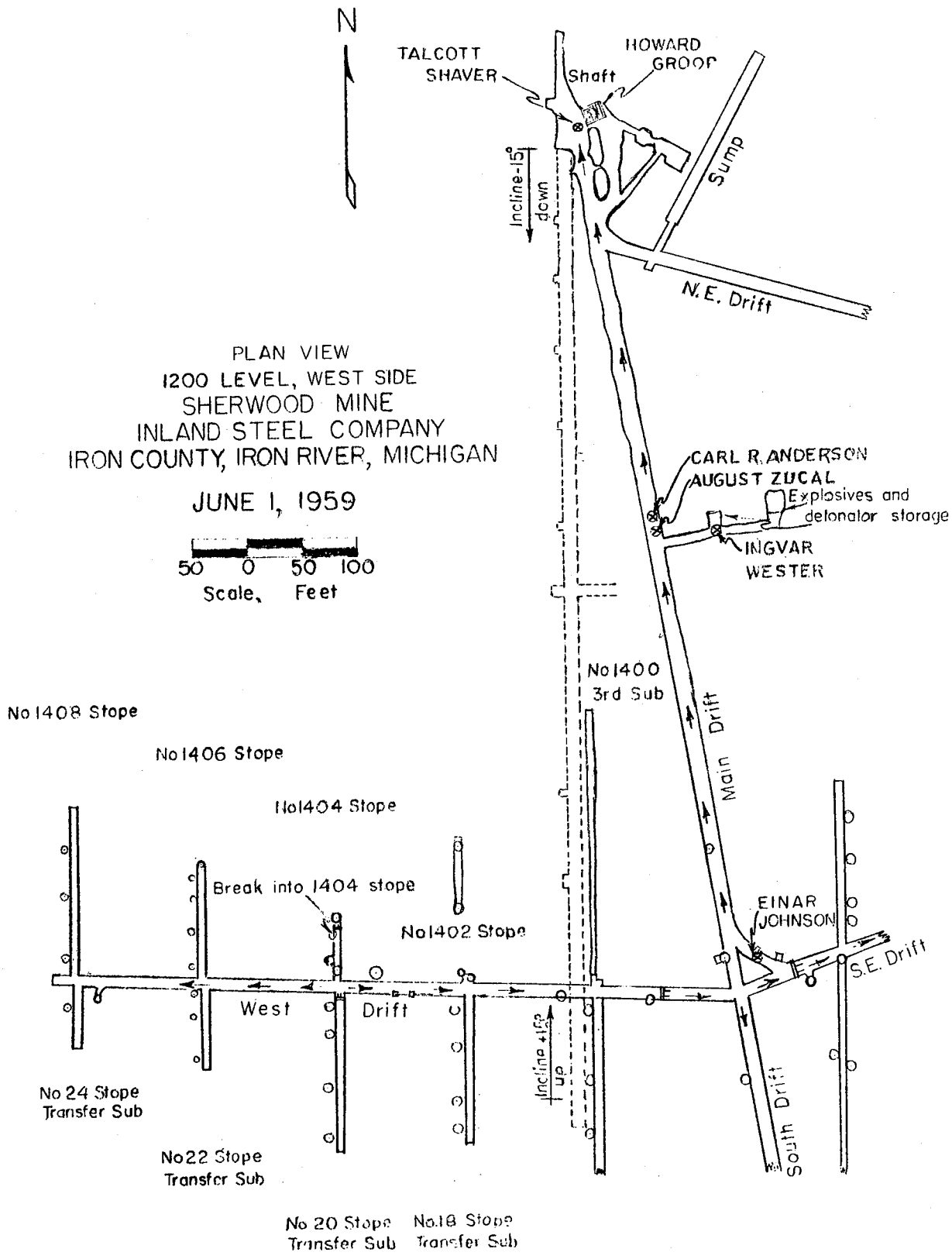

N
TALCOTT
SHAVER
Shaft
HOWARD
GROOF
Incline-15°
down
Sump
N.E. Drift
PLAN VIEW
1200 LEVEL, WEST SIDE
SHERWOOD MINE
INLAND STEEL COMPANY
IRON COUNTY, IRON RIVER, MICHIGAN
JUNE 1, 1959
50 0 50 100
Scale, Feet
CARL R. ANDERSON
AUGUST ZUCAL
Explosives and
detonator storage
INGVAR
WESTER
No 1400
3rd Sub
Main Drift
No 1408 Stope
No 1406 Stope
No 1404 Stope
Break into 1404 stope
No 1402 Stope
EINAR
JOHNSON
S.E. Drift
West
Drift
Incline 41°
up
South Drift
No 24 Stope
Transfer Sub
No 22 Stope
Transfer Sub
No 20 Stope
Transfer Sub
No 18 Stope
Transfer Sub
LEGEND
Forces
Locations of fatally injured
Destroyed brattices

Figure 1

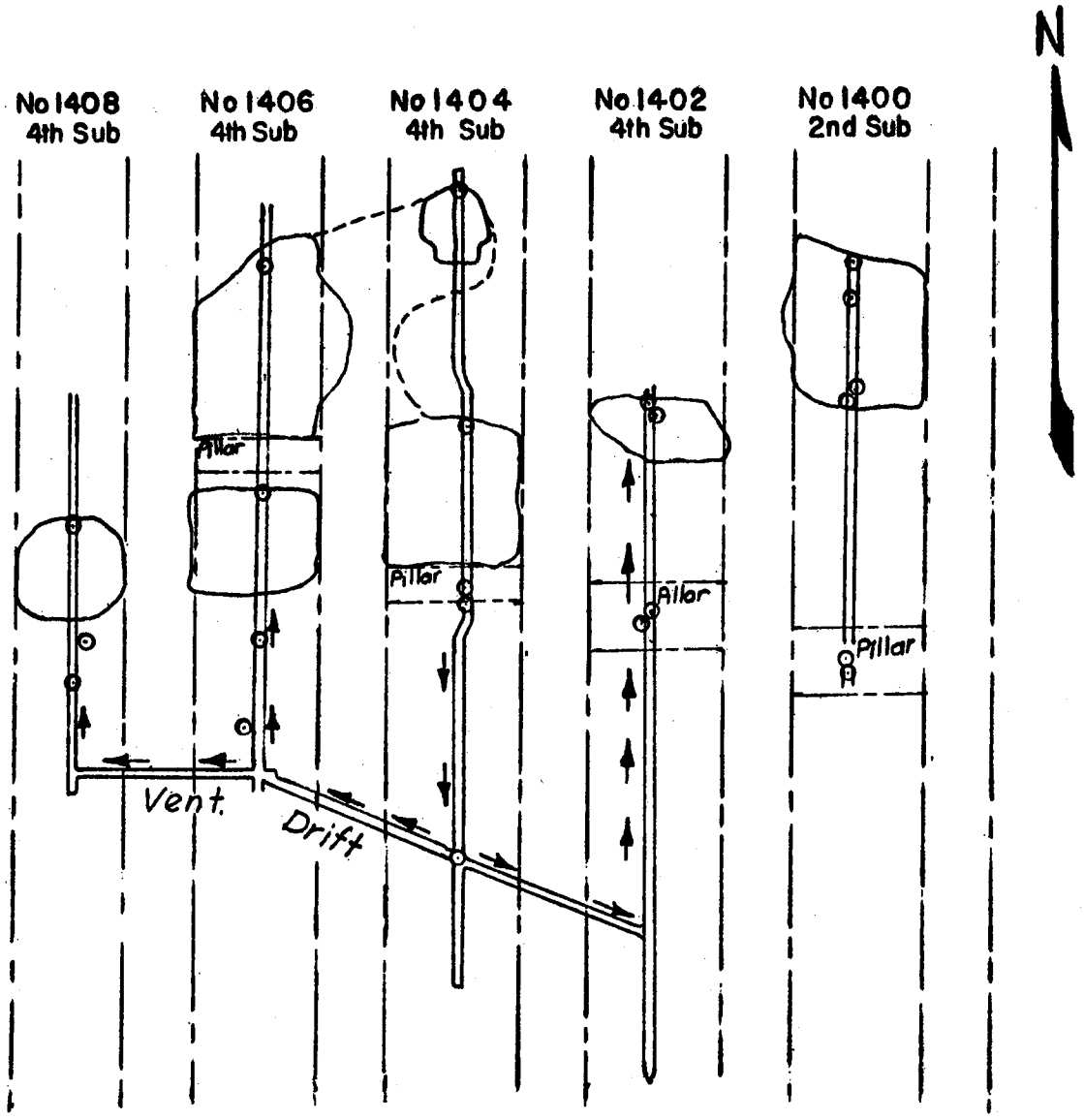
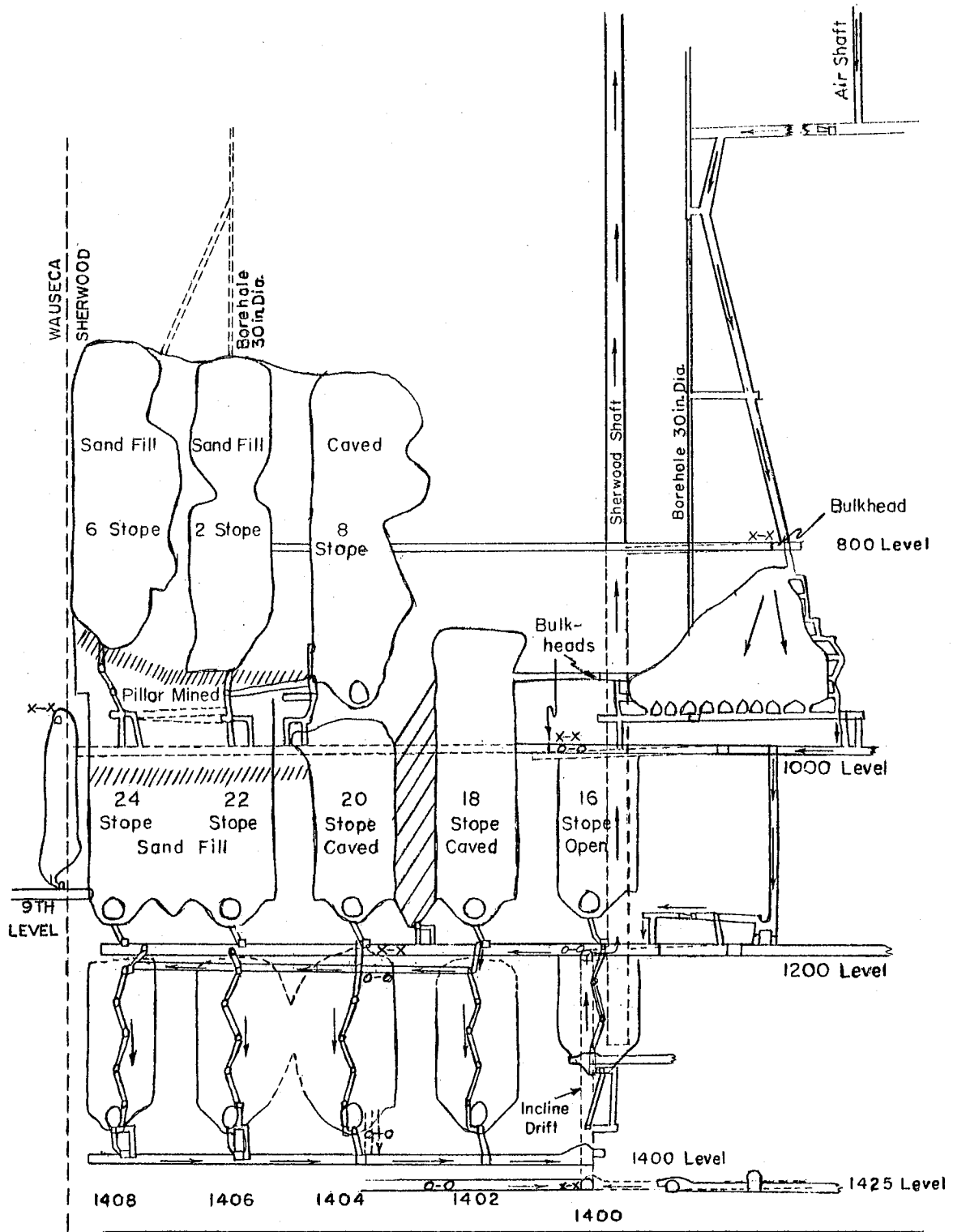


Figure 2. — Plan view of 1220 sublevel (ventilation drift) showing direction of forces.



LEGEND

Ventilation ——→

Fans ▷◁

Air samples x–x

Dust samples o–o

E–W Longitudinal Section, West Side
SHERWOOD MINE
INLAND STEEL COMPANY
IRON COUNTY, IRON RIVER, MICHIGAN
JUNE 1, 1959

50 0 50 100
Scale, Feet

Figure 3

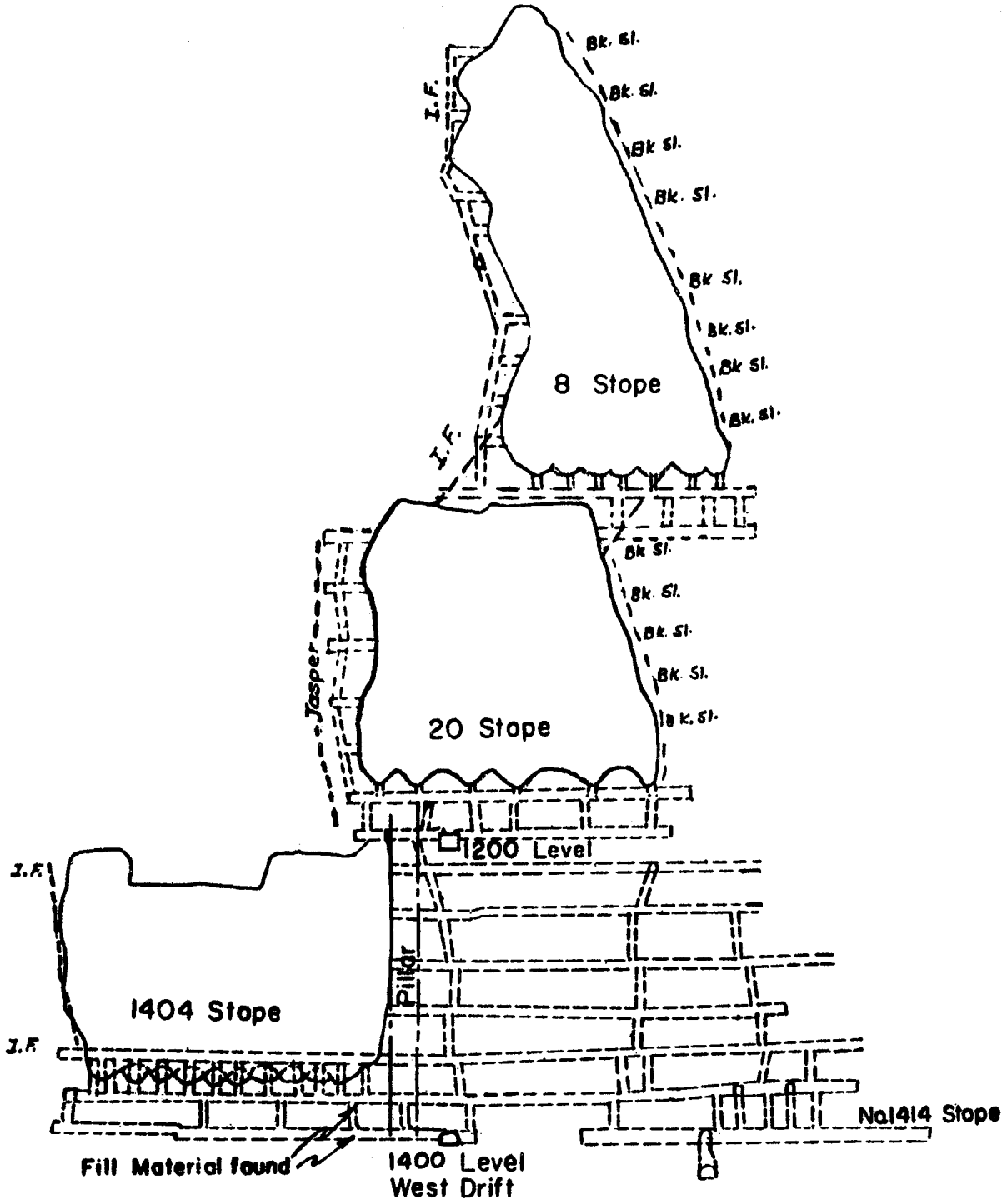


Figure 4.- N-S CROSS SECTION THROUGH 1404 STOPE
LOOKING EAST

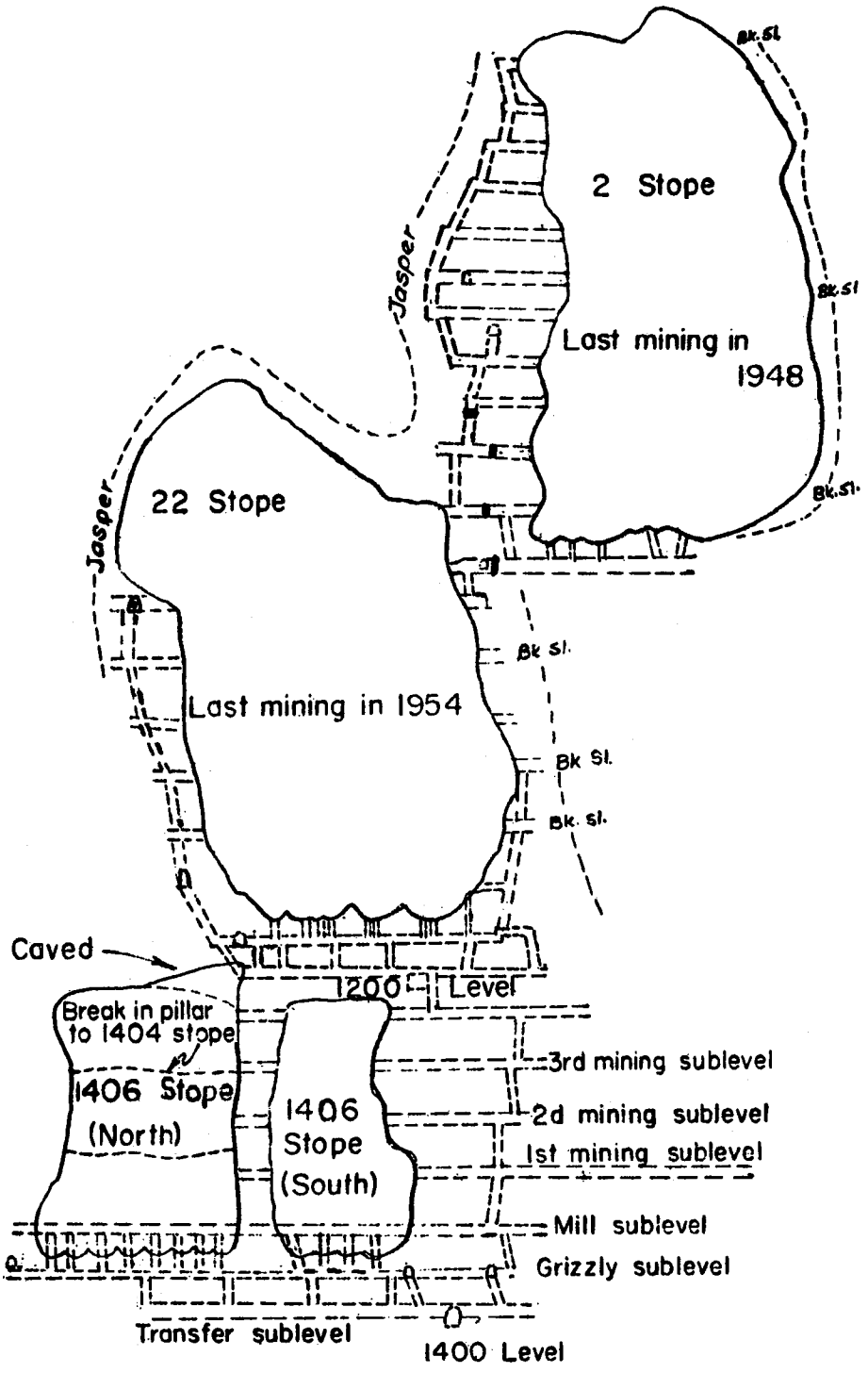


Figure 5.— N-S CROSS SECTION THROUGH 1406 STOPE LOOKING EAST

COPY

LIST AND DESCRIPTION OF SAMPLES FROM SHERWOOD MINE, INLAND STEEL COMPANY, IRON RIVER, IRON COUNTY, MICHIGAN

Collector's Sample No.	Branch of Health Research Laboratory No.	Description and Sampling Location	Date Collected	Date Received by BHR Laboratory	Collector
---	59-11-G	Mine dust (brown-black)	6-5-59	6-9-59	R. O. Pynnonen
N-52	59-12-G	Mine dust (brown-black) from 1425 level	6-6-59	6-12-59	A. D. Look
---	59-13-G	Mine dust (gray) from 1404 scraper sublevel	6-6-59	6-12-59	A. D. Look
---	59-16-G	Pyritic-carbonaceous slate breccia adjacent to bedded slate (large pieces - 2 to 4 inches)	6-16-59	6-18-59	A. D. Look
---	59-17-G	Bedded pyritic-carbonaceous slate adjacent to ore, 1425 level (large pieces - 2 to 4 inches)	6-16-59	6-18-59	A. D. Look
S-445	59-18-G	Material collected at roof outside 1000 level bulkhead - apparently result of fire gases leaking through bulkhead. (This sample was almost completely water soluble)	6-18-59	6-23-59	L. J. Zaverl
S-492	59-19-G	Material (brown-black) - "fly ash" - deposited as mud following inrush of hot vapors; collected 50 feet north of junction of east-west drift with No. 1 north-south belt line. Material collected from power cables suspended approximately 12 inches from roof at right angle to forces	6-18-59	6-23-59	L. J. Zaverl

COPY

ULTIMATE ANALYSIS AND SULFUR FORMS DETERMINATIONS IN SAMPLES FROM SHERWOOD MINE, INLAND STEEL COMPANY, IRON RIVER, IRON COUNTY, MICHIGAN

(Analysis Section, Branch of Bituminous Coal, Pittsburgh, Pennsylvania)

	Sample Identification					
Collector's sample No.		N-52				S-492
Branch of Health Research Laboratory No.	59-11-G	59-12-G	59-13-G	59-16-G	59-17-G	59-19-G
Date collected	6-5-59	6-6-59	6-6-59	6-16-59	6-16-59	6-18-59
Date received	6-9-59	6-12-59	6-12-59	6-18-59	6-18-59	6-23-59
Collector	R. O. Pynnonen	A. D. Look	A. D. Look	A. D. Look	A. D. Look	L. J. Zaverl
	Amount Present (as received), Percent					
Moisture	5.4	1.5	7.7	1.8	1.0	3.8
	Ultimate Analysis					
Hydrogen	1.1			.5	.4	1.0
Carbon	5.2	5.7	3.6	16.8	11.3	7.5
Nitrogen				.4	.2	
Sulfur	6.2	6.9	9.8	14.1	16.7	5.9
Ash	75.9	80.7	64.8	71.3	78.5	76.2
	Sulfur Forms					
Sulfate	2.56	2.68	6.84	.313	.261	2.59
Pyritic	3.39	3.96	2.94	13.064	16.167	3.09
Organic	.25	.21	0.0	.713	.272	.23
CO_2				.05	.04	

Signed: Roy F. Abernethy
6/15, 6/18, 6/29, and 7/8/59

COPY

QUALITATIVE X-RAY DIFFRACTION ANALYSIS OF SAMPLES FROM SHERWOOD MINE, INLAND STEEL COMPANY, IRON RIVER, IRON COUNTY, MICHIGAN

(Branch of Health Research, Pittsburgh, Pennsylvania)

	Sample Identification						
Collector's Sample No.		N-52				S-445	S-492
Branch of Health Research Laboratory No.	59-11-G	59-12-G	59-13-G	59-16-G	59-17-G	59-18-G	59-19-G
Date collected	6-5-59	6-6-59	6-6-59	6-16-59	6-16-59	6-18-59	6-18-59
Date received	6-9-59	6-12-59	6-12-59	6-18-59	6-18-59	6-23-59	6-23-59
Collector	R. O. Pynnonen	A. D. Look	A. D. Look	A. D. Look	A. D. Look	L. J. Zaverl	L. J. Zaverl
Compound	Estimated Amount Present						
Free silica, alpha quartz, SiO_2	Large amount	Large amount	Medium amount	Large amount	Large amount	None detected	Large amount
Feldspars, mainly microcline, $K_2O.Al_2O_3.6SiO_2$	Medium amount					SAMPLE PRINCIPALLY AMORPHOUS MATERIAL	
Pyrite, FeS_2	Medium amount	Medium amount	Medium amount	Large amount	Large amount		Medium amount
Muscovite (mica), $H_2KAl_3Si_3O_{12}$	Small amount	Small amount	Small amount	Small amount	Small amount		Small amount
Kaolinite, $Al_2O_3.2SiO_2.2H_2O$	Possible small amount	Small amount					
Hematite, Fe_2O_3	Possible small amount	Possible small amount					
Marcasite, FeS_2			Possible small amount				
Unidentified crystalline material	Small amount	Small amount	Small amount	Small amount	Small amount	Small amount	Small amount

NOTE: As copper radiation was used in analysis the iron content of these samples causes abnormally low intensities of mineral patterns. This absorption effect does not alter the quantitative determination of free silica.

Signed: P. J. Colbassani and H. W. Lang
6/16 and 6/29/59

COPY

SEMI-QUANTITATIVE SPECTROGRAPHIC ANALYSIS OF SAMPLES
FROM SHERWOOD MINE, INLAND STEEL COMPANY,
IRON RIVER, IRON COUNTY, MICHIGAN

(Branch of Health Research, Pittsburgh, Pennsylvania)

Sample Identification							
Collector's Sample No.		N-52				S-445	S-492
Branch of Health Research Laboratory No.	59-11-G	59-12-G	59-13-G	59-16-G	59-17-G	59-18-G	59-19-G
Date collected	6-5-59	6-6-59	6-6-59	6-16-59	6-16-59	6-18-59	6-18-59
Date received	6-9-59	6-12-59	6-12-59	6-18-59	6-18-59	6-23-59	6-23-59
Collector	R. O. Pynnonen	A. D. Look	A. D. Look	A. D. Look	A. D. Look	L. J. Zaverl	L. J. Zaverl
Element	Estimated Amount Present, Percent						
Iron	20-30	20-30	30-40	30	20-30	5-10	20-30
Silicon	20-30	20-30	10-20	10-20	20	0.5	10
Aluminum	5	5	1-5	5	5	1-5	5-10
Sodium	1	1	1	0.5	0.5	0.5	1
Calcium	0.5	0.5	0.5	.1	.1	1	0.5
Magnesium	.5	.5	.5	.5	.5	10	.5
Titanium	.5	.5	.1	.5	.5		.5
Copper	.1	.1	.1	.1	.01	.1	.01
Manganese	.1	.5	.5	Possible trace	Possible trace	.5	.1
Potassium	Present	Present	Present	Present	Present	1-5	1-5
Chromium	Possible trace	Possible trace			Possible trace		
Vanadium				.1	.5		
Boron				.01			
Barium							Trace

Signed: P. J. Colbassani and H. W. Lang
6/16/59, 6/29/59

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DEPARTMENT OF THE INTERIOR
BUREAU OF MINES
Pittsburgh, Pa.
Analytical Report

Branch of Health Research
Lab. Number 59-18-G

Sample No. Can No. S445 Laboratory No. 49441

Sample of Material collected at roof outby 1000 level bulkhead

From Sherwood mine, Inland Steel Company, Iron River, Michigan

Sampled _____ Received at lab. 7/1/59 Analyzed 7/8/59

Section or Bureau Br. of Health Research Collector L. J. Zaverl

ANALYSIS

	Percent
Silicon, Si	0.7
Aluminum, Al	4.4
Iron Fe	6.3
Calcium, Ca	.7
Magnesium, Mg	4.0
Sulfate, SO_4	41.3
Moisture and combined water	38.9

The material is essentially a mixture of hydrated sulfates or iron, aluminum, and magnesium.

Date 7/9/59 (Signed) W. H. Ode, Chemist

COPY

Bruceton
July 9, 1959

Memorandum

To: Chief, Branch of Health Research

Through: Acting Chief, Branch of Dust Explosions
Health and Safety Research Testing Center

From: Murray Jacobson

Subject: Explosibility of five dusts from Sherwood Mine

Explosibility tests were made on five samples of mine dust submitted by Mr. J. Westfield and Mr. A. D. Look, through the Branch of Health Research. The dusts were collected at the Sherwood Mine, Inland Steel Co., Iron River, Iron County, Mich.

The laboratory tests show that three of the dusts (2304-A, 2304-B and 2304-E as identified below) present no explosion hazard. The two other dusts (2304-C and 2304-D) presenting a slight hazard would propagate explosion flame when dispersed in air.

The samples were designated as follows:

Branch of Health Research Lab. No.	Description
59-11-G	Fine dust from Sherwood Mine (Bureau of Mines Lab. No. 2304-A)
59-12-G	Black-brown powdery material from 1425 level, Sherwood Mine (Lab. No. 2304-B)
59-16-G	Pyritic-carbonaceous slate breccia adjacent to bedded slate, 1425 level (Lab. No. 2304-C)
59-17-G	Bedded pyritic carbonaceous slate adjacent to ore, 1425 level (Lab. No. 2304-D)
59-19-G	Material deposited as mud following inrush of hot vapors - collected from power cables in North-South belt drift, 1200 foot level (Lab. No. 2304-E)

Following receipt of the samples the particle size distribution was determined by sieving, and the moisture content was determined by drying a few grams at 105° C. for 2 hours. As received sample 2304-A contained 2.1% and 2304-B contained 28.5% material coarser than a No. 20 U.S. Standard sieve, samples 2304-C and 2304-D were originally received in large pieces and were crushed by the Health Research group. The coarse fraction was removed prior to testing. Sample 2304-E contained no plus No. 20-sieve particles. Results of the sieve analyses of the through No. 20-sieve fractions, and the moisture determinations are listed in the following table:

Sample No.	Cumulative percent through sieve No.			Moisture content, percent by weight
	20	100	200	
2304-A	100	91.9	80.6	5.4
2304-B	100	50.0	34.8	1.3
2304-C	100	42.8	24.8	2.1
2304-D	100	41.8	24.4	1.1
2304-E	100	63.8	46.6	2.7

The tests were made on the samples in the fineness as received and on the through No. 200-sieve portions. Samples 2304-A and B were tested in oxygen as well as in air.

Dust clouds of the five subject samples did not ignite in air at concentrations ranging up to 8 oz./cu. ft. in the presence of high-voltage induction sparks, a heated coil, or the flame from a 75-mg. tuft of guncotton.

When the dusts were dispersed in air through the experimental furnace, ignitions were obtained in clouds of 2304-C and D at a temperature of 630° C. Samples 2304-A, B and E did not ignite in air at temperatures up to 1,000° C., the highest tried; in an atmosphere of oxygen, dense showers of sparks were observed with 2304-A and B at temperatures of 700° C. and higher. Ignition of 2304-B was observed in oxygen at 950° C. and higher temperatures; no ignitions were noted in clouds of 2304-A.

The relative flammability of samples 2304-C and D at 700° C. was 35%.

The ignition temperatures of quiescent layers of the through No. 200-sieve dusts were 400°, 400°, 360°, 360°, and 390° C. for samples 2304-A through E respectively.

The test results indicate that dust clouds of 2304-C and D can be ignited by heated surfaces or open flames in air and might constitute a potential explosion hazard. Samples 2304-A, B and E present no explosion hazard in air.

/s/ MURRAY JACOBSON

Murray Jacobson