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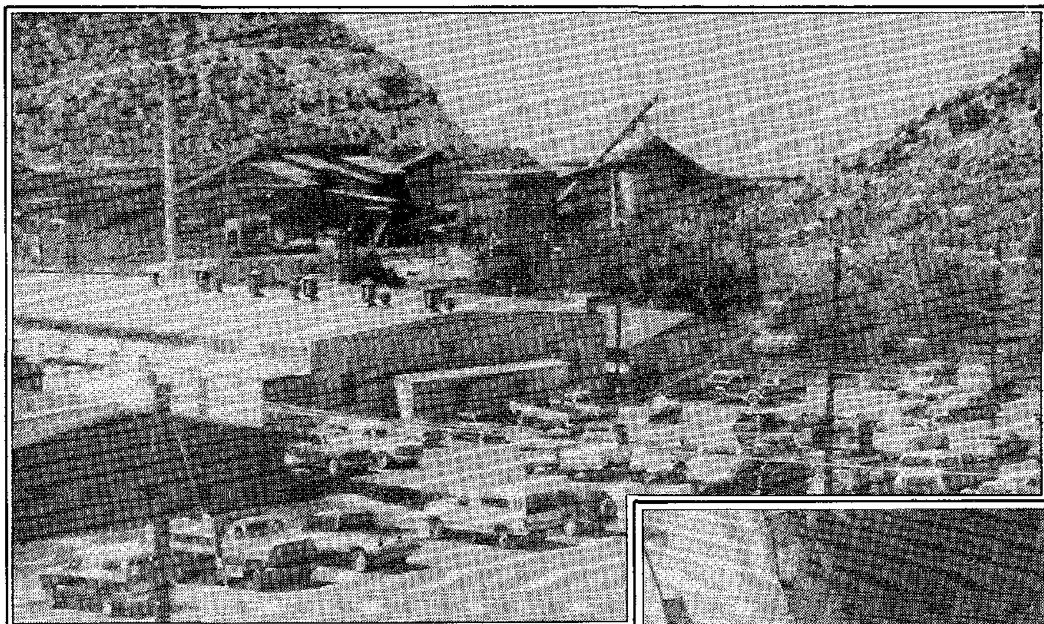
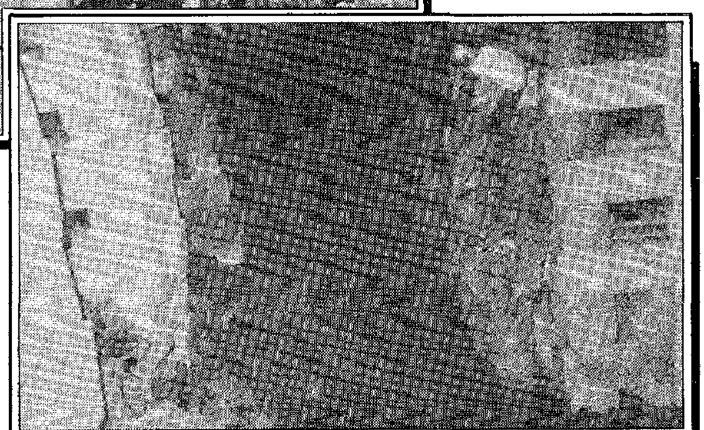
The History of Gate Road Performance at the Sunnyside Mines: Summary of U.S. Bureau of Mines Field Notes

By J. R. Koehler





United States Department of the Interior

Bureau of Mines

U.S. Department of the Interior Mission Statement

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally-owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

Cover photographs: Top, surface operations at the Sunnyside Coal Mines, Sunnyside Coal Co., Sunnyside, UT; bottom, ground conditions in the two-entry yield-pillar-based tailgate approximately 400 ft outby the longwall face, 22nd Left gate roads, Sunnyside No. 1 Mine.

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The History of Gate Road Performance at the Sunnyside Mines: Summary of U.S. Bureau of Mines Field Notes

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UNITED STATES DEPARTMENT OF THE INTERIOR
Bruce Babbitt, Secretary

BUREAU OF MINES

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

With Factors for Conversion to Units of the International System

Abbreviation	Unit of measure	To convert to—	Multiply by—
ft	foot	meters	0.30
in	inch	centimeters	2.54

THE HISTORY OF GATE ROAD PERFORMANCE AT THE SUNNYSIDE MINES: SUMMARY OF U.S. BUREAU OF MINES FIELD NOTES

By J. R. Koehler[1]

ABSTRACT

The U.S. Bureau of Mines (USBM) ground control research program includes several projects focused on developing design criteria for yielding-pillar-based longwall gate road systems. As part of this program, mining practices at the Sunnyside Mines, Sunnyside Reclamation and Salvage Co., Sunnyside, UT, are being documented to preserve the long history of yield pillar system evolution on the property. Published information describing the specific in-mine performance of the numerous gate road configurations utilized at the Sunnyside Mines is very limited. To overcome this deficit, USBM personnel interviewed 30 longtime mine employees representing nearly 700 years of mining experience at the Sunnyside operations. Mining conditions in 12 specific areas in the Nos. 1, 2, and 3 Mines were discussed in the interviews. Also, broad topics such as general mining practices, safety, and geology were often addressed during the discussions. Comprising the body of this report is an extensive record of the events and conditions experienced while mining the identified areas. In addition, eight significant conclusions were developed that accurately summarize the general opinions of the interviewed personnel regarding mining conditions and practices at Sunnyside.

[1]Mining engineer, U.S. Bureau of Mines, Denver Research Center, Denver, CO.

INTRODUCTION

The U.S. Bureau of Mines (USBM) current ground control research program includes several projects dedicated to elevating the state of the art in longwall gate road design. One of these projects, Comparative Study of Gate Road Designs, is focused on developing design criteria for yielding-pillar-based longwall gate road systems. In support of this research, project personnel are examining mining practices at the Sunnyside Mines, Sunnyside Reclamation and Salvage Co. (SRS), Sunnyside, UT, to document the long history of yield pillar system evolution on the property. Since mining was initiated at Sunnyside in 1896, a wide variety of both conventional and novel approaches to solving practical coal mining problems have been attempted at the site. In addition to adapting the yield pillar concept to longwall mining, Sunnyside introduced many innovations to the western U.S. coalfields, including entry stabilization by hydraulic backfilling, the application of yielding steel arches, single-entry gate roads, and advancing tailgates on retreat longwall sections.

In October 1989, USBM personnel initiated a plan to conduct an investigation into historical gate road design practices and performance at the Sunnyside complex. The primary purpose of the study was to preserve, for research and design engineers, the experience acquired in coal mine entry design at the Sunnyside properties.

A comprehensive library of printed articles and documents describing various aspects of mining practices and entry performance on the property was assembled; over 3,000 pages of technical reports, accident records, roof control plans, and other mine documents related to gate road design and performance were collected. Much of the history of Sunnyside is preserved in this literature; however, published information describing the *specific in-mine performance* of various gate road configurations, pillar sizes, panel orientations, etc. is very limited. To overcome this deficit, project personnel conducted interviews of longtime Sunnyside employees, generating over 1,000 pages of field notes from which to recreate the history of gate road performance at the mines.

The Sunnyside property encompasses several specific mining operations (fig. 1) representing 98 years of underground coal extraction. Longwall mining has been practiced at Sunnyside for 33 years, with some of the most unique and novel applications of the longwall method ever attempted in the United States being tried on the property. It was anticipated that a detailed portrayal of encountered ground conditions would be acquired by conducting the interviews. Essentially, the information collected through this process would fill the voids in available published data on gate road performance.

In mid-1990, personal interviews were initiated with 30 longtime Sunnyside employees representing nearly 700 years of mining experience at the mines. To ensure complete representation of mining across the property, 12 specific areas of interest were identified on large-scale mine maps for discussion purposes (figs. 1-4). While the interviews focused primarily on these designated areas of the operation, the discussions were not limited in any fashion. Many details were learned during the interviews regarding the events and conditions experienced while mining these areas. A summary of this detailed information comprises the body of this report. In addition, broad topics such as general mining practices, safety, geology, or overall mining conditions were often addressed during the discussions.

The interviews were openly conducted in an informal manner and were intended to simply provide general background information relative to entry design practices and performance at the mining operation; the subsequent conversations are not considered testimonials, but rather, are an accumulation of "raw data" like that collected in any scientific investigation. The information presented in this report is an objective, comprehensive review of the experiences and opinions of the Sunnyside coal miners and in no way represents the position of the USBM.

OPERATIONAL OVERVIEW

Underground coal mining has been conducted on the Sunnyside property since at least 1896. The oldest available accident records from the early 1930's indicate that the mines were once owned by the Calumet Coal Co. By the early 1940's, the Utah Fuels Co. owned the properties and leased the No. 2 Mine to the Kaiser Steel Co. to supply metallurgical-grade coal for their Fontana, CA, steelmaking facilities. In 1950, Kaiser Steel purchased the entire property from Utah Fuels to secure a permanent supply of coking coal for the Fontana operation. The Kaiser Steel Co. owned and operated the mines until 1984 when the properties were purchased by the Kaiser Coal Co., a wholly owned subsidiary of Perma Resources. Perma Resources was in no way associated with Kaiser Industries, but retained the Kaiser name for business purposes. The Kaiser Coal Co. operated the mines until

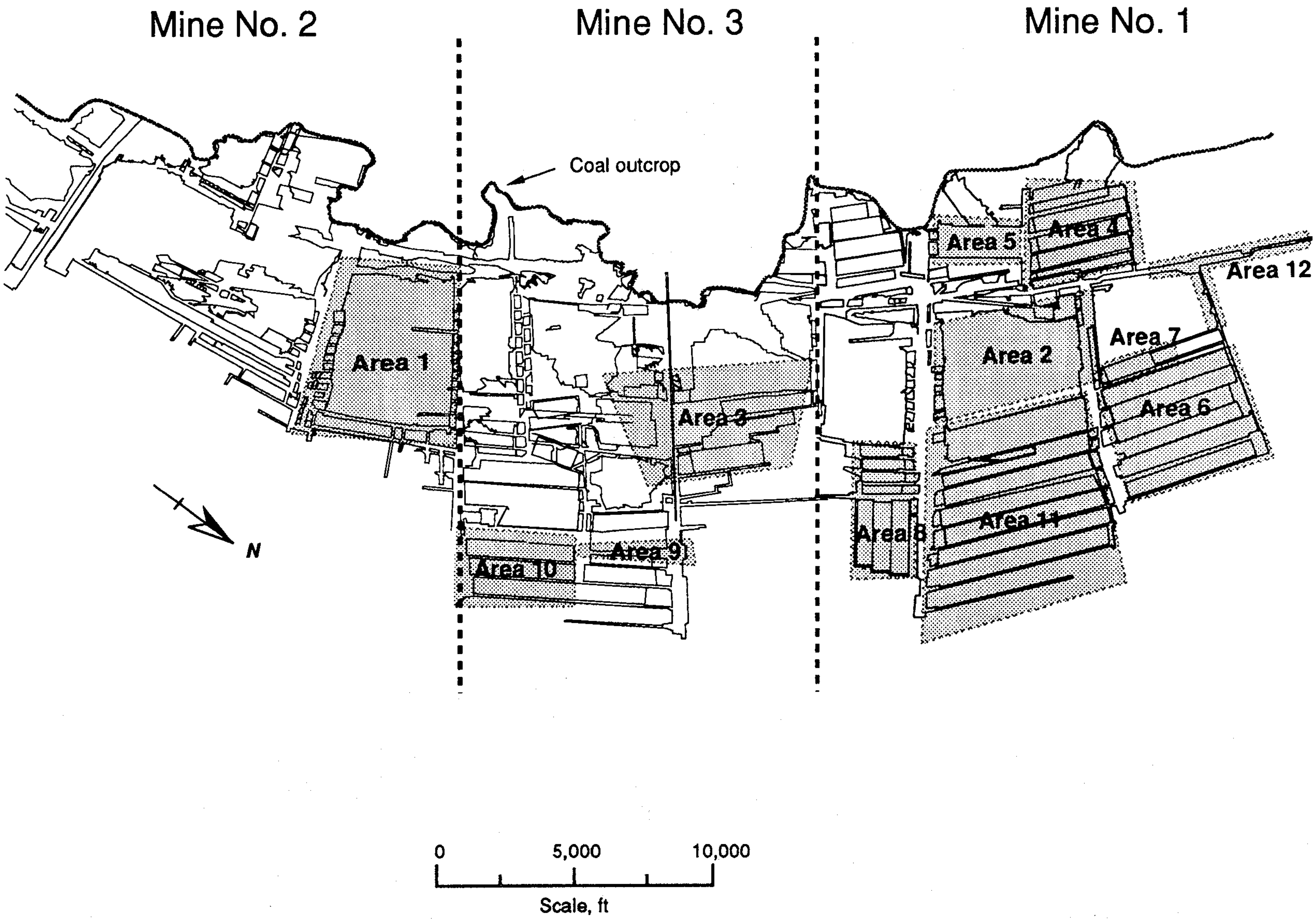

Figure 1.—Boundary map of Sunnyside Nos. 1, 2, and 3 Mines showing interview areas and extent of workings.

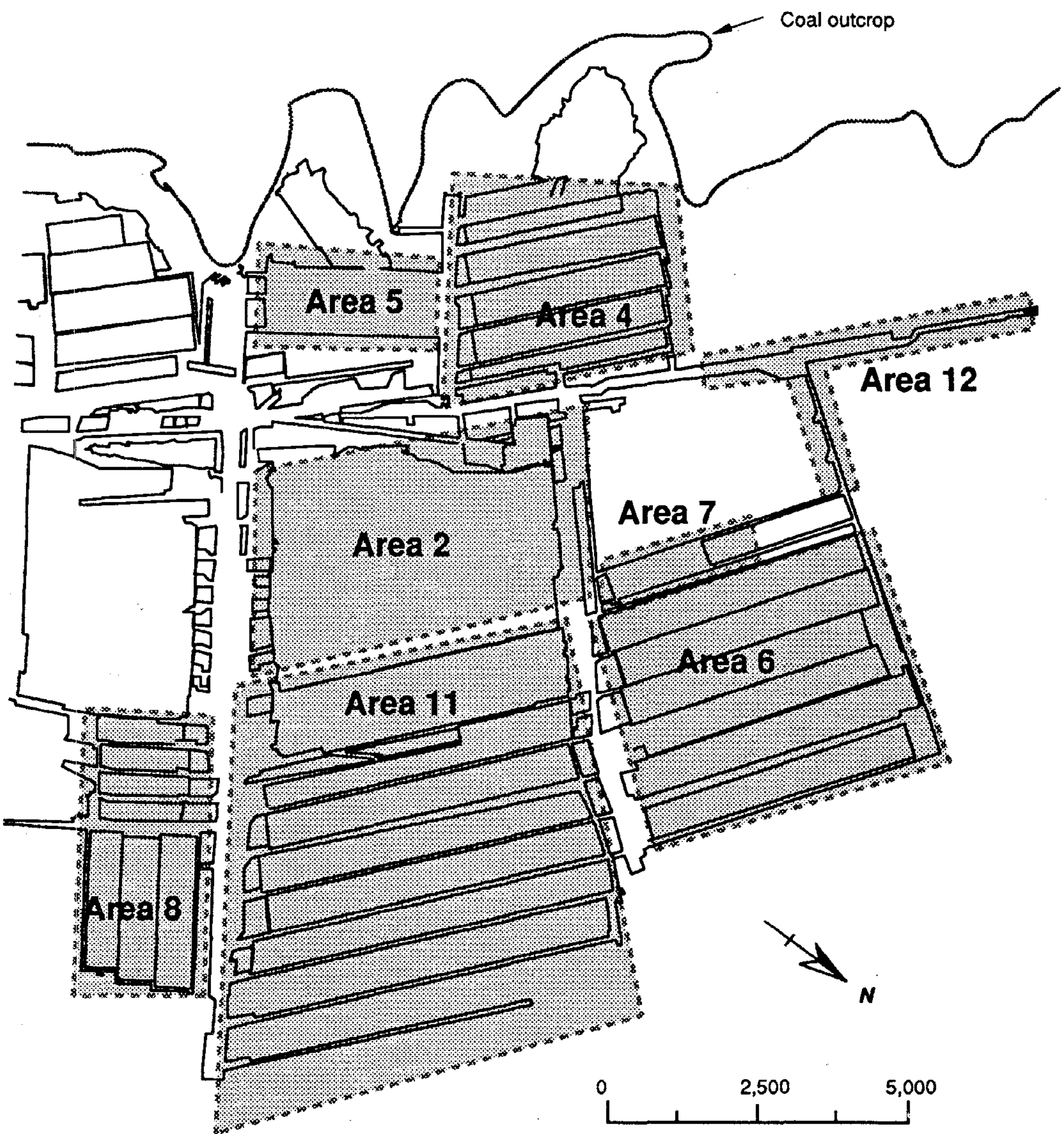

Figure 2.—Map of Sunnyside No. 1 Mine showing interview areas.

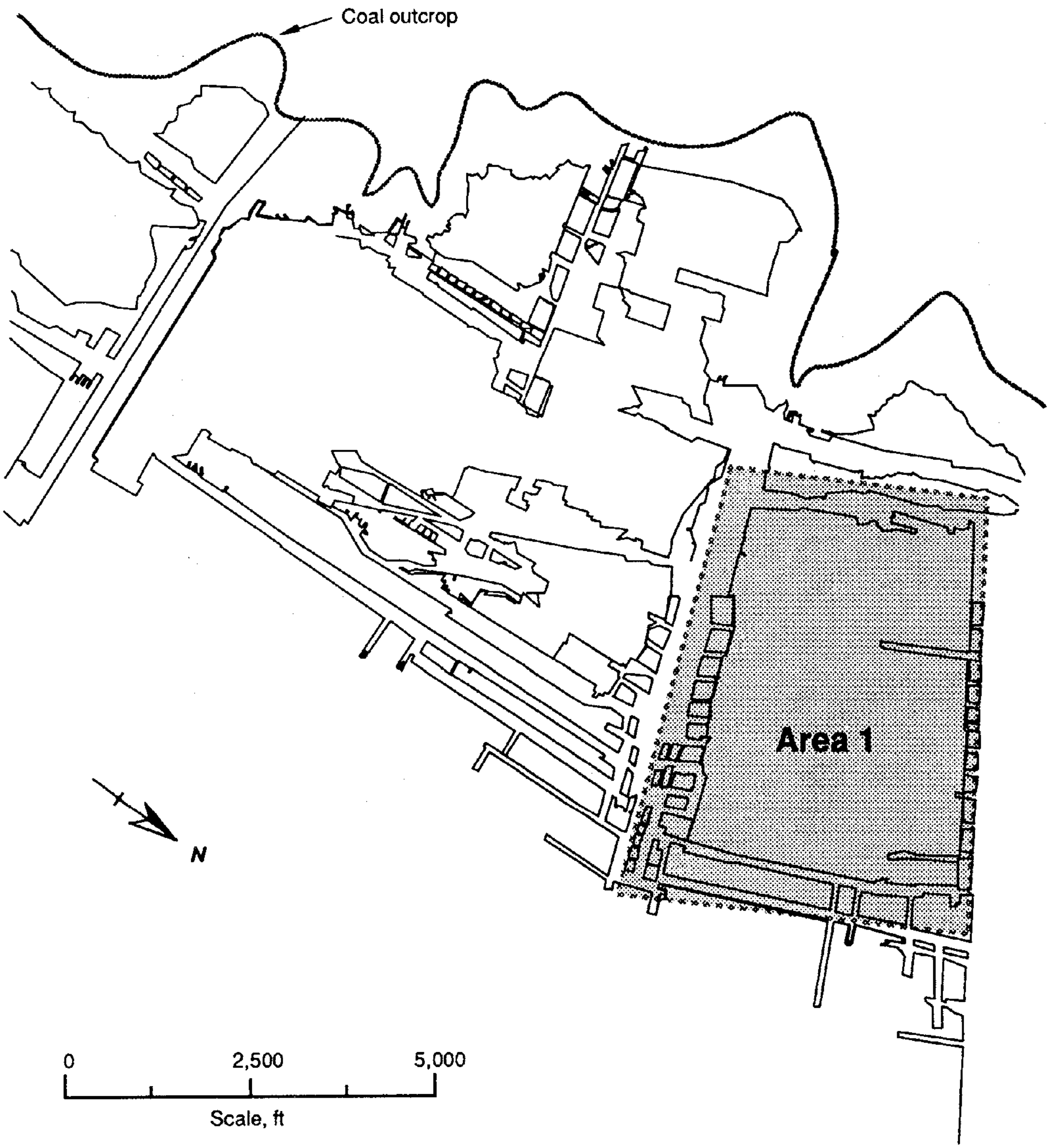

Figure 3.—Map of Sunnyside No. 2 Mine showing interview area.

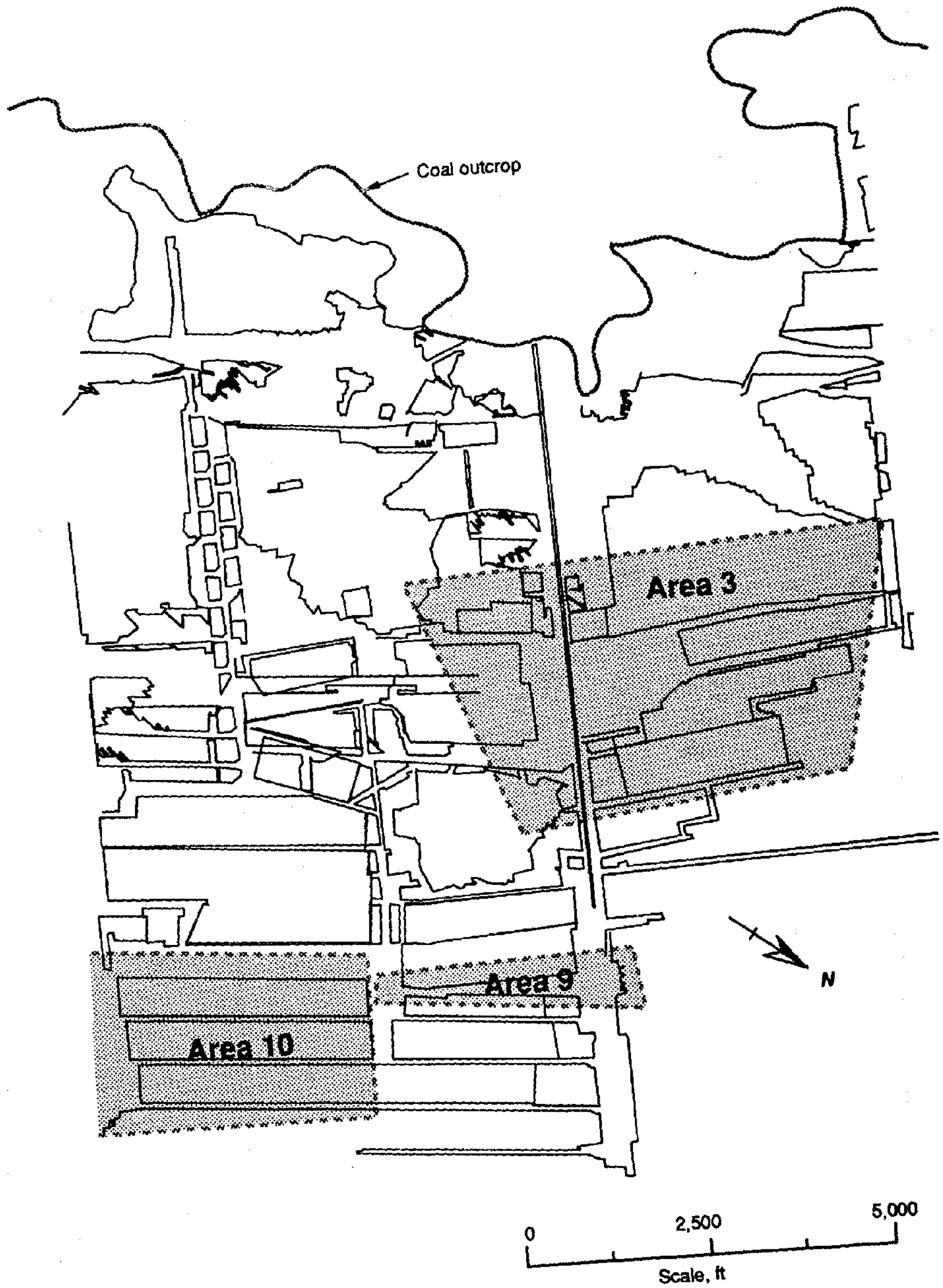

Figure 4.—Map of Sunnyside No. 3 Mine showing interview areas.

April 1988, when operations ceased for business reasons. In March 1989, the Sunnyside Mines were officially reopened by the Sunnyside Reclamation and Salvage Co. (SRS). SRS changed their corporate name to the Sunnyside Coal Co. in May 1990; however, for the purposes of this report, the present-day owners will be referred to as "SRS," the corporate name during the time the interview sessions were initiated.

Until the introduction of mechanized mining equipment in the 1930's and 1940's, development of room-and-pillar workings at Sunnyside was performed by hand using an undercut and blast sequence on the advance. Coal was hauled to the surface in narrow gauge wooden cars drawn by stout horses or mules. Artificial roof support consisted of wooden posts and cribs placed as needed; pattern roof bolting had not yet been introduced to the mines; however, small-scale trials of roof bolts began in the late 1940's and early 1950's.

The first truly mechanized mining equipment at Sunnyside was introduced in the early 1940's. The working face was advanced using a "conventional" undercutting machine in conjunction with blasting, and coal cars were loaded using a duck-bill loader and shaker conveyor. The next major technological advancement was marked by the deployment of the continuous mining system in the early to mid-1950's. Pattern roof bolting and other, more innovative artificial support, such as yielding steel arches, were introduced during this time.

Perhaps the most important technological innovation brought to Sunnyside was the longwall mining system, first introduced to the mines in 1961. The first longwall face at Sunnyside consisted of two- and three-legged, 20-ton Dowty[2] supports. Almost 2 million raw tons of coal were extracted from the Nos. 1 and 3 Mines during the period from 1961 to 1968 using this initial set of equipment. Later, longwall chocks, followed by the more advanced longwall shield systems, were utilized extensively in the Nos. 1 and 3 Mines.

From 1961 until the present, many innovative gate road configurations have been attempted at Sunnyside. Examples include advancing tailgates on retreating longwall panels and retreating single-entry longwalls. Other innovations include variable-width faces, the use of up to four different types of longwall supports on the same face, and tubular, culvert-like tailgate escapeway supports. The experience gained through the use of these novel approaches clearly underscores the need for thorough documentation of Sunnyside's history.

Currently, the No. 1 Mine is the only mine at the Sunnyside complex in operation; the No. 2 and No. 3 Mines are presently idled. At the No. 1 Mine, run-of-mine coal is transported from the working faces to the surface preparation plant via a belt conveyor network, where it is cleaned and prepared for rail shipment to customers. Production from the No. 1 Mine for 1990 was approximately 750,000 short tons of clean coal. Annual coal production is achieved using one continuous miner section and one longwall section. The continuous miner section is employed exclusively for the development of longwall gate roads including startup room and bleeder entry development. The current longwall face equipment consists of approximately 124 Westfalia two-legged, lemniscate-type shield supports with a yield capacity of 560 tons each. With these supports, full extraction of the seam in the vertical direction is possible for seam heights ranging from 52 to 132 in. A Joy 3LS double-ranging drum shearer with 66-in-diam drums is utilized on the current longwall panel, commonly referred to as "22nd Left."

Since longwall mining was initiated at Sunnyside, a wide variety of longwall equipment has been used to extract the 42 completed panels. Following technical advancements, Sunnyside longwall operations have progressed from the fragile 20-ton "ironing-board-type" props mentioned previously, to the modern shield support system currently in use. Much of Sunnyside's longwall equipment history, from 1961 to the present, can be viewed at their outdoor museum located on the surface.

GEOLOGIC OVERVIEW

The Sunnyside Mines are located in eastern Carbon County, UT, approximately 27 miles southeast of the town of Price. The mine portals, situated at an elevation of 6,750 ft, are located at the base of the western Book Cliffs, a series of steep escarpments that delineate the southern edge of the Roan Plateau. The cliffs rise sharply several thousand feet above the valley floor, resulting in abrupt changes in mining cover depth over very short horizontal distances. Depth of cover ranges from several hundred feet at the outcrop to over 2,500 ft within the current mining area.

Physiographically, the Book Cliffs Coalfield is included in the Colorado Plateau province, with the Uinta Basin to the north, the San Rafael Swell to the south, and the Wasatch Plateau to the west.[3] The beds of the coalfield dip 3° to 12° to the north and northeast, away from the

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

[3]Scheibner, B. J. Geology of the Single-Entry Project at Sunnyside Coal Mines 1 and 2, Sunnyside, Utah. BuMines RI 8402, 1979, 106 pp.

regional dome of the San Rafael Swell, an asymmetrical anticline approximately 30 by 80 miles in extent. Typically, the major faults of the coalfield are found in scattered clusters and are usually no more than a few miles in length and less than 25 ft in displacement. Oftentimes, extreme ground stability problems are experienced in and around these fault zones.

The coalbeds of economic importance in the Book Cliffs Coalfield are Upper Cretaceous in age and are confined to the Blackhawk Formation of the Mesaverde Group. The Mesaverde Group consists of three formations, which are, in ascending order, the Blackhawk, the Castle Gate Sandstone, and the Price River Formation (fig. 5). The Mancos Shale, which directly underlies and often intertongues with the Blackhawk Formation, was deposited in an offshore marine environment. The Blackhawk Formation was deposited in a marine-to-deltaic transitional environment. In comparison, the Castle Gate Sandstone and the Price River Formation were formed in a continental environment.[4]

The lowest bed of the Blackhawk Formation is the Kenilworth Sandstone member. The coal-bearing portion of the Blackhawk Formation lies above the Kenilworth Sandstone and has been divided roughly into three members.[5] The lower division, which contains the Kenilworth Coalbed, consists of alternating mudstone, sandstone, shaley sandstone, shale, and coal. The middle division is dominated by massive cliff-forming sandstone, but near the top has lagoonal deposits, which include the Upper and Lower Sunnyside Coalbeds. The upper division is a sequence of mudstone, shaley sandstone, shale, and coal. The entire Blackhawk Formation is approximately 700 ft thick.

The cliff-forming Castle Gate Sandstone overlies the Blackhawk Formation. It is approximately 180 ft thick in the mine area and is composed mainly of fine- to medium-grained light-gray sandstone. The Price River Formation overlies the Castle Gate Sandstone and is approximately 500 ft thick at the mine site. It is composed of interbedded sandstones and shales, the sandstone grading from thin bedded to massive ascending through the sequence.[6] The remaining overburden at the mine site comprises the geologic units of the North Horn, Colton, Wasatch, and Green River Formations, which form the uppermost reaches of the Book Cliffs.

The significant coal seams found within the Blackhawk Formation include, in ascending order, the Kenilworth, Gilson, Rock Canyon, and Sunnyside beds. Of these seams, the Sunnyside is considered the only coalbed of commercial interest in the mine permit area; it varies in thickness from a few inches in the west near Kenilworth, UT, to as much as 24 ft in a single bed in parts of the Sunnyside district. At the mine site, the coal seam often separates into two distinct beds with as much as 75 ft of siltstone intervening; however, in general, the upper and lower beds are considered localized splits of the same formation.[7] Typically, the Lower Sunnyside Seam is 3 to 7 ft thick while the Upper Sunnyside Seam ranges from 4.5 to 10 ft in thickness. Local thickness variations in the coal are due primarily to differential compaction and to channel-fill sandstone bodies that scour the coal from above to various depths.

Structures in the Sunnyside coal include banding and a particular type of cleavage known as "eye coal," as well as joints and fracture zones. Eye coal derives its name from numerous smooth and shining, crudely equidimensional to elongate spots on nearly parallel cleavage planes. The size of individual eyes in the Sunnyside coal ranges from 1 inch to more than 6 inches in diameter. The eyes have no third dimension.[8] Several structural differences can be observed between the coals of the Upper and Lower Sunnyside beds. The Lower Sunnyside is characteristically very hard, relatively unfractured, and forms a competent rib.[9] However, the Upper Sunnyside, although also very hard, is often shattered vertically in long, thin, irregular fragments.[10] Run-of-mine coal ranks as high-volatile, bituminous "A" or "B" quality that is low in both sulfur and ash. Sunnyside coal is primarily utilized as the high-volatile fraction for the blending of metallurgical coke.

The composition of the immediate roof and floor of the Sunnyside Mines can vary substantially over a few hundred horizontal feet, whether in the Lower or Upper Sunnyside splits. These local variations are caused by the extensive intertonguing of various rock types resulting from continuously changing depositional environments. Five basic rock types are found in the immediate roof, floor, and interburden surrounding the upper and lower beds. They are (1) dark brown or black mudstone, (2) gray-brown sandy siltstone, (3) interbedded siltstone and sandstone, (4) fine-grained quartzose sandstone, and (5) fine-grained calcareous sandstone.

[4]Report to Kaiser Steel Co. for coal slurry pond permit application, 1973, 9 pp.; available upon request from J. R. Koehler, BuMines, Denver, CO.

[5]Fisher, D. J. The Book Cliffs Coal Field in Emery and Grand Counties Utah. U.S. Geol. Surv. Bull. 852, 1936, 104 pp.

[6]Work cites in footnote 4.

[7]Osterwald, F. W., J. O. Maberry, and C. R. Dunrud. 1981 Bedrock, Surficial, and Economic Geology of the Sunnyside Coal Mining District, Carbon and Emery Counties, Utah. U.S. Geol. Surv. Prof. Pap. 1166, U.S. GPO, 1981, 68 pp.

[8]Work cited in footnote 7.

[9]Diamond, W. P. (BuMines, Pittsburgh, PA). Private communications, 1977; available upon request from B. J. Scheibner, BuMines, Spokane, WA.

[10]Work cited in footnote 3.

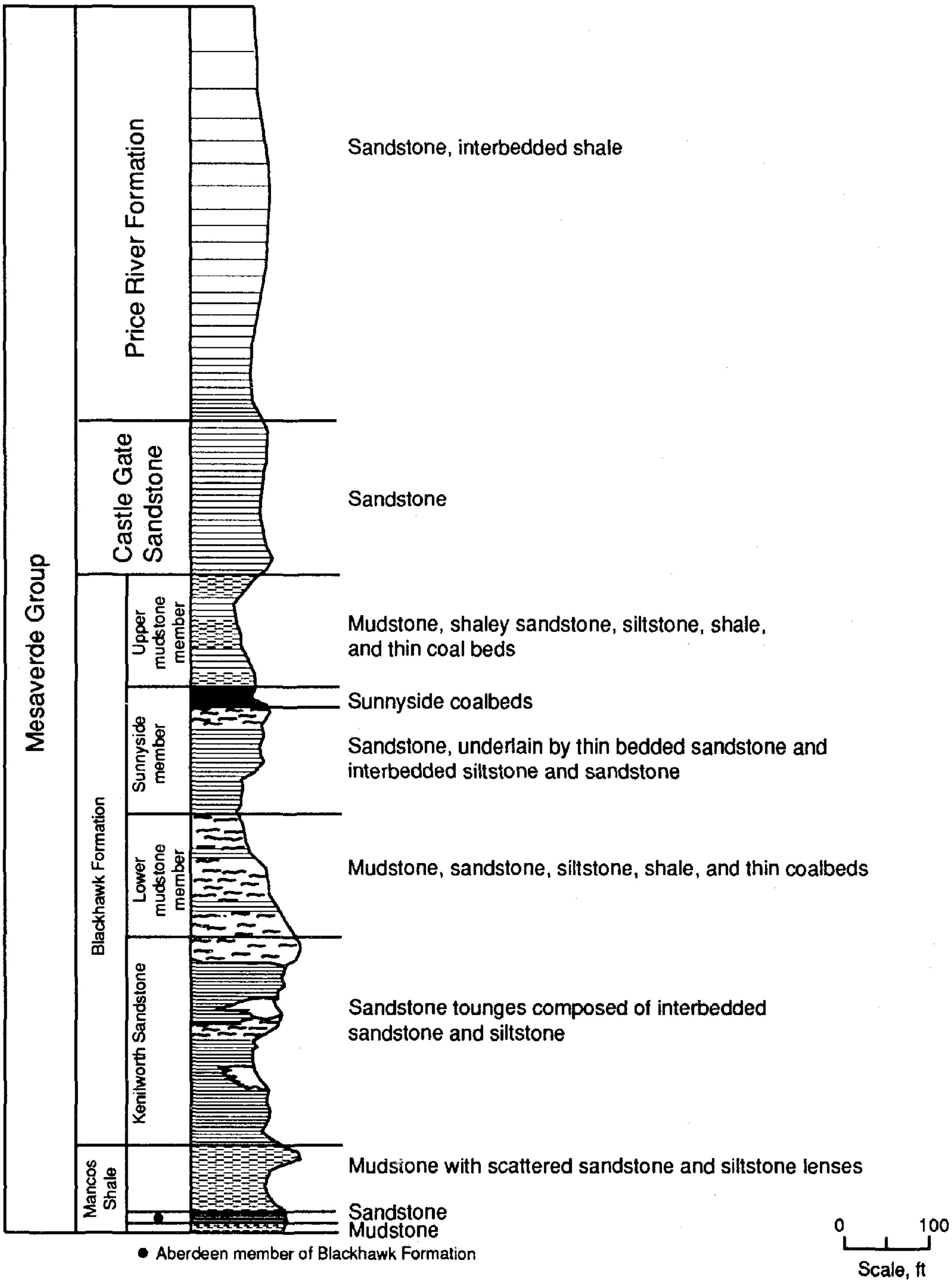

Figure 5.—Generalized stratigraphic section of Mesaverde group for Sunnyside mining district (after Scheibner, work cited in footnote 3).

In general, the dark brown mudstone occurs immediately above and below the Upper and Lower Sunnyside Coalbeds and varies in thickness from several inches to tens of feet. This rock is usually extremely hard and is often highly carbonaceous or calcareous. Also, this material is sometimes jointed and locally slickensided several feet above or below the coal horizon. The gray-brown sandy siltstone is generally found in the rock parting between the splits or in lenses above the Upper Sunnyside Seam. It varies in thickness from 1 to 8 ft and is also often extremely hard. The interbedded siltstone and sandstone usually occurs as "sandbar-type" features in the parting between the seams and can be several tens of feet thick. Small lens-shaped deposits of coal are sometimes found interbedded with this material. Lastly, the fine-grained quartzose and calcareous sandstones occur irregularly as lenses or channel-fill deposits above, below, or between the coal splits. They are most common in the upper portion of the dark brown mudstone and have been noted to contain small amounts of water, and on occasion, complex hydrocarbons.[11]

FIELD NOTES SUMMARY

OVERVIEW OF PARTICIPANT MINING EXPERIENCE

Prior to the interviews, participants provided a general overview of their career experience in underground coal mining to aid USBM personnel in determining the experience base of each individual. This information allowed the USBM researchers to develop a line of questions which would best utilize the experience of the specific individual. A summary of the positions held and approximate years of experience in those positions for all participants is provided below.

Position title	*Cumulative experience, years*
Mine supervisor	50
Mine engineer	40
Longwall foreman	40
General maintenance	90
General longwall crew	100
Longwall shearer operator	35
Timberman	30
Mantrip rope rider	25
Roof bolter operator	50
Shuttle car operator	45
Conventional or continuous miner operator	40
Beltman	20
Trackman and haulage	35
Fireboss	40
Motorman	30
Total	670

SUMMARY OF FIELD NOTES BY AREA

Area 1

Areas 1 and 2 include the earliest examples of mining performed by those interviewed. Room-and-pillar mining began in area 1 (fig. 6) in the late 1940's and continued until early 1971. Cover depth ranged from 500 ft to over 2,000 ft, and general roof conditions were reported to be extremely poor. Water and methane concentrations were considered average and seemed to be of little consequence to daily operations. There were no old workings above or below the main seam in this area; however, the coal was very thick across the area, with mining heights occasionally exceeding 20 ft. Approximately the top 5 to 8 ft of the seam was extracted during development, with the remaining coal recovered on the retreat cycle. Because of the extreme mining height, telephone pole-like timbers had to be used to support many of the openings in the production panels. From the upper reaches of area 1 to approximately 9th Left, no roof bolts were used on development or retreat. Later, in the mid-1950's, wedge-type roof bolts were used to support the roof in the production panels.

As mining progressed downdip, ground conditions in the main haulageways suffered from the inherently poor roof, greater mining depth, long standtime, and mining-induced load transfer from the retreated panels. An extensive program of roof bolting was undertaken to mitigate these problems. About halfway down the slope (mining cover depth of approximately 1,000 ft), at 7th Left, yielding steel arches were installed to further support the unstable ground. Later, extensive backfilling around the arches and in the abandoned panels was required to maintain the integrity of the slopes.

Prior to the development of area 1, room-and-pillar production rooms and crosscuts in the Nos. 1, 2, and 3 Mines were driven on the advance. This system proved workable when the cover depth was shallow, usually described as less than 500 to 1,000 ft; however, once cover depths exceeded 500 to 1,000 ft, full development of the panels on the advance could not be safely conducted because of extremely poor roof conditions and stress-related coal bumps.

Most of the panels in area 1 were developed using the two-entry system to establish the cross-panel ventilation loop (fig. 7). On retreat, rooms and crosscuts were

[11]Work cited in footnote 3.

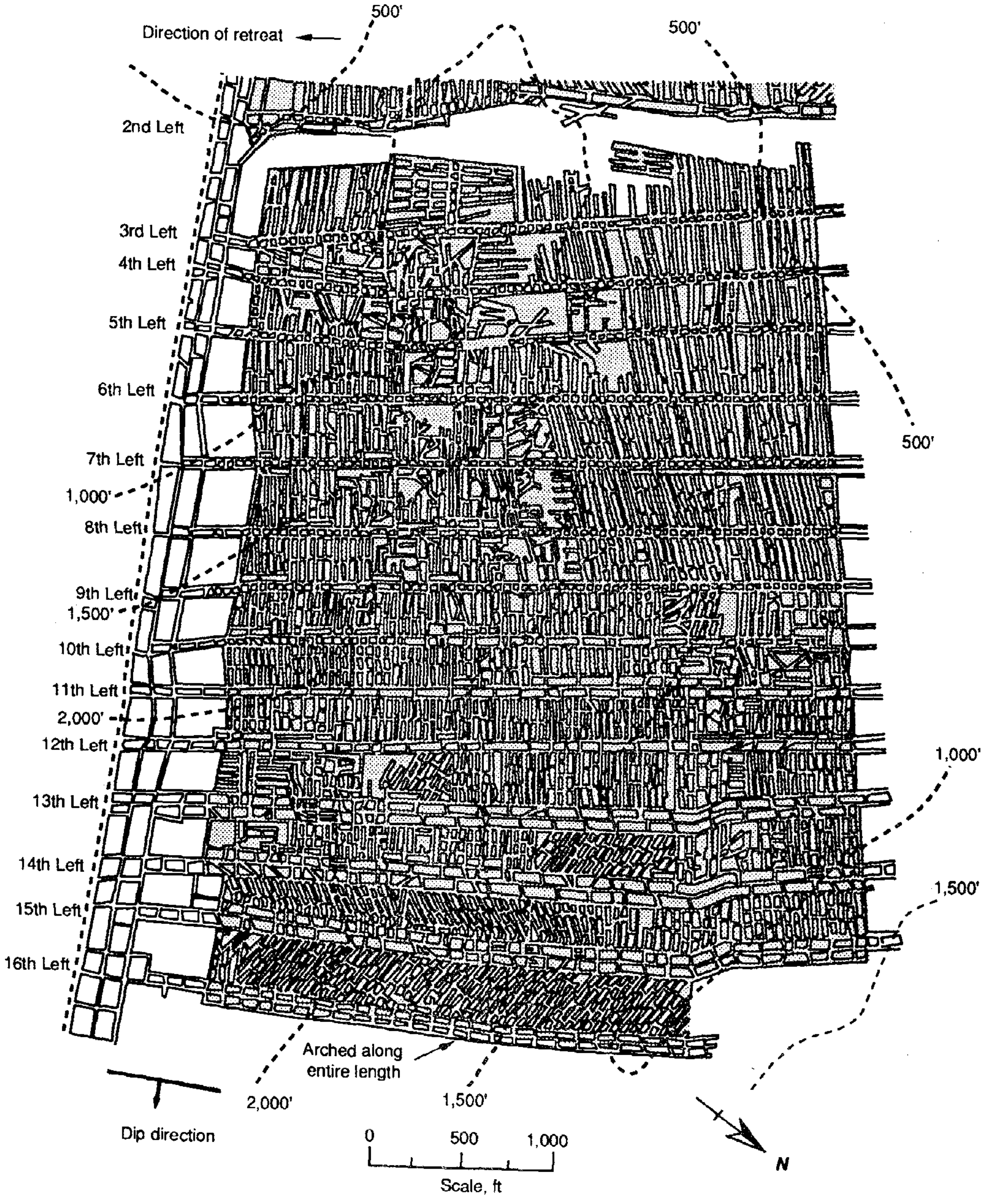

Figure 6.—Detailed map of area 1.

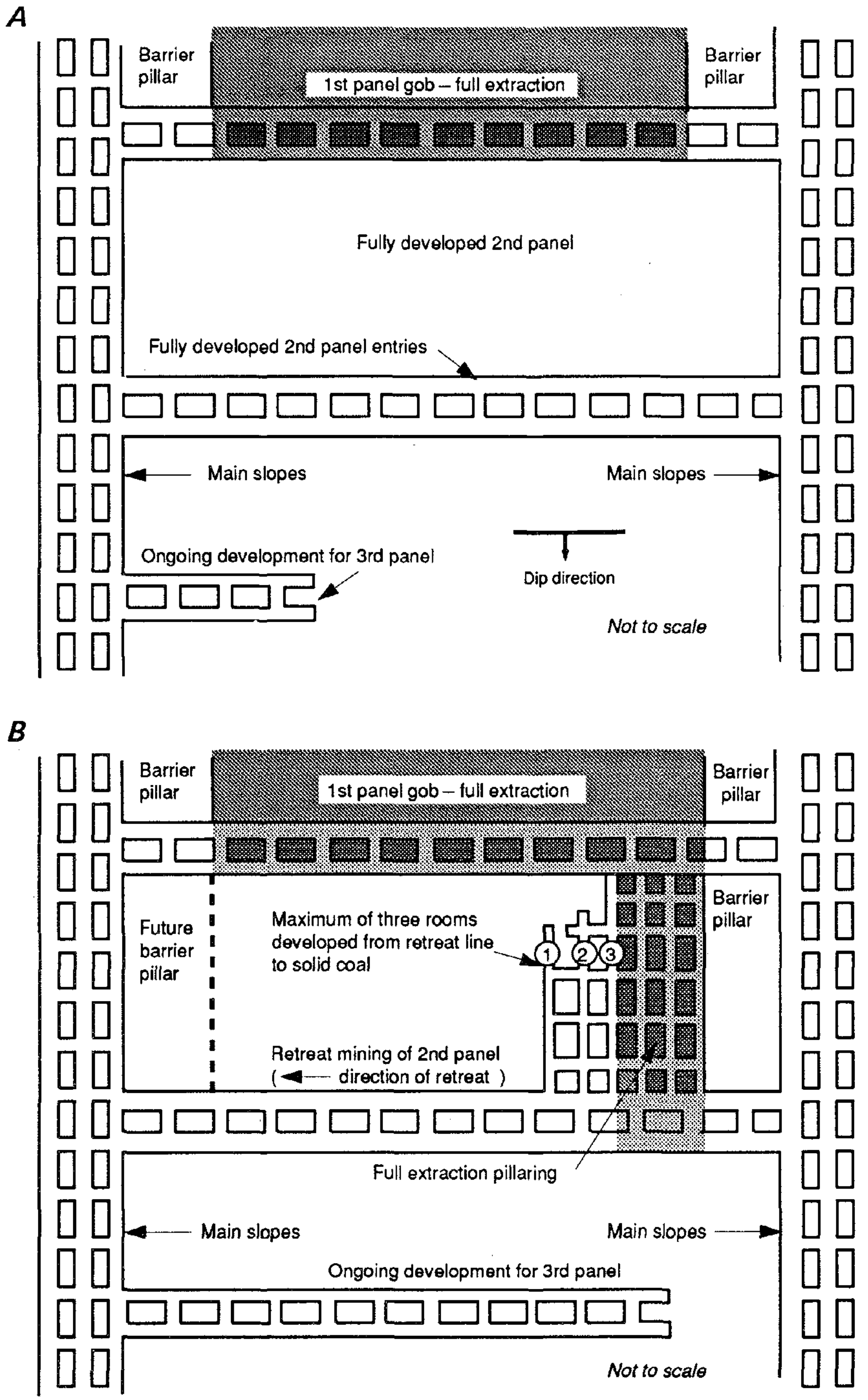

Figure 7.—Typical room-and-pillar panel mining at Sunnyside. *A*, Development sequence; *B*, retreat sequence.

developed updip from the two-entry system. A maximum of three rooms were developed from the retreat line to the remaining solid panel to help minimize roof control problems and bumps. Also, full extraction was attempted to promote uniform caving. Still, pillar bumps along the retreat line and in the newly developed rooms were severe, serious injuries were common, and the retreat of this area was often described as a "total disaster." The larger bump events were reported to have derailed locomotives, thrown 25-ton conventional mining machines and coal cars against the roof, and caused earth movements felt several miles away in the town of Sunnyside. At least one bump-related fatality was reported in the 13th Left panel. In 14th Left, several attempts to destress the panel entry chain pillars were made using the water infusion technique; however, this program was considered a failure as overburden loads apparently shifted to the next available structure, usually resulting in a significant bump event.

In the 13th, 14th, and 15th Left panels, a third entry, oriented parallel to the two-entry panel access, was developed back toward the main slopes approximately 200 to 300 ft ahead of the retreat line to provide access for a 12-car haulage train. No information could be acquired regarding the effect this short section of additional entry had on overall ground conditions; however, it was generally reported that ground conditions worsened, especially in terms of roof falls and bumps, as more ground was opened up, and as it was, the two-entry systems were difficult to keep open. The 16th Left panel entries, developed on the three-entry system, were the last set of production openings to be developed in area 1. These entries had to be supported with steel arches along their entire length to control the movement of the surrounding strata; however, it was reported that this technique met with limited success. The ground stability problems experienced in 16th Left were attributed to the wider span required to develop three entries and the fact that all three entries were driven on the advance.

Area 2

As with area 1, area 2 (fig. 8) includes the earliest examples of mining performed by those interviewed. Room-and-pillar panel development began in the area in the early 1950's, and retreat mining continued until 1966. Overburden depth ranged from 1,000 to 2,000 ft, and general roof conditions were described as being extremely poor. Significant quantities of clay in the immediate roof, as well as an extensive system of preexisting fractures, were listed as the primary causes of the roof problems. As a result of these geologic conditions, the roof was very difficult to support using conventional methods of reinforcement such as timbers, cribs, and roof bolts. A major fault, trending southeast to northwest, also contributed to the overall instability of this area of the mine. Mine personnel reported that mining conditions deteriorated significantly after crossing the fault, with poor mining conditions found on either side, depending upon which room-and-pillar panel miners were in at the time.

No old mine workings existed above or below the room-and-pillar panels that comprise area 2. High coal ranging from 12 to 14 ft was encountered throughout most of the area. The sulfur content of the coal was of significant proportions, most notably in the upper reaches of the area, to burn the eyes of the miners working in the dust at the face or in the return airways. Also, water quantities and methane concentrations began to increase, especially as mining advanced downdip. It was learned that the increasing natural occurrence of both water and methane is typical for the entire Sunnyside property as operations venture under greater cover. Contributing to the natural increase in water with depth was water that slowly percolated downhill from the previously mined panels. Although the miners had to contend with more water on each successive downhill panel, water quantities did not create an excessive hardship and were not considered to have contributed significantly to the poor mining conditions found in area 2. Also, the higher concentrations of methane were reported to be of little consequence to the extraction of the area.

The panels in area 2 were developed using the same approach as was used in most of area 1 (fig. 7). Because of the cover depth, no attempts were made to fully develop rooms on the advance. Rather, on retreat, a maximum of three rooms were developed updip, from the retreat line to the remaining solid panel, to minimize roof control and bump problems. Few bump events were reported during development of the initial panel entries; however, severe bumps were encountered during retreat mining. Consistently incomplete recovery of remnant pillar stumps and resulting cantilevering roof were overwhelmingly identified as the primary causes of the bump activity. The major fault intersecting this area was also identified as contributing to the severity of the ground conditions. Inherently unstable roof, increased severity of bumps, and a higher frequency of bump-related roof falls were identified as being associated with approaching and crossing this fault.

As a result of the incomplete recovery of pillars during retreat mining and the inherently unstable mine roof, injury rates increased dramatically once pillar recovery was initiated, and at least three bump-related fatalities were reported to have occurred. Production pillars were reduced to 15 to 20 ft wide, and room and crosscut widths kept at a minimum to mitigate pillar bumps and related roof falls. It was reported that this approach significantly reduced the frequency and severity of these events.

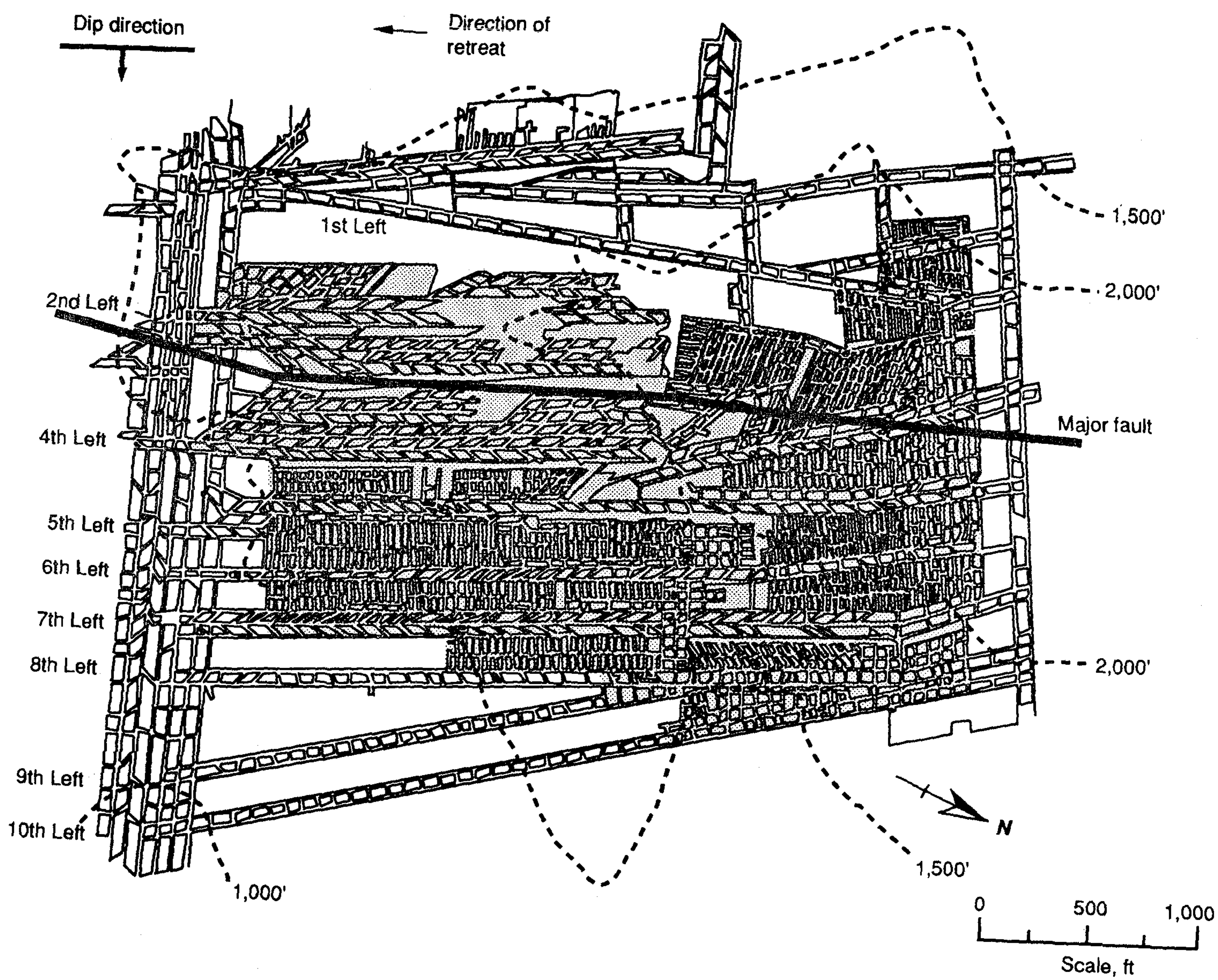

Figure 8.—Detailed map of area 2.

As mining progressed downdip, serious stability problems began to occur along the main haulageways because of weak roof, long standtime, and load transfer from the adjacent room-and-pillar retreat sections. It was at this time that the use of yielding steel arches and the practice of backfilling were introduced to the mine. Placement of the arches began after the depth of cover exceeded approximately 1,000 ft. Once the area was roof bolted, the steel arches were installed. To further stabilize the area, extensive backfilling was done around the arches and in the surrounding worked-out panels. Coke breeze from the beehive coke ovens in the town of Sunnyside was first used as the backfill material. Later, waste from the coal wash plant was introduced to the backfilling operations.

The first three-panel entry systems developed, 2nd Left, 4th Left, and 5th Left, all utilized the three-entry system for the initial cross-panel ventilation loop. This entry configuration was chosen not from a ground control standpoint, but rather to provide enough working faces to accommodate the latest mechanized mining equipment. The remaining panels in area 2 were developed on the two-entry system. Reports varied as to the differences in ground control performance between the two- and three-entry systems, but it was generally agreed that the more ground opened up, the higher incidence of roof falls and general stability problems.

Area 3

Area 3 (fig. 9) contained the first five production panels extracted using the longwall mining method. Because of the challenging multiple-seam mining conditions to be encountered, this area was chosen by mine management to test the performance of the longwall system. The management felt that if the longwall system was a success in area 3, it would work well throughout the Sunnyside properties.

The first longwall face began production in November 1961, and longwall mining in the area continued until May 1966. Overburden depth ranged from just under 500 ft to nearly 1,500 ft. The first three panels were located in the Lower Sunnyside Seam, which was approximately 4 to 6 ft thick in this area. On development, lower seam roof conditions were described as being fair to very poor; however, by the time longwall mining began, the roof had further deteriorated because of induced stress from old room-and-pillar remnant structures 20 ft above in the Upper Sunnyside Seam. The floor of the lower seam was also described as being relatively soft, which may have contributed to entry stability problems. The last two longwall panels were located in the Upper Sunnyside Seam, which was approximately 5 ft thick over the panel lengths. Natural roof conditions in the upper seam were reportedly much better than those encountered in the lower seam, and no old workings were present in the lower seam to affect upper seam mining operations. No information was available describing floor conditions in the upper seam. Water and methane were present in the lower seam in what were described as "average amounts," and seemed of little consequence to mining activities. No unusual amounts of water were reported in the upper seam; however, methane concentrations were said to be higher than average.

The first longwall panel was located on the south side of the No. 3 Mine main slopes between the 7th and 8th Right entries in an area originally developed some years earlier for room-and-pillar work. Both the headgates and tailgates for the panel utilized multiple-entry systems with 40- by 80-ft or larger pillars. Also, both headgates and tailgates were located below a row of reportedly heavily loaded pillars in the upper seam. The depth of mining cover over the panel was approximately 1,000 ft. Supplemental support in the gate roads included yielding steel arches, roof bolts, and heavy cribbing to support the openings under the heavy pressure from the upper seam works.

The longwall face equipment consisted of 20-ton Dowty two- and three-legged supports. Typical operational problems included supports tipping over along the face because of the uneven floor and roof surfaces caused by the soft floor conditions and highly fractured roof. Also, face bumps and resulting seam squeezes often "metal-bound" the supports, which then had to be excavated by hand to be freed.

Ground control problems began immediately after longwall mining was initiated. Face bumps were prevalent and were often accompanied by instantaneous floor heave in the entries and along portions of the face. On several occasions, the face conveyor (panline) was pushed tight against the roof by the heaving floor. It was unanimously agreed upon among those interviewed that the ground pressure resulting from the upper seam works, in conjunction with the limited capabilities of the face equipment, was responsible for the hazardous mining conditions. Lost-time injuries were numerous; however, no fatalities were reported. Mine management did not consider the longwall system "proven" after the mining of the first face because of the operational difficulties and low production rates encountered.

The second and third longwall panels were located on the north side of the No. 3 Mine main slopes between the 6th, 7th, and 8th Left gate roads. These three-entry gate roads were originally driven as room-and-pillar developments, as with the first longwall panel gate roads. A major roof fall in the 6th Left entries, the tailgate for the second panel, required the development of a 450-ft-long "offset" fourth entry prior to longwall mining to provide

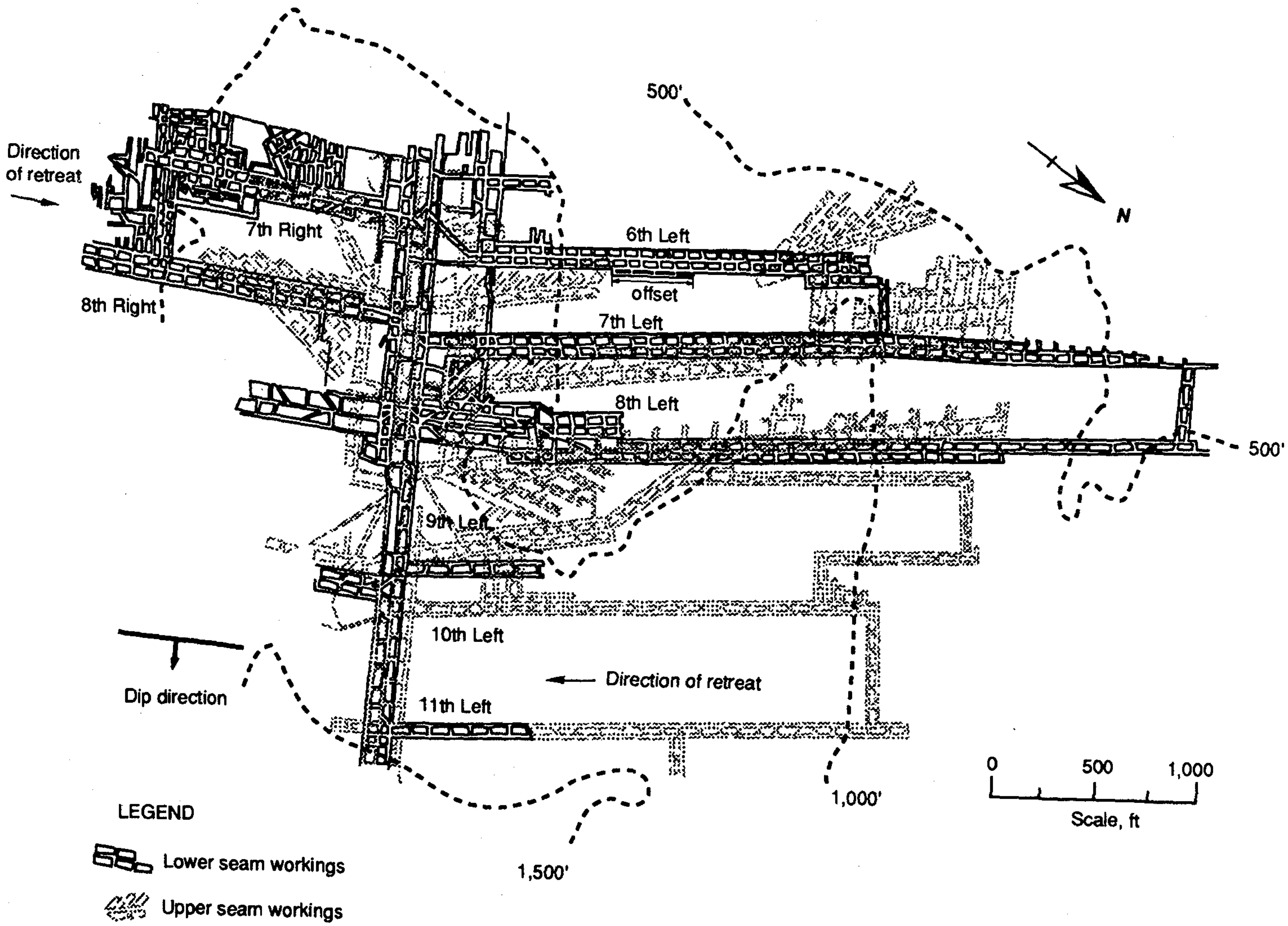

Figure 9.—Detailed map of area 3.

escapeway access. The wide span of opened ground across the existing three-entry system was claimed to be the reason for the roof instability in this area. Small, yielding-type pillars approximately 10 ft wide were used in this offset. Information regarding the performance of this offset section of tailgate was not available.

In the second and third panels, seam interburden thickness was approximately 40 ft and mining cover depth ranged from 500 to 1,000 ft. As with the first panel, excessive amounts of supplemental support were reportedly required to maintain the integrity of the headgates and tailgates. Also like the first panel, overlying room-and-pillar works created zones of severe pressure on the gate roads and the faces. Lost-time injuries were common as the face and gate road pillars bumped violently, especially along the tailgates. Those interviewed unanimously agreed that the remnant pillars in the upper seam were largely responsible for the ground instabilities encountered during the mining of these panels.

The fourth and fifth panels mined were located in the Upper Sunnyside Seam between the 9th, 10th, and 11th Left entries and were not subjected to the multiple-seam interaction experienced on the first three panels. The face width of the fourth panel was altered several times along its length because, as in the first three panels, the development entries had originally been driven for the room-and-pillar system. To accommodate the changing face width, longwall supports were added or removed on the maintenance shift. Even with this added inconvenience, production rates of 50 tons per worker-shift, considered high for the day, were achieved.

The original room-and-pillar developments in the 9th and 10th Left entries were driven using the three-entry system on advance. Chain pillar dimensions were 40 by 80 ft in the three-entry sections. However, to mitigate floor heave problems and supplemental support requirements, such as extensive cribbing, the remaining portions developed for the longwall were driven on the two-entry system utilizing a 30- by 110-ft chain pillar design. From this time forward, all *new* developments for longwall mining utilized the two-entry system until the passage of the 1969 Coal Mine Health and Safety Act.

Area 4

Areas 4 and 5 (figs. 10-11), known inclusively as the "inside raise," contain some of the most shallow yet most steeply pitching longwall panels on the Sunnyside properties. In addition, area 4 (fig. 10) includes two- and three-entry gate roads accessing adjacent longwall panels under similar mining conditions.

Following completion of the longwall panels in area 3, the two- and three-legged Dowty supports were moved to the No. 1 Mine to maintain continuous longwall extraction on the property. Longwall mining in area 4 began in 1968 and continued until November 1972, when the last of five panels was completed. Overburden depth ranged from under 500 ft to almost 2,000 ft, and seam dip varied from 7% to 10%. All longwall mining occurred in the 4.5- to 6-ft-thick Lower Sunnyside Seam with the exception of the 6th North panel entries. Water and methane concentrations were at a minimum; however, the sulfur content of the coal was high. Sulfur-related vision problems were experienced on the longwall face where water-goggle-type glasses had to be worn occasionally to protect the eyes. The immediate roof in this area was described as average to very good and the floor was reported to be comparatively soft, especially in the 3rd North panel.

Typical of mining practices at Sunnyside, the general mining of area 4 progressed downdip. The 1st and 2nd North panel entries utilized the three-entry system and had originally been developed in the late 1950's and early 1960's for room-and-pillar extraction. The depth of mining cover across these entries varied from under 500 ft to just over 1,000 ft. As a headgate, the 2nd North entries performed satisfactorily. Intermittent heave caused by the soft floor was the only problem reported. More significant problems began when 2nd North became the tailgate for the 3rd North panel. Apparently, the 45- by 85-ft chain pillars in 2nd North did not yield on first panel mining, resulting in significant floor heave and pillar and tailgate corner bumping (when mining cover depth exceeded approximately 750 ft). When the longwall face reached a point approximately 15 to 30 ft from the upcoming crosscut, the outby pillar (or pillars) would oftentimes bump violently. This activity was often accompanied by a bump along the face, usually within 30 ft of the tailgate corner. While most of the face bumps were reportedly minor, several of those interviewed recalled the panline being pushed to the roof on occasion by the accompanying floor heave.

In an effort to mitigate both the bump and heave problems in 2nd North, a destressing program was initiated. Pillars were drilled and volley-fired about 50 ft ahead of the face. This method was reported to have significantly reduced the frequency and severity of uncontrolled pillar bumps; however, drilling the pillars was very dangerous because of the highly loaded ground. Oftentimes the drilling activity initiated the very bump event that the miners were attempting to avoid.

To alleviate the floor heave problems encountered in the 2nd North headgate (which utilized 45- by 85-ft chain pillars), the pillars in the 3rd North entries were reduced in size to 30 by 90 ft about halfway down the panel length to induce controlled yielding. Pillar yielding upon development would both reduce peak loads applied to the floor and mitigate the long-term effects of sustained high floor

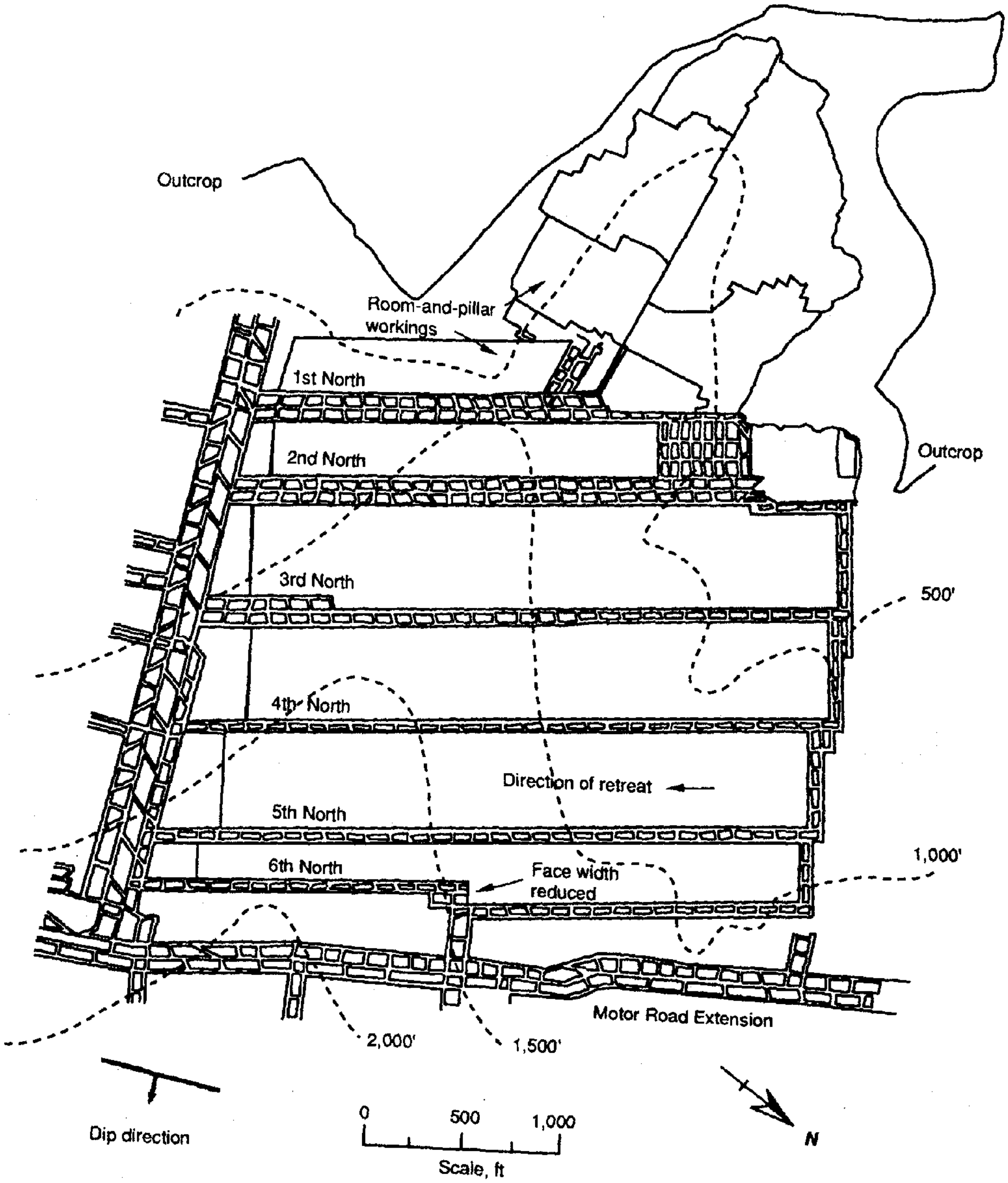

Figure 10.—Detailed map of area 4.

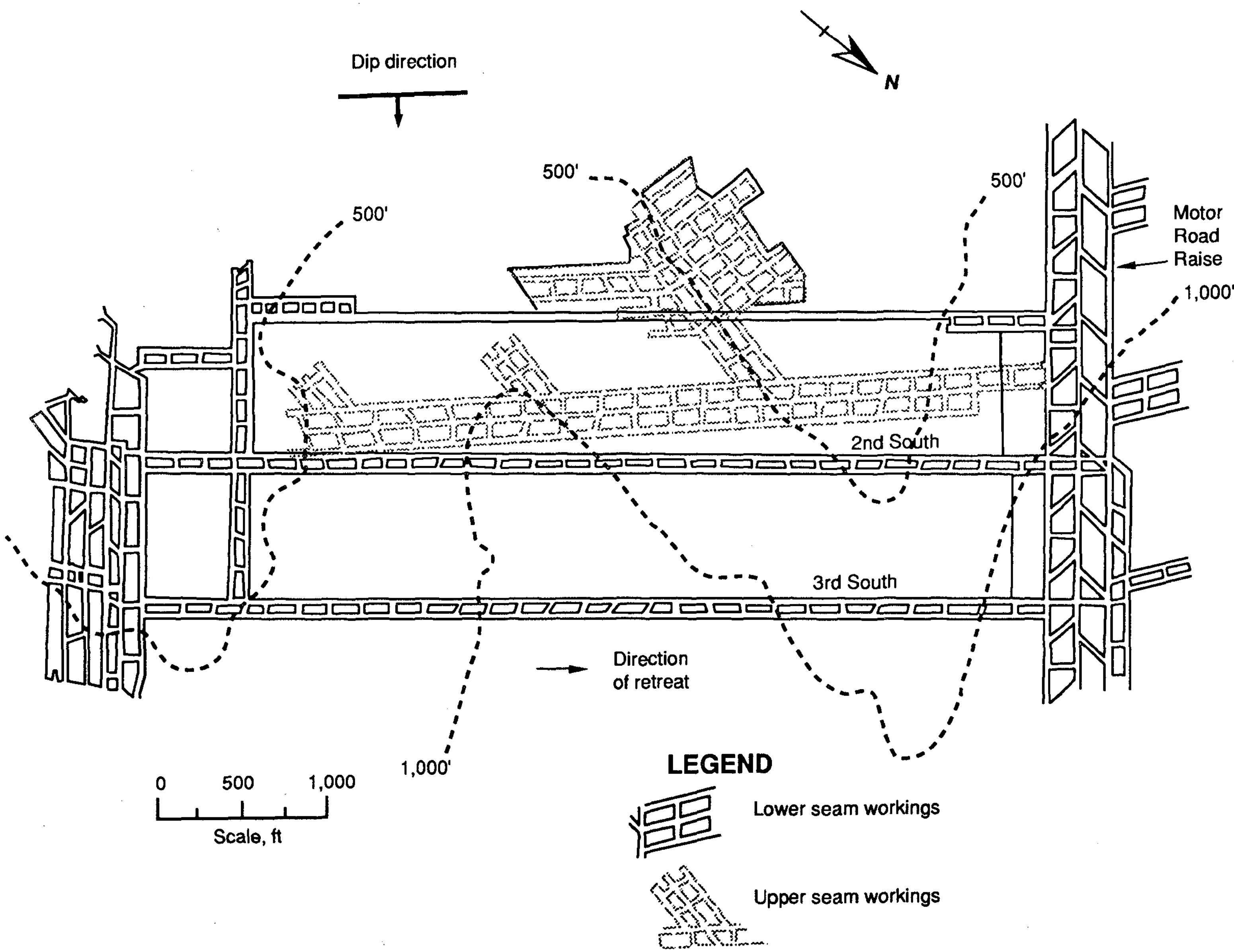

Figure 11.—Detailed map of area 5.

loads. An additional effect of the yield pillar design was the elimination of tailgate pillar bumps, a benefit later realized when the 4th North panel was retreated. During the mining of the 4th North panel, the occurrence of bumps in the 3rd North tailgate decreased dramatically over what had been experienced in the 2nd North tailgate, until the face approached the larger pillar design. As was the case in 2nd North, the larger pillars supporting the outby half of 3rd North bumped as the face neared, and tailgate destressing had to be performed through the remainder of 4th North panel mining.

Mining of the 5th North and 6th North panels was said to be some of the easiest found on the property with the exception of an entry alignment problem in the 6th North entries. In these panels, the cave behind the longwall supports was tight, resulting in excellent ventilation of the working face.

In the 5th and 6th North area, intertonguing rock splays resulting from the transitional depositional environment displaced the coal seam in an irregular fashion. These rock-to-coal-to-rock transitions made it very difficult for the development crews to distinguish the Lower Sunnyside from the Upper Sunnyside Seam. Upon driving the 6th North longwall startup room, the 5th North entries could not be located. Surveying checks revealed that the 5th North entries lay several feet below the startup room. To successfully mine the 6th North panel, a tailgate was cut using the shearer, and large-diameter holes were regularly shot in the floor to provide a path for ventilation and an escapeway into the 5th North entries. Eventually, the immediate roof of the 6th North longwall face began to drop toward the 5th North entries and the face was driven downward into the 5th North tailgate. An exact description of the geologic transition from the face into 5th North could not be obtained. Another interesting feature of the 6th North panel was that the face width was reduced about halfway through extraction of the panel. This was done to widen the barrier pillar between the active longwall area and the Motor Road Extension.

With the exception of intermittent floor heave, the three-entry *headgates* were reported to have performed as well as the adjacent two-entry designs in area 4. Noticeable differences in performance were experienced when the entry systems were used as tailgates. In general, the two-entry tailgates were reported to be much easier than the three-entry tailgates to support and maintain. Significantly less supplemental support per foot of entry was required to maintain the escapeway in the two-entry tailgates regardless of pillar size used. Bump problems, however, were associated with both entry systems, depending on the pillar size used. As with the nonyielding 45- by 85-ft pillar design used in the 1st and 2nd North three-entry systems, the same pillar design was found to cause bumps in the 3rd North two-entry system. Both the two-entry and three-entry gate roads suffered what appeared to be guttering of the roof along the pillar riblines, especially in the farthest downhill entry. This was thought to be caused by excessive weight riding down the hill because of the steepness of the seam in this area.

Area 5

Area 5 (fig. 11) was similar to area 4 in that cover depth was relatively shallow and the coal seam was steeply dipping. In addition, area 5 includes another example of a tailgate that was developed on the retreat using the longwall shearer. Longwall mining in area 5 was initiated in late 1972 and continued until late 1974. Cover depth ranged from under 500 ft to just over 1,000 ft, and the seam dip was estimated to be 7% to 10%. The longwall panels were located in the Lower Sunnyside Seam, which ranged in thickness from 3.5 to 5.5 ft in the area. A three-entry room-and-pillar development, driven in the Upper Sunnyside Seam in the late 1950's, overlaid the first panel, 2nd South; however, no seam interaction problems were reported when 2nd South was mined. The second panel, 3rd South, was not overlain by old workings. Both panels utilized two-entry gate road configurations with 25- by 95-ft yielding chain pillars.

The immediate roof in the area was reported to be good. No comments as to the quality of the floor were noted. Water and methane were at a minimum and posed no problems to mining, whether on development or retreat. The coal had a high sulfur content, similar to area 4, and related vision problems were reported by members of the longwall face crew.

Following Sunnyside convention, general mining progressed downdip. The 2nd South panel was mined first, followed by the 3rd South panel. The tailgate for the 2nd South panel was driven on the retreat using the longwall shearer. This mining practice was followed nearly to completion of the panel when an unspecified blockage of the tailgate disrupted ventilation of the face. To finish the 2nd South panel, a short section of two-entry gate road was developed from the Motor Road Raise to the tailgate, thereby reestablishing the needed ventilation course.

Aside from ventilation, the major problem experienced during the mining of 2nd South was a pinching-out of the seam on the southern end of the panel. Seam thickness was as little as 3.5 ft, requiring that roof rock be mined with the coal. In this area of the panel, shearer bits had to be changed as many as eight times per face pass. During one of these bit changes, a fatality occurred when an employee became entangled in the rotating shearer.

Mining of the 3rd South panel reportedly progressed without incident. Seam thickness was said to be approximately 5.5 ft, and the roof caved tight behind the longwall supports, making for excellent face ventilation. In general, mining in area 5 was reported to be some of the easiest experienced to that point in time; face and pillar bumps were almost nonexistent, no floor heave problems were reported, and injury rates were apparently very low.

Area 6

Area 6 (fig. 12) includes two longwall panels that were mined using single-entry gate road systems. Longwall mining began in the area in mid-1969 and continued until 1980. In 1985, a final sixth panel was extracted downdip of the first five. Cover depth ranged from just under 1,500 ft to just over 2,000 ft, and all longwall mining occurred in the 6-ft-thick Lower Sunnyside Seam. No old works existed above any of the six panels mined. Water was considered a problem, especially in the single-entry gates because of heavy percolation downhill from the uphill gob areas. Methane concentrations were reported to be average to very high, while the immediate roof was described as being average to poor. No comments as to the quality of the floor were available. Several rolls of the coal seam were experienced in the downdip panels.

Development and retreat mining of the upper three panels, 12th Left, 13th Left, and 16th Left, were described as being incident-free and, in general, favorable conditions prevailed. All three panels utilized two-entry gate road configurations with yielding chain pillars 25 ft in width and 80 to 130 ft in length.

The fourth panel, 17th Left, was developed using both single- and two-entry sections in the headgate. Two 1,500-ft-long single-entry sections were separated by a 1,500-ft long two-entry section. Entry width in the single-entry system was 26 ft, and a separation barrier constructed of wooden cribs and sheet metal was erected down the center of the entry. Cribs were set on 7- to 8-ft centers to support the opening, and the sheet metal was nailed to the cribs to provide both a ventilation and fire barrier. A section of wire-reinforced concrete cribs was tried in the outby section of the single entry. The miners reported that the concrete cribs performed better than the conventional wooden cribs in terms of supporting the roof and limiting convergence; however, several of the miners complained of handling problems with the concrete cribs because of the sharp reinforcing wires. In the two-entry section, a typical Sunnyside yield pillar, nominally 25 ft wide, was used between the openings.

Among the miners interviewed, several who assisted in developing 17th Left expressed concerns about the single entry. The primary objection was the lack of an additional escapeway, as they considered the divided opening a single passage. The second most common complaint was the intermittent lack of adequate ventilation caused by severe leakage through the separating barrier. As convergence occurred in the entry, the steel paneling would buckle and tear, allowing substantial short-circuiting of air to the return side. Excessive amounts of labor were required to continuously patch the holes in the barrier.

In addition to the escapeway and ventilation problems, it was reported that lack of work space and water buildup made development more difficult than in a multiple-entry system. Significant time was consumed in moving equipment to and from the face in the cramped quarters of the single opening, and machinery-related accidents were always a major concern. Compounding the space-related problems was the fact that the development crews could never get out of the water because there was no downhill entry for it to run into.

While the development of the 17th Left entry was troublesome, conditions upon retreat of the panel seemed to improve. Although water accumulations continued to be a problem, the longwall crew reported excellent mining conditions in the single-entry sections, with no coal bounce activity or floor heave noted. In the single-entry sections, no forward stress abutment effects were noticed ahead of the face; however, convergence behind the face in the future tailgate was severe and excessive amounts of cribbing had to be installed to keep the entry open. When the longwall reached the two-entry section, the face width was not reduced. Instead, the shearer was run across the uphill entry to recover the row of chain pillars.

Development of the 18th Left single-entry gate progressed much the same as 17th Left. The depth of mining cover in 18th Left was similar to that found above the 17th Left panel. The entry width was reduced to 21 ft and, rather than cribs, a single row of large timbers was used to support the opening and provide a separation barrier. Once again, sheet metal panels were nailed to the timbers in an effort to reduce ventilation losses and provide fire protection. The rate of advance improved dramatically when shuttle cars were replaced by an extensible belt conveyor, which simplified the removal of mined coal. As in the case of 17th Left, negative comments centered around the lack of an additional escapeway, inadequate ventilation, minimal workspace, and water accumulation problems.

The retreat of the 18th Left panel witnessed improved ground control, but suffered operational problems. Again, no bounce or heave activity was reported and ground conditions along the face were relatively good. Maintenance of the 17th Left tailgate, however, proved to be the most challenging aspect of the retreat process. Heavy cribbing

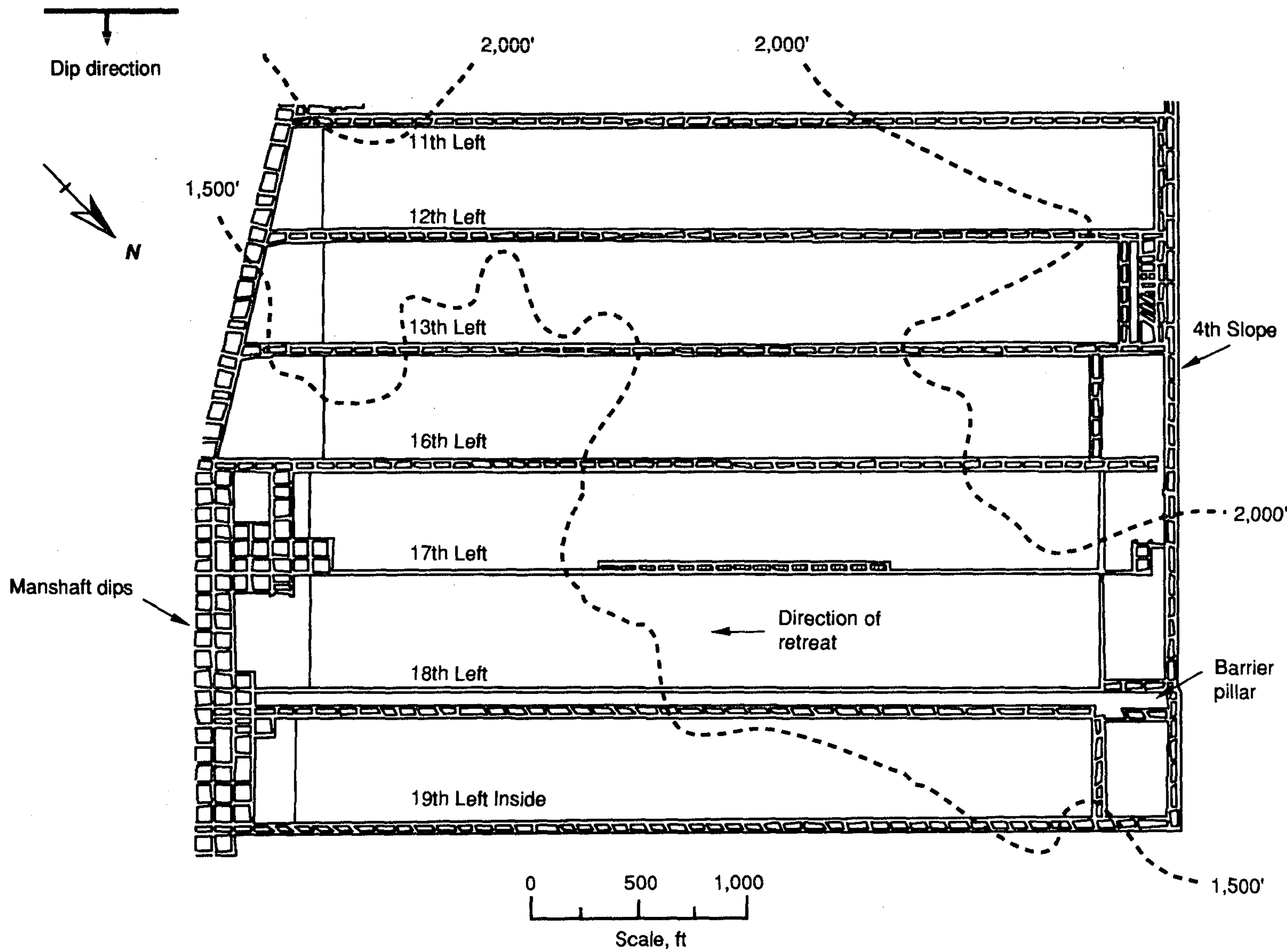

Figure 12.—Detailed map of area 6.

was required to maintain the travelability of the tailgate, especially the first 100 ft outby the tailgate corner. Removal of dust and methane from the face was poor because of ventilation restrictions caused by the tailgate cribbing. Adding to the problem, convergence in the headgate caused the separating barrier to leak, thereby further reducing the amount of air available on the longwall. Eventually, however, the 18th Left panel was completed, and no fatalities and few injuries were incurred. Several years later, a sixth panel (19th Left Inside), separated from 18th Left by a barrier pillar, was successfully mined, thus finalizing operations in this block of coal.

Area 7

Area 7 (fig. 13) contains another example of a longwall tailgate developed on the retreat. Longwall mining in area 7 began in September 1978, and continued until October 1981, when the longwall equipment was abandoned and the panel permanently sealed. The depth of cover was very uniform along the length of the panel, deviating little from 2,000 ft. In this area, the Upper and Lower Sunnyside Seams were difficult to distinguish from one another; however, mine maps indicate the longwall panel was located in the 6-ft-thick lower seam. Several of the interviewed mine personnel reported that seam rolling was exceptionally pronounced along the panel length. The floor was composed of a 2- to 4-ft-thick layer of very soft material with a 2- to 4-ft-thick coal seam immediately below this parting. The immediate roof was described as being average to poor. The same fault system that complicated mining in area 2 crossed the longwall panel on the north end at a 45° angle. The displacement of the fault in the 10th Left headgate was approximately 4 ft. Water and methane concentrations were reported to be average and were of little consequence to daily operations.

As in areas 4 and 5, the tailgate was cut by the shearer during the retreat of the panel. Immediately after the opening was created, the roof was bolted, wooden cribs were installed, and yielding steel arches were set to hold the heavy ground. Despite the substantial supplemental support, the tailgate was nearly impossible to keep open because of a severe squeeze condition. Apparently, excessive load was overriding the 150-ft-wide barrier pillar separating area 7 from area 6, making the tailgate difficult to maintain. As a result of the load transfer from the downdip works, severe bumps along the face and in the tailgate along the barrier pillar began soon after longwall mining was initiated. Several of the bumps were apparently recorded as earthquake-scale events at the University of Utah seismograph center in Salt Lake City. Many lost-time accidents from bumps or bump-related roof falls were incurred; however, no fatalities were suffered.

Several other factors contributed significantly to the poor mining conditions encountered in this block. The soft rock parting in the floor failed readily under the weight of the longwall chocks, allowing the coal beneath it to heave into the face. In addition, the face conveyor was underpowered, and difficulties in getting the coal up the slope and off the face were common. Excessive spillage from the conveyor was common, and on many occasions the chocks would become "metal-bound" between the roof and floor. The time consumed supporting the tailgate, shoveling the face, and freeing the chocks only compounded the problems by allowing further floor heave to occur.

About a third of the way through mining of the panel, the face was idled and a two-entry gate was driven from the 4th Slope southeast to the existing tailgate to establish a more conventional escapeway and ventilation arrangement. This was done to eliminate the time and labor needed to support the heavy ground in the tailgate, thereby expediting extraction of the panel. Longwall mining resumed once the two-entry tailgate was connected to the face. Shortly thereafter, a devastating bump took place in the tailgate near the face corner. Upon inspection by mine personnel, it was discovered that approximately 1,500 ft of the single-entry tailgate behind the face had been destroyed. Several of those interviewed reported that the roof above the barrier pillar had rebounded to the point that a caplamp could be shone downdip across the barrier into airspace as far as the eye could see. Shortly after this event, the longwall panel, complete with all the face equipment, was abandoned, and the area was permanently sealed.

Area 8

Area 8 (fig. 14) includes three longwall panels that were mined updip rather than along the strike in the usual Sunnyside convention. Development of the upper room-and-pillar sections, 13th and 14th Right, began in the early 1960's. Retreat of the room-and-pillar sections began in late 1967 and continued until late 1969. Immediately after completion of the room-and-pillar sections, development of the first of three uphill-oriented longwall panels was initiated. Longwall mining in these panels began in early 1971 and continued until December 1974. The final longwall panel, located between the room-and-pillar sections and the uphill-oriented panels, was mined from mid-1976 until mid-1977.

Cover depth ranged from just under 1,000 ft at the upper room-and-pillar sections to over 2,000 ft along the farthest downdip portions of the uphill-oriented longwall panels. All of the mining in area 8 took place in the Lower Sunnyside Seam, and no old workings were present above the area. High coal (thickness unspecified) was

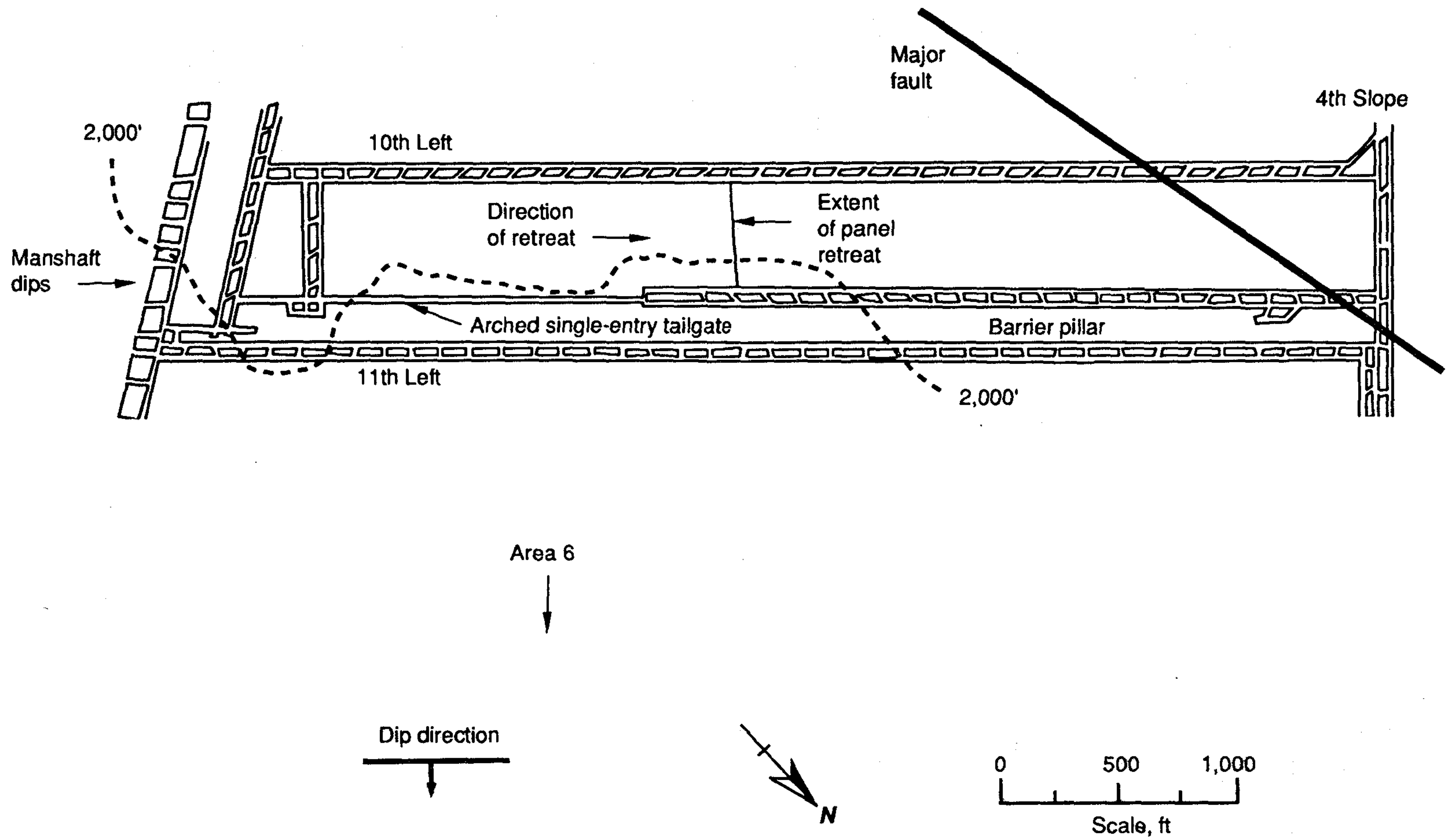

Figure 13.—Detailed map of area 7.

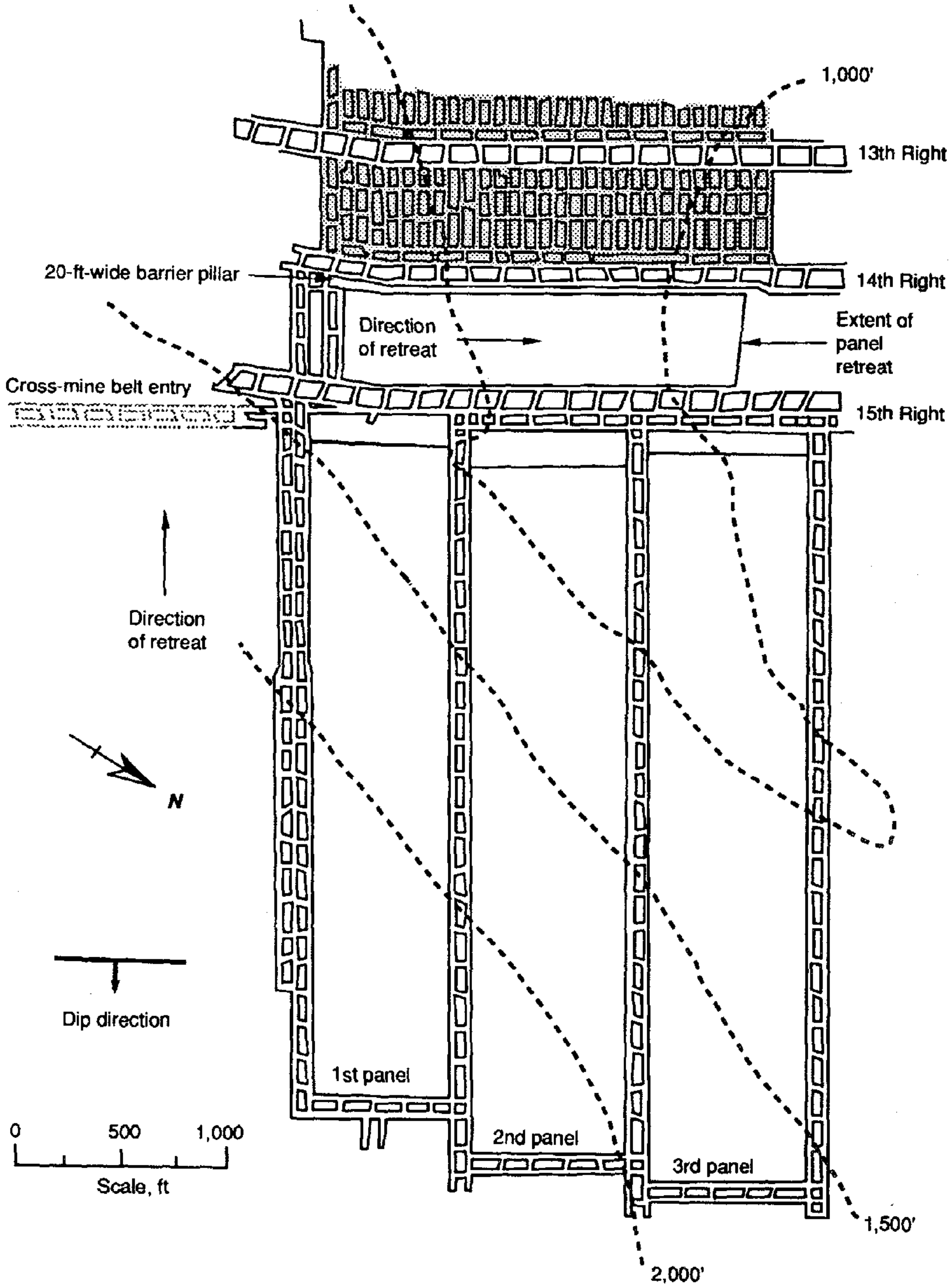

Figure 14.—Detailed map of area 8.

found in the upper room-and-pillar sections; however, the coal seam pinched down to 4 to 5 ft in the start-room areas at the bottom of the uphill longwall panels. Water was not a problem in the room-and-pillar sections, the first uphill longwall panel, or the last "conventional" longwall panel (mined along the strike). In the second and third uphill panels, accumulated water caused problems for the first few weeks until mining progressed sufficiently uphill. Methane was not a problem in the room-and-pillar sections; however, high natural concentrations of methane in the uphill longwalls, coupled with the updip panel orientation, resulted in methane problems during retreat. The last longwall panel, 15th Right, oriented along the strike, also had methane problems, but this was attributed to poor ventilation. The immediate roof in area 8 was described as being average. No direct comments as to the quality of the floor were available.

Discussion of the mining of the room-and-pillar sections was limited because of the interest in the uphill-oriented longwall panels. Mining conditions in the room-and-pillar sections were reported to be very good, with few incidences of ground control problems.

The first gate road for the uphill longwall panels was driven using the three-entry system because development began right after passage of the 1969 Health and Safety Act, which required the belt entry be on a separate split of air. In fact, because the mine engineers were fearful of the ground control problems associated with three-entry tailgates subjected to second panel loads, three-entry gates were developed in several areas in the Nos. 1 and 3 Mines where the entry systems would only be used for first panel mining. Following this plan, use of three-entry systems for tailgates would be avoided provided a variance for two-entry use was approved.

After approval of a variance, a two-entry headgate for the first uphill panel was driven, and longwall mining was initiated. As mentioned above, water was not a problem on the first panel; however, methane problems began soon after panel startup. High natural concentrations of methane, coupled with the uphill orientation of the panels; resulted in significant gas problems. Ventilation would have been more than adequate because of the tight cave achieved on these panels; however, because of the low density of methane relative to air, gas released from the downhill gob exaggerated the high natural concentrations. This problem worsened as retreat mining progressed uphill and as each successive panel was extracted because of the ever-increasing amount of gob area. In an attempt to alleviate the problem, a 7-ft-diam return air shaft was bored from the surface to the 15th Right submains. As a result, air flow was substantially improved and the large volume of gas emitted from the downhill gob areas was successfully ventilated.

On first panel mining, the three-entry tailgate suffered severe floor heave and rib sloughage within approximately 100 ft of the face. A great deal of labor was required to shoot the floor and hand shovel the debris in order to keep the tailgate travelable. In the two-entry headgate, intermittent roof instabilities were encountered, but were apparently successfully dealt with. Also, coal haulage from the section was slow because of the uphill travel direction of the loaded belt conveyor. Bumps occurred regularly along the face and in the tailgate, but were minor in terms of magnitude.

On the second panel, longwall supports manufactured by the Wilde Co. were utilized. The Wilde supports suffered from extensive hydraulic problems and regularly failed while in place. Most of the second and third uphill panels were mined using hydraulic "duke-type" supports to supplement the Wilde supports. Floor heave and small roof falls were common along the face because of the inability of the Wilde supports to hold the abutment pressures.

Despite the various equipment problems, mining of the second and third panels was completed and no fatalities were reported. Several of the personnel interviewed indicated that overall, the two-entry gate roads performed better than the three-entry gate road even though the three-entry gate road was not subjected to second panel loads. Apparently, the two-entry systems suffered significantly less floor heave and rib sloughage, and required less artificial support to maintain. Advantages of mining updip included leaving the water downhill; achieving a seemingly tighter cave than normal, which helped ventilation; improved chock stability; and improved shearer operation from cutting along the strike. Disadvantages included water in the startup room of successive panels, excessive uphill methane migration requiring more efficient ventilation, and increased conveyor loads.

The final longwall panel in area 8, 15th Right, was retreated along the strike in the conventional Sunnyside orientation. It was generally felt that the extraction of this panel was a mistake because no barrier pillar was left on the downhill side of the panel. This action subjected the 15th Right cross-mine belt entry, a life-of-mine opening, to excessive abutment pressures. In addition, the previously mined uphill room-and-pillar sections and longwall activity below 15th Right resulted in heavy panel loading prior to longwall mining.

Ground conditions during the mining of this panel were very poor, especially at the tailgate end of the face. Roof conditions were described as being fair; however, the heavily loaded tailgate suffered severe bumping on a regular basis. A 20-ft-wide barrier pillar, intended to separate the panel from the old 14th Right room-and-pillar works immediately uphill, was thought responsible for much of the bump activity.

The 15th Right panel provided the fourth example within the interview areas where a tailgate was driven with the shearer during retreat. In addition, the tailgate for this panel was unique because it consisted of a sectioned steel pipe set in a depression in the floor between two cribs. Reports as to the diameter of the pipe varied from 3 to 4 ft; however, everyone confirmed that the pipe was bolted together from four quarter-circle segments about 2 ft long. As mining progressed, the area surrounding the pipe caved and heaved, and the pipe began to collapse. Short sections of timber, and later steel rail, were used inside the pipe to keep it open. Eventually the restrictions became too severe for a man to crawl through, and extraction of the panel was discontinued. Ventilation of dust and methane was a significant problem while the pipe was in use because of the restricted area available for airflow.

The final unique feature of this panel was that four different brands of shields and chocks were used to support the face. Because of the high coal, most of the supports were operated in the fully extended mode. As a result, the extraction height along the face was irregular.

Area 9

Area 9 (fig. 15) featured a tapered two-entry system that served as the tailgate for the 16th Right panel. It was hoped that the interviews would provide information about the relative performance of the various pillar sizes along the length of these entries as the adjacent longwall panel was extracted. Unfortunately, few of the personnel interviewed worked in this area; those who did could not remember many details, and subsequently, little valuable information was collected.

The tapered gate road was developed in late 1981. Longwall mining in the 16th Right panel began in 1982 and was completed in 1983. Information on the geologic and mining conditions was very limited. Cover depth ranged from just under 1,500 ft to just over 2,000 ft along the panel length. All mining took place in the Upper Sunnyside Seam, and no old workings were present to cause seam interaction problems. No details were provided regarding water, methane, seam thickness, extraction height, or roof and floor conditions.

The 16th Right entries were developed prior to driving the tapered tailgate; therefore, the lower entry of the tapered tailgate section was oriented along the strike (parallel to 16th Right) to maintain a constant face width for the 16th Right panel. The upper entry of the tapered tailgate section was not developed parallel to the lower entry, which resulted in smaller pillar widths as development progressed inby. This was done to allow the tailgate to be driven as far inby as possible without breaking into the abandoned 15th Right headgate and creating ventilation and stability problems. The crosscuts in the newly developed tailgate were driven off the upper entry at approximately 45° to eliminate sharp corners from the face into the tailgate, thus providing the most efficient ventilation pathway possible.

As retreat mining progressed toward the submains, the size of the pillars in the tailgate increased. It was reported that bump activity and severity increased with increasing pillar size. Several of those interviewed described the upper entry as being difficult to keep open; however, no specifics as to the cause of the stability problems were available.

Area 10

Area 10 (fig. 16) includes adjacent two- and three-entry gate road systems under deep cover. In addition, although the three-entry system, 15th Right, was only used for first panel mining, the supporting chain pillars were approximately 25 to 35 ft wide, making this set of gates especially interesting. Since the yield pillar design currently being used in the two-entry systems in the No. 1 Mine is 30 ft in width, it was felt that information on 15th Right would provide insight into the potential performance of three-entry yield pillar designs under Sunnyside conditions.

Development of the longwall panel entry systems for the 16th, 17th, and 18th Right panels began in early 1971 and continued intermittently into the early 1980's. As in the case of the three-entry system in area 8, the 15th Right gates were developed in the interim between enactment of the 1969 Health and Safety Act and the approval of a variance to mine on two entries in the No. 3 Mine. Longwall mining was initiated in 1981 and continued until early 1987.

Cover depth ranged from just under 1,500 to 2,500 ft, and all longwall extraction took place in the 5- to 6-ft Upper Sunnyside Seam. No old workings were present in the area to cause seam interaction. Water concentrations were described as average; however, water seepage from the uphill gobs, and subsequent increases in accumulation in the lower panels, was thought to weaken the already soft floor. The immediate roof was described as being good in most areas, with zones of weakness encountered on occasion. The primary roof material was said to be limestone, and fossils of seashells appeared regularly. Methane concentrations were average to high. Production delays caused by high gas levels occurred frequently as a result of the natural concentrations of methane and poor ventilation due to the long ventilation distance.

The first panel mined was 16th Right, which utilized the 15th Right three-entry tailgate (one row of 25- by 85-ft

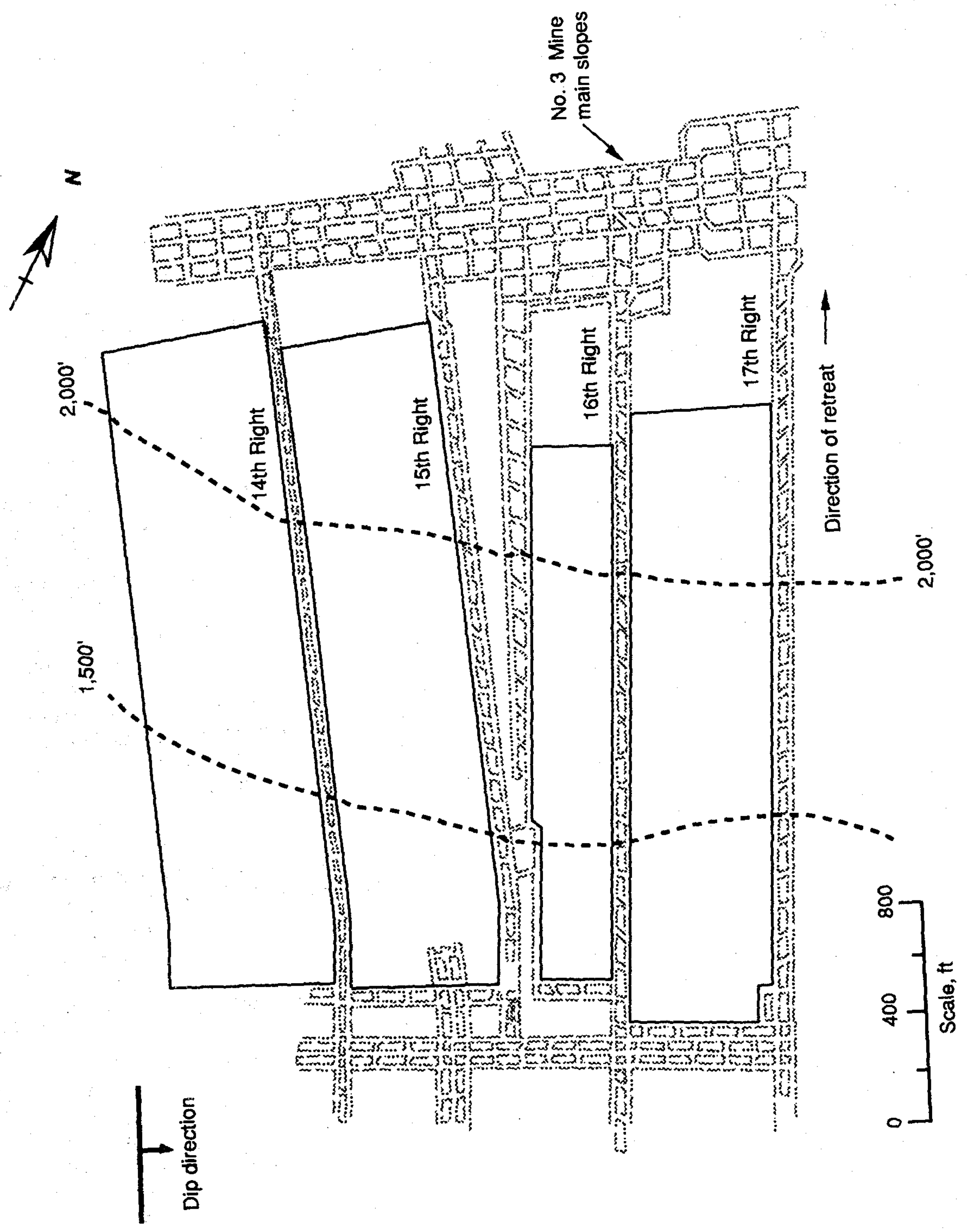

Figure 15.—Detailed map of area 9.

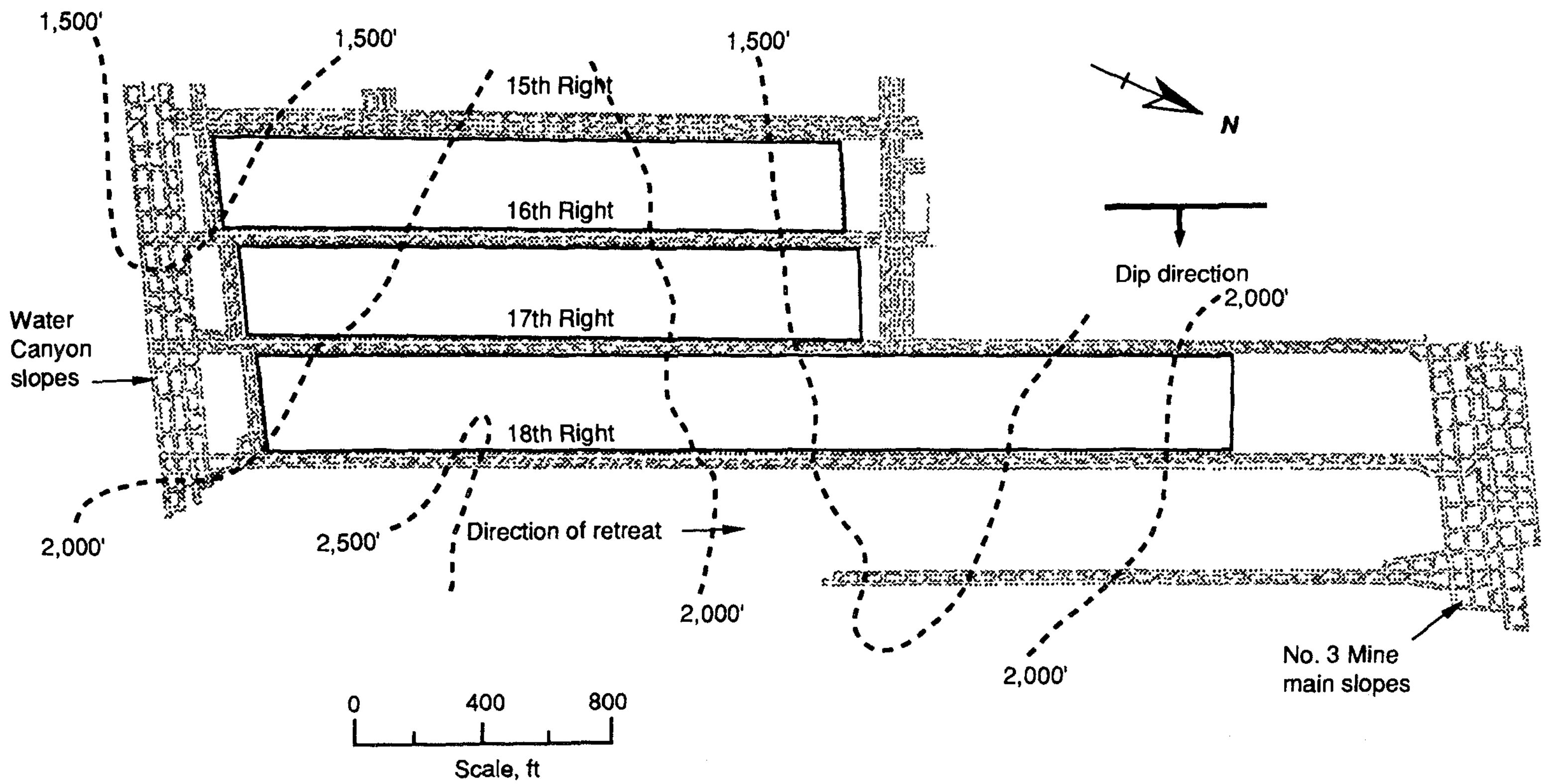

Figure 16.—Detailed map of area 10.

pillars, one row of 35- by 85-ft pillars) and the 16th Right two-entry headgate (one row of 30- by 85-ft pillars). The depth of mining cover over the 16th Right panel varied between 1,500 and 2,000 ft. Even on first panel mining, the three-entry tailgate was nearly impossible to maintain as an escapeway. Large numbers of wooden cribs were installed to support the roof, and one person interviewed likened the area to a "forest." As retreat of the panel progressed, crib rolling due to floor heave was severe, often completely blocking the escapeway. This required extensive rehabilitation to continue mining safely. Following the interviews, it was learned that the panel-side row of chain pillars in 15th Right had apparently been recovered with the longwall as the panel was retreated. This fact was not made available during the interviews; therefore, no further information was collected pertaining to this practice.

On the other side of the panel in the two-entry headgate, the floor heaved ahead of the face because of the soft floor material and water seepage. Headgate heave problems were reportedly not as severe as those in the tailgate. Bumps were common throughout the mining of the 16th Right panel, especially in the three-entry tailgate.

During mining of the 17th Right panel, conditions in the two-entry tailgate, 16th Right, were said to be improved over the three-entry configuration of the previous panel, especially in terms of roof fall activity. Rather than tailgate bumps, however, 17th Right was plagued with face bumps, and one miner reported that he felt the worst bumps in the area were encountered during the mining of this panel. Also, roof falls ahead of the longwall supports were common because of the many zones of weakness. To further compound the difficult conditions, floor heave along the face occurred regularly because of the soft floor material. As mining progressed to the 18th Right panel (30- by 85-ft headgate pillars), ventilation of methane became a significant problem because of the great distance from an available fresh air supply. No fatalities were suffered during longwall mining of the entire area; however, lost-time injuries from the bump activity were common, and many of those interviewed concurred that this was one of the toughest single-seam blocks to be extracted in the No. 3 Mine.

Several of the miners interviewed did not work on the longwall crews but, rather, were responsible for developing the "Water Canyon" slopes to the southeast of the area. The ground in this area was said to be highly loaded, and extremely hard bumps were reported to have occurred. Bumping was so severe driving the slopes downhill that heavy machinery was often displaced or overturned. Excessive rib sloughage was also a problem, and violent bursts of coal from the ribs caused numerous injuries. Accompanying the bumps was floor heave that required extensive cleanup efforts to maintain a travelable entry height. Ground conditions worsened as the miners attempted to drive past the 18th Right headgate, and it was not long before mine management decided to discontinue further attempts to develop downhill. The depth of mining cover at which development was stopped was approximately 2,200 ft.

Area 11

Area 11 (fig. 17) contains a number of relatively recent longwall panels, and the only currently active longwall panel on the Sunnyside properties is located within the area's boundary. Development of the room-and-pillar panels in the upper reaches of the area began in late 1957, and retreat mining of these blocks continued until mid-1969. Longwall mining was initiated in the area in November 1979, and has continued until the present. Depth of mining cover ranges from just under 1,000 ft to over 2,500 ft, and all of the mining in the area is in the 6- to 12-ft-thick Lower Sunnyside Seam. No old workings overlie the lower seam in this area.

Water ingress into area 11 was reported to be average in terms of new water sources exposed by mining; however, as with other cases at Sunnyside where the general extraction progressed downdip, water percolation from the uphill gobs, and subsequent accumulation in the tailgates, was reported to create travelway maintenance problems. Typical of downslope panels at Sunnyside, methane concentrations were said to be high. Several miners reported that methane concentrations appeared to increase to a new average level downslope of the 20th Left gate roads. Interestingly, highly volatile hydrocarbons resembling light crude oil were encountered oozing from the immediate roof in 20th, 21st, and 22nd Left in distinct zones roughly adjacent to one another across the longwall panels. While mining through these zones, extra precautions such as additional atmospheric composition and ventilation performance checks were taken because of the increased fire hazard created by the presence of the hydrocarbons.

The immediate roof in the upper reaches of the area was said to be similar to that found in area 2. Very poor roof conditions were encountered in panels 11th Left through 16th Left. Below 16th Left, average roof conditions improved; however, significant areas of poor roof were still found on an intermittent basis. The immediate floor of the area was described as average, with zones of soft, easily damaged material encountered on occasion. The only gate road system identified as having consistently soft floor conditions was 22nd Left.

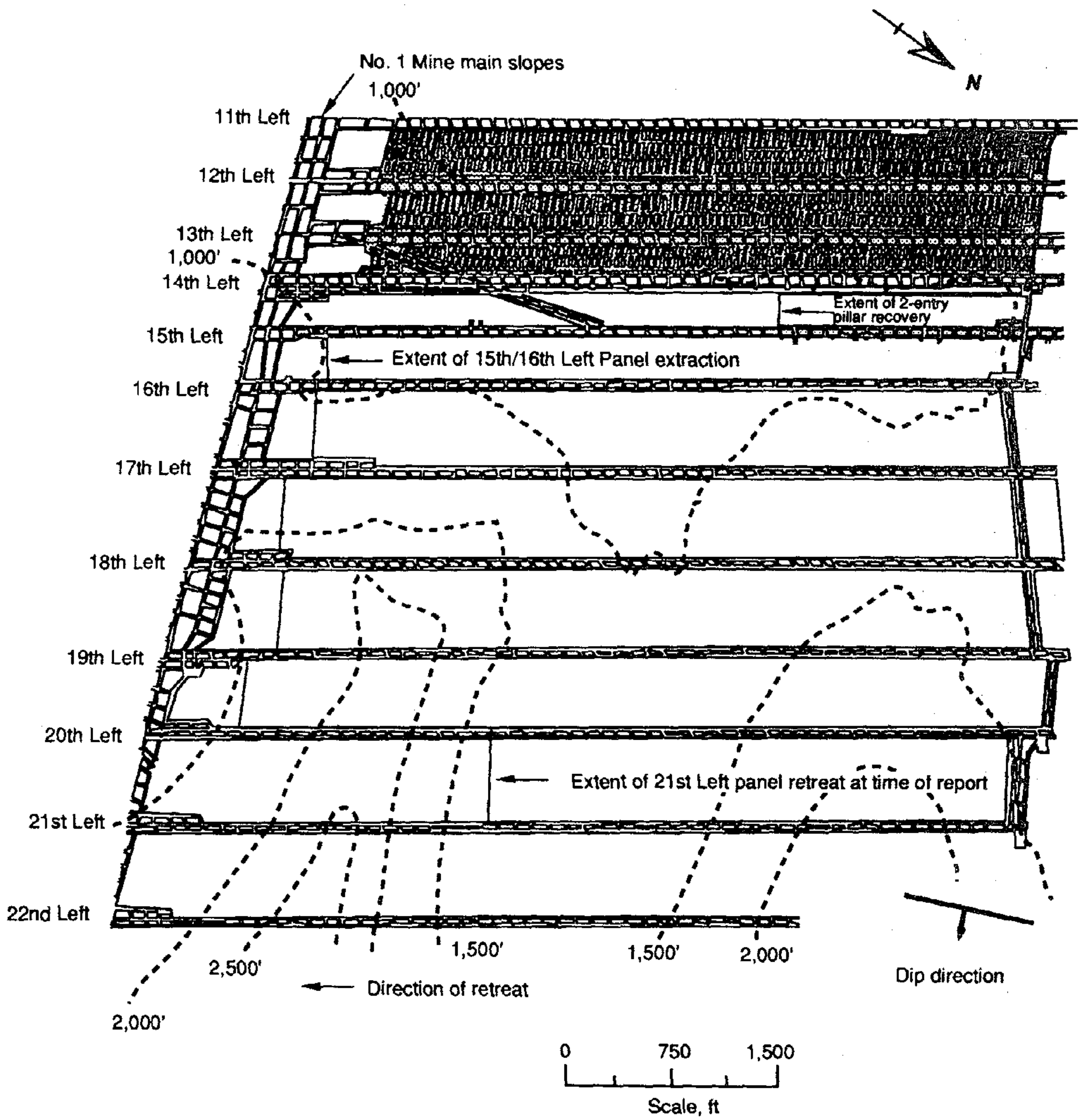

Figure 17.—Detailed map of area 11.

All of the room-and-pillar panels in area 11 (11th, 12th, 13th, and 14th Left) were developed using the two-entry system (55- by 85-ft conventional pillars). As with areas 1 and 2, rooms were not developed on the advance in order to minimize potential stability problems. Rather, a maximum of three rooms were developed on retreat between the cave line and the remaining solid panel, uphill from the panel entries. For these four panels, a third entry, oriented parallel to the two-entry panel access, was developed during retreat operations back toward the main slopes approximately 200 to 300 ft ahead of the retreat line to provide access for haulage trains. No information could be acquired regarding the effect this short section of additional entry had on overall ground conditions; however, it was generally reported that ground conditions worsened, especially in terms of roof falls and bumps, as more ground was opened up.

No significant bump events were experienced during initial development of the panel entries. On retreat of the panels, however, severe bumps similar to those encountered in area 2 were a regular occurrence. These events, coupled with the very poor existing roof conditions, made extraction of these panels very hazardous. Lost-time accidents occurred on a regular basis once retreat was initiated, and two miners were fatally injured in mid-1964 in a bump-induced roof fall that occurred during retreat of 11th Left. In 1965, one miner was fatally injured during retreat operations by a roof fall in a crosscut of the newly developed three-entry section of 12th Left.

The 15th/16th Left panel, the first section in area 11 to be mined using the longwall method, includes a tailgate that was developed along its entire length as a single entry. Originally blocked out as a narrow room-and-pillar panel utilizing 15th Left as the primary panel access, the 15th/16th Left longwall was created by driving a startup room up the slope from 16th Left toward 14th Left. The single-entry tailgate for the 15th/16th Left panel was created by continuous miner from the 14th Left dogleg to the longwall startup room approximately 3,600 ft inby. A 40-ft-wide barrier pillar was left between the single-entry tailgate and the 14th Left bottom entry because of the previous full extraction of the 14th Left panel.

Perhaps the most unique aspect of the 15th/16th Left panel was that the 15th Left entries ran right down the center of the panel itself. Heavy cribbing was installed in the entries and crosscuts of 15th Left in advance of the face to allow the longwall to mine into these open areas and recover the chain pillars. Unfortunately, this system did not perform as well as expected, and the face width was decreased after one-third of the panel was mined. Specific problems included heavy bumping in the 15th Left chain pillars ahead of the face; excessive roof falls in the 15th Left crosscuts, especially when the face broke through the chain pillars; and high artificial support costs related to the extensive cribbing required to mine through the open areas.

Upon completing the 15th/16th Left panel, the mine returned to using a more conventional 500- to 600-ft-wide face for the remaining blocks in area 11. A new shield-type longwall face was purchased for the 17th Left panel, and, in January of 1982, the 17th Left longwall crew set a world record for coal production in a 24-hour period. Besides the new equipment, improved immediate roof conditions contributed substantially to the success of 17th Left.

Mining of the 18th Left panel progressed smoothly; however, moderate bumps were experienced on occasion on the face, usually within 100 ft of the tailgate corner, and in the 17th Left tailgate chain pillars, usually within the first 200 ft ahead of the face. Mining cover depth along the panel varied from less than 1,000 ft to over 1,500 ft. Although the average immediate roof of 19th Left was regarded as poor, chain pillar width was decreased from 40 ft in 18th Left to 30 ft in 19th Left to mitigate the severity and frequency of tailgate pillar bumps. Depth of mining cover along 19th Left ranged from 1,500 ft to over 2,000 ft. Apparently, the 30-ft-wide pillars performed as expected, as pillar bumps were virtually eliminated when 19th Left became the tailgate for the 20th Left panel; however, face bumps close to the tailgate corner continued to occur.

Approximately halfway through the mining of the 19th Left panel, a large-scale methane ignition occurred in the headgate on a weekend downshift as a result of an unplanned interruption in ventilation. A damaged electrical cable in 19th Left ignited the methane that had collected over the weekend, and an explosion ensued. Although thrown a considerable distance down the headgate by the resulting air blast, the section fireboss, the only person in the area at the time of the ignition, was otherwise uninjured.

The 20th Left gate roads, which also utilized a 30-ft-wide yield pillar design, were developed concurrent with the mining of the 19th Left panel. Immediate roof conditions in 20th Left varied from poor in general to extremely poor in several sections along the gates. To mitigate roof falls in the very poor sections, the development crews began to leave approximately 1 to 2 ft of top coal to help support the roof. No one could recall the location along the gate road where this procedure was started; however, the miners emphasized that the top coal had to be roof bolted within several hours of exposure, especially in the presence of water, to prevent it from falling. Once bolted, the top coal was said to significantly improve the stability of the roof in comparison with mining the seam rock-to-rock. Other interesting aspects of 20th Left included an abrupt decrease of 1 to 2 ft in seam thickness near crosscut 39, the presence of crude-oil-like hydrocarbons oozing from the roof at several locations along the gate, and the introduction of remote monitoring systems for mining environment and microseismic activity monitoring.

Mining of the 21st Left panel was approximately half completed and development of the 22nd Left gate roads about two-thirds completed at the time of the interviews. Once again, the 30-ft-wide yield pillar design used in 19th and 20th Left was utilized for both the 21st and 22nd Left gates. The immediate roof of both 21st and 22nd Left was described as being very similar to that of 20th Left; however, the coal thickness in 22nd Left decreases to about 6 ft. Approximately 2 ft of roof rock is being removed with the coal to provide adequate clearance for unrestricted equipment travel because of the thin seam conditions in the 22nd Left gate. While this action exposes more competent roof strata, thereby lessening roof fall potential, a new problem related to roof stability at the rib is created by the rock brow formed at the pillar edges. As the pillar rib yields and sloughing occurs, a cantilevering rock overhang is formed along the ribs. With exposure to water and air over time, this overhang becomes unstable, resulting in increased hazards for those traveling too close to the rib.

Mining of the 21st Left panel has proceeded relatively smoothly in regard to bump activity. Bumps have reportedly been limited to the longwall face area within approximately 100 ft of the tailgate corner, which is typical of the most quiet panels at Sunnyside. Members of the face crews and the section firebosses have observed that the tailgate roof is exceptionally stable. Also, noticeable tailgate crib loading appears to occur when the face is approximately 75 ft away. In general, from a ground control standpoint, the extraction of 21st Left has been relatively uneventful thus far.

Perhaps the most important gate road design change initiated during the mining of area 11 was the reduction of the yield pillar width to 30 ft. The miners stated that there were no noticeable differences in performance of the 40-ft-wide design and the 30-ft-wide design when the pillars were subjected to first panel loads. The difference in performance became quite clear, however, when these two designs were subjected to full tailgate loads. The 40-ft-wide pillars seemed to bump more frequently and with greater force, while the 30-ft-wide pillars rarely bumped at all. In addition, tailgate roof stability throughout the mining cycle seemed to improve when the 30-ft-wide design was used.

Area 12

Area 12 (fig. 18) was included in the interview discussions because of its close proximity to the B-Canyon coal lease. This area consists of the "Motor Road Extension," a life-of-mine set of openings along the strike of the seam, and the 4th Slope, a two-entry development driven downdip for haulage access to areas 6 and 7. Development of the Motor Road Extension began in late 1956 and continued until mid-1960, and development of the 4th Slope portion of area 12 began in early 1976 and continued until late 1977. Mining cover depth ranged from under 500 ft along the Motor Road to just over 2,000 ft down the 4th Slope.

The Motor Road Extension was developed in both the Upper and Lower Sunnyside Seams depending on the roof quality and coal thickness encountered; however, no multiple-seam or "stacked" development occurred. The 4th Slope entries included in area 12 were driven in the Upper Sunnyside Seam exclusively. In area 12, the lower seam ranged in thickness from 6 to 12 ft, and the upper seam ranged in thickness from 3 to 8 ft. Water concentrations were described as being average, and methane release was average to high (in a few isolated locations). The sulfur content of the coal was high from time to time, and sulfur-related vision problems were reported by members of the development crews.

The Motor Road Extension was developed to provide a permanent haulage route from the 4th Slope and as an exploratory drivage to determine the feasibility of full-scale mining in the B-Canyon lease. The Motor Road was originally a three-entry drivage, but a fourth entry was later added on the uphill side to provide an additional escapeway; however, this practice was discontinued at the "S-curve" feature because the immediate roofs of both the upper and lower seams could not support the four-entry span, which became nearly impossible to hold open.

The first one-third of the Motor Road Extension was driven in the Lower Sunnyside Seam using a roadheader-type mining machine. To ensure long-term stability of the Motor Road, steel arches were set on approximately 5-ft centers soon after development because the immediate roof was extremely poor and quickly deteriorated when exposed to moisture and air. Seeking better roof conditions, miners drove the Motor Road entries up through an 8-ft-thick rock parting separating the upper and lower seams. Immediate roof conditions improved somewhat in the Upper Sunnyside Seam, so development of the Motor Road continued. Use of the roadheader was discontinued at this time in favor of a continuous miner because of the poor rates of advance suffered with the roadheader.

Development of the Motor Road in the upper seam continued until the seam pinched out at a fault located at the S-curve. The Motor Road entries were once again driven through the rock parting back into the lower seam to continue the push toward B-Canyon. Development of the Motor Road was continued to the boundary of the

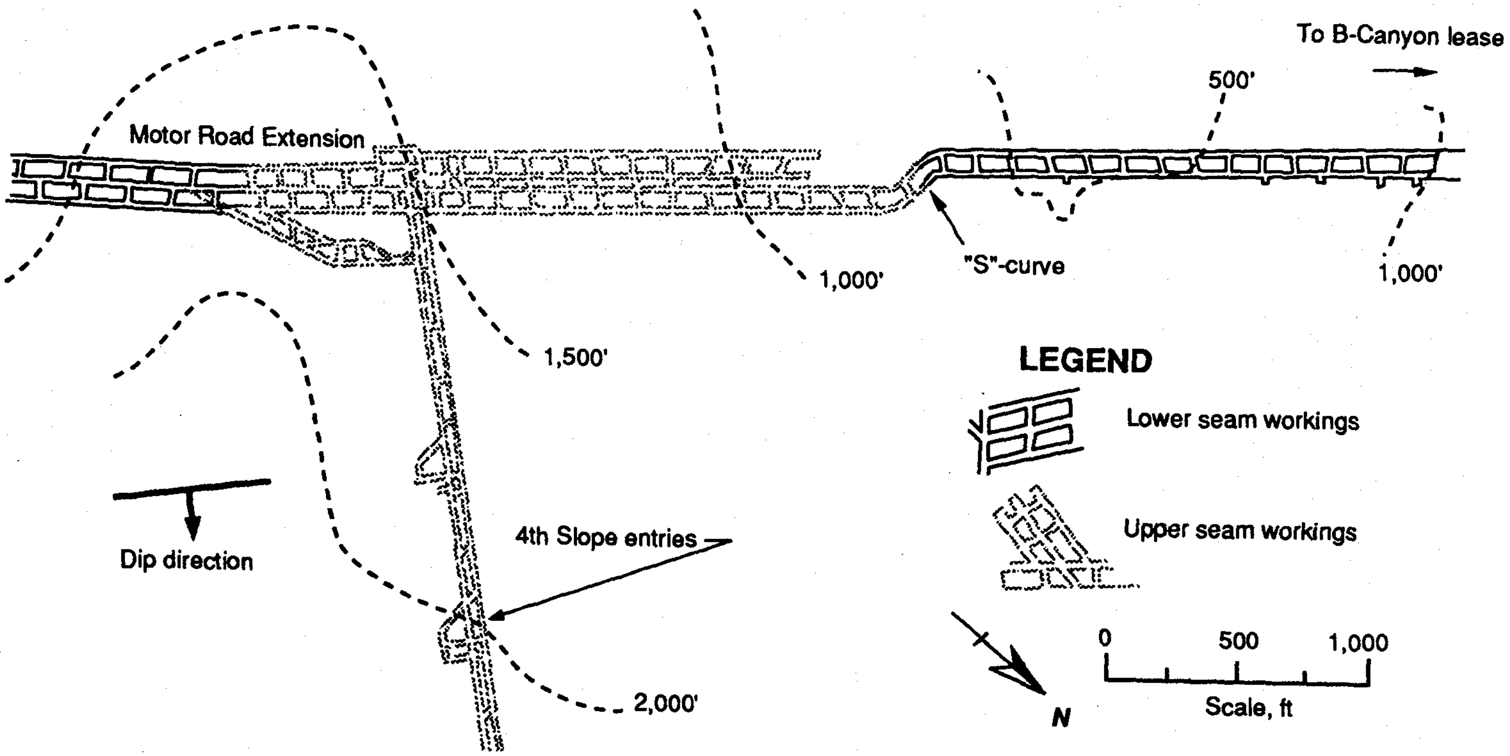

Figure 18.—Detailed map of area 12.

B-Canyon lease. The miners reported that the immediate roof of the lower seam slowly improved from very poor at the S-curve to good near B-Canyon. Also, the thickness of the lower seam remained uniform at approximately 8 ft, and the coal durability, strength, and quality seemed to improve as B-Canyon was approached.

The 4th Slope was developed on a two-entry system downdip from the Motor Road Extension to provide for access and ventilation to areas 6 and 7. Development was confined to the Upper Sunnyside Seam to take advantage of the improved immediate roof conditions found during drivage of the Motor Road Extension; however, roof conditions began to deteriorate soon after making the turn downhill, and methane levels increased substantially as well. Despite the poor roof conditions, development continued downhill relatively smoothly until a major north-trending fault was encountered below the 4th Slope entries shown in figure 12. This was the same fault system blamed for the ground stability problems experienced in area 2. As the fault zone was approached, bumping began to take place on the working face of the two-entry drivage. The frequency and severity of the bumps increased as mining advanced through the fault zone; however, no bump-related fatalities and few lost-time injuries were reported. When mining progressed through the fault zone, the bumping ceased, and problems were once again limited to supporting the poor roof and providing adequate ventilation for the high methane levels.

CONCLUSIONS

In reconstructing the 30-year history of longwall gate road design practices and performance at the Sunnyside Mines, USBM personnel discovered that published information describing the *specific in-mine performance* of various gate road configurations, pillar sizes, panel orientations, etc. was very limited. Personal interviews of 30 long time Sunnyside employees, representing nearly 700 years of underground mining experience, were conducted to provide information from which a data base of gate road performance information could be established. This report provides an accurate summary of the over 1,000 pages of field notes taken during the interview process. For convenience, the information contained in the body of this report is presented in highly condensed form in table 1.

To ensure complete representation of mining across the property, 12 specific areas in the Nos. 1, 2, and 3 Mines were chosen for discussion. Many details were learned during the interviews of the events and conditions experienced while mining the specific coal panels located in these areas. Often, broader topics, such as general mining practices, safety, geology, or overall mining conditions, were addressed during the discussions. The general opinions of the interviewed personnel regarding mining conditions and practices at the Sunnyside Mines are as follows; these conclusions in no way represent the position of the USBM relative to the presented material.

- The geologic conditions at Sunnyside have *always* played a *major* role in defining and narrowing the scope of possible panel layouts, gate road configurations, and pillar sizes that promote stable ground conditions.
- The Sunnyside miners have learned that because of the geologic conditions on the property, cantilevering roof near the working face results in *severe* ground instabilities such as bumps and related roof falls. In general, the severity of bumps is proportional to the amount of hanging roof. This generalization is applicable to both longwall and retreat room-and-pillar sections.
- Large coal pillars can be safely *developed* under deep cover at Sunnyside; however, substantial evidence exists to suggest large, stiff pillar designs become highly bump-prone when subjected to *full* Sunnyside longwall abutment loads.
- When a yielding-pillar-based gate road system is employed, limiting the *overall width* of the gate road is considered very important to ensuring roof stability throughout the complete mining cycle. The probability of roof instability increases as the width of the zone disturbed by mining increases. The depth of the workings appears to be a major factor affecting the maximum safe width.
- Sunnyside's current gate road configuration, a two-entry yield pillar system, has virtually eliminated severe tailgate *pillar* bumps and has contributed to reducing *face* bumps near the tailgate corner.
- Almost without exception, the miners, including development crew personnel, expressed their comfort in working in the current gate road configuration they have developed over the last 30 years. The only major qualification is that all current safety requirements are followed to the letter.

• Gate road design innovations or modifications that can be *technically demonstrated to definitively improve safety* will be fully supported by the employees. Many of the employees question the need to "fix something" they feel is not broken.

• It is unknown if a yielding-pillar-based gate road system of three or more entries will provide improved overall safety at Sunnyside. Any attempts at such configurations should be tried under mining cover of less than 1,000 ft. Based on their experience, the miners believe that the probability for success using a yielding-pillar-based gate road system of three or more entries greatly decreases at cover depths greater than 1,000 to 1,500 ft because of the ensuing squeeze condition and subsequent roof instability.

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Table 1.—Summary of geotechnical data for Sunnyside coal panels by interview area

Area and entry system	Entry configuration	Pillar dimensions (width × length, ft)	Seam height, ft	Cover depth, ft	Immediate roof quality	Immediate floor quality	Methane concentration	Water inflow	Unique features	Ground stability characteristics
Area 1:										
2nd Left	2-entry RP	50 × extremely variable.	6-20	500-1,000	Extremely poor.	NA	Average	Average	No roof bolts	Severe pillar bumps and bump-related roof falls upon retreat.
3rd Left	do.	30 × 30	6-20	500-1,000	do.	NA	do.	do.	do.	Severe pillar bumps and bump-related roof falls upon retreat; narrow support pillars reduced entry bumps.
4th Left	do.	30 × 30	6-20	500-1,000	do.	NA	do.	do.	do.	Do.
5th Left	do.	25 × 30	6-20	500-1,000	do.	NA	do.	do.	do.	Do.
6th Left	do.	25 × 30	6-20	1,000-1,500	do.	NA	do.	do.	do.	Do.
7th Left	do.	25 × 30	6-20	1,000-1,500	do.	NA	do.	do.	do.	Do.
8th Left	do.	25 × 30	6-20	1,000-1,500	do.	NA	do.	do.	do.	Do.
9th Left	do.	30 × 30	6-20	1,000-1,500	do.	NA	do.	do.	do.	Do.
10th Left	do.	30 × 30	6-20	1,000-1,500	do.	NA	do.	do.	1st roof bolts in mine	Do.
11th Left	do.	35 × 120-160	6-20	1,000-2,000	do.	NA	do.	do.	None	Do.
12th Left	do.	40 × 30-160	6-20	1,000-2,000	do.	NA	do.	do.	do.	Do.
13th Left	do.	40 × 30-160	6-20	1,000-2,000	do.	NA	do.	do.	3rd entry driven on retreat	Do.
14th Left	do.	50 × 110-150	6-20	1,000-2,000	do.	NA	do.	do.	3rd entry driven on retreat; pillar destressing attempted.	Severe pillar bumps and bump-related roof falls upon retreat; wider support pillars increased entry bump occurrence.
15th Left	do.	50 × 110-150	6-20	1,000-2,000	do.	NA	do.	do.	3rd entry driven on retreat	Do.
16th Left	3-entry RP	35 × 60-90	6-20	1,000-2,000	do.	NA	do.	do.	Arched along entire length	Severe pillar bumps and bump-related roof falls upon retreat; wide span of 3 entries required steel arches.
Area 2:										
2nd Left	do.	60 × 120-650	12-14	1,500-2,000	do.	NA	High	do.	4th entry driven on retreat	Severe pillar bumps and bump-related roof falls upon retreat.
4th Left	do.	50 × 90	12-14	1,500-2,000	do.	NA	do.	do.	None	Do.

See explanatory notes at end of table.

Table 1.—Summary of geotechnical data for Sunnyside coal panels by interview area—Continued

Area and entry system	Entry configuration	Pillar dimensions (width × length, ft)	Seam height, ft	Cover depth, ft	Immediate roof quality	Immediate floor quality	Methane concentration	Water inflow	Unique features	Ground stability characteristics
Area 2—Continued:										
5th Left	3-entry RP	50 × 110	12-14	1,500-2,000	Extremely poor.	NA	High	Average	None	Severe pillar bumps and bump-related roof falls upon retreat; production pillar sizes reduced to 15-20 ft to mitigate bumps.
6th Left	2-entry RP	35-60 × 50-120	12-14	1,500-2,000	do.	NA	do.	do.	do.	Do.
7th Left	do.	50 × 50-100	12-14	1,500-2,000	do.	NA	do.	do.	3rd entry driven on retreat	Do.
8th Left	do.	50 × 50-100	12-14	1,000-2,000	do.	NA	do.	do.	None	Do.
9th Left	do.	50 × 70	12-14	1,000-2,000	do.	NA	do.	do.	do.	Do.
10th Left	do.	50 × 70	12-14	1,000-2,000	do.	NA	do.	do.	do.	Do.
Area 3:										
7th Right	3-entry LW	40 × 80-90	4- 6	1,000	Fair to poor; highly fractured.	Poor; soft	Average	do.	Tailgate for first Sunnyside longwall panel; entries and panel overlain by pillars in upper seam.	Severe face bumps, instantaneous floor heave on face and in entries; heavy artificial support required.
8th Right	do.	40 × 80-90	4- 6	1,000	do.	do.	do.	do.	Headgate for first Sunnyside longwall panel; entries and panel overlain by pillars in upper seam.	Do.
6th Left	do.	40 × 40-80	4- 6	500-1,000	do.	do.	do.	do.	Entries and panel overlain by pillars in upper seam; 4th entry offset required to avoid roof fall.	Severe face and pillar bumps; heavy artificial support required to maintain entries.
7th Left	do.	40 × 40-80	4- 6	500-1,000	do.	do.	do.	do.	Entries and panel overlain by pillars in upper seam.	Severe face and pillar bumps; heavy support required, especially in TG.
8th Left	do.	40 × 40-80	4- 6	500-1,000	do.	do.	do.	do.	do.	Do.
9th Left	2-entry LW	30 × 90-110	5	500-1,000	Fair to good.	NA	High	do.	Upper seam mining; variable face width.	Excellent ground stability; yielding pillars significantly reduced bumps; less artificial support required because of reduced span.
10th Left	do.	30 × 90-110	5	500-1,000	do.	NA	do.	do.	do.	Do.
11th Left	do.	30 × 90-110	5	500-1,000	do.	NA	do.	do.	Upper seam mining	Do.

See explanatory notes at end of table.

Table 1.—Summary of geotechnical data for Sunnyside coal panels by interview area—Continued

Area and entry system	Entry configuration	Pillar dimensions (width × length, ft)	Seam height, ft	Cover depth, ft	Immediate roof quality	Immediate floor quality	Methane concentration	Water inflow	Unique features	Ground stability characteristics
Area 4:										
2nd North	3-entry LW	45 × 85	4.5-6	500-1,000	Fair to very good.	Poor	Low	Low	Steeply pitching seam; volley-firing to destress TG pillars.	Intermittent floor heave as HG; floor heave, pillar and face bumps as TG.
3rd North	2-entry LW	45 × 85 30 × 90	4.5-6	500-1,000	do.	Poor; soft	do.	do.	Steeply pitching seam; pillar width reduced to mitigate TG bumps.	Reduced pillar size resulted in reduced floor heave and few TG pillar bumps.
4th North	do.	25 × 95	4.5-6	500-1,500	do.	Poor	do.	do.	Steeply pitching seam	Yield pillar design virtually eliminated TG pillar bumps.
5th North	do.	35 × 85	4.5-6	1,000-1,500	do.	do.	do.	do.	do.	Yield pillar size adjusted to improve roof stability.
6th North	do.	35 × 85	6	1,000-2,000	do.	do.	do.	do.	Tailgate driven on retreat by shearer because of entry alignment problem.	Excellent HG and TG ground stability; tight cave.
Area 5:										
2nd South	do.	25 × 95	3.5-5.5	500-1,000	Good	NA	do.	do.	Tailgate driven on retreat by shearer; steeply pitching seam.	Do.
3rd South	do.	25 × 95	5.5	500-1,000	do.	NA	do.	do.	Steeply pitching seam	Do.
Area 6:										
11th Left	do.	25 × 80-110	6	2,000	Fair to poor.	NA	Average to very high.	High	None	Excellent HG and TG ground stability.
12th Left	do.	25 × 80-110	6	1,500-2,000	do.	NA	do.	do.	do.	Do.
13th Left	do.	25 × 80-130	6	1,500-2,000	do.	NA	do.	do.	do.	Do.
16th Left	do.	25 × 70-90	6	1,500-2,000	do.	NA	do.	do.	do.	Do.
17th Left 1-entry sections.	1-entry LW	NAp	6	1,500-2,000	do.	NA	do.	do.	Retreating 26-ft-wide single-entry LW; steel and timber ventilation barrier; concrete cribs.	No coal bumps or floor heave; excessive convergence after face passage; heavy artificial support required in TG.
17th Left 2-entry section.	2-entry LW	25 × 80	6	1,500-2,000	do.	NA	do.	do.	Chain pillars recovered on retreat by longwall.	Pillar recovery uneventful.
18th Left	1-entry LW	NAp	6	1,500	do.	NA	do.	do.	Retreating 21-ft-wide single entry LW; steel and timber ventilation barrier.	No coal bumps or floor heave.
19th Left inside.	2-entry LW	30 × 60-130	6	1,500	do.	NA	do.	do.	None	Excellent ground stability in HG and TG.

See explanatory notes at end of table.

Table 1.—Summary of geotechnical data for Sunnyside coal panels by interview area—Continued

Area and entry system	Entry configuration	Pillar dimensions (width × length, ft)	Seam height, ft	Cover depth, ft	Immediate roof quality	Immediate floor quality	Methane concentration	Water inflow	Unique features	Ground stability characteristics
Area 7:										
10th Left	2-entry LW	25 × 70-120	6	2,000	Fair to poor.	Poor; very soft.	Average	Average	4-ft displacement fault intersected entries.	Adequate ground stability in entries; coal bumps on face due to override.
10th Left 1-entry TG section.	1-entry LW	NAp	6	2,000	do.	do.	do.	do.	Tailgate driven on retreat by shearer.	Earthquake-scale coal bumps along face and barrier pillar; heavy artificial support required; severe load override.
10th Left 2-entry TG section.	2-entry LW	25-30 × 60-100	6	2,000	do.	do.	do.	do.	2-entry driven from 4th Slope to eliminate use of 1-entry TG.	Extremely severe coal bump destroyed 1-entry TG; panel abandoned prematurely.
Area 8:										
3-entry updip TG for 1st panel.	3-entry LW	20-30 × 60-100	4-5	1,500-2,000	Fair	NA	High	do.	Entry system only subjected to first panel longwall loads.	Severe floor heave and rib sloughage; minor coal bumps on face and in TG pillars.
2-entry updip HG for 1st panel.	2-entry LW	30 × 60-95	4-5	1,000-2,000	do.	NA	do.	do.	None	Intermittent roof falls in HG; tight cave behind face; good overall mining conditions.
2-entry updip HG for 2nd panel.	do.	30 × 60-95	4-5	1,000-2,000	do.	NA	do.	do.	do.	Good overall mining conditions; tight cave behind face.
2-entry updip HG for 3rd panel.	do.	30 × 60-95	4-5	1,000-1,500	do.	NA	do.	do.	do.	Do.
15th Right	3-entry LW/H	60 × 90 25 × 70-90	4-5	1,000	do.	NA	do.	do.	Entry system originally developed as life-of-mine haulage opening; four types of longwall supports used.	Steel arches required to support middle entry to maintain cross-mine belt.
1-entry TG for 15th Right.	1-entry LW	NAp	4-5	1,000	do	NA	do.	do.	Tailgate driven on retreat by shearer; steel pipe used as tailgate behind face.	Severe coal bumps in TG, especially from barrier pillar; convergence-related closure of steel pipe forced premature abandonment.

See explanatory notes at end of table.

Table 1.—Summary of geotechnical data for Sunnyside coal panels by interview area—Continued

Area and entry system	Entry configuration	Pillar dimensions (width × length, ft)	Seam height, ft	Cover depth, ft	Immediate roof quality	Immediate floor quality	Methane concentration	Water inflow	Unique features	Ground stability characteristics
Area 9:										
16th Right	2-entry LW	30 × 70-90	NA	1,500-2,000	NA	NA	NA	NA	None	Good overall mining conditions.
16th Right Tapered-pillar TG.	do.	25-75 × 70-90	NA	1,500-2,000	NA	NA	NA	NA	Tapered pillars; pillar widths decreased from 75 to 25 ft travelling inby.	Coal bump frequency and severity increased with increasing pillar width.
Area 10:										
15th Right	3-entry LW	25 × 70-100 35 × 70-100	5-6	1,500-2,000	Good; weak zones.	Poor; soft	Average to high.	Average	Panel-side row of chain pillars recovered on retreat; entry system only subjected to first panel longwall loads.	Severe convergence and roof falls; severe floor heave and coal bumps; very heavy artificial support required to maintain TG.
16th Right	2-entry LW	30 × 60-100	5-6	1,500-2,000	do.	do.	do.	do.	None	Some floor heave ahead of face in HG.
17th Right	do.	30 × 70-200	5-6	1,500-2,000	do.	do.	do.	do.	do.	Severe coal bumps along face as HG; floor heave and roof falls on face due to weak roof and floor.
18th Right	do.	30 × 85	5-6	1,500-2,500	do.	do.	do.	do.	do.	Do.
Water Canyon Slopes.	4-entry H	55 × 30-190	5-6	1,500-2,200	do.	do.	do.	do	do.	Extremely severe coal bumps displaced equipment; excessive rib sloughage.
Area 11:										
11th Left	2-entry RP	55 × 70-90	6-12	1,000	Very poor	Fair; zones of soft material.	High	do.	3rd entry driven on retreat	Severe pillar bumps and bump-related roof falls upon retreat.
12th Left	do.	55 × 70-90	6-12	1,000	do.	do.	do.	do.	do.	Do.
13th Left	do.	55 × 70-90	6-12	1,000	do.	do.	do.	do.	do.	Do.
14th Left	do.	55 × 70-90	6-12	1,000	do.	do.	do.	do.	do.	Do.
15th Left	2-entry LW	40 × 70-90	6-12	1,000	do.	do.	do.	do.	Portion of 15th Left chain pillars recovered using longwall spanning 15th and 16th Left panels.	Face width of 15th/16th Left panel reduced approximately 1/3 through mining because of hazardous conditions mining into open areas.

See explanatory notes at end of table.

Table 1.—Summary of geotechnical data for Sunnyside coal panels by interview area—Continued

Area and entry system	Entry configuration	Pillar dimensions (width × length, ft)	Seam height, ft	Cover depth, ft	Immediate roof quality	Immediate floor quality	Methane concentration	Water inflow	Unique features	Ground stability characteristics
Area 11—Continued:										
16th Left	2-entry LW	40 × 70-90	6-12	1,000	Very poor	Fair; zones of soft material.	High	Average	Headgate for 15th/16th Left panel; face width reduced because of hazards in retrieving 15th Left chain pillars.	Severe pillar bumps ahead of face when recovering 15th Left chain pillars.
17th Left	do.	40 × 70-90	6-12	1,000	Fair to poor	do.	do.	do.	24-hour world coal production record.	Excellent mining conditions encountered; some minor bumps.
18th Left	do.	40 × 70-90	6-12	1,000-1,500	do.	do.	do.	do.	None	Excellent HG mining conditions; moderate pillar and face bumps as TG.
19th Left	do.	30 × 70-110	6-12	1,500-2,000	do.	do.	do.	do.	Chain pillar width reduced to 30 ft to mitigate TG bumps.	Excellent HG mining conditions; reduced pillar width decreased TG pillar bumps; however, moderate face bumps continued.
20th Left	do.	30 × 70-110	6-12	1,500-2,000	Poor to extremely poor.	do.	do.	do.	Highly volatile hydrocarbons from roof; 1 to 2 ft of top coal left to support roof.	Excellent HG mining conditions; occasional moderate face bumps.
21st Left	do.	30 × 70-110	6-12	1,500-2,500	do.	do.	Very high.	Average	do.	Do.
22nd Left	do.	30 × 70-110	6-12	1,500-2,500	do.	Poor; soft	do.	do.	Highly volatile hydrocarbons from roof; 2 ft of roof rock removed to expose competent rider seam roof.	No longwall mining yet at time of report.
Area 12:										
Motor Road Extension.	2-entry H 3-entry H 4-entry H	50 × 110 60 × 100 60 × 100 25 × 100	([1])	500-1,500	do.	NA	Average to high.	do.	Motor road extension driven in upper and lower seams depending on roof conditions; steel arches required.	Poor roof conditions required use of 2-entry system to limit total span of entries.

See explanatory notes at end of table.

Table 1.—Summary of geotechnical data for Sunnyside coal panels by interview area—Continued

Area and entry system	Entry configuration	Pillar dimensions (width × length, ft)	Seam height, ft	Cover depth, ft	Immediate roof quality	Immediate floor quality	Methane concentration	Water inflow	Unique features	Ground stability characteristics
Area 12:										
Continued										
4th Slope . .	2-entry H	25 × 150-200	([2])	1,500-2,000	Poor to extremely poor.	NA	Average to high.	Average . .	None	Moderate coal bumps on development face when approaching and crossing fault zones.

H Haulage and access.
HG Headgate.
LW Longwall gate road.
NA Not applicable.
NAp Not applicable.
RP Room and pillar.
TG Tailgate.
[1]Lower seam 6 to 12 ft, upper seam 3 to 8 ft.
[2]Upper seam 3 to 8 ft.

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