

Information Circular 8896

Surface Subsidence Over Longwall Panels in the Western United States

Monitoring Program and Preliminary Results
at the Deer Creek Mine, Utah

By Frederick K. Allgaier



UNITED STATES DEPARTMENT OF THE INTERIOR
James G. Watt, Secretary

BUREAU OF MINES
Robert C. Horton, Director

This publication has been cataloged as follows :

Allgaier, F. K. (Frederick K.)

Surface subsidence over longwall panels in the Western United States. Monitoring program and preliminary results at the Deer Creek Mine, Utah.

(Information circular : 8896)

Includes bibliographical references.

Supt. of Docs. no.: I 28.27:8896.

1. Mine subsidences--Utah. 2. Coal mines and mining--Utah. I. Title. II. Series: Information circular (United States. Bureau of Mines) : 8896.

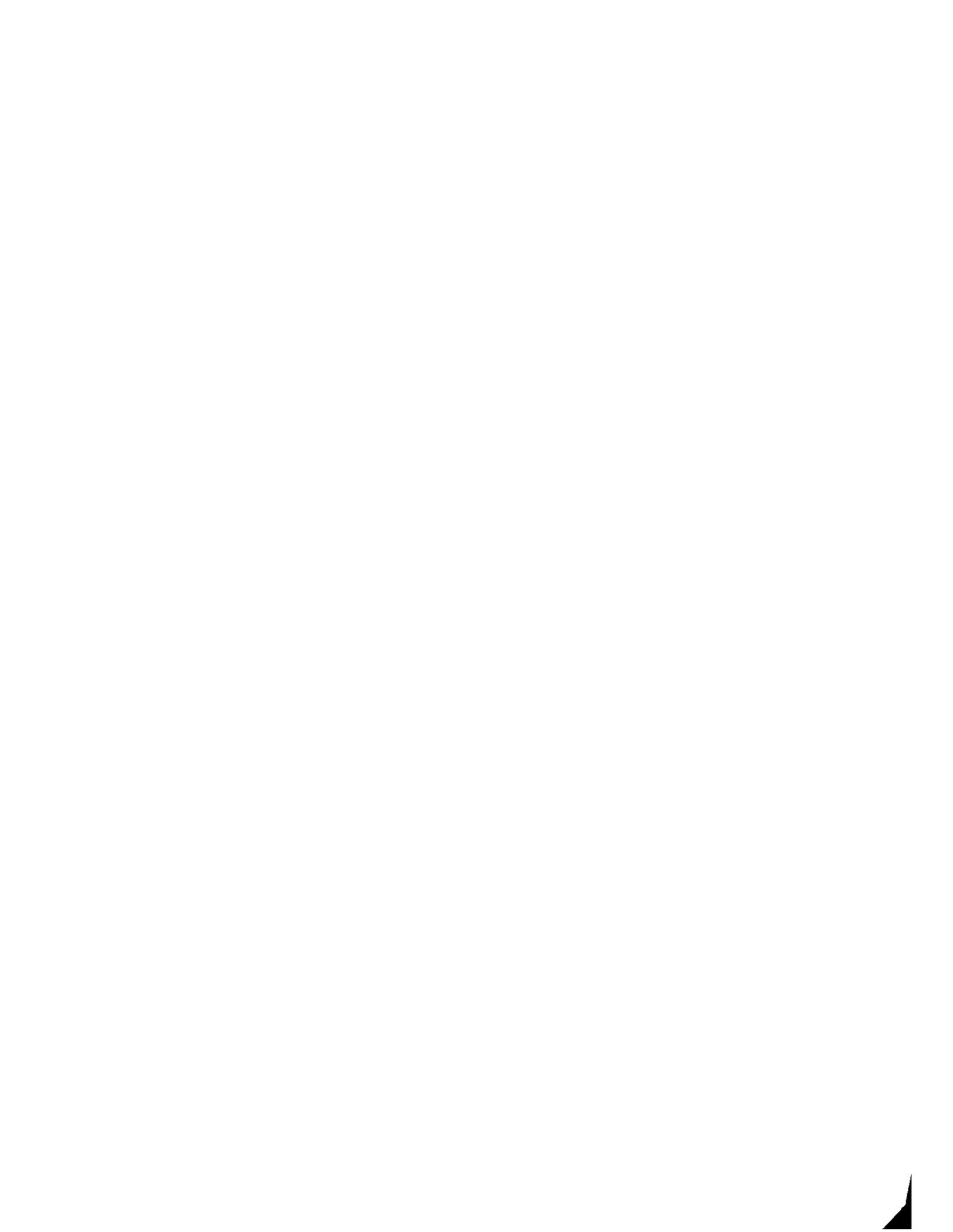
TN295.U4 [TN319] 622s [622'.334] 82-600171 AACR2

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SURFACE SUBSIDENCE OVER LONGWALL PANELS IN THE WESTERN UNITED STATES

Monitoring Program and Preliminary Results at the Deer Creek Mine, Utah

By Frederick K. Allgaier¹

ABSTRACT

This is the first in a series of progress reports on the longwall subsidence research program at the Bureau of Mines Denver Research Center. As part of this program, the Bureau and the Utah Power and Light Co. are cooperating on a study conducted at the Deer Creek Mine, which is directed toward developing the capability to estimate the surface subsidence resulting from longwall mining in a geologic, topographic, and mining environment common to coalfields in the Western United States.

A monitoring network has been established at the Deer Creek Mine to measure subsidence over four adjacent longwall panels. To date, two panels have been mined. Subsidence began as the first panel was mined and continued for 1 year following completion of the panel, during which time the adjacent panel was mined. A maximum of 2.7 feet of subsidence occurred over the two longwall panels mined at a depth of 1,500 feet. Because of the length of time that subsidence continued after mining, the final subsidence profiles and angle of draw have not yet been determined.

¹Mining engineer, Denver Research Center, Bureau of Mines, Denver, Colo.

INTRODUCTION

Population density and surface development over active coal mines in Great Britain and other parts of Western Europe have dictated for many years that surface subsidence and its effects be thoroughly understood and that mine engineering practices be developed to reduce these effects. It is only recently that the need to develop a subsidence data base representative of U.S. mining conditions has been recognized. In addition, longwall mining has only recently begun to gain substantial acceptance in the United States, particularly in the West. Hence, subsidence from longwall mining is still a largely unknown and unpredictable quantity.

The public sector and various State and Federal Government agencies that own the surface over much of the western coal deposits have become increasingly concerned about the effects of subsidence on future land use, as well as its impact on surface and subsurface hydrology and surface structures. Consequently, mining companies are being required to examine more closely the possible surface impacts of underground mining.

A major problem now faced by mine operators and landowners in the Western United States is the lack of actual case-history data that document subsidence sufficiently for use in estimating subsidence values and environmental impacts for specific properties. Factors such as strong, massive sandstone members in the overburden, thick and multiple seams, deep cover, and extreme variations in overburden thickness over a single panel due to mountainous topography are common in the Western United States and can have significant impact on subsidence characteristics.

As mine operators and environmental agencies attempt to address subsidence issues in the mine planning and permitting process, the lack of applicable subsidence information, experience, and prediction capabilities becomes apparent. Bureau of Mines research in subsidence from longwall mining is directed toward fulfilling the needs of the industry in the premining evaluation of surface damage and in facilitating the permitting process. As part of this program, the Bureau's Denver Research Center and the Utah Power and Light Co. are cooperating on a study conducted at the Deer Creek Mine in Emery County, Utah.

The major objectives of the Deer Creek study are to (1) measure surface subsidence caused by longwall mining in the Blind Canyon coal seam, (2) determine the timing, rate, and areal extent of subsidence, (3) establish the final subsidence profiles, (4) correlate mining and geologic variables with measured subsidence values, (5) evaluate predictive capabilities with regard to actual, measured subsidence versus theoretical values, and (6) determine the effects of subsidence on current and potential land use.

This report describes the Deer Creek study site, the methods and instruments used in subsidence surveys, and the status of the monitoring program, and includes a preliminary discussion of the surface subsidence measured through 1980. The final subsidence profiles and a complete analysis of the subsidence data from this site will be contained in a future report. Additional reports covering similar subsidence investigations at other mines are also planned.

ACKNOWLEDGMENTS

The Utah Power and Light Co., Mining and Exploration Department, provided valuable assistance in conducting this research. In particular, Don Dewey, Chris Shingleton, John Bootle, Jeff McKenzie, and Roger Fry have made significant

contributions to the project. Without the access they provided to company property, mine plans, survey data, drill logs, and other information relating to the Deer Creek Mine, this study could not have been conducted.

The efforts of Bureau of Mines personnel who performed the field work for the project are also acknowledged. Laura

Swatek, in the Bureau's Mine Engineering Division, prepared the geologic description of the study site for this report.

THE DEER CREEK MINE STUDY SITE

Site Selection

The Bureau selected the Deer Creek Mine, owned by Utah Power and Light Co., as one of the sites for monitoring subsidence over longwall panels, because it contains specific mining and overburden features for which few or no subsidence field data exist. These features include 1,500 feet of overburden containing a significant percentage of strong sandstone members, an extraction height of 10 feet, and a lower seam to be longwall mined, which will present an opportunity to study subsidence from multiple seam mining. Also, the timing of the project was such that monitoring could begin over the first in a series of four adjacent longwall panels. This was important

because one of the questions to be answered by the study is how much area must be mined, in terms of either face advance or width over adjacent panels, before subsidence occurs at the surface. The conditions at the Deer Creek Mine are somewhat representative of many western mines; therefore, the results are expected to be applicable to mines in other western areas.

Site Description

The study site over the Deer Creek Mine is located on East Mountain in Emery County, Utah, approximately 10 miles west of the town of Huntington. The site includes parts of sections 14, 15, 22, and 23; T 17 S; R 7 E on the Mahogany Point

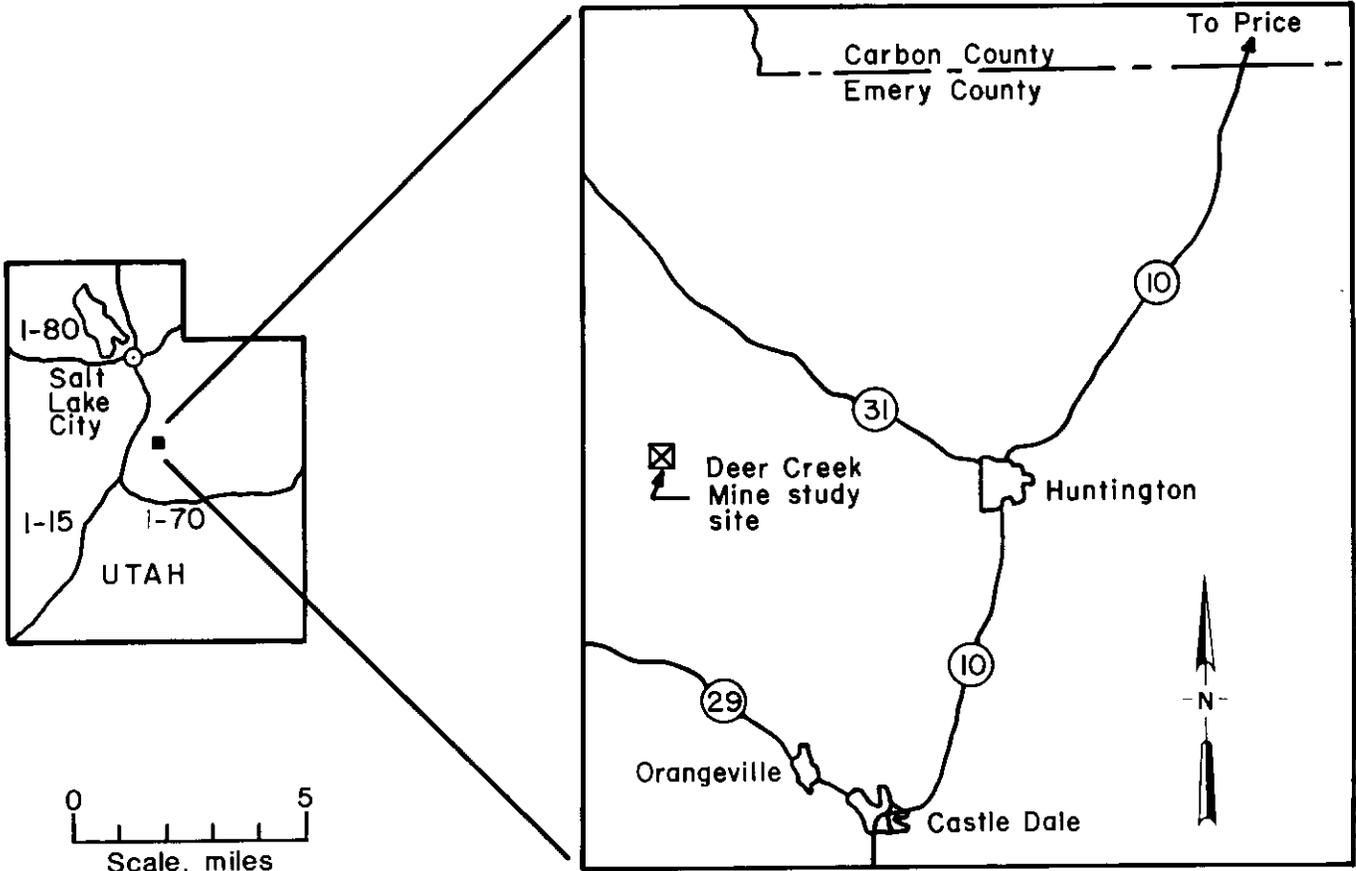


FIGURE 1. - Project location map.

and Red Point 7.5-minute U.S. Geological Survey quadrangle maps.² The project site location is illustrated in figure 1. Portions of the study site are within the boundaries of the Manti-LaSal National Forest, and the remainder is controlled by Utah Power and Light Co. Approximately 500 acres are included in the monitoring area over four adjacent longwall panels.

The topography over the panels is generally rolling, with no outcrops or vertical faces (figs. 2-3). The maximum ground slope in the area is approximately 45 percent, with a maximum relief of 300 feet over the entire site. No unusual problems due to topography were encountered in either the installation or monitoring of the subsidence network.

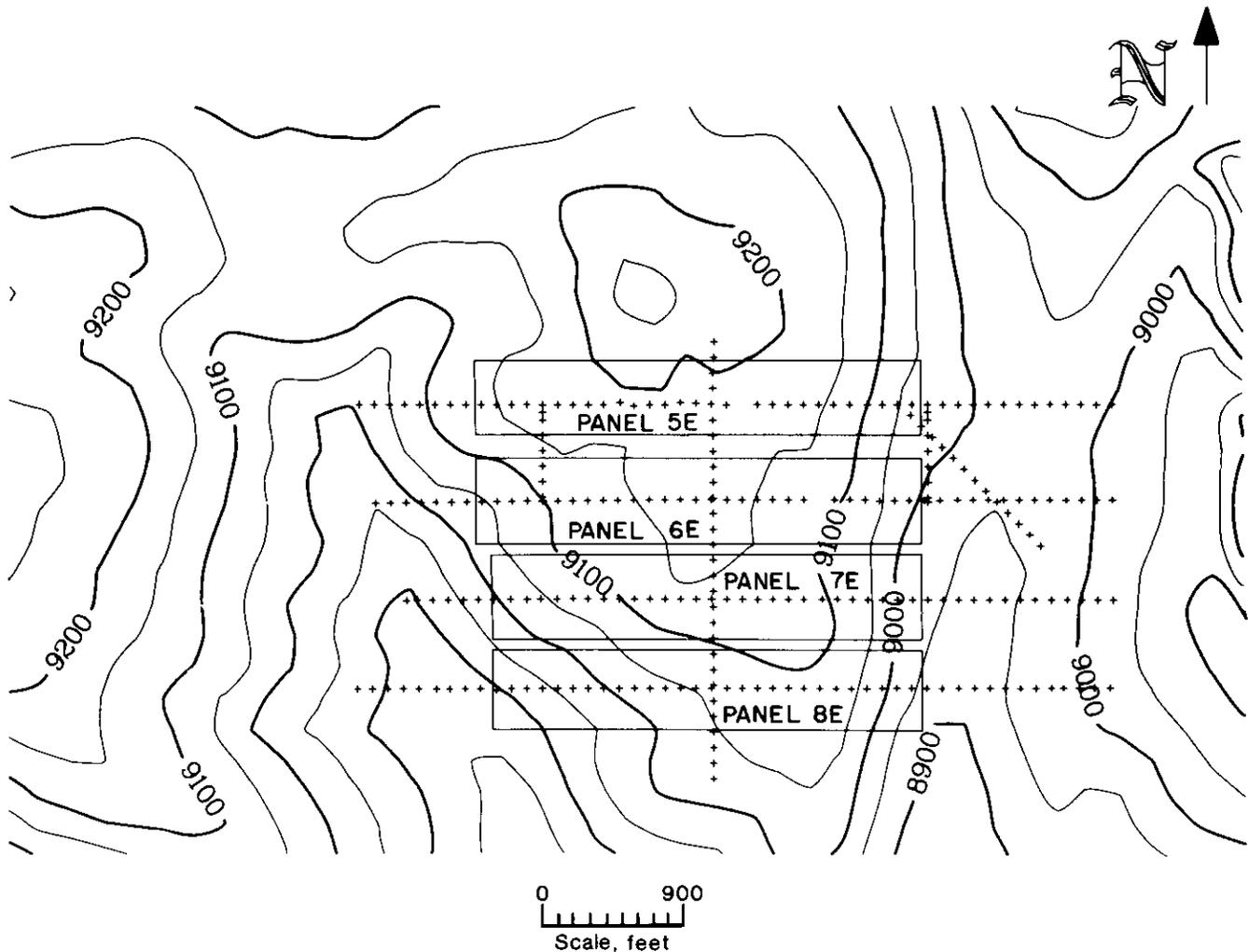


FIGURE 2. - Surface contours over the longwall panels. The subsidence monitoring network, shown as lines of crosses, is discussed in the section "Monument Locations."

²U.S. Geological Survey maps N3915-W11107.5/7.5 and N3915-W11100/7.5, 1979.

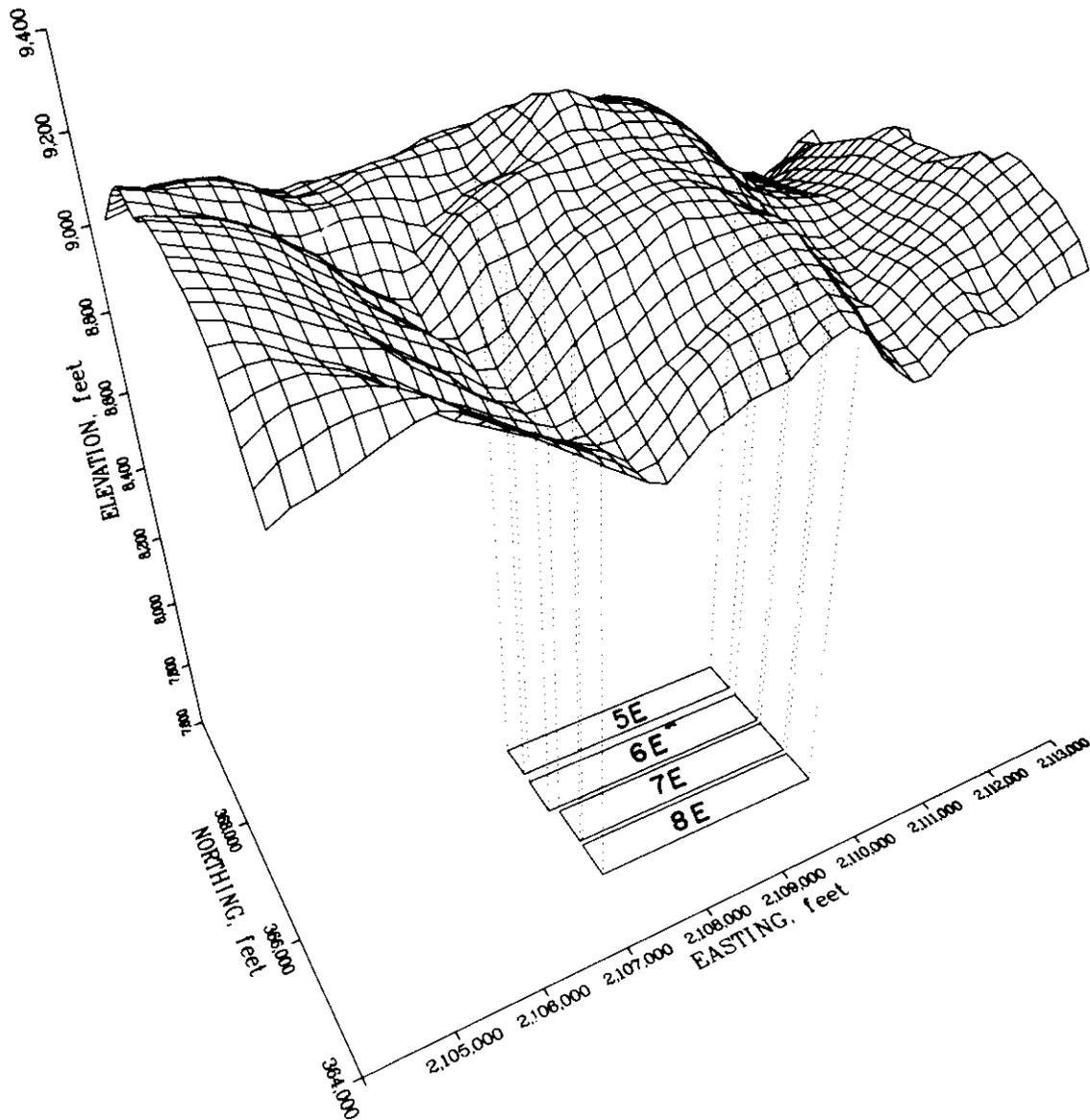


FIGURE 3. - Surface topography.

The average surface elevation of the study site is 9,100 feet, and vegetation consists mostly of sagebrush, with some significant areas of pine and aspen (fig. 4). The location of the longwall panels is such that surface vegetation over three of the four panels is entirely

sagebrush, which allowed clear line of sight for the monitoring surveys. Approximately one-half of the first panel (5E) lies under a wooded area, which required cutting and clearing of survey sight lines.



FIGURE 4. - Typical surface features over the longwall panels.

The elevation of the site is a significant factor in the monitoring program. Early fall and late spring snowfalls, which can make the site inaccessible from October into June, prevent subsidence monitoring surveys from being carried out at equal intervals throughout the year. Therefore, the magnitude and timing of any subsidence occurring during the winter months must be interpolated between the last survey performed in the fall and first survey in the spring of the next year.

Regional Geology

The Deer Creek Mine is located in central Utah on the Wasatch Plateau, a

broad, linear structure that lies generally in a north-south direction (fig. 5). The strata dip gently westward in the eastern part of the plateau because of the presence of the west flank of the San Rafael Swell. The western part of the plateau marks the transition into the highly faulted and complex region of the Great Basin.³

Sedimentary rocks form the majority of the stratigraphic sequence within the

³Davis, F.D., and H. H. Doelling. Coal Drilling at Trail Mountain, North Horn Mountain, and Johns Peak Areas, Wasatch Plateau, Utah. Utah Geol. and Miner. Survey Bull. 112, 1977, p. 4.

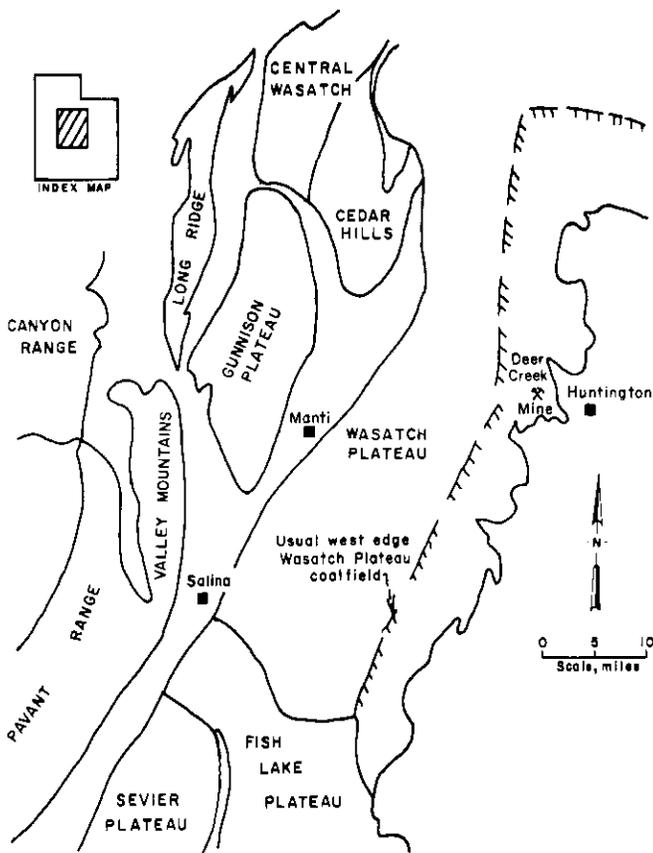


FIGURE 5. - Regional geologic structures.

Wasatch Plateau region. The sequence consists of one limestone unit and alternating sandstones, siltstones, and mudstones. The two major coalbeds occur within the lower portion of the stratigraphic section. The rocks are subdivided into seven formations (fig. 6) and range in age from early Cretaceous to Paleocene.⁴

⁴Spieker, E. M. The Transition Between the Colorado Plateaus and the Great Basin in Central Utah. Guidebook to the Geology of Utah. No. 4. Utah Geol. Soc., 1949, p. 52.

Faults are a very prominent feature in this area (fig. 7), representing a transitional zone between the Wasatch Plateau and the Great Basin to the west.⁵ These are high-angle, normal faults trending nearly north-south. Vertical displacements of stratigraphy range from 0.5 foot to nearly 200 feet. The longwall operations involved in this study are being conducted between the Pleasant Valley Fault to the west and the Deer Creek Fault to the east. There are no known faults crossing the longwall panels.

Stratigraphy

Drill hole records supplied by Utah Power and Light Co. were used to determine the stratigraphy of the overburden above the longwall panels. The generalized stratigraphic section (fig. 8) illustrates that sandstones and interbeds of siltstones, sandstones, and mudstones are predominant units. The two major sandstone units are the Castlegate Sandstone, which is found in the lower Price River Formation, and the Star Point Sandstone, which is located in the lower Blackhawk Formation below the Blind Canyon Coal Seam (fig. 6). In this area, the Castlegate Sandstone is described as a buff to gray, massive, fine-grained, well-cemented unit with occasional silty bands occurring throughout. The Star Point Sandstone is a light-gray, fine-grained unit that is well sorted and quartzose. The total percentage of sandstone in the overburden is between 35 and 45; 35 percent represents that occurring in thick beds, and 45 percent includes all thin beds and laminations.

⁵Work cited in footnote 3.

System	Group	Formation	Thickness, feet	Description
Tertiary	Wasatch	Flagstaff Limestone	100-1,000	Light-gray to cream limestone; thin and even-bedded; dense; fossiliferous; ledge- and cliff-forming.
		North Horn Formation	900-2,000	Mostly red-brown, and salmon-colored shales; varying thicknesses of sandstone, freshwater limestone and conglomerate; slope-forming.
Cretaceous	Mesaverde	Upper Price River Member	400-800	Mostly tan and gray, medium-to coarse-grained sandstone and some gray shale and conglomeratic sandstone; ledge- and slope-forming.
		Price River Formation		
		Castlegate Sandstone Member	150-500	Light-gray, yellowish-brown and white, medium-to coarse-grained sandstone and conglomeratic sandstone; cliff-forming.
	Disconformity			
	Blackhawk Formation	400-1,000	Light-to medium-gray sandstones; gray to black shale; gray siltstones; important coalbeds in lower half; sandstones weather tan, brown, yellowish-brown; ledge- and slope-forming.	
		Star Point Sandstone	200-1,000	Tan, light-gray, and white massive sandstones separated by one or more shale tongue; cliff-forming.
	Mancos Shale	Masuk Shale	300-1,300	Light-gray to blue-gray sandy marine shale; thins to west and south; slope-forming.

FIGURE 6. - Regional stratigraphy. (Modified from Utah Geological and Mineral Survey Bulletin 112, 1977, p. 4.)

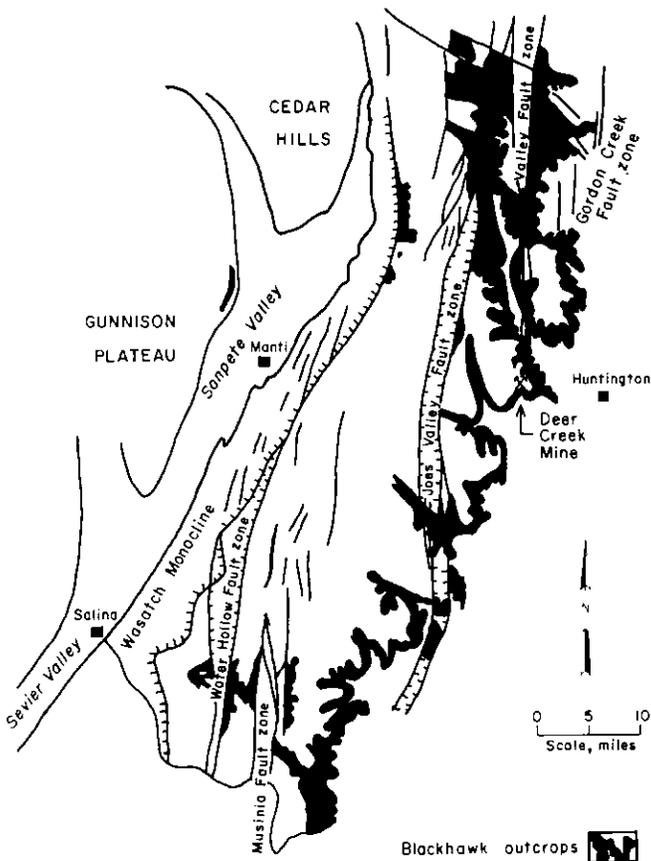


FIGURE 7. - Regional faulting.

The Deer Creek Mine produces coal from the Blind Canyon Seam in the coal-bearing zone of the Blackhawk Formation. The Blackhawk Formation consists mainly of medium- to fine-grained interbedded sandstones, carbonaceous mudstones, and siltstones. The Blind Canyon Seam, with a coal thickness of 14.3 feet in the panel area, is described as a hard, dense, bright-attrital coal and is ranked as high volatile, B-bituminous. Figure 9 illustrates the general stratigraphy of the coal seam, the immediate roof, and the immediate floor as determined from drill hole records supplied by Utah Power

and Light Co. The jointing pattern within the coal seam and surrounding strata consists of vertical joints with an average trend of $N 21^{\circ} W$. The joints are very pronounced in the sandstone units and tend to be faint to undistinguishable within the mudstone units. Spacing of the joints is considered moderate, with an average spacing of 10 to 20 feet.

Mine Plan

The mining plan for the longwall panels at the Deer Creek Mine is shown on figure 10. It consists of four adjacent panels oriented in an east-west direction to be retreat mined from the east toward the main entries to the west.

A room-and-pillar section (4E) north of the first panel was mined prior to the development of the longwall panels. This section consisted of 20-foot-wide rooms on 100-foot centers with crosscuts on 80-foot centers. Pillar mining was not conducted; however, 1 to 2 feet of floor coal was mined on retreat, increasing the mining height to 10 feet. A 200-foot barrier pillar was left between third east section (3E) and fourth east section (4E), which includes the tailgate entries for the first longwall panel (5E).

The first panel was developed using a three-entry system, and the remaining three panels were developed by two entries on 50-foot centers and crosscuts on 105-foot centers.

Mining height for the first two longwall panels averages 10 feet. The length of both panels 5E and 6E is 2,500 feet, with face lengths of 480 feet and 540 feet, respectively.

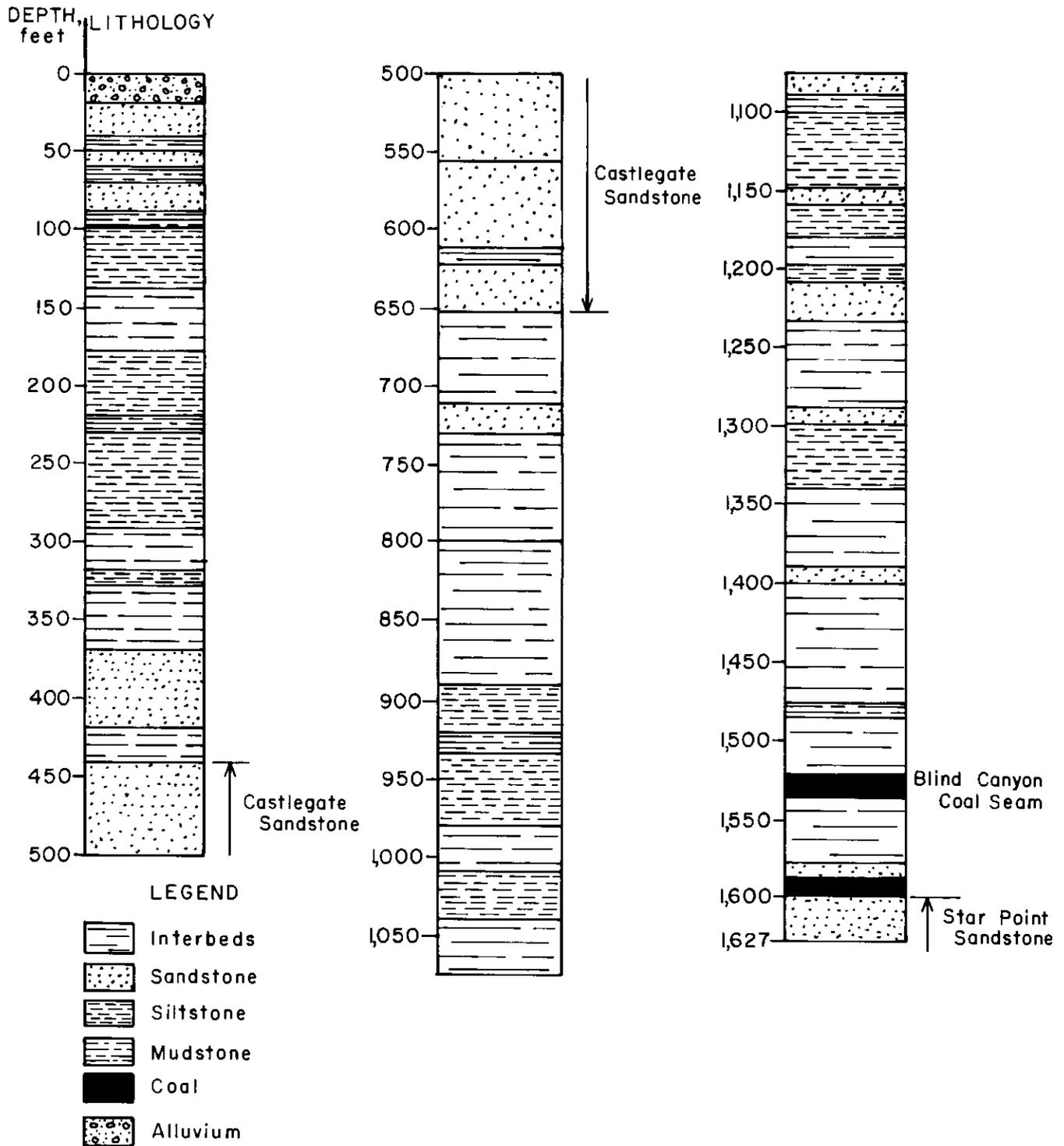


FIGURE 8. - Generalized overburden stratigraphy.

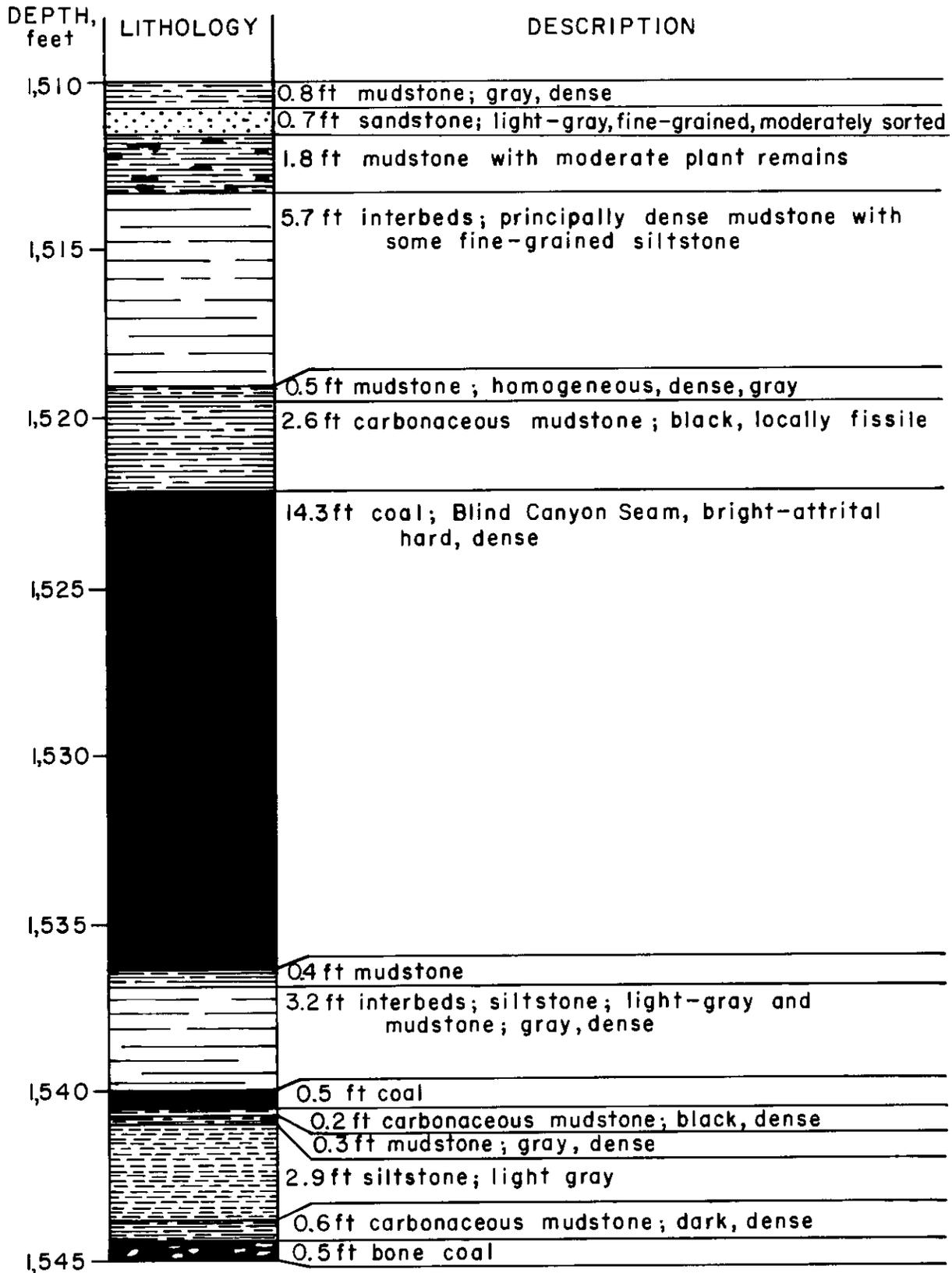


FIGURE 9. - Coal seam stratigraphy.

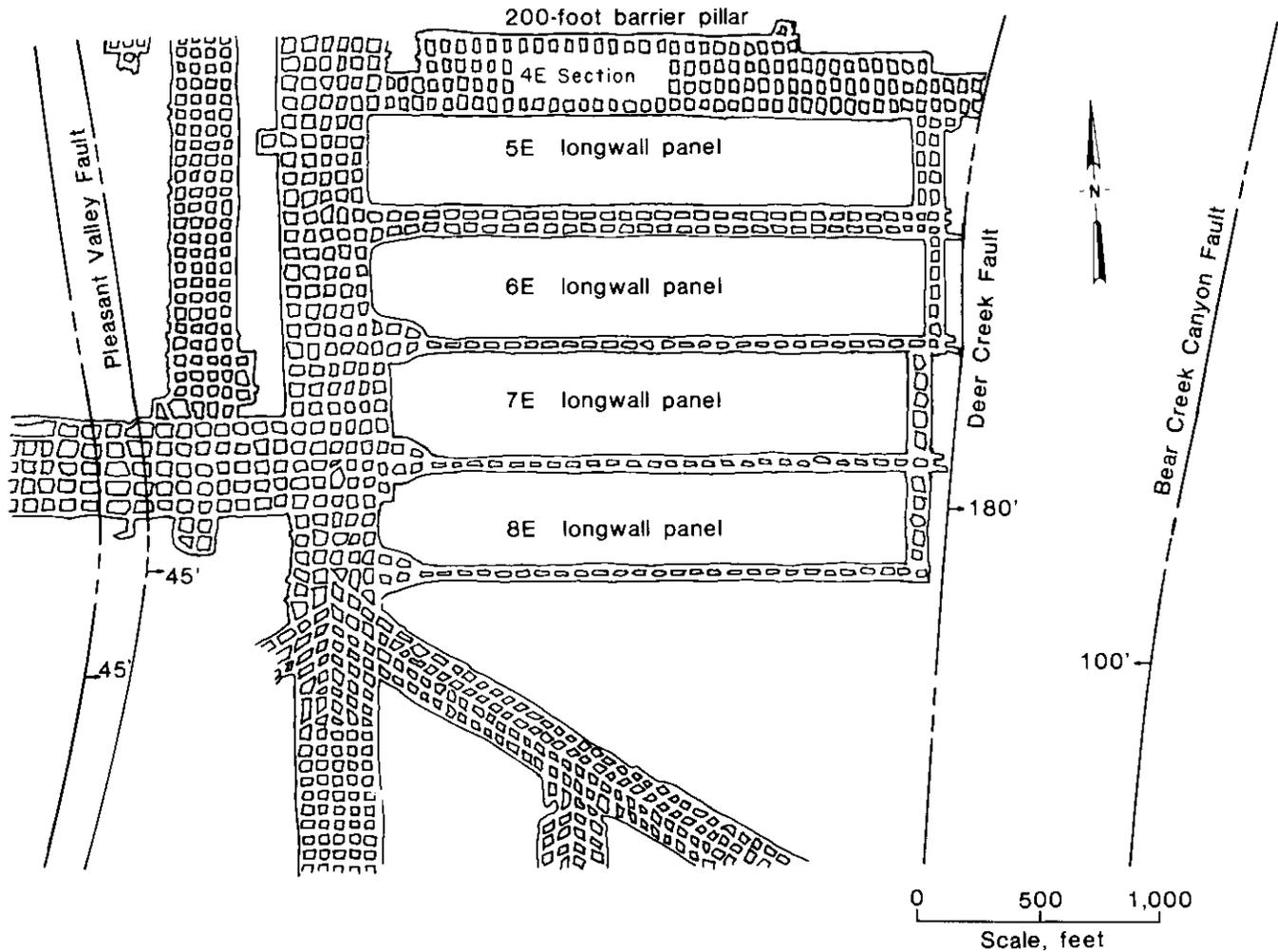


FIGURE 10. - Mine plan with local faulting.

The depth of cover over the first two panels ranges from a maximum of 1,580 feet to a minimum of 1,300 feet (fig. 11). The maximum overburden occurs near the center of the panels and decreases toward both ends. The seam dips only 1.3 degrees to the northwest and therefore has little effect on the depth of cover, which is controlled almost entirely by the surface topography.

Mining of the first panel began in May 1979 and was completed in December 1979.

The second panel was mined between February and December 1980.

A 400-foot barrier was left between the end of the panels and the main entries to the west. Unmined coal remains between the longwall panel starting rooms and the Deer Creek Fault, approximately 200 feet to the east. There has been no previous mining either above or below the panels, although the Wilberg Mine will subsequently undermine this section of the Deer Creek Mine.

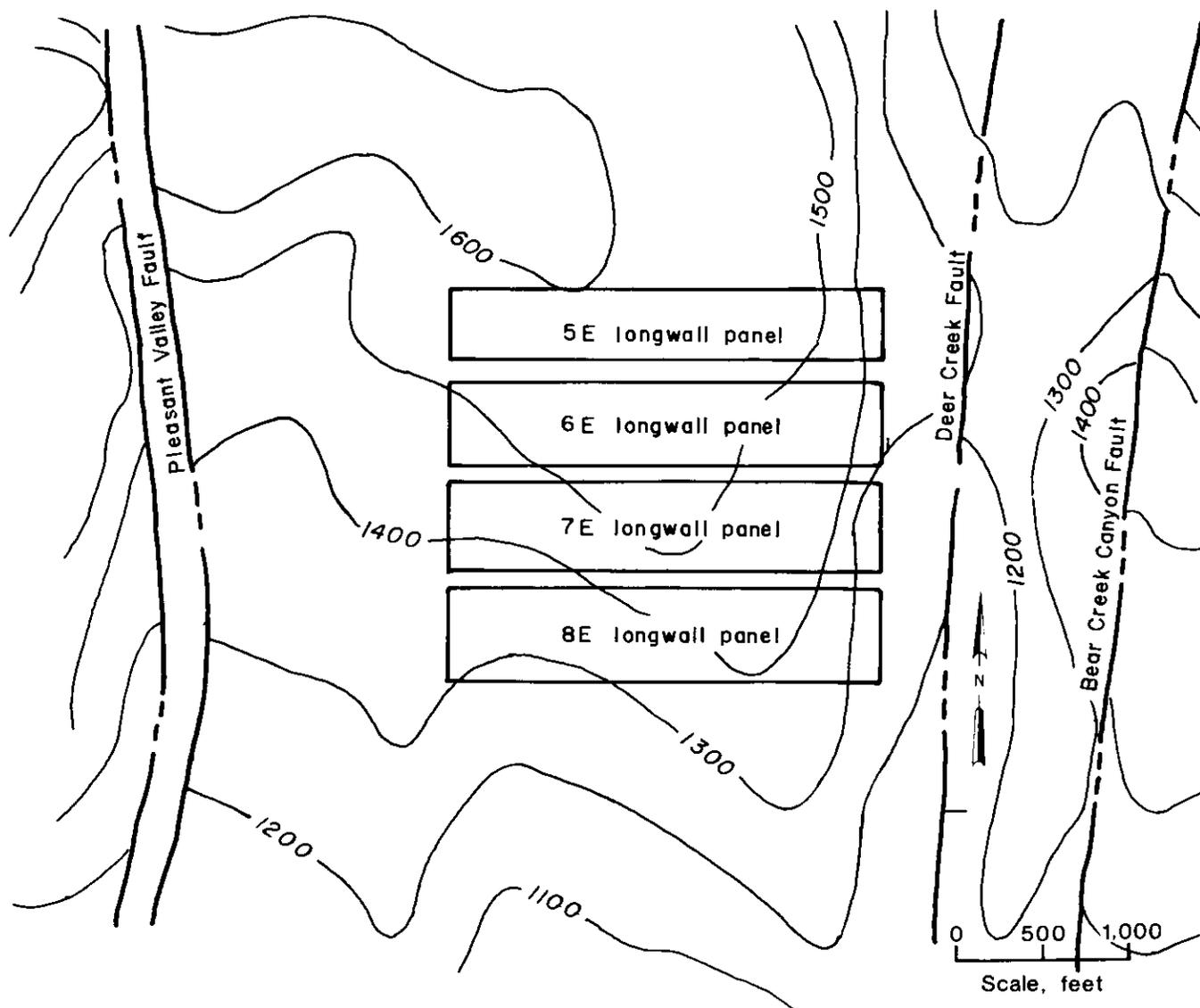


FIGURE 11. - Overburden isopachs.

SUBSIDENCE MONITORING PROGRAM

Monitoring Program Design

Several factors influenced the design of the subsidence monitoring program at the Deer Creek Mine. The most important consideration was that the information collected would meet the established project objectives of determining the maximum subsidence, the areal extent of subsidence, and the rate at which subsidence progresses down the panels. In addition, final subsidence profiles would be developed and analyzed with respect to

the overburden geology and mine layout and then correlated with existing predictive techniques. Major items that affect the subsidence data being collected are surveying accuracy and frequency, monument location, in terms of both spacing and layout over the panel, monument construction, and surveying instrumentation. Constraints on the monitoring program caused by the short field season and personnel limitations affect the number and type of surveys performed and thus the final project results.

Monument Locations

The locations of the subsidence monuments were established on the basis of coordinate survey data supplied by Utah Power and Light Co. for points on the surface in or near the study site and for the location of the longwall panels. Both the underground and surface surveys are tied to the Utah State plane coordinate system, which allows direct correlation between surface and underground positions.

Soil cover in the area ranges from a few feet to approximately 20 feet in depth. Although the soil is moderately rocky, it is of adequate depth to permit the monuments to be installed with few problems. The only area where monuments were difficult to install was at the center of the first panel (5E) on a topographic high near the transverse line of monuments (fig. 2). Problems in this area were solved by changing the monument location by a few feet to an area that could be penetrated. In no case was a monument omitted from a planned location because of inability to drive it into rocky soil.

The network layout used for this site is shown on figure 2. It consists of one line of monuments approximately centered over the long axis of each panel and several transverse lines located at specific positions over the panel. This type of monitoring layout produces both transverse and longitudinal subsidence profiles. In addition, a diagonal line of monuments on the east end of the panels was included to provide more data on the angle of draw and the interaction of the combined subsidence at the corners of the two adjacent panels. The transverse line of monuments running north-south at the center of the panels lies over the area of maximum overburden; the transverse line over the western end of the panels lies over the area of minimum overburden thickness; and the transverse monument line just east of the panels is over an area expected to be affected by the angle of draw.

The location of stable, remote control points is governed by topography and vegetation, which affect the line of sight to the subsidence monuments. The locations of the underground workings also dictate the areas that will remain stable throughout the life of the project. At the Deer Creek site it was not always possible to locate control points on stable ground because the topography blocked lines of sight to the subsidence monuments. In these instances, control points were located over the panels and tied to at least two stable points with vertical and horizontal surveys. The accurate location of these control points was established for each survey of the monitoring network.

Monument Spacing

Monument spacing on the subsidence monitoring network is 100 feet. This spacing was felt to be a practical compromise between the more accurate determination of strain and angle of draw that is possible with decreased spacing and the increased cost of installing and surveying the additional points. The 100-foot spacing, an average of 0.07 times the overburden depth, is somewhat larger than the 0.05 recommended by the National Coal Board (NCB) Subsidence Engineers' Handbook.⁶ However, the NCB acknowledges that there is a practical limit to reducing monument spacing and that further research is needed before the optimum spacing can be defined. As part of the continuing work at the Deer Creek site, selected portions of the fourth longwall panel will be monumented with 50-foot spacing, and the resulting angles of draw and direct strain measurements will be compared with similar measurements from the panels with monuments on 100-foot centers.

Monument Construction

Two different types of monuments have been used on the project (fig. 12). One

⁶National Coal Board, Great Britain. Subsidence Engineers' Handbook. 1975, p. 33.

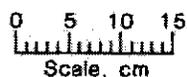


FIGURE 12. - Subsidence monuments.

type consists of 1-1/2-inch pipe cut to length, with a bevel on one end to facilitate installation. The other type is 1-inch steel rod with a machined point. Both types of monuments were driven into the ground to a depth of 3 to 5 feet with either a gas-powered hammer (fig. 13) or a sledge hammer. Approximately 6 inches of the pipe or rod extend above the ground to accommodate the target used in the horizontal position surveys. Minimizing the height of the monuments above the ground decreases the error in the horizontal position that results as the monuments tilt during subsidence. The 1-inch rods have two advantages over the 1-1/2-inch pipes. They are easier to drive into rocky ground to the required depth, and material costs for 6-foot-long monuments were \$8.80 for the pipe and only \$4.60 for the 1-inch rods.

Monument Installation and Survey Schedule

In the fall of 1978, monuments were installed over the first half of the first longwall panel (5E), and remote control points were located. The initial traverse survey, performed in October prior to mining, provided the

monument baseline elevations and coordinate positions.

The second traverse survey was performed in July 1979 when approximately 700 feet of the panel had been mined. At this time, no subsidence was detected over the mined-out area of the first panel.

The second half of the first panel was monumented and the entire network surveyed in early September 1979. This provided initial monument positions for the second half of the network, as well as the third survey of the first half of the panel, which, by the end of September, had retreated 1,500 feet.

In September the decision was made to extend the monitoring program to the adjacent panels; however, early snowfalls made the site inaccessible and work over the second panel (6E) was delayed until the following spring. At this time (September), only 10 points had been located over the second panel. It was projected that panel 5E would be completed in another 8 months, based on the face advance per month for the first 3 months of mining; however, the face



FIGURE 13. - Monument installation with a gas-powered hammer.

advance increased by an average of 150 feet per month, and panel 5E was completed in 5 months. When the site again became accessible in 1980, the second panel had retreated 1,200 feet.

A complete survey on the first two panels, run in early July 1980, indicated that subsidence had progressed down the first panel during the winter months. In 1980, monuments were installed over panels 7E and 8E (fig. 2), and the baseline positions were established. Five additional surveys, including two direct level surveys, were run on the first two networks at monthly intervals into early December.

The site was accessible in 14 of the 28 months from September 1978, when preliminary field work on the project began, through December 1980. Field work was performed at the site in 11 of the 14 months, including 12 surveys on all or part of the monitoring network. Five of the twelve surveys were performed by the Bureau's contract surveyor during 1980; the remaining seven surveys were performed by Bureau personnel.

All network layout and installation was performed by the Bureau and required a total of 375 worker-hours. This included reconnaissance, control point location, subsidence monument stakeout, and monument installation. A total of 260 monuments have been installed over the four longwall panels. Additional monuments for direct strain measurements are being installed over the fourth panel during 1981. The seven traverse surveys performed by Bureau personnel involved 205 worker-hours. (Hour totals do not include the travel time involved in reaching the remote study site.)

Monitoring Procedures

The Deer Creek subsidence monitoring program was designed to measure both vertical and horizontal movement of the subsidence monuments. It was recognized that, although the initial and final monument elevations showing the final subsidence profile and the associated

horizontal strains were of prime importance, another objective of the study was to determine the timing and rate of subsidence development. This required several periodic surveys during the summer months when the site was accessible.

Based on the project objectives and the time and personnel constraints, it was determined that traverse surveys would be run by Bureau personnel during the first year of monitoring (1979). These surveys would provide both horizontal and vertical monument positions and allow the required number of surveys to be completed during the short field season. The Bureau was able to obtain a contract surveyor to perform approximately 50 percent of the surveys in 1980, and both traverse and direct level surveys were run on the monitoring networks.

The traverse surveys were run using an electronic distance-measuring instrument (EDM) and a second-order, optical-reading theodolite with micrometer readings of 1 second (fig. 14). The EDM accuracy is ± 0.02 foot +6ppm. For the traverse surveys, horizontal and vertical angles and slope distance were measured to each subsidence monument from instrument stations with known coordinates. The elevation and coordinates of the instrument stations were established from stable points beyond the influence of mining. To insure the stability of instrument stations located on nonsubsiding ground and to accurately determine the position of instrument stations located over the panels, a closed traverse survey was run through all instrument stations and control points as part of each survey.

To facilitate the surveying of the more than 250 subsidence monuments, a target mounting unit was built for use in performing the traverse surveys. This target unit (fig. 15), which holds a prism for distance measurement and a target for angle measurement, is clamped securely onto the subsidence pin and then leveled. The unit requires minimal setup time, is compact and lightweight, and provides a stable target at a constant height above the monument. The standard mounting stud

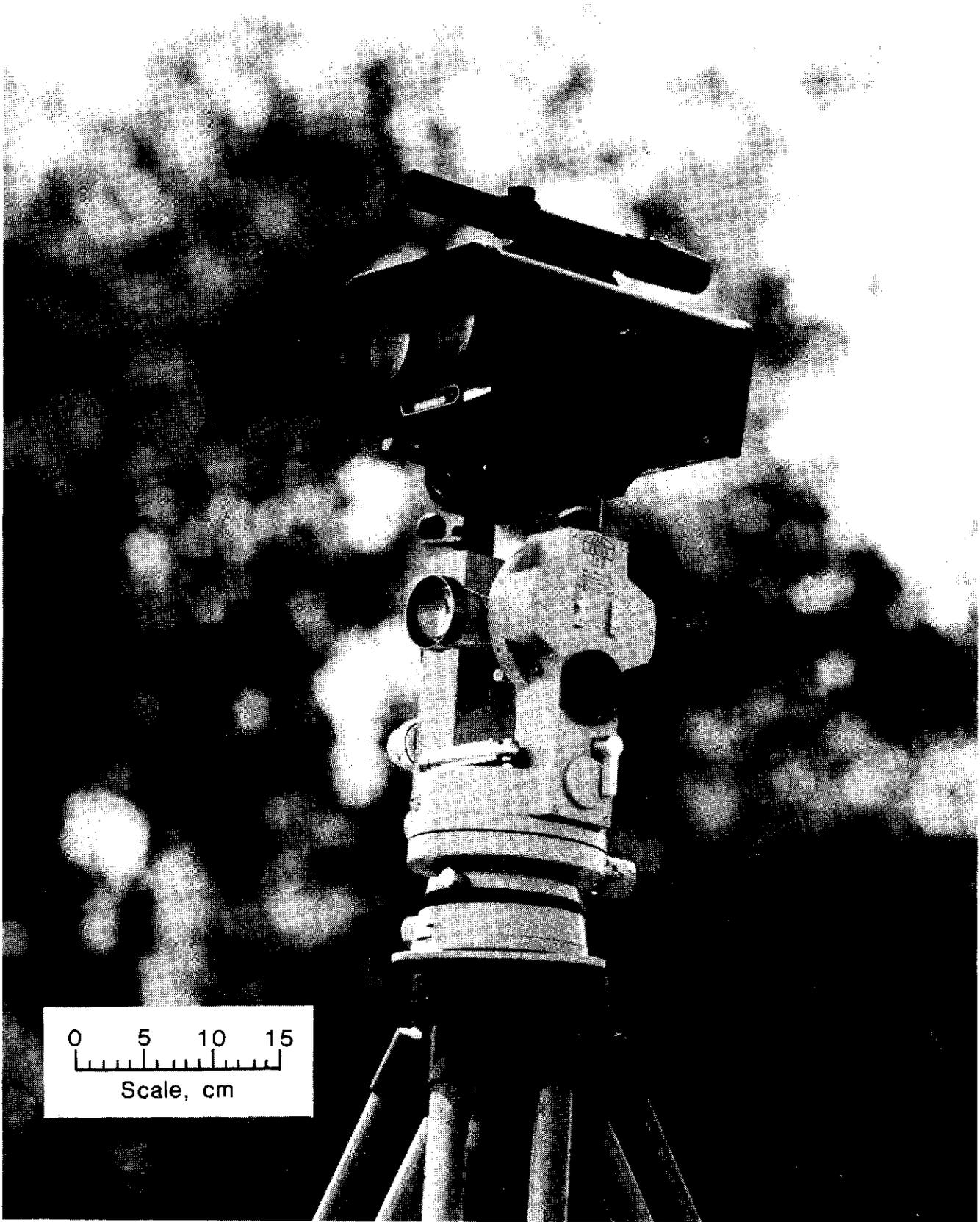


FIGURE 14. - Theodolite with distance meter.

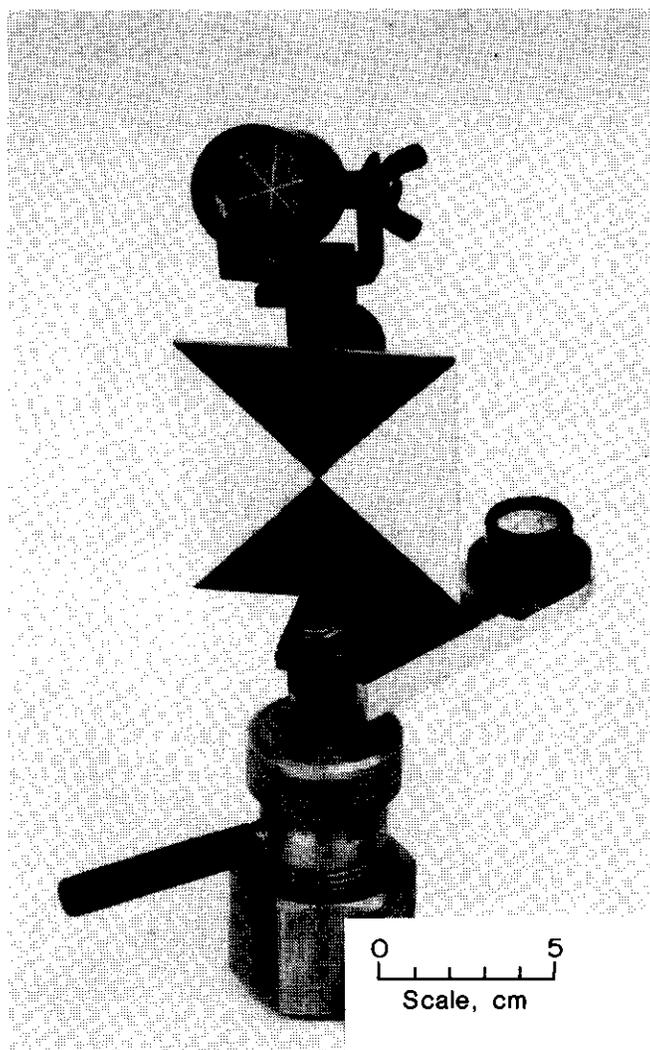


FIGURE 15. - Target-prism unit.

will accept any target assembly that may be required, as well as vertical extensions to improve visibility.

Beginning in 1980 with contract surveys, two standard, direct level surveys were run on the monitoring networks. These surveys were run to third-order accuracy using an automatic, self-leveling level and a level rod with 0.01-foot graduations (fig. 16). The accuracy of elevations from direct level surveys is greater than that from traverse surveys, which compute elevations from vertical angles and slope distance. The third-order level surveys have a maximum allowable closure error of 0.05 foot times the square root of the length of

the level line in miles ($0.05\sqrt{M}$), which resulted in a standard error calculated from several level surveys of 0.02 foot. The elevations computed from the traverse surveys yielded a standard error of 0.08 foot.

Although the direct level surveys produce more accurate results than the traverse surveys, consideration must be given to the substantial extra cost of running level surveys in addition to traverse surveys, which are required to obtain horizontal positions. Continued monitoring at the Deer Creek site will utilize both level and traverse surveys, with more emphasis placed on vertical displacement and thus the direct level surveys.

Measured Surface Subsidence

Longitudinal subsidence profiles for panels 5E and 6E are shown on figures 17 and 18, respectively. Results of the last two surveys, run in October and December 1980, indicate that subsidence was still occurring over both of the panels. Therefore, the final subsidence profile for the first panel (5E) cannot be determined until the surveys are completed in 1981. Similarly, the final profile for panel 6E will be determined in 1982.

To date, the maximum subsidence measured over the two panels was 2.7 feet, which occurred near the midpoint of the panel lengths and south of the 5E panel centerline toward the chain pillars between panels 5E and 6E. The maximum subsidence was approximately 27 percent of the extraction height. The subsidence contours as of December 1980 are shown on figure 19. The maximum subsidence measured over the centerline of panel 5E was 2.6 feet, while the maximum over panel 6E was 1.6 feet. Figure 17 shows a significant amount of subsidence occurring over panel 5E as panel 6E was mined during 1980. This indicates that subsidence will continue over panel 6E and increase as the adjacent panel (7E) is mined during 1981.

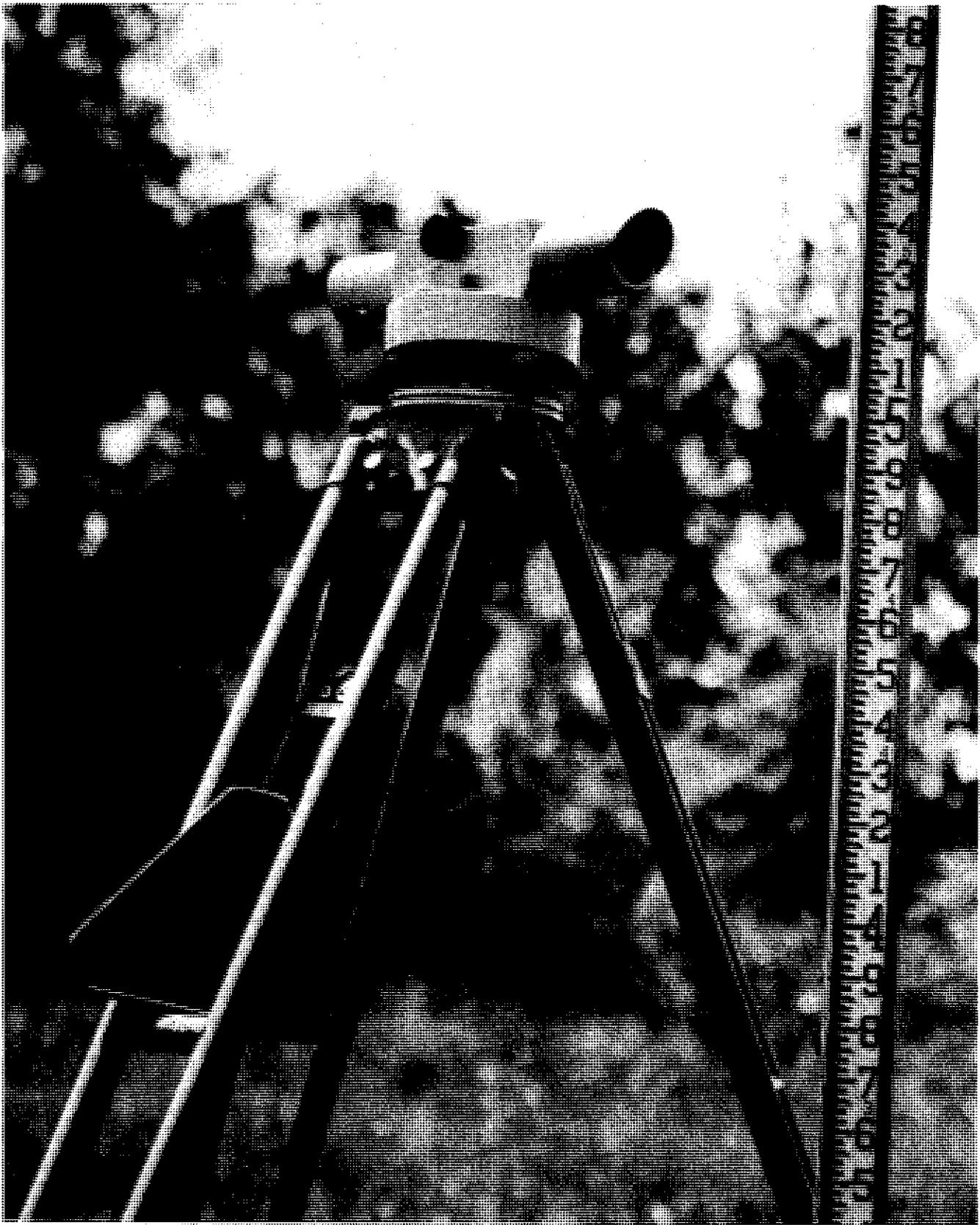


FIGURE 16. - Level instrument and rod with 0.01-foot graduations.

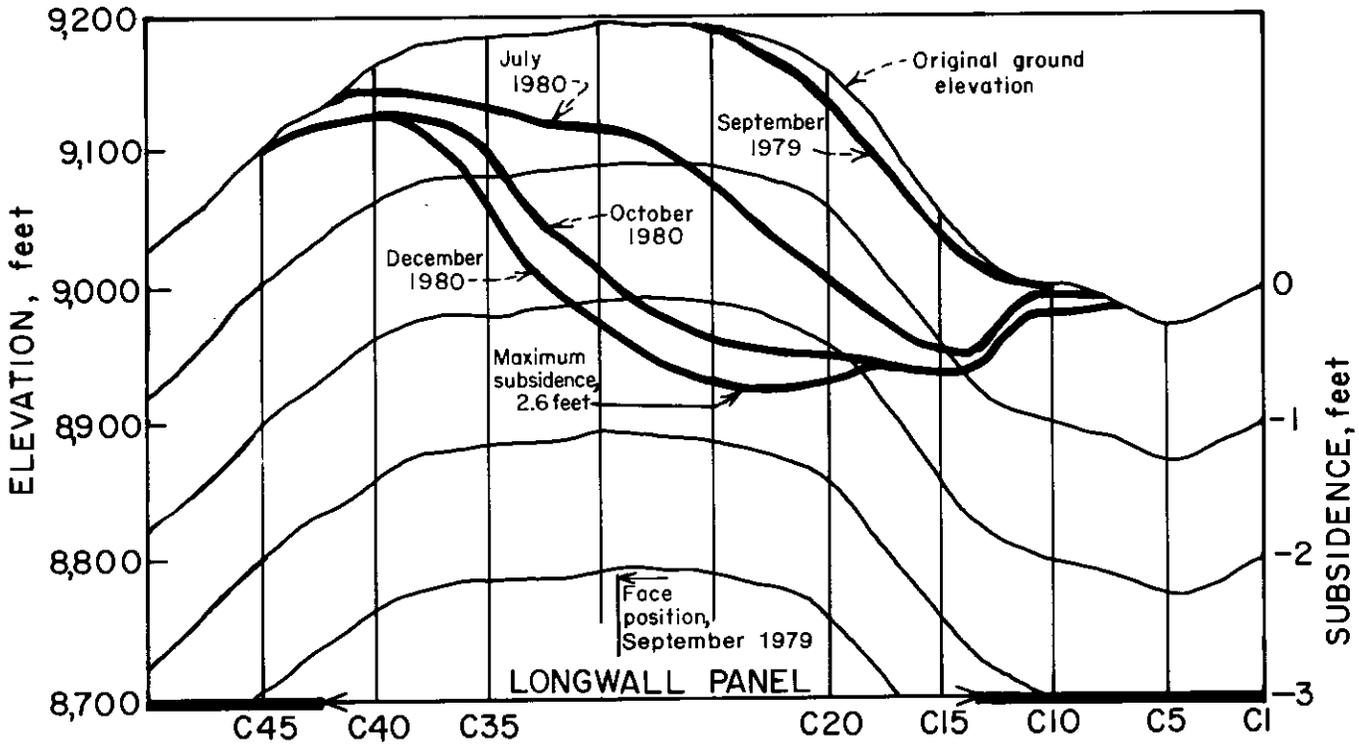


FIGURE 17. - Subsidence profiles—panel 5E.

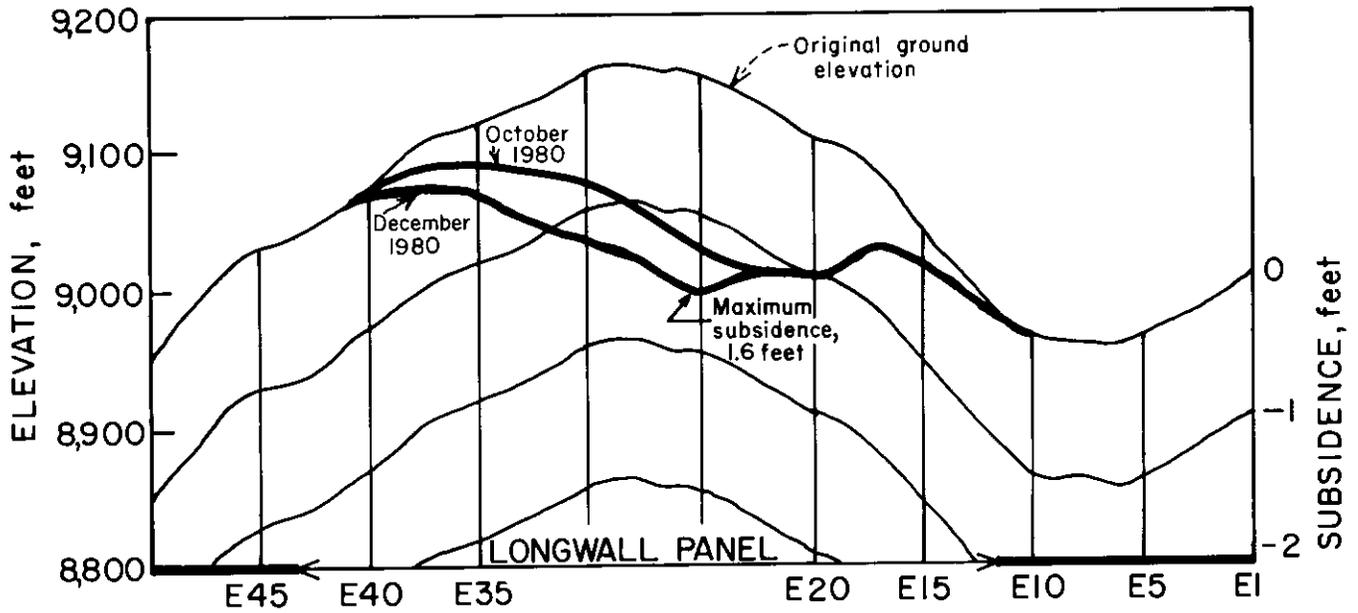


FIGURE 18. - Subsidence profiles—panel 6E.

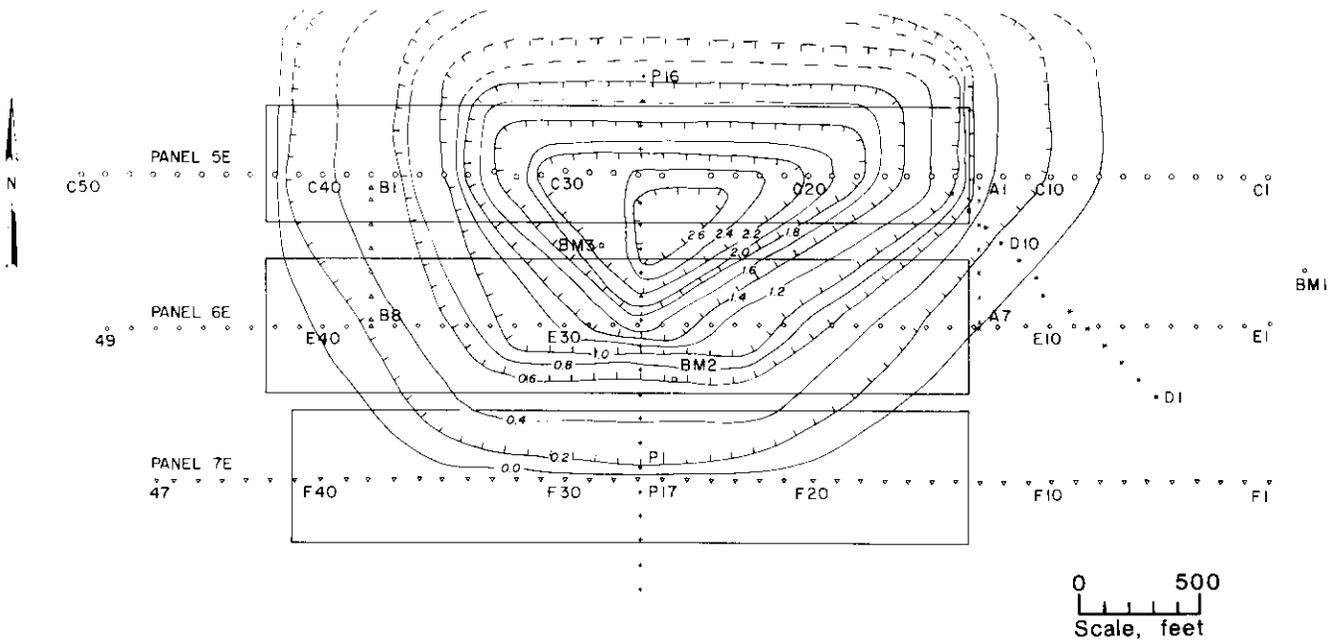


FIGURE 19. - Subsidence contours.

The two longwall panels completed to date have face lengths of 480 and 540 feet. The total mined width for the first panel, including two 20-foot entries, is 520 feet, which represents an average width-to-depth ratio of 0.36. This ratio is less than that required for maximum subsidence and thus assures a subcritical condition; that is, the width of the opening is insufficient to allow the maximum possible subsidence to occur. A subcritical condition is characterized by a U-shaped subsidence profile; whereas, a supercritical condition results in a flat-bottomed subsidence profile, in which more than one point near the center of the panel reaches maximum subsidence.

A subsidence profile across the two panels is shown on figure 20. The total mined width across both panels, including entries and chain pillars, is approximately 1,200 feet, which represents a width-to-depth ratio of 0.80. This total width also produces the characteristic subcritical U-shaped subsidence profile. At this point in the subsidence development, there was no evidence in the subsidence profile of the two rows of chain pillars between the two mined panels.

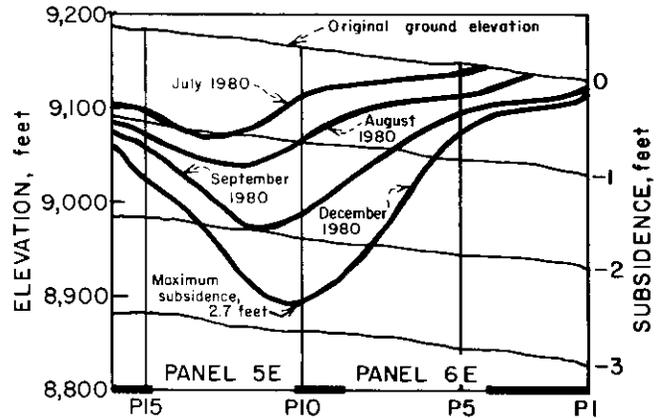


FIGURE 20. - Subsidence profiles across panels 5E and 6E.

Because subsidence was not complete over the west end of the panels at the time of the last survey, the east end of the first panel is the only location at which an angle of draw can be calculated at this time. As monitoring continues, there will be a minimum of 10 separate locations at which the angle of draw will be measured. The calculated angle of draw for the east end of panel 5E is 27 degrees from vertical. This figure is based on elevations from traverse surveys and will reflect the accuracy of this survey method. The angle of draw,

determined by the limit of subsidence beyond the panel, is extremely sensitive to surveying error; therefore, several measurements, including some with greater accuracy, will be required before the angle of draw for the Deer Creek site can be confidently stated. In addition, a major fault occurs beyond the east end of the panels in the area affected by the angle of draw. This fault could tend to decrease the angle of draw and may account for the 0.7-foot step in the subsidence profile between two adjacent points approximately 150 feet east of the panel. Continued measurements will also clarify the effect, if any, of this fault on the angle of draw.

Subsidence Development

The first indication of subsidence over panel 5E occurred in the September 1979 survey (fig. 17). When monument elevations were compared with those from the initial survey, the first 1,400 feet of the panel showed approximately 0.25 foot of subsidence. At this time, the long-wall face had retreated 350 feet beyond the last point of measured subsidence. The July 1979 survey had shown no subsidence over this panel, which indicates that the initial subsidence occurred between July and September 1979. At the midpoint of this time span, in August, the face had advanced 1,050 feet. At a minimum, the face had advanced 550 feet (as of July) before any subsidence was measured at the surface.

Following the September 1979 survey, the site became inaccessible until July, because of heavy snowfalls. Mining of the first panel (5E) was completed in December 1979. The next survey was performed on July 9, 1980. At this time, the subsidence over panel 5E had increased to a maximum of 1.6 feet and had progressed down the entire length of the panel. The adjacent panel (6E) had retreated approximately 1,400 feet at the time of this survey.

Between July and December 1980, subsidence continued over panel 5E, increasing in magnitude in the direction of mining.

During November 1980, there was no additional subsidence over the first 700 feet of panel 5E; however, continued settling of up to 0.4 foot occurred over the remainder of the panel.

Between July and December 1980, subsidence over panel 6E reached a maximum of 1.6 feet near the midpoint of the panel length (fig. 18). As with panel 5E, there was no additional subsidence over the first 700 feet of panel 6E during November 1980. Up to 0.5 foot of subsidence occurred during November over the second half of panel 6E, at the same position on the panel length as the 0.4 foot measured over panel 5E and mentioned above. Panel 6E was completed in December 1980, and third panel (7E) mining began in February 1981.

Data Processing

All calculations and much of the plotting from the subsidence surveys are performed by computer. Although the calculation of coordinates and evaluations from field survey notes is not complex, the large number of points included in each survey, along with the number of surveys to be performed over the duration of the study, makes computer calculation and data storage advantageous.

Field data from the subsidence surveys are typed into a computer file, printed out, and then compared with the field notes so that obvious errors can be edited prior to computing position coordinates for the subsidence points. The raw survey data for the traverse surveys entered into the computer file consist of station names, horizontal and vertical angles, slope distances, and the target and instrument heights. Before the subsidence point coordinates are computed, the instrument station positions are checked and adjusted if necessary. The northing, easting, and elevation of each subsidence monument is then computed and stored in a data file representing that particular survey. This information can be readily accessed and used as input for programs that perform calculations such as coordinate or elevation differences

between any two surveys. The coordinate data as well as the results of any calculations can be printed out or plotted depending on the nature of the results and the intended use. In addition, the raw input data from the field books are held in storage and can be printed out anytime questions arise involving the field data. If changes are required, the data can be edited and rerun to produce the corrected coordinate data.

Data input for the direct level surveys consists of station names and rod readings. The computer program calculates point elevations and closure errors and then adjusts the monument elevations accordingly. Resulting elevations are stored on file for access by other programs in the same manner as the results of the traverse surveys. The input data are also stored and can be recalled for checks and editing.

CONCLUSIONS

Planned subsidence monitoring over the Deer Creek Mine includes the surface area over four adjacent longwall panels. To date, only two panels have been mined; therefore, results presented herein are preliminary to the final subsidence conditions.

The maximum subsidence measured over the two mined longwall panels was 2.7 feet as of December 1980, some 27 percent of the extracted seam height. Subsidence was continuing over both panels at this time; therefore, the final subsidence profiles could not be determined. The preliminary estimate of the angle of draw is 27 degrees.

An appreciable impact of adjacent panel mining on the final subsidence profiles over previously mined panels has been established. The time lag between initial

mining and measurable subsidence, along with the time during which subsidence continues to occur, means that the adjacent panel is mined before the subsidence over the previous panel is complete. This interaction precludes isolation or definition of subsidence from mining a single panel.

Topography is not expected to influence the subsidence significantly because of the rolling nature of the terrain, with no abrupt changes in the overburden thickness relative to the depth of mining.

Through December 1980, there was no evidence of surface damage from subsidence over the two mined panels. No cracking or downwarping of the surface was visible during any of the surveys.