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Subsidence Resulting From Multiple-Seam Longwall Mining in the Western United States - A Characterization Study

United States Department of the Interior, Bureau of Mines

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Subsidence Resulting From Multiple-Seam Longwall Mining in the Western United States—A Characterization Study

By Robert C. Dynl

Mission: As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally-owned public lands and natural and cultural resources. This includes fostering wise use of our land and water resources, protecting our fish and wildlife, 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 assure that their development is in the best interests of all our people. The Department also promotes the goals of the Take Pride in America campaign by encouraging stewardship and citizen responsibility for the public lands and promoting 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.
Subsidence Resulting From Multiple-Seam Longwall Mining in the Western United States—A Characterization Study

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CONTENTS

Abstract ................................................................. 1
Introduction ......................................................... 2
Acknowledgments .................................................. 2
Deer Creek-Wilberg Mines study site ............................. 2
Stratigraphy ......................................................... 2
Regional geology .................................................. 2
Topography ......................................................... 3
Mine layouts ....................................................... 3
Subsidence monitoring program ................................. 11
Monitoring network layout ...................................... 11
Subsidence monument construction and installation ....... 11
Survey description and monitoring schedule .............. 11
Survey methods ................................................... 11
Survey schedule .................................................. 12
Data analysis .................................................... 13
Subsidence development ....................................... 13
Final values ...................................................... 14
Critical width ...................................................... 14
Angle of draw ..................................................... 15
Maximum subsidence ........................................... 15
Subsidence from 1985 through 1989 ........................... 18
Conclusions ....................................................... 19
References ......................................................... 20

ILLUSTRATIONS

1. Study site location map .......................................... 3
2. Generalized overburden stratigraphy ......................... 4
3. Regional geologic structures ................................... 5
4. Typical surface features ....................................... 6
5. Study site surface topography and monument network .... 6
6. Subsidence monument layout .................................. 7
7. Subsidence contours measured during mining of longwall panels at study site .......................... 8
8. Total station instrument ...................................... 12
9. Level instrument .............................................. 12
10. Subsidence development for Deer Creek and Wilberg panel midpoints ........................................ 14
11. Final subsidence configuration, September 1985 ....... 15
12. September 1985 subsidence profile ......................... 16
13. August 1989 subsidence profile ............................ 18

TABLE

1. Deer Creek-Wilberg Mines subsidence survey monitoring schedule ............................................... 12
INTRODUCTION

The problems associated with mine subsidence are multiplying as mining interests increasingly conflict with expanding surface development and environmental concerns. As a result, the coal mining industry requires improved technical methods to demonstrate that underground mining can be conducted in a manner that eliminates or controls subsidence-related material damage and meets approved postmining land-use requirements as regulated by the Surface Mining Control and Reclamation Act (SMCRA). In the Appalachian and Illinois coal regions of the United States, a tremendous amount of subsidence research has been conducted, and methods now exist to predict subsidence caused by underground mining in these regions. The behavior of subsidence over underground mining operations in these regions has been extensively researched and documented by various State and Federal research efforts, as well as by several universities (1-3).

The technology developed to predict and control subsidence in other regions of the United States, and other parts of the world where subsidence characteristics are defined and prediction methods have been developed, cannot be applied to mines in the Western United States because of significant differences in geology, topography, and mining conditions. Unfortunately, there is a lack of understanding of even the most basic subsidence parameters necessary to address prediction and control technology in western U.S. coal regions, mainly due to the lack of subsidence research. Subsidence research efforts in the Western United States have been initiated by the U.S. Bureau of Mines and other agencies and research organizations (4-5), but many of these studies are not complete. As a result, the behavior of subsidence over western underground mines is not well understood, forcing western mine operators to develop subsidence abatement plans that cannot be considered reliable.

In an effort to quantify the behavior of subsidence occurring over western U.S. underground mining operations, the Bureau initiated an extensive research program involving monitoring and evaluating subsidence over various longwall and room-and-pillar mining operations (6-11) and developed subsidence prediction models (12-15). This research program is to understand the characteristics of subsidence due to western U.S. underground mining, so that predictive and mitigative measures can be formulated and adopted that will ensure maximum resource recovery while protecting environmental concerns. The results of a portion of this research program have been previously published (7-4).

This report presents the complete analysis of the Deer Creek-Wilbert Mines multiple-seam longwall subsidence study area, located in south-central Utah. The study site is situated over 10 longwall panels from 2 overlying longwall mining operations, and was monitored from 1978 to 1985, with an additional survey taken in 1989.

ACKNOWLEDGMENTS

The Utah Power and Light Co. (UP&L) provided valuable assistance in conducting research. In particular, Rodger C. Fry, manager of Geology, and David R. Smallbone, director of Permitting, Compliance and Services, provided company field data and access to the study area. Without their assistance, this study could not have been conducted.

DEER CREEK-WILBERT MINES STUDY SITE

The Deer Creek-Wilbert subsidence study area is located on the Wasatch Plateau in central Utah approximately 10 miles west of Huntington (fig. 1). The study site area is located over the Deer Creek and Wilbert Mines; the Deer Creek Mine operates in the Blind Canyon coal seam, while the Wilbert Mine operates in the underlying Hiawatha coal seam (fig. 2). The separation of the two seams is approximately 50 ft.

STRATIGRAPHY

Drilling records provided by UP&L were used to determine the stratigraphic column overlying the two coal seams at the Deer Creek-Wilbert subsidence area. Generally, the overburden consists of sandstone and interbeds of siltstone and sandstone. Approximately 45 pt of the stratigraphic column consists of sandstone, with 35 pt of the sandstone occurring in thick beds. Figure 2 shows the generalized stratigraphic column for the subsidence area. A more detailed description of the regional stratigraphy can be found in reference 2. The massive Castlegate Sandstone layer was of particular interest, because it was not known how this layer would affect subsidence development, magnitude, or extent in the study area.

REGIONAL GEOLOGY

The Wasatch Plateau is a broad, linear sedimentary structure that lies in a general north-south orientation
The sedimentary layers dip slightly westward in the eastern portion of the plateau because of the presence of the west flank of the San Rafael Swell. The western portion of the plateau transitions into the Great Basin.

TOPOGRAPHY

Figures 4 and 5 show the general surface topography of the Deer Creek-Wilberg subsidence study area. It is generally rolling terrain with an average elevation of approximately 9,000 ft and a total elevation differential of approximately 400 ft. The ground cover consists of mostly sagebrush, with several large areas of pine and aspen.

MINE LAYOUTS

The subsidence study area is situated over portions of the Deer Creek and Wilberg Mines. Four Deer Creek longwall panels were monitored; the 5, 6, 7, and 8 East longwall panels were mined in the Blind Canyon coal seam. Six longwall panels from the Wilberg Mine were also monitored; the 6, 7, 8, 10, 11, and 12 Right longwall panels were mined in the Hiawatha coal seam, situated approximately 50 ft below the Deer Creek Mine workings. Figure 6 shows the positions of the Deer Creek and Wilberg panels monitored at the study area, including the subsidence monument lines and control points.

The four Deer Creek longwall panels were retreat mined, beginning with the 5 East panel, then the 6 East, 7 East, and ending with the 8 East panel. The 5 East panel was mined from May 1979 through December 1979, 6 East from February 1980 through January 1981, 7 East from February 1981 through March 1982, and 8 East from May 1982 through January 1983. The mining height of the four Deer Creek panels was 8 ft.

The six Wilberg longwall panels were also retreat mined, with 10 Right mined first, followed by 11 Right. As 11 Right neared completion, a second longwall system began to mine 8 Right. The first longwall then completed 11 and 12 Right, while the second longwall completed 8 and 7 Right. As mining progressed in 6 Right, a fire broke out and, as a result, the entire mine was sealed. The 10 Right longwall panel was mined from April 1982 through March 1983; mining began on this panel at approximately the same time that mining on the fourth Deer Creek panel in the study area, 8 East, began. The 11 Right longwall panel was mined from April 1983 through November 1983, 12 Right from February 1984 through August 1984, 8 Right from September 1983 through January 1984, 7 Right from March 1984 through September 1984, and 6 Right in November and December 1984. The mining height of the Wilberg panels averaged 8 ft; the northernmost 12 Right panel extraction height was approximately 7 ft, and the extraction height increased approximately linearly to 9 ft down to the southernmost 6 Right panel.

Figure 7 shows the sequence of panel extraction for both mines.
Figure 3.—Regional geologic structures.

Figure 4.—Typical surface features.

Figure 5.—Study site surface topography and monument network.
Figure 7.—Subsidence contours (1-ft intervals) measured during mining of longwall panels at study site—Continued.  F, October 1981; G, June 1982; H, November 1982; I, June 1983; J, October 1983.

Figure 7.—Subsidence contours (1-ft intervals) measured during mining of longwall panels at study site—Continued.  K, June 1984; L, September 1984; M, June 1985; N, September 1985. Panels correspond to those shown in figure 6.
SUBSIDENCE MONITORING PROGRAM

The subsidence monitoring network was designed to detect the subsidence that occurred in the study area by using a series of survey monument lines situated over various portions of the study area. Surveys of these monument lines were to provide the transverse and longitudinal profiles of subsidence occurring over the Deer Creek and Wilberg longwall panels. The main constraint on the network, therefore, was that each survey line be long enough to allow the limits of the subsidence profiles to fall somewhere inside the outer monuments in each line. An angle of draw of approximately 40° was chosen as the design limit for determining the extent of the survey lines.

MONITORING NETWORK LAYOUT

Figure 6 shows the Deer Creek-Wilberg subsidence monitoring network. The Deer Creek 5 East through 8 East longwall panels were monitored with survey lines that extended down their longitudinal axes and extended approximately 1,200 ft past the ends of the panels. (Details on the construction and installation of the survey monuments are provided later in this report.) These lines, designated as line C for 5 East, line E for 6 East, line F for 7 East, and line G for 8 East, were used to obtain overall longitudinal subsidence profiles of the four panels. The Wilberg 12 Right and 11 Right longwall panels were also monitored with longitudinal survey lines; line M was located over the 11 Right panel, and line N was over the 12 Right panel. The remaining Wilberg panels were not monitored using longitudinal survey lines, since the monuments used for the Deer Creek panels were close enough to the longitudinal centerlines to obtain the required information.

In addition to the longitudinal survey lines, two major transverse survey lines were installed to monitor the propagation of subsidence occurring normally to the longitudinal subsidence propagation. Line P was located over the midpoint of the four Deer Creek longwall panels and extended approximately 1,500 ft south of the lower boundary of the 8 East Deer Creek longwall panel. Line T was located over the midpoint of the 11 Right and 12 Right Wilberg panels, with the outermost monument located approximately 300 ft north of the upper boundary of the 12 Right panel. The remaining Wilberg panels were monitored using the survey lines installed for the Deer Creek longwall panels.

Several control points were installed to provide datums from which the survey network could be referenced. These control points are shown as "BM" stations in figure 6. Several control points were used, mainly to ensure that at least one stable (nonsubsiding) reference point was available for a datum. Cross-check surveys were periodically run between control points to verify stability.

SUBSIDENCE MONUMENT CONSTRUCTION AND INSTALLATION

Two types of subsidence survey monuments were used in the survey network. One design consisted of a 1-1/2-inch-diameter steel pipe, usually 6 ft long, with a bevel on one end to facilitate installation. The other design consisted of a 1-inch-diameter steel rod, usually 5 ft long, with a machined point on one end to facilitate installation. The steel pipe was used for lines C, E, F, G, and P; the steel rod was used for lines M, N, and T. The overall survey network was not installed at one time: lines C, E, F, G, and P were installed in 1978-79, while lines M, N, and T were installed in 1982. The steel pipe used to install the first portion of the network proved to be expensive and difficult to transport and install, so the decision was made to use the steel rod. Also, the price was approximately 50 pct less per unit than for the steel pipe.

Installation of the monuments was accomplished by simply pounding them to a depth of 3 to 5 ft with a gasoline-powered hammer or a sledgehammer. The pipes were cut off approximately 6 in above the ground surface if they could not be driven that far. The steel rods were easier to drive into the ground than the steel pipes; most steel rods were driven until approximately 6 in was left exposed. The primary reason for leaving such a small amount of the pipe or rod exposed above the ground surface was to minimize the effect of subsidence-induced heave. The equipment used for installing the monuments included a level, a transit, and a precision steel pipe, usually 1-1/2 in in diameter.

Surveying of the subsidence monuments was questioned with regard to the possible effects of frost heave. Although the frost penetration zone for the area is estimated at 2.5 ft, and the monuments were all driven well below that depth, there was some concern as to whether the monuments would be affected by seasonal ground shrinkage and swelling. A study of the vertical displacement data of stable (nonsubsiding) monuments, however, clearly showed that frost heave was not a problem. The vertical variance of the stable monuments fell well within the surveying accuracy used at the site.

SURVEY DESCRIPTION AND MONITORING SCHEDULE

Survey Methods

The subsidence monitoring network was surveyed using several different methods. To obtain precise horizontal coordinate values for each monument, as well as the BM stations, a surveying "total station" was used. The total station (fig. 8) is an electronic distance-measuring instrument coupled with a precision theodolite.

Vertical movement of the subsidence monitoring network was measured using third-order leveling procedures. The equipment used for this type of surveying consisted of an automatic, self-leveling level instrument and a level rod with 0.01-ft graduations (fig. 9). The accuracy of this type of surveying is greater than that of traverse surveys.

Survey Schedule

Table 1 shows the complete schedule of surveys taken at the Deer Creek-Wilberg subsidence study site. No surveys were taken in the winter or early spring months of any year during the study. Because of the remoteness of the site and the severe weather that accompanies winter and spring in the study area, the site was accessible only 7 months of the year. This slightly reduces the quality of the data set, but the overall trend of the subsidence propagation can still be gleaned from the data, and the impact of not surveying during these months is considered minimal.

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Note: Line designations correspond to those shown in figure 6.
DATA ANALYSIS

The data obtained from the surveys taken at the Deer Creek-Wilberg subsidence study site were transferred to personal computer (PC)-based computer files for reduction and analysis. A Bureau-developed survey calculation and subsidence data management computer program was developed to facilitate subsidence data analysis. The first step in the analysis was to transfer the survey data from the field notebooks to computer via the survey calculation program. Once the data were in the proper format, the subsidence data management computer program was used to prepare portions of the data for various analyses. These analyses consisted of organizing portions of the data into a suitable format for input into one of several computer programs available for two-dimensional and three-dimensional contour mapping and graphics software packages. After the data were presented graphically, all subsidence values of interest could be obtained.

SUBSIDENCE DEVELOPMENT

The first longwall panel mined at the Deer Creek-Wilberg study area was the 5 East longwall panel of the Deer Creek Mine. Subsidence was not detected over this panel until the face had retreated between 550 and 1,050 ft. Figure 7 shows the development of subsidence as a result of mining the four Deer Creek and six Wilberg longwall panels. The subsidence contours shown in this figure are 1-ft intervals; therefore, figure 7 shows no subsidence unless at least 1 ft of subsidence occurred. Also, the dashed-line contours in figure 7 indicate an approximate limit of the subsiding area. As would be expected, the point of maximum subsidence moved to remain centered over the approximate centroid of the mined area. Figure 10 shows the timing, rate, and duration of subsidence occurring over the midpoints of the Deer Creek and Wilberg longwall panels, except for the 6 Right Wilberg panel, as this panel was not directly monitored. Figure 10d shows the behavior of the ground surface above the midpoints of the four Deer Creek panels from the time before any mining occurred in the study area to when the study area temporarily stabilized in the summer of 1983 after Deer Creek mining was completed. Therefore, figure 10d illustrates the behavior of the Deer Creek panel midpoints subjected only to subsidence induced by mining at the Deer Creek Mine. It is apparent from figure 10d that subsidence occurring at this study area began to stabilize in August 1983. It is inferred, therefore, that if the underlying Wilberg panels had not been mined, the subsidence values shown in figure 10d would have been the maximum subsidence values for these particular points. Figure 10d shows that the time required for each survey monument to stabilize from the subsidence became progressively shorter from the first to the last panels to be mined.

Figure 10b shows the behavior of the ground surface at the midpoints of the 7, 8, 10, 11, and 12 Right Wilberg longwall panels. The subsidence originates at the time that the study area stabilized in the summer of 1983 and continues until the last survey was taken in the fall of 1985. Thus, the amount of subsidence shown in figure 10b is differential in that these survey points had already been subjected to significant amounts of subsidence due to the mining of the Deer Creek panels. This differential subsidence can be attributed to the influence of the mining of the Wilberg panels, since the Deer Creek subsidence had stabilized before the period covered in figure 10b.

Figure 10b shows that the ground surface over the midpoints of each of the Wilberg panels took approximately the same amount of time to undergo complete subsidence. This behavior is apparently contrary to the way the ground surface over the Deer Creek panel midpoints behaved when subjected to Deer Creek mining (fig. 10d). This difference is not surprising, however, because of the differences in mining sequence of the Deer Creek and Wilberg Mines. The four Deer Creek panels were mined sequentially, beginning with the 5 West panel and ending with 8 East (fig. 7d). The Wilberg panels, on the other hand, were not mined in such an orderly manner (fig. 7g-n), which probably accounts for the differences in subsidence development (fig. 10). It is possible that as the Deer Creek longwall panels were sequentially mined the overburden induced surface movement had already occurred.

The eventual collapse of the bridging overburden layers caused by excessive span distances would likely result in more rapid subsidence development and stabilization than if the overburden were simply to continue to bridge and gradually sag. The fact that the behavior of the ground surface was different for the Wilberg mining can also be explained by the mining sequence and the response of the overburden. Adjacent panels were not mined in sequence in the Wilberg Mine: Mining occurred concurrently in two areas of the study site (fig. 7g-n). Thus, any correlation between time required for stabilization and extraction sequence for the Deer Creek panels could not be applied directly to the Wilberg panels. Also, assuming that the overburden was already fractured and not bridging because of the effects of the previous Deer Creek mining, the overburden response to Wilberg mining would likely be more uniform and independent of extraction sequence.

The subsidence behavior that occurred at the Deer Creek-Wilberg study site does not reflect the behavior found in other mining regions. The National Coal Board's "Subsidence Engineers' Handbook" (6), often used by mining operators in the United States for general subsidence characterization guidelines, states that subsidence normally occurs when the face of a longwall panel is within about three-quarters of the overburden depth of the first subsiding panel. This is obviously not the case here; subsidence was first detected over the Deer Creek 5 East longwall panel at approximately the location of monument C13, which is actually behind the location of face advance. Also, it has been shown in other mining regions that subsidence over a particular point is complete when the face has advanced a distance of approximately 70 pct of the overburden depth in front of the first stabilized ground surface point (6). Again, the behavior of subsidence at the Deer Creek-Wilberg study area completely contradicts this theory; subsidence at the site continued well beyond this limit.

Figure 10—Subsidence development for Deer Creek (a) and Wilberg (b) panel midpoints.

FINAL VALUES

Figures 7v and 11 show the final orientation of the subsidence caused by mining all panels in the study area in 1985. The network was apparently stabilizing in 1985; based on the subsidence values of subsiding monuments in the network, subsidence had decreased to less than 0.15 ft/y. This would indicate that all active subsidence had ended, and all that remained was simply residual subsidence.

Critical Width

Critical width is defined as the width (w) of a mined panel required to cause the complete subsidence (S_{com}) of exactly one point on the ground surface. A supercritical width (w is greater than the critical width) causes more than one point on the ground surface to undergo complete

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Maximum Subsidence

Before discussing the maximum values of subsidence that occurred at the Deer Creek-Wilberg subsidence study area, it is important to distinguish between the definitions of maximum subsidence and maximum possible subsidence. Maximum possible subsidence, as defined by the National Coal Board's 'Subsidence Engineers' Handbook' (6), is the maximum possible value of vertical movement of a point on the surface caused by mining a critical (or supercritical) area. Since the study area is believed to be subcritical, no conclusions about maximum possible subsidence (or subsidence factor as calculated from the maximum possible subsidence) can be made. Maximum subsidence, however, is defined as the maximum vertical movement caused by mining a subcritical area. Therefore, the following discussion of maximum subsidence and subsidence factors assumes that these values were governed by subcritical mined areas.

The maximum subsidence that occurred through 1985 at the Deer Creek-Wilberg subsidence study area was 11.6 ft; this value occurred at location P3. The subsidence factor calculated for the maximum subsidence location when the study area temporarily stabilized in 1983 was 0.68, or, in other words, 68% of the extraction height was seen as subsidence on the surface. The subsidence factor calculated for the maximum subsidence location at the end of 1985 was 0.73. This result indicates that the subsidence factor was influenced by mining a second seam in the study area. Although it may be reasonable to assume that the subsidence factor is dependent only on the material properties of the overburden and the total areal extent of the mined void, the results obtained at this site indicate that additional factors govern the magnitude of the subsidence factor. A logical additional parameter for formulating subsidence factor would be the behavioral characteristics of the overburden after being influenced by...
the upper Deer Creek longwall panels. Obviously, the condition of the overburden was changed by Deer Creek mining, so the characteristics of the overburden when subjected to the Wilberg mining may have been significantly different, which might account for the different subsidence factor.

**SUBSIDENCE FROM 1985 THROUGH 1989**

A final survey of the Deer Creek-Wilberg subsidence study area was conducted in August 1989, to detect any further subsidence occurring in the area since the last survey in 1985. The center portion of the study area, monitored by lines C, E, and F, did not experience any detectable movements. The portions of the study area monitored by lines G, M, N, and T, however, each continued to subside to varying degrees (fig. 13). This is not surprising, since the last portions of the study area to be undermined were in these areas. The 12 Right, 7 Right, and 6 Right Wilberg longwall panels were the last panels in the area to be mined; it was in these areas that the largest amount of continuing subsidence was detected in 1989. Line G subsided an additional 0.8 ft at location G20; line M subsided 0.4 ft at location M34; line T subsided 3.9 ft at location T12; and line N subsided 2.6 ft at location N35.

The line G profile (fig. 13A) is not the smooth, predictable profile normally seen; rather, the profile is slightly irregular, with the maximum value of subsidence not occurring at the midpoint of the line (as was found

![Figure 12: September 1985 subsidence profile—Continued. G, Line M; H, line N; I, line T.](image1)

![Figure 13: August 1989 subsidence profile.](image2)
in all surveys through 1985). This is explained by analyzing the influence of the 6 Right Wilberg longwall panel. The 6 Right panel was forced the maximum value away from the midpoint of the 7 Right panel (location G26), and has moved to it location G29, which is much closer to the midpoint of the 6 Right panel. If 6 Right had not been mined at all, the line G profile probably would have experienced maximum subsidence at approximately G26.

From 1985 to 1989, the profiles of lines M, N, and T were influenced mostly by the mining of an additional Wilberg longwall panel located immediately to the north of 12 Right. This panel, Wilberg 13 Right, was not monitored as part of this study. Mining of 13 Right began in September 1984, after the completion of 12 Right. Mining of the Deer Creek panels was completed in December 1983, and the panel mined in 1984 did not cause any detectable subsidence in the study area, how­ever, it is likely that the subsidence resulting from mining 13 Right influenced the line M profile.

The entire line N profile (fig. 13C) subsided from 1985 to 1989. N35 subsided 2.6 ft, while N65 subsided 0.3 ft. Owing to the close proximity of line N to the 13 Right longwall panel, most of the subsidence occurring at the line N location was likely a result of mining the 13 Right panel, while a smaller portion of the total subsidence was due to continued settlement caused by mining 12 Right. Line T (fig. 13D) subsided 3.9 ft at location T12; location T12 is located between the 12 and 13 Right Wilberg longwalls, so subsidence was apparently influenced by both panels. Since a portion of line T is situated over the 13 Right panel mined in 1987, the majority of movement experienced by line T was probably due to the 13 Right panel. This explanation is further validated by the fact that subsidence caused by the 7 and 6 Right panels, mined approximately when the 12 Right panel was mined, was only 0.8 ft in magnitude, as shown by the 1989 line G profile.

**CONCLUSIONS**

The Bureau monitored the Deer Creek-Wilberg multiple-seam longwall subsidence study area from 1979 to 1985; an additional survey was conducted in 1989. When the study area temporarily stabilized in 1983 (2.2) after the four Deer Creek longwall panels had been pulled, approxi­mately 315 acres of ground surface were affected by the resulting subsidence. In 1985, when the study area again stabilized after all Wilberg panels in the study area were pulled, approximately 476 acres of ground surface were affected. The maximum subsidence occurring at the study area was 11.6 ft; however, no visible damage to the ground surface was detected. No apparent changes in vegetation, ground surface features, or drainage patterns were found. No cracks were discovered, presumably because of the unconsolidated nature of the immediate topsoil and its ability to shift and fill when exposed to ground surface movements. The portion of the study area undergoing the greatest amount of subsidence was barren of trees and tall shrubbery, so no visible tilting or deformation of vegetation was observed.

When the Deer Creek site temporarily stabilized in 1983, the time required for the area to stabilize was approximately 46 months. As the Wilberg panels were mined, the time for stabilization increased to approxi­mately 73 months, or an additional 27 months from the temporary stabilization. Results show that as the four Deer Creek panels were sequentially mined the time required for stabilization over those panels subsequently diminished. In other words, the subsidence over the first Deer Creek panel to be mined took the longest to stabil­ize, and the subsidence occurring over the last Deer Creek panel to be mined took the shortest amount of time to stabilize. Results also show that the subsidence due to mining the six Wilberg panels did not display the same behavior as was seen for the Deer Creek Mine subsidence. This is probably attributable to the fractured state of the overburden after being undermined by the Deer Creek panels and to the nonsequential order of the Wilberg panels.

The subsidence factor found for the study area when subsidence caused by mining the upper Deer Creek Mine panels temporarily stabilized in 1983 was 0.66. When the study area again stabilized in 1985 after the underlying Wilberg panels were mined, the subsidence factor increased to 0.73. The amount of subsidence measured on the ground surface at the study area was therefore not a constant value for each of the two seams, as might be expected, but rather was a function of multiple-seam effects.

The Castlegate Sandstone may also influence other subsidence parameters, such as angle of draw, areal extent, or maximum subsidence, at the site to a significant degree, but no specific analyses of overburden were conducted in this study.

This report summarizes findings regarding the charac­teristics of multiple-seam longwall coal mine subsidence. The data collected from this study cannot be used alone to predict subsidence in the Wasatch Plateau region of the United States. Continued data collection and research will provide further insight into the mechanics of subsidence and how subsidence develops in response to underground mining in the West. This particular study only evaluated the surface response to multiple-seam longwall subsidence, and did not address overburden contributions to subsidence behavior. The results of this study, however, provide meaningful insight into the behavior of multiple­seam subsidence in western U.S. conditions, and while these results are used in conjunction with more detailed studies, subsidence prediction should be possible.

**REFERENCES**


