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Surface Subsidence Over Longwall Panels in the Western United States—Final Results at the Deer Creek Mine, Utah

By Frederick K. Allgaier

UNITED STATES DEPARTMENT OF THE INTERIOR

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

ft	feet	pct	percent
in	inch	yr	year

SURFACE SUBSIDENCE OVER LONGWALL PANELS IN THE WESTERN UNITED STATES–FINAL RESULTS AT THE DEER CREEK MINE, UTAH

By Frederick K. Allgaier[1]

ABSTRACT

This report presents the final data from a 5-yr Bureau of Mines study designed to determine the surface subsidence characteristics resulting from longwall coal mining in a geologic environment common to the Western United States. It includes a description of the geologic setting of the study site, the mine plan, measurement techniques, and results of the monitoring program. Measured subsidence values were obtained over four adjacent longwall panels. Major subsidence characteristics such as longitudinal and transverse profiles, angles of draw, time-related subsidence development, and critical width are discussed. The maximum subsidence value of 5.8 ft was 68 pct of the mining thickness. The average angle of draw was 30°. Subsidence at the center of the first panel continued for 46 months following undermining. The lengths of the longwall panels precluded a definitive determination of the critical width and maximum possible subsidence.

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INTRODUCTION

This report is the second and concluding part of a Bureau of Mines study of surface subsidence characteristics resulting from longwall coal mining at the Deer Creek Mine in Emery County, UT. The first part was published as Bureau Information Circular (IC) 8896, entitled "Surface Subsidence Over Longwall Panels in the Western United States. Monitoring Program and Preliminary Results at the Deer Creek Mine, Utah."[2] The study involved the measurement of surface movements above the Deer Creek Mine, owned by Utah Power and Light Co. (UP&L), Salt Lake City, UT. Geologic and mining information was supplied by UP&L.

An objective of the Bureau's subsidence research program is to provide a means of predicting surface subsidence so as to maximize resource recovery while conserving surface land values. In order to adequately characterize subsidence in the United States and develop predictive technology, data must first be obtained from a sufficient number of representative sites. The mining and geologic conditions at the Deer Creek Mine are representative of many western coal mines; therefore, the results of this study are expected to be applicable to other western mining areas.

The minimal amount of subsidence data available from the Western United States is due to a lack of research efforts. In many cases, data obtained by mining companies may not be available to other researchers. There are very few published case history subsidence investigations from active mining areas in the Western United States. This limited availability and distribution of subsidence information and data have hindered both the development of subsidence technology, and the efforts of mining companies to comply with the Surface Mining Control and Reclamation Act. The data from this study can be used to develop new prediction methods or to modify existing methods so that more accurate estimates can be made of subsidence under similar conditions in the Western United States.

ACKNOWLEDGMENTS

The Utah Power and Light Co. provided valuable assistance in conducting this research. In particular, Don Dewey, Director of Special Projects, Chris Shingleton, Director of Technical Services, and Rodger Fry, Director of Exploration, 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.

DEER CREEK MINE STUDY SITE

The Deer Creek Mine is located on the Wasatch Plateau in central Utah approximately 10 miles west of the town of Huntington (fig. 1). The study site area is located over four adjacent longwall panels. The surface elevation of the study area averages 9,100 ft, and the topography is generally rolling, with a maximum ground slope of 45 pct.

Two major coal seams are being mined in this area, the Blind Canyon and the Hiawatha. The Deer Creek Mine is located in the Blind Canyon coal seam which is approximately 50 ft above the Wilberg Mine in the Hiawatha coal seam.

The overburden consists mostly of sandstones and interbeds of siltstone and sandstone. The total percentage of

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[2]Allgaier, F. K. Surface Subsidence Over Longwall Panels in the Western United States. Monitoring Program and Preliminary Results at the Deer Creek Mine, Utah. BuMines IC 8896, 1982, 24 pp.

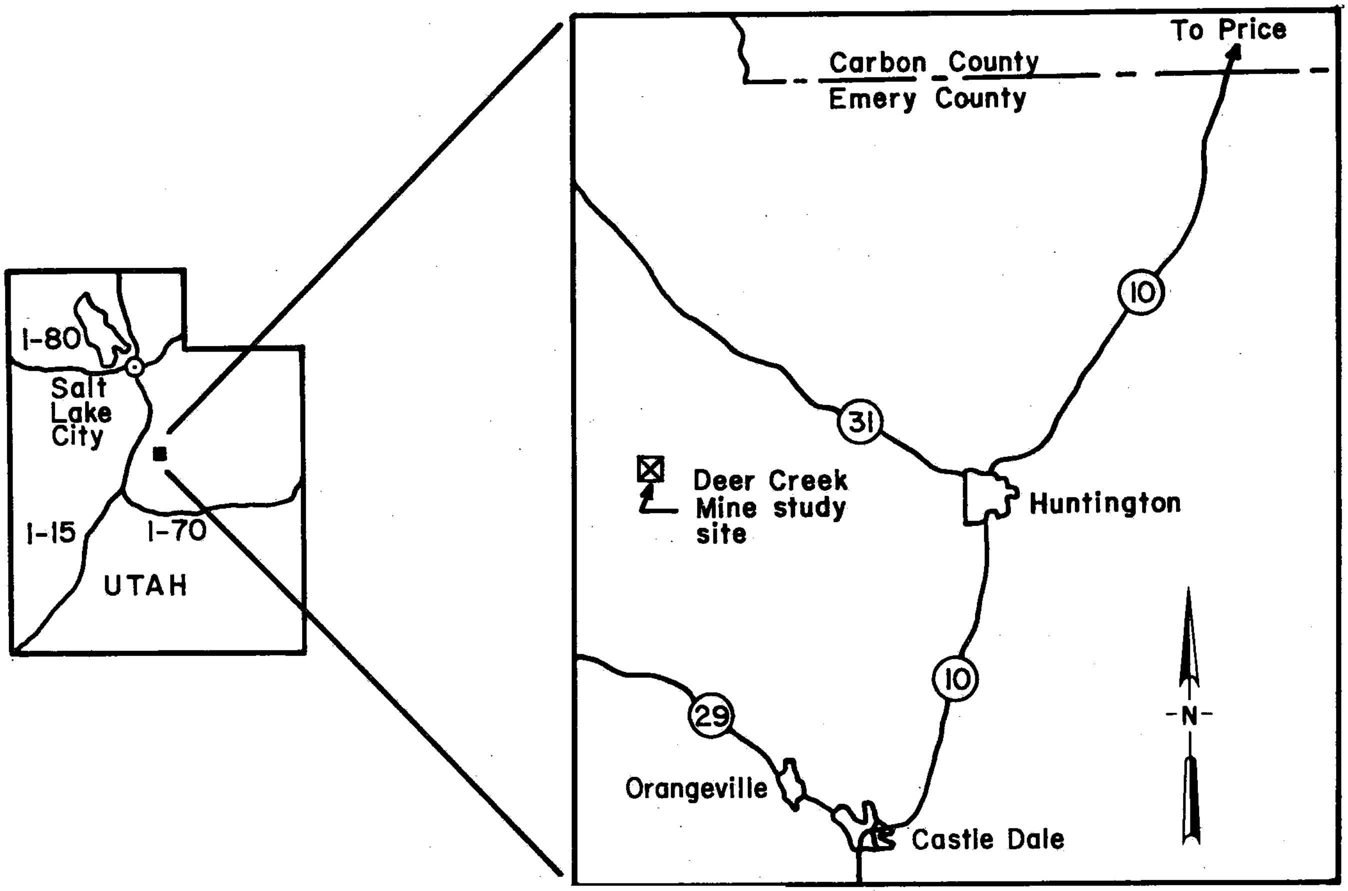

FIGURE 1.—Project location map.

sandstone in the overburden is 45 pct, with 35 pct occurring in thick beds (fig. 2). The Deer Creek Fault is located near the east end of the study panels; however, there are no faults crossing the panels (fig. 3).

DEER CREEK MINE PLAN

The mine plan for the portion of the Deer Creek Mine involved in this study consists of four adjacent longwall panels that were retreat mined from east to west in the sequence 5E through 8E (fig. 4). There were room-and-pillar sections mined to the north (4E) and south (9E) of the longwall panels. To the north of panel 5E, section 4E was mined with a total mining height of 10 ft. Section 4E was mined prior to panel 5E. Pillars were not mined in section 4E, and the extraction was 52 pct. North of section 4E was a 200-ft-wide barrier pillar and then another room-and-pillar section, 3E, which had an extraction of 50 pct. South of panel 8E, a room-and-pillar section, 9E, was mined after completion of the longwall panel 8E. Panel 8E was completed in January 1983, and section 9E was completed in January 1984. The extraction in section 9E was 52 pct. Subsidence over panel 8E stabilized prior to any effect from mining in 9E. The four longwall panels involved in this study were partially undermined by longwall panels in the Wilberg Mine after subsidence measurements were completed. Undermining began below panel 5E in April 1982. The transverse line of subsidence monuments was undermined in November 1982. The data presented in this report

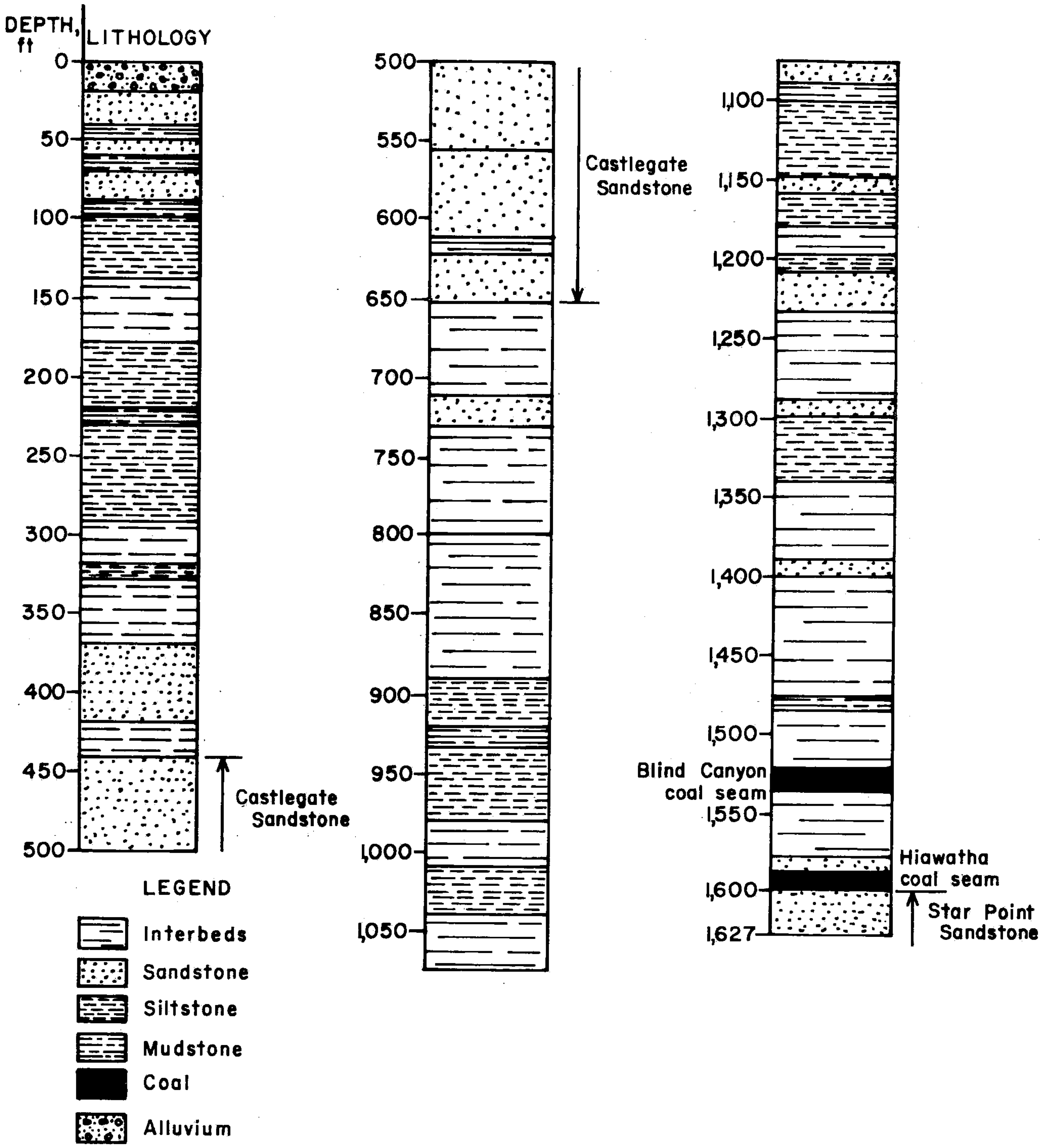

FIGURE 2.–Generalized overburden stratigraphy.

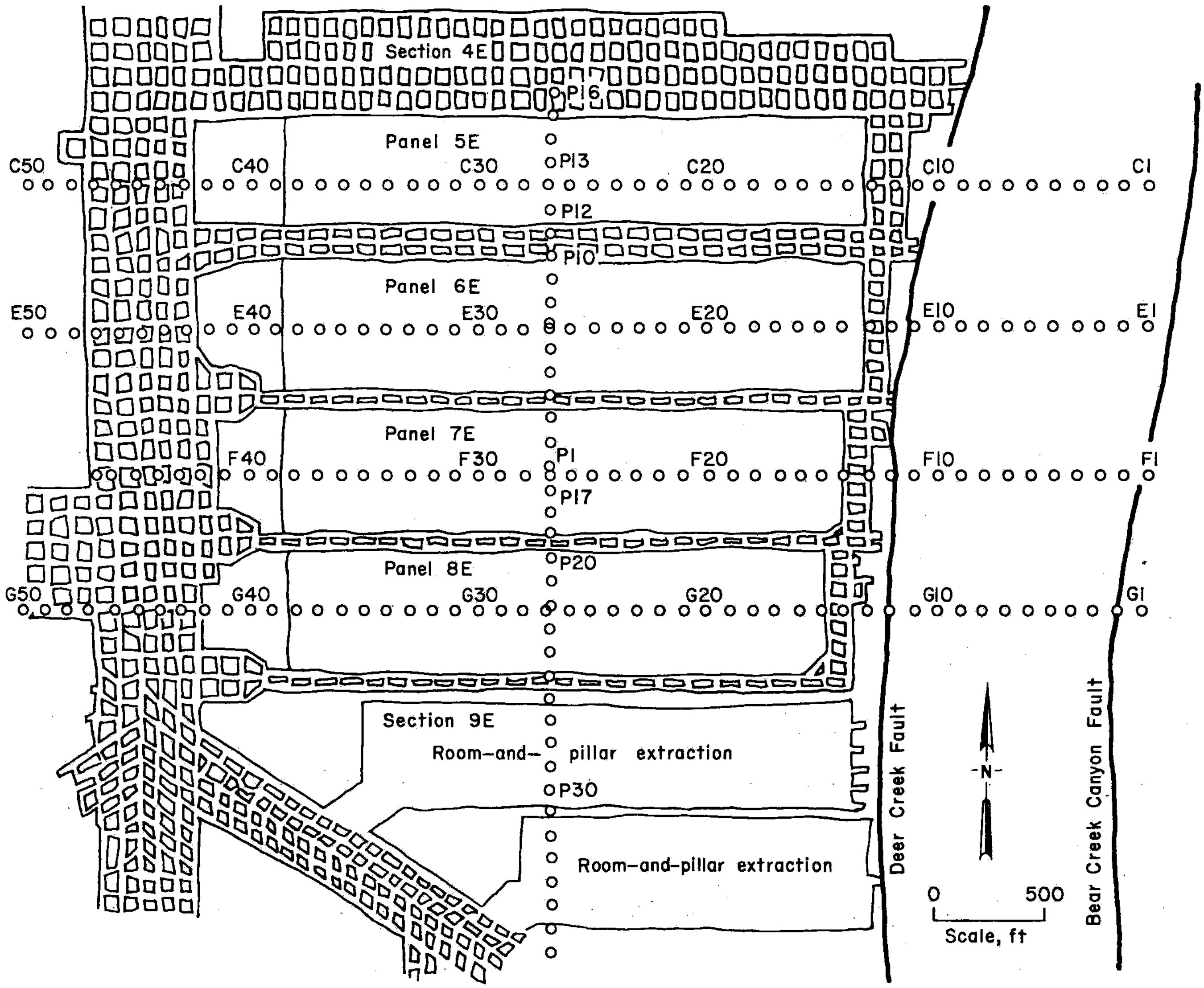

FIGURE 3.–Deer Creek Mine plan with subsidence monuments shown as dots.

were obtained prior to surface movements caused by mining in the lower seam and do not include any multiseam effects.

Panel 5E was developed using three entries; the remaining three panels were developed with two entries. Entries 18 ft wide were driven on 50-ft centers with crosscuts on 100-ft centers. Dimensions of the mined areas of the four panels are as follows: 5E, 480 by 2,500 ft; 6E, 540 by 2,500 ft; 7E, 500 by 2,450 ft; and 8E, 520 by 2,300 ft. The average depth cover over the four panels was 1,500 f Mining in panel 5E began in December 1979, and panel 8E was completed in January 1983. Face positions for each month during the mining period are shown in figure 4. The average distance the face moved per month in the four panels was 220 ft, including the time it took to move equipment between panels.

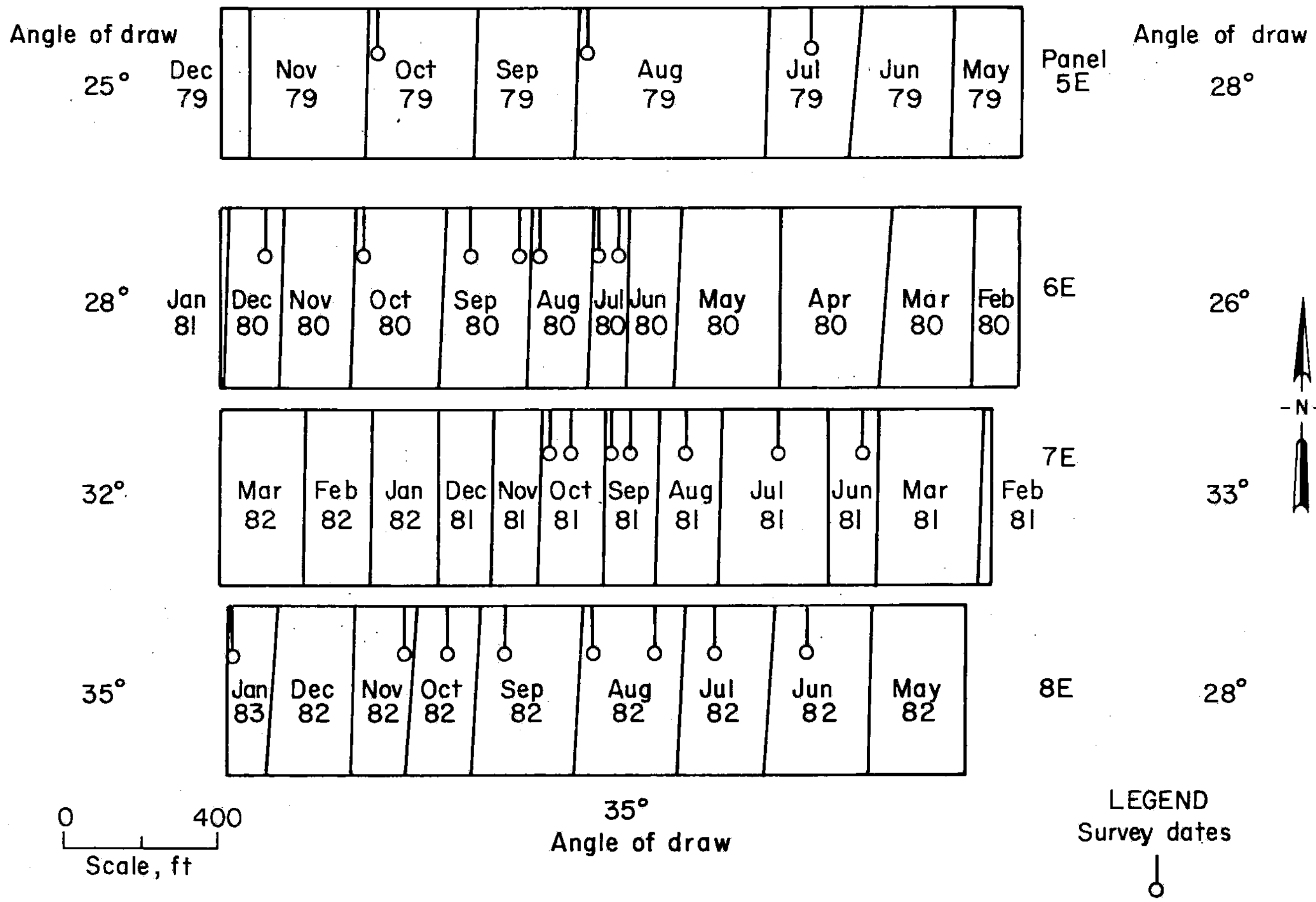

FIGURE 4.—Face positions and survey dates.

SUBSIDENCE MONITORING NETWORK

The subsidence monitoring network consists of lines of survey monuments located over the longitudinal axis of each panel and a transverse monument line across the centers of the panels (fig. 3). Monument spacing was 100 ft except over panel 8E, where 50-ft spacing was used over the edges of the panel. The purpose of the reduced spacing was to provide a comparison of angle-of-draw calculations for 50- and 100-ft monument spacings.

Subsidence monuments were constructed of either 1-in-diam steel rods or 1.5-in-diam steel pipes. Monuments were driven to a depth of between 3 and 4 ft, depending on the depth of the soil cover. Approximately 6 in of the monuments extended above the ground to accommodate the survey target used in the horizontal position surveys. Vertical movement of the monuments due to frost heave or other local soil conditions did not exceed 0.03 ft, the accuracy of the elevation surveys. This value is the average standard deviation of the elevations for all nonsubsiding monuments over the duration of the project. Any vertical movement of the monuments not caused by subsidence was less than this value.

SUBSIDENCE MONITORING SURVEYS

Initial base line locations were determined following installation of the subsidence monuments and prior to any subsidence activity. Horizontal coordinates for each monument were established by traverse survey procedures from control stations with known coordinates, which were located on stable ground beyond the subsidence areas. Traverse surveys were used only when horizontal coordinates were required in addition to elevations. The majority of the periodic surveys conducted during subsidence activity needed only to establish elevations for the subsidence monuments. For these surveys, elevations of the monuments were determined using third-order direct level surveying techniques.[3] Closed loops were run from a stable control point into the subsidence area and then back to the control point.

Periodic monitoring surveys were performed on a monthly basis while the site was accessible during the summer months; the site was typically inaccessible from November to June because of snow cover. The lack of data for these time intervals did not adversely affect the overall results of the project because adequate data were obtained during the summer months over the 5-yr monitoring period to establish the subsidence profiles. A total of 26 surveys were conducted during the study, including a baseline survey prior to mining (fig. 4).

Data from each survey were stored as separate computer files, which were compared to other surveys to produce numerical records of the subsidence, such as coordinate or elevation differences, or were plotted as subsidence profiles, subsidence contours, plan plots of the monitoring network, and horizontal vector plots. Additional details on the surveying techniques, equipment, and accuracy are contained in the preliminary report on this study, published as Bureau IC 8896.

SUBSIDENCE PROFILES

The final longitudinal subsidence profiles for panels 5E, 6E, 7E, and 8E are shown in figure 5, and the final transverse subsidence profile across the midpoints of the panel lengths is shown in figure 6. Data for these profiles are contained in the appendix.

The maximum subsidence measured over the four panels was 5.8 ft, which occurred over panel 6E at station P6 on the transverse monument line. This point is approximately 200 ft north of the center of the four panels. The 5.8 ft represents 68 pct of the average extraction height of 8.5 ft over the four panels.

It is apparent from the transverse subsidence profile crossing the four panels (fig. 6) that the chain pillars between panels crushed out to some degree and did not significantly reduce the subsidence above the pillars. There are no characteristic undulations or bumps in the subsidence profile that would occur above the pillars if they remained stable.

The maximum change in overburden depth due to topography is 175 ft along the panel lengths and 160 ft across the panel widths. Figure 7 shows the surface elevations over panel 6E, which is typical of the overburden variations over the four panels; maximum overburden occurs near the center of the panel lengths and decreases toward both ends. Figure 8 shows the overburden variation across the panels. The maximum overburden occurs over panel 5E and the minimum over panel 8E; the elevation difference is approximately 160 ft. This difference is approximately 11 pct of the average overburden depth and should have little effect on the magnitude of subsidence or the shape of the subsidence profile. For example, using the National Coal Board (NCB) prediction method,[4] this change in overburden across a 1,500-ft-wide opening would change the subsidence factor by only 0.005.

[3]U.S. Department of Commerce. Classification, Standards of Accuracy, and General Specifications of Geodetic Control Surveys. Rockville, MD, June 1980, 12 pp.

[4]National Coal Board, Production Department. Subsidence Engineers' Handbook. London, 1975, 111 pp.

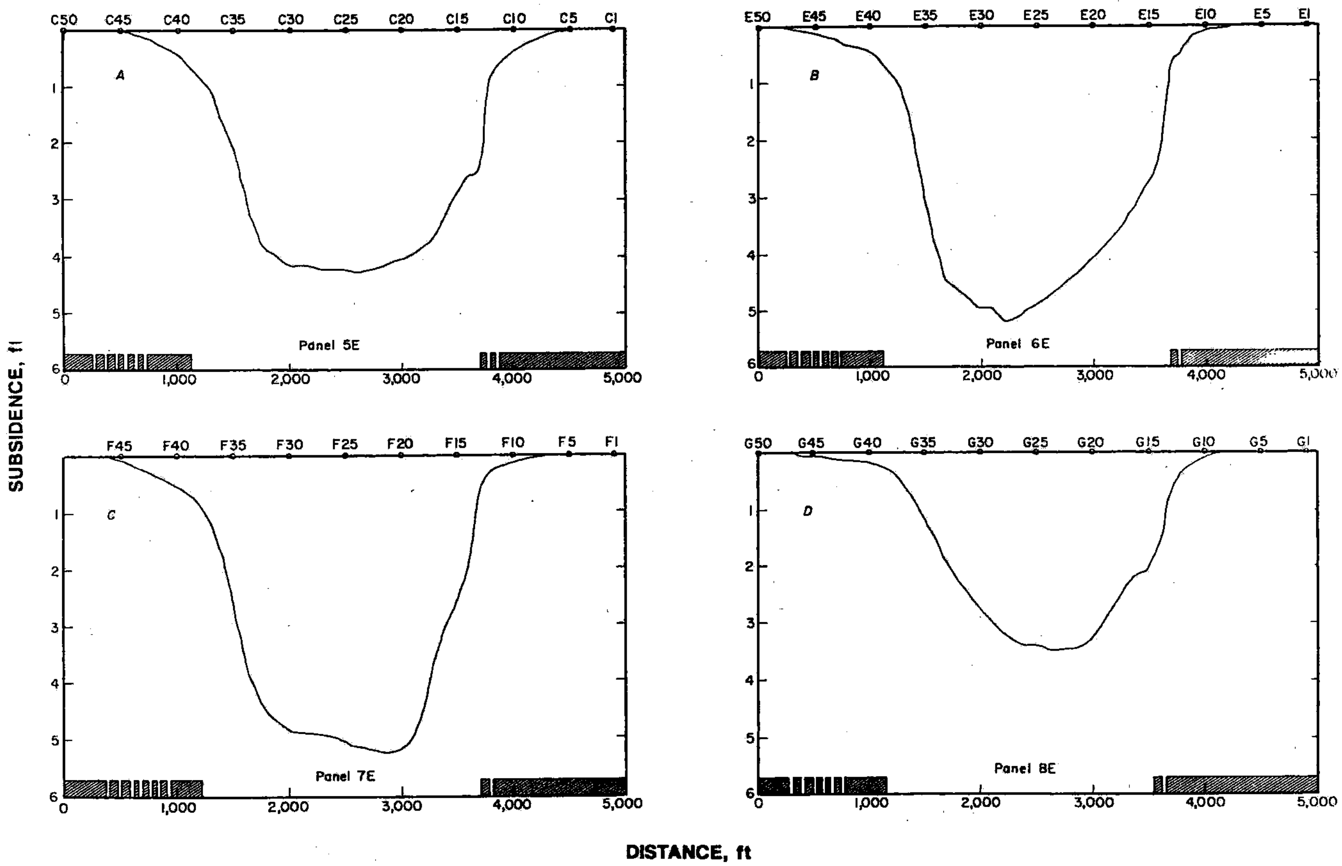

FIGURE 5.–Subsidence profiles. *A*, **panel 5E;** *B*, **panel 6E;** *C*, **panel 7E;** *D*, **panel 8E. Shaded areas indicate unmined coal.**

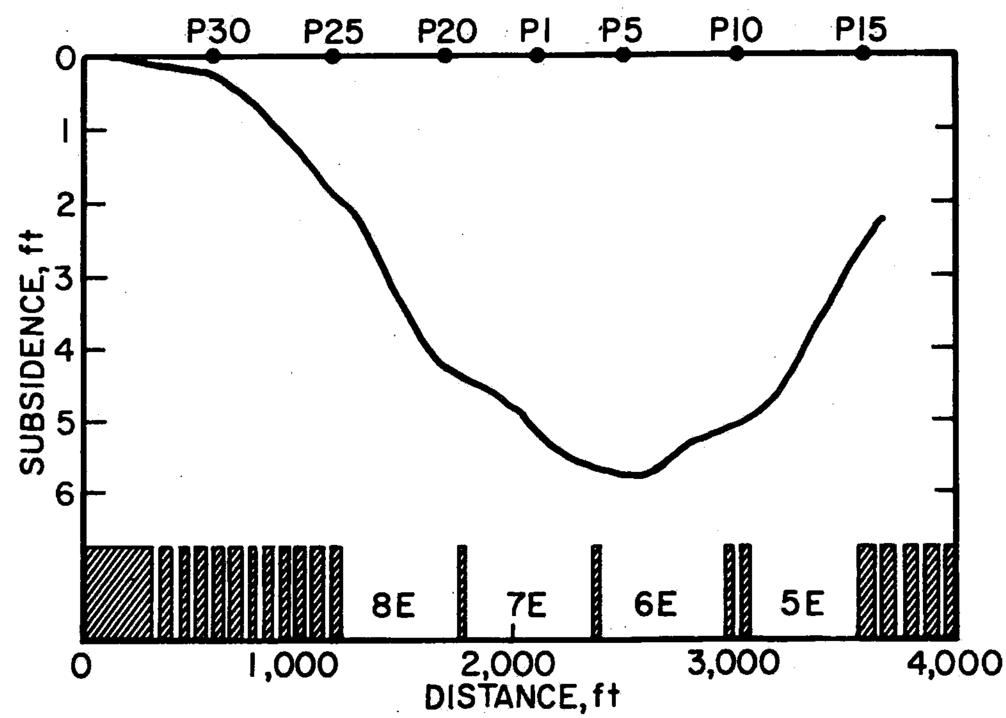

FIGURE 6.–Transverse subsidence profile. Shaded areas indicate coal pillars.

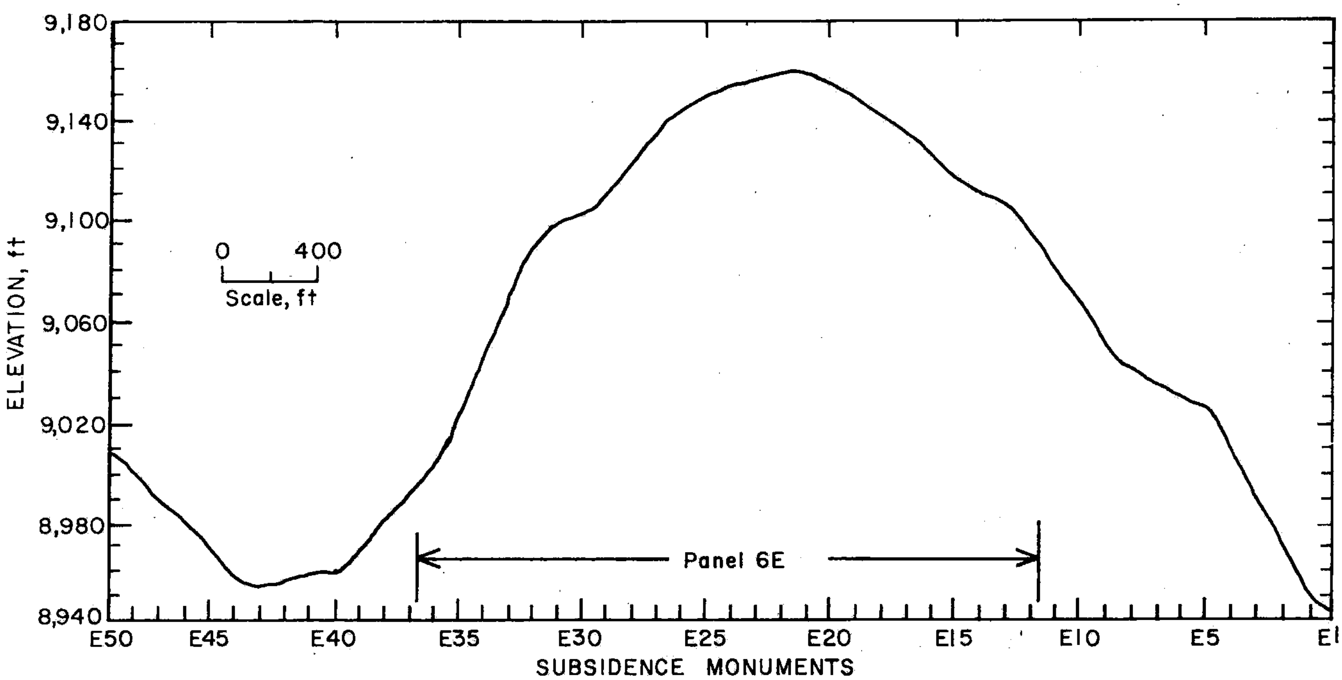

FIGURE 7.–Surface elevation profile above panel 6E.

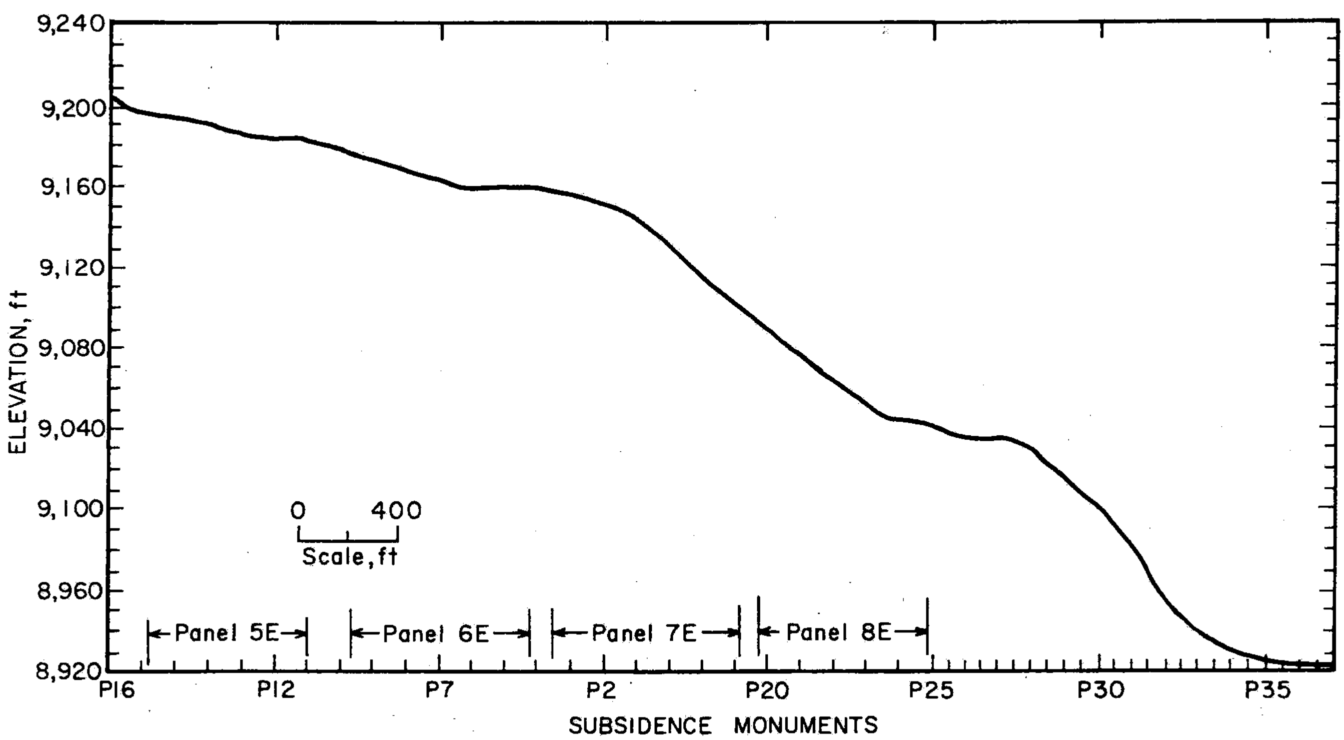

FIGURE 8.–Transverse surface elevation profile.

ANGLE OF DRAW

The angle of draw from a vertical reference was calculated for each end of the four panels and for the transverse monument line extending beyond the south edge of panel 8E. The calculated angles of draw are shown on figure 4.

Angle-of-draw calculations are very sensitive to the accuracy of the surveys used to measure vertical movement. Assuming the overburden depth and the location of the limit of mining are known, the angle of draw is dependent on locating the point of zero subsidence. The more accurate the surveys, the farther the point of apparent zero subsidence moves away from the mined area, thus resulting in larger calculated angles of draw. Conversely, less accurate surveys result in smaller angles of draw. Elevations used to calculate angles of draw were determined by trigonometric and differential leveling. The average standard deviation for elevations of nonsubsiding monuments was 0.08 ft for trigonometric leveling and 0.03 ft for differential leveling.

Another factor that can affect the angle-of-draw calculations is the spacing of the subsidence monuments. Monument spacing was 100 ft over panels 5E, 6E, and 7E and 50 ft over panel 8E. The effect of reduced monument spacing is to reduce the distance over which the point of zero subsidence is interpolated. Reduced monument spacing can improve the accuracy of the angle-of-draw determination, but will not tend to increase or decrease its magnitude. The average of the eight angles of draw beyond the ends of the panels, and the one angle of draw at the end of the P line of monuments south of panel 8E is 30°.

At the east ends of the panels, the subsidence profiles cross the Deer Creek Fault. The expected effect of the fault would be to reduce the angles of draw.[5] A comparison of the angles on either ends of the panels does not support this expectation. On two panels, the angles are smaller on the east ends, and on the other two panels, the angles are smaller on the west ends. Although there is no major effect on the angle-of-draw values, the fault did change the shape of the subsidence profiles. On each of the four longitudinal profiles, there is a distinct step or increase in slope of the profiles between monuments 10 and 13 (fig. 5).

SUBSIDENCE DEVELOPMENT

Over the first mined panel, 5E, subsidence did not occur at the surface until the face had retreated between 550 and 1,050 ft. Subsidence continued to occur over this panel for approximately 4 yr as the three panels to the south were mined. The progression of subsidence over the four panels as a function of face position is shown on a series of subsidence contour plots (fig. 9). Figure 9*F* represents the final subsidence values.

The timing, rate, and duration of subsidence over the four panels is illustrated in figure 10. The subsidence values near the midpoint of each panel length (monument 27) are plotted against time. Initial subsidence at the midpoints of the first and second panels mined occurred at 3 and 2 months, respectively, after the points were undermined. Initial subsidence at the midpoints of the third and fourth panels mined preceded undermining by 3 and 11 months, respectively. Subsidence at the midpoint of panel 8E began as the face passed under the midpoint of the adjacent panel, 7E.

The length of time from undermining to final subsidence became progressively shorter from the first through the last panel. It took 46 months for monument C27 to reach final subsidence after it had been undermined, while monument

[5]Lee, A. J. The Effect of Faulting on Mining Subsidence. Min. Eng., London, v. 125, 1965-66, pp. 735-745.

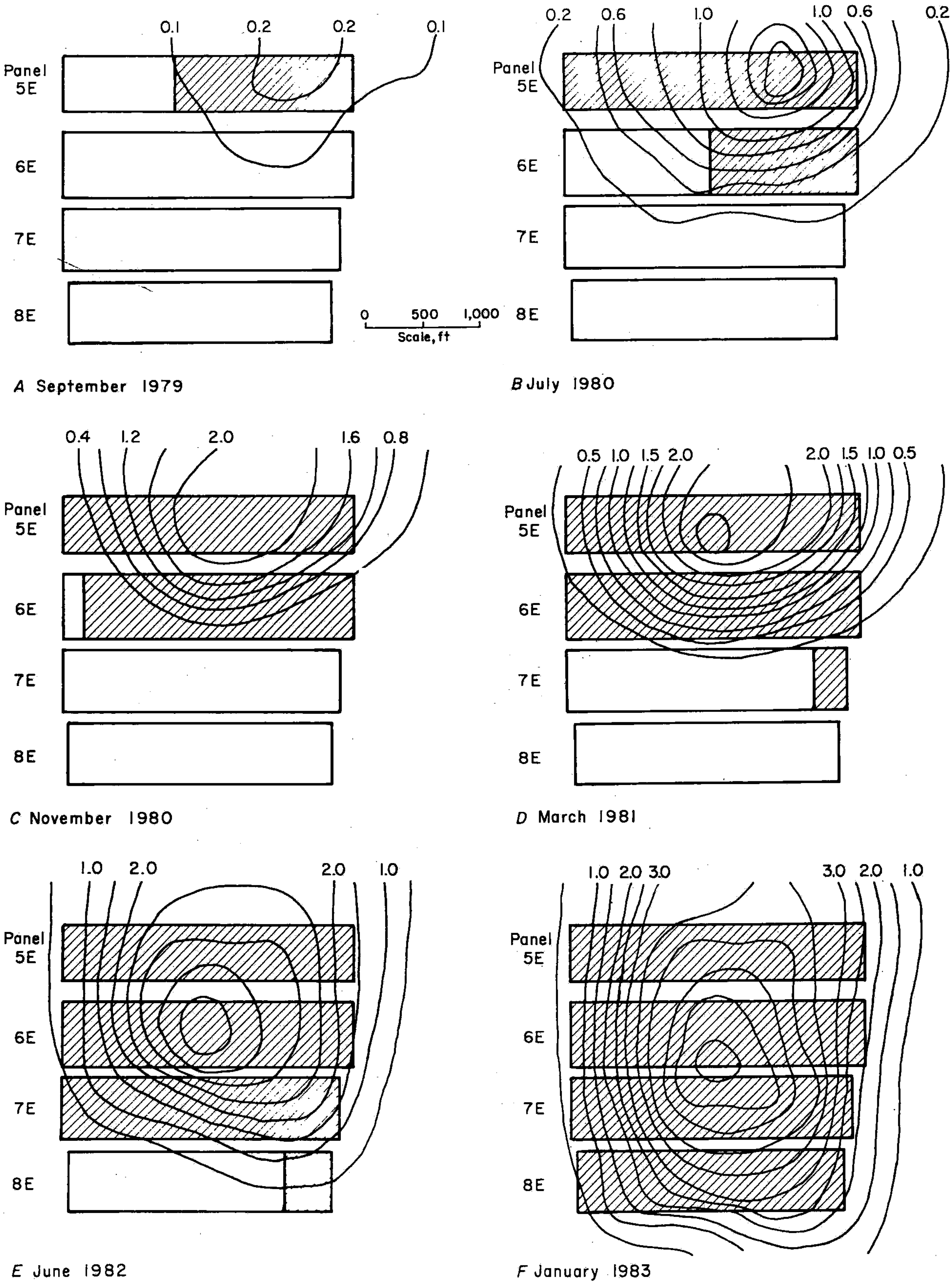

FIGURE 9.–Subsidence contours relative to face positions. Shaded areas indicate mined portions of the panels.

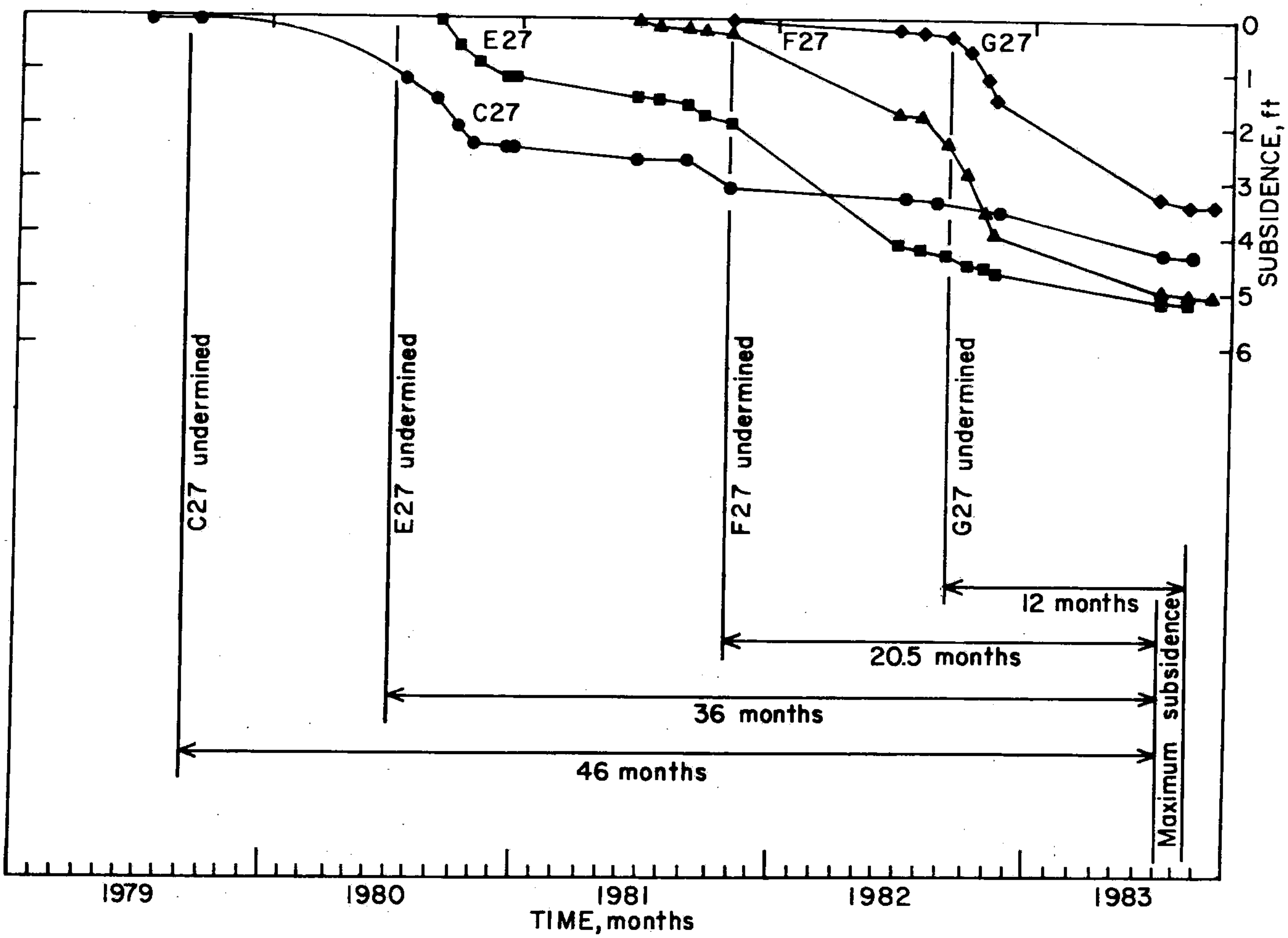

FIGURE 10.–Subsidence development for panel midpoints.

G27 reached final subsidence in only 12 months. Although the elapsed time between undermining and final subsidence varied greatly, the midpoints stabilized at the final subsidence values at nearly the same point in time, between July and September 1983.

CRITICAL WIDTH

An important parameter to be investigated in this study was the critical extraction width. The critical width is the minimum dimension of an extraction area required to cause maximum possible subsidence in the center of the area, and is represented as a function of the seam depth. For instance, in British coalfields the critical width is 1.4 times the depth of the seam.[6] When an extraction area increases and the minimum dimension reaches the critical width, the point at the center of subsidence profile will reach maximum possible subsidence. As the minimum dimension of the extraction area exceeds the critical width and

[6]Work cited in footnote 4.

becomes supercritical, the subsidence profile assumes a characteristic flat-bottomed shape, with more than one point reaching maximum possible subsidence.

The extraction area at the Deer Creek study site is nearly square. The extraction width across the four panels, 2,400 ft, is approximately equal to the average panel length of 2,432 ft. The shape of the transverse subsidence profile (fig. 6) indicates that the Deer Creek Mine extraction area is subcritical. There is no indication that the profile is beginning to flatten out near the center; therefore, the critical width is greater than the final extraction width of 2,400 ft. Using the average overburden depth of 1,500 ft, the critical width is at least 1.6 times the depth.

Further mining to the south would increase the extraction width beyond the panel lengths, and the transverse profile would have a flat bottom; however, the subsidence at the center of the panels would continue to be constrained by the length of the panels and would not be expected to increase beyond the maximum measured value of 5.8 ft. Because the panel lengths are not greater than the extraction width required to cause the transverse profile to flatten out, a determination of the critical width, and thus, the maximum possible subsidence cannot be made. Mining did occur south of the study panels in the 9E room-and-pillar section. During the time 9E was being mined, the center of the transverse profile was affected by longwall mining in the Wilberg Mine below the Deer Creek Mine; thus, it was not possible to differentiate the subsidence due to each mining operation.

The relationship between the angle of draw and critical width parameters from this site results in a contradiction when compared to existing definitions. According to the NCB,[7] the angle of draw can be used to define the critical width; the critical width should be directly proportional to the angle of draw (fig. 11*A*). At the Deer Creek Mine site, this relationship is not evident (fig. 11*B*). In the NCB case, the angle of draw over solid, unmined coal can be projected over the caved panel to define the critical width. At the Deer Creek Mine site, the angle of draw over solid coal (30°) is at least 8° less than the angle over the caved panel required to define the critical width (38.6°).

One explanation for this condition is that the Deer Creek Mine extraction area is critical or supercritical. This possibility is supported by the fact that the angle required to reach the point of maximum subsidence, P6, on the transverse profile from the north edge of the extraction area is within 1.5° of the average calculated angle of draw (fig. 12). If this is the case, the points on the profile for a distance of 475 ft south of point P6 toward P1 should also reach the maximum subsidence value of 5.8 ft and produce the flat-bottomed profile characteristic of a supercritical extraction area. The maximum additional subsidence required for this condition, Δs, is 0.5 ft (fig. 12). This would mean that a condition existed that prevented an area over panels 6E and 7E from reaching maximum subsidence.

Strata bridging in one of the massive sandstone layers in the overburden, such as the Castlegate Sandstone, is one possible explanation for a delay in subsidence at this location. This cannot be confirmed, because there was no instrumentation in the overburden and because the subsidence from subsequent, adjacent mining was combined with that from mining in a lower seam. A finite-element analysis of the Deer Creek Mine conditions and overburden stresses indicated that a strata bridge could support the overburden load across one panel width.

[7]Work cited in footnote 4.

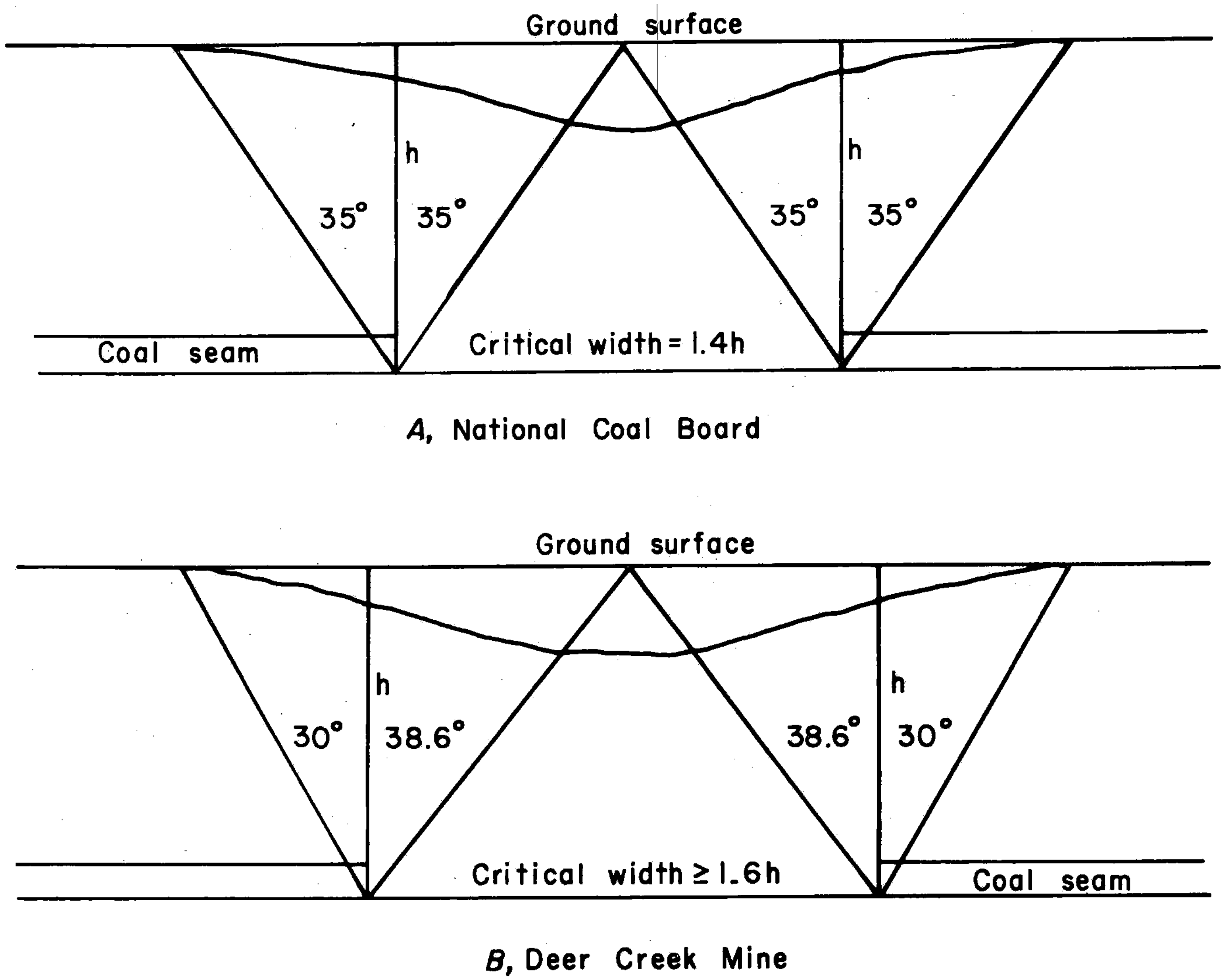

FIGURE 11.–Critical mining widths from NCB (*A*) and Deer Creek Mine (*B*).

Another possible cause of incomplete subsidence could be a minimal amount of support from the chain pillars. The location of these chain pillars relative to the transverse subsidence profile (fig. 6) is such that they could be preventing the small amount of additional subsidence necessary to produce the characteristic flat-bottomed profile of a supercritical extraction area. Again, because no additional panels were mined to the south before the subsidence was influenced by mining in the lower seam in the Wilberg Mine, this possible cause cannot be confirmed.

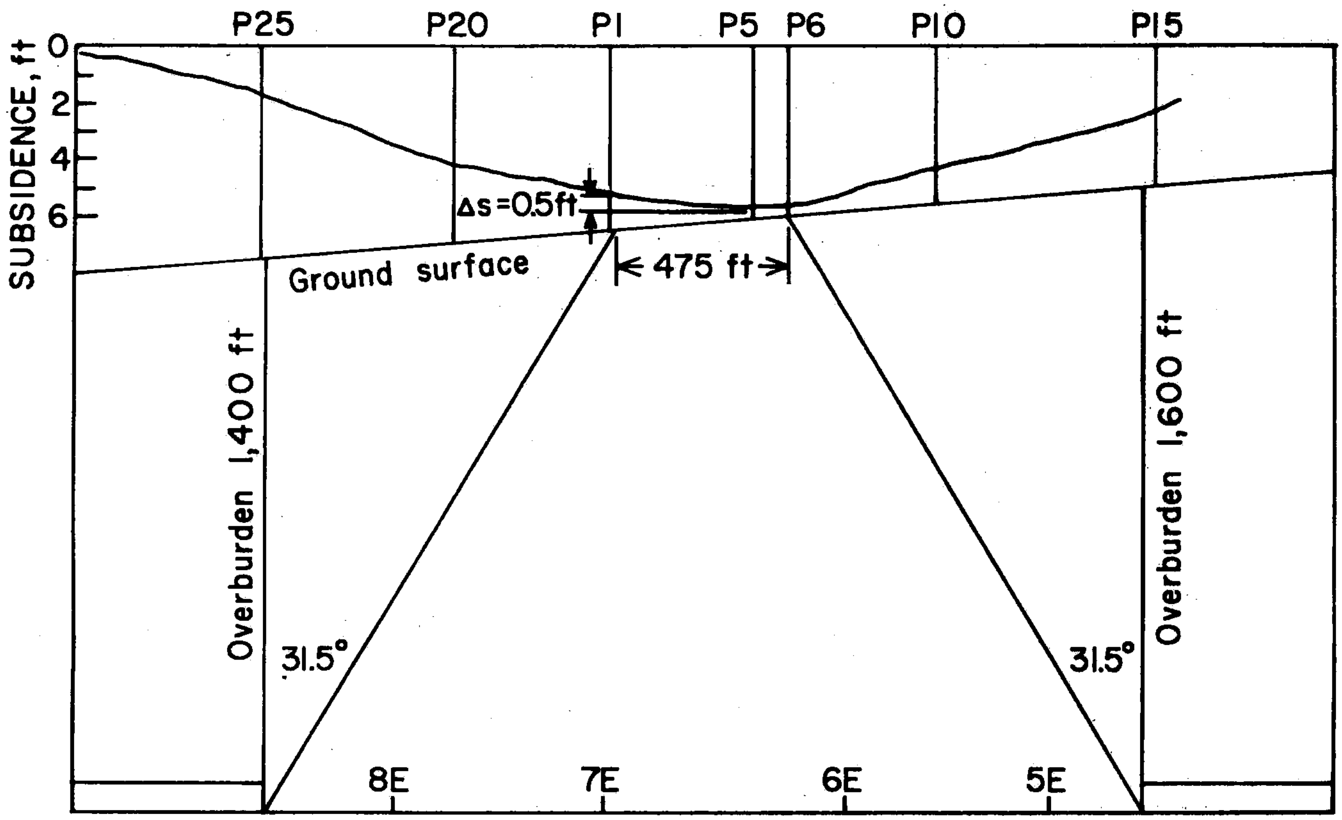

FIGURE 12.—Deer Creek Mine extraction width and subsidence profile.

CONCLUSIONS

The final maximum subsidence factor was 0.68, although it cannot be confirmed that this value represents the maximum possible subsidence because the extraction dimensions precluded determination of the critical width.

The time required to reach final subsidence after undermining can be as much as 4 yr owing to adjacent panel effects.

The average angle of draw was 30°. This value can be used to define the limit of subsidence beyond the limit of mining, but it cannot be used to determine the critical width.

A major fault increased the slope of the subsidence profile in the vicinity of the fault, but did not reduce the lateral extent of subsidence. However, the magnitude of subsidence beyond the fault was reduced.

An area of 315 acres was gradually lowered by mining of the four longwall panels. During the 4 yr that subsidence was monitored at this site, there was no evidence of damage to the land surface, vegetation, or drainage patterns. There was no visual indication of any surface depressions, and no surface cracks that would adversely affect the foreseeable value or use of this land. The absence of tension cracks can be attributed, in part, to the fact that the chain pillars between panels did not remain stable, which would have caused an uneven subsidence profile across the panels.

Any continuation of this research should begin by making a detailed comparison of these results to other case studies in an attempt to isolate the mining or geologic variables controlling specific aspects of the resulting subsidence. Future studies should be designed to refine the angle-of-draw estimates obtained in this study, define the critical extraction width, which is needed to determine the area necessary to cause maximum possible subsidence, and obtain meaningful and accurate strain values. These are the parameters that are the most important for predicting the magnitude and extent of possible adverse effects of subsidence from future mining. Once these parameters are known, efforts can be made to eliminate or mitigate these effects through the engineering design of mines and of surface facilities that may be subject to subsidence.

APPENDIX.—MEASURED SUBSIDENCE VALUES PLOTTED IN FIGURES 5 AND 6

Monument	Subsidence, ft	Monument	Subsidence, ft	Monument	Subsidence, ft	Monument	Subsidence, ft	Monument	Subsidence, ft
C1	0.1	E1	0.0	F1	0.1	G1	0.0	P16	2.2
C2	.1	E2	.0	F2	.1	G2	.1	P15	2.6
C3	.2	E3	.0	F3	.1	G3	.1	P14	3.1
C4	.2	E4	.0	F4	.1	G4	.1	P13	3.6
C5	.2	E5	.0	F5	.1	G5	.1	P12	4.7
C6	.2	E6	.0	F6	.1	G6	.1	P11	4.9
C7	.3	E7	.1	F7	.2	G7	.1	P10	5.1
C8	.3	E8	.1	F8	.2	G8	.1	P9	5.3
C9	.4	E9	.1	F9	.2	G9	.1	P8	5.4
C10	.4	E10	.1	F10	.2	G10	.2	P7	5.7
C11	.6	E11	.2	F11	.2	G11	.2	P6	5.8
C12	.9	E12	.5	F12	.3	G12	.4	P5	5.7
C13	2.3	E13	.9	F13	.6	G13	.7	P4	5.6
C14	2.6	E14	2.3	F14	1.8	G14	1.6	P3	5.7
C15	2.9	E15	2.8	F15	2.5	G15	2.0	P2	5.4
C16	3.2	E16	3.1	F16	2.9	G16	2.1	P1	5.1
C17	3.6	E17	3.4	F17	3.5	G17	2.3	P17	4.7
C18	3.8	E18	3.6	F18	4.3	G18	2.6	P18	4.6
C19	4.0	E19	3.9	F19	4.9	G19	3.0	P19	4.4
C20	4.0	E20	4.1	F20	5.2	G20	3.2	P20	4.2
C21	4.1	E21	4.2	F21	5.2	G21	3.4	P21	3.9
C22	4.2	E22	4.4	F22	5.2	G22	3.4	P22	3.4
C23	4.2	E23	4.6	F23	5.2	G23	3.5	P23	2.8
C24	4.3	E24	4.8	F24	5.1	G24	3.5	P24	2.2
C25	4.2	E25	4.9	F25	5.1	G25	3.4	P25	1.9
C26	4.2	E26	5.0	F26	5.0	G26	3.4	P26	1.6
C27	4.2	E27	5.1	F27	5.0	G27	3.3	P27	1.3
C28	4.2	E28	5.2	F28	4.9	G28	3.2	P28	.8
C29	4.1	E29	4.9	F29	4.8	G29	3.0	P29	.5
C30	4.2	E30	4.9	F30	4.8	G30	2.7	P30	.3
C31	4.0	E31	4.8	F31	4.7	G31	2.5	P31	.2
C32	3.9	E32	4.7	F32	4.5	G32	2.2	P32	.1
C33	3.6	E33	4.4	F33	4.2	G33	2.0	P33	.1
C34	2.9	E34	3.8	F34	3.6	G34	1.6	P34	.1
C35	2.1	E35	3.0	F35	2.6	G35	1.2	P35	.0
C36	1.6	E36	2.0	F36	1.8	G36	.8	P36	.0
C37	1.1	E37	1.2	F37	1.2	G37	.6	P37	.0
C38	.8	E38	.8	F38	.8	G38	.4		
C39	.6	E39	.6	F39	.7	G39	.2		
C40	.4	E40	.5	F40	.5	G40	.2		
C41	.3	E41	.4	F41	.4	G41	.2		
C42	.2	E42	.4	F42	.4	G42	.2		
C43	.1	E43	.3	F43	.3	G43	.1		
C44	.1	E44	.2	F44	.3	G44	.0		
C45	.0	E45	.2	F45	.2	G45	.1		
C46	.0	E46	.1	F46	.2	G46	.1		
C47	.1	E47	.1	F47	.1	G47	.1		
C48	.1	E48	.1			G48	.0		
C49	.0	E49	.0			G49	.0		
C50	.0	E50	.0			G50	.0		

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