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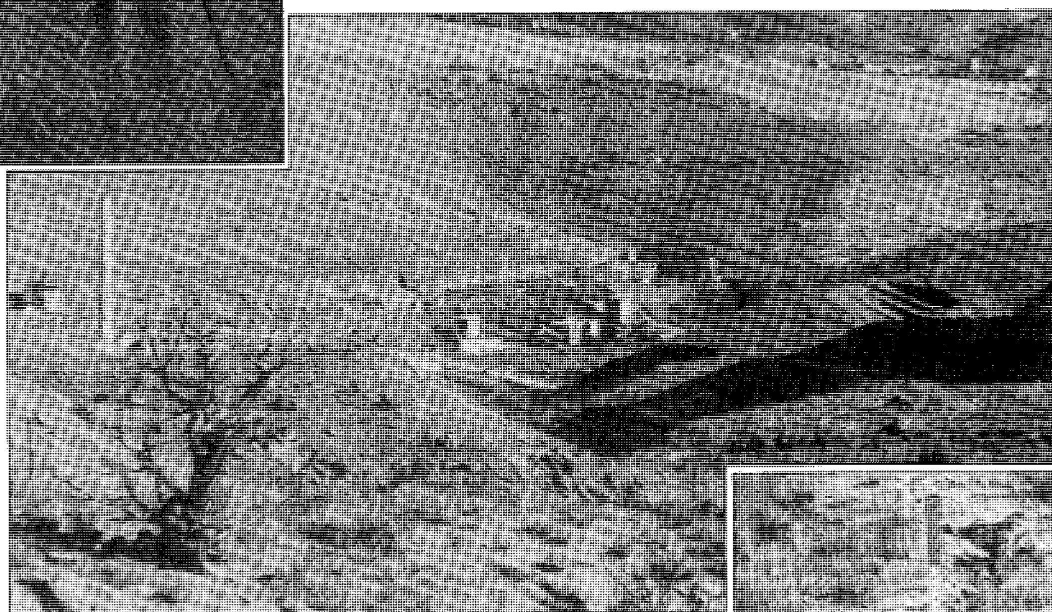
By Jeff A. Magers



United States Department of the Interior

Bureau of Mines

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UNITED STATES DEPARTMENT OF THE INTERIOR
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BUREAU OF MINES

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ILLUSTRATIONS

UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

°	degree	min	minute
ft	foot	pct	percent
in	inch		

SURFACE SUBSIDENCE OVER A ROOM-AND-PILLAR MINE IN THE WESTERN UNITED STATES

By Jeff A. Magers[1]

ABSTRACT

This report summarizes the results from the subsidence research study completed by the U.S. Bureau of Mines at the Roadside Mine, Powderhorn Coal Co., Palisade, CO. This research was conducted from February 1981 to August 1985, with additional data obtained during July 1991, to evaluate residual subsidence. The Bureau studied subsidence at three distinct room-and-pillar sections at separate locations over the mine and determined the maximum subsidence values and surface subsidence profiles for each mining section. Maximum subsidence of 3.0 ft occurred over the room-and-pillar sections, with overburden depths ranging from 50 to 600 ft. Surface tension cracks had occurred, and were still evident during the residual subsidence survey.

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INTRODUCTION

The research described in this report is part of a comprehensive effort by the U.S. Bureau of Mines to develop a subsidence data base representative of western U.S. mining conditions. This data base will provide researchers and mine operators with the information needed to further understand the effects of subsidence. This understanding is needed by mine operators to predict how mining and geologic parameters affect the magnitude and extent of subsidence in the West, thereby allowing for a mine design that will avert or limit the adverse effects of subsidence.

In 1977, Congress passed the Surface Mining Control and Reclamation Act. Section 516 (5) (1) of the act requires the operator to "...adopt measures...to prevent subsidence causing material damage...." Therefore, a methodology to predict subsidence is needed by mine operators to avoid or mitigate damage resulting from mining. Extensive information exists regarding subsidence research in the Appalachian and Illinois coal regions of the United States (*1*);[2] however, information regarding subsidence research in the West is limited. Western coal mining conditions include strong massive sandstone members, thick and multiple coal seams, and extreme variations in overburden thicknesses, and while research efforts have been initiated by the Bureau (*2-5*), a complete data base does not exist that fully addresses subsidence prediction and control technologies in the West.

The Bureau's research program is directed toward fulfilling the needs of industry in the premining evaluation of subsidence impact potential and in facilitating the permitting process. The immediate benefit to the mining industry from the completion of additional western U.S. subsidence research studies is a much more accurate and quantitative understanding of the behavior of subsidence occurring over room-and-pillar and longwall operations in geologic conditions unique to the West. The ability to predict subsidence and associated damage will allow mine operators to extract resources that are currently sterilized because the technology does not exist to predict the resulting surface subsidence effects to the degree necessary to ensure that adverse impacts can be minimized.

This case study was one of several conducted by the Bureau that together would begin to provide the subsidence data necessary to characterize western U.S. mine subsidence.

Once general subsidence parameters can be estimated, the potential impacts of the subsidence can be evaluated. The capability to conduct this type of evaluation will benefit mine operators and regulatory agencies that must assess subsidence impacts.

The major objectives of this study were to (1) present measured surface subsidence caused by room-and-pillar mining in the Cameo "B" 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; and (5) evaluate the long-term residual subsidence.

This particular site was selected for the following reasons: (1) coal is mined by the room-and-pillar method; (2) shallow sandstone overburden was present throughout the study site; and (3) several structures and two streams were undermined.

ACKNOWLEDGMENTS

The Powderhorn Coal Co. provided valuable assistance in conducting this research. In particular, mine engineers William Poloske and Larry Reschke 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 Roadside Mine, this study could not have been conducted.

ROADSIDE MINE STUDY SITE

SITE SELECTION

The Bureau selected the Roadside Mine to monitor subsidence because the site had specific mining and overburden features for which little or no subsidence field data exist, including shallow sandstone overburden, full extraction room-and-pillar mining, and two streams. The site also has manmade structures (pipelines, power lines, and water storage tanks) overlying the mine.

SITE DESCRIPTION

The Roadside Mine is located on Federal and private coal leases approximately 4 miles northeast of Palisade,

[2]Italic numbers in parentheses refer to items in the list of references at the end of this report.

adjacent to Interstate Highway 70, in Mesa County, CO (fig. 1). The site includes parts of sections 26, 34, 35, T 10 S; R 98 W on the Cameo 7.5-min U.S. Geological Survey quadrangle map, and parts of sections 1 and 2, T 11 S; R 98 W on the Palisade and Cameo quadrangle maps. Approximately 300 acres are included in the monitoring areas. Three distinct areas were designated to be monitored over the duration of this study: the northwest section, the southwest section, and the third-west section. The topography over the panels is generally rolling, with a few vertical faces bordering the northwest study area (fig. 2). The maximum ground slope in the general area is approximately 45 pct, with maximum topographical relief occurring over the third-west section. The average surface elevation of the study site is 5,300 ft. Vegetation consists mostly of sagebrush, with some heavily forested areas in the third-west monitoring section. The location of the monitoring area in the north is such that surface vegetation allowed clear lines of sight for the monitoring surveys. The southern section lies under a partially wooded area that required some cutting and clearing to establish clear lines of sight. Cottonwood Creek, a perennial stream, is located over the third-west section. Another perennial stream, Rapid Creek, which is located north of the monitoring section, was also undermined. Several service roads overlie the mine property and provide access to both the Rapid Creek and Cottonwood Creek drainage. Two 8-in-diam waterlines belonging to the city of Palisade and a 24-in-diam waterline belonging to the Ute Water Conservancy District traverse the property, including the monitored southwest section. These waterlines are used for public drinking water and irrigation. Electrical transmission lines providing service to both the mine and water plant traverse the northwest undermined area.

REGIONAL GEOLOGY

Coal is produced from the Cameo "B" Seam, a sequence of carbonaceous coal-bearing strata within the Bookcliffs Coalfield. The Cameo "B" Seam is one of the four definable coal seams within the Mount Garfield Formation, Mesaverde Group (fig. 3). A more detailed stratigraphic column of the Mount Garfield Formation (in the immediate proximity of the Cameo "B" Seam) is shown in figure 4. The scale on this geologic column begins at the approximate site elevation for all three sections. This

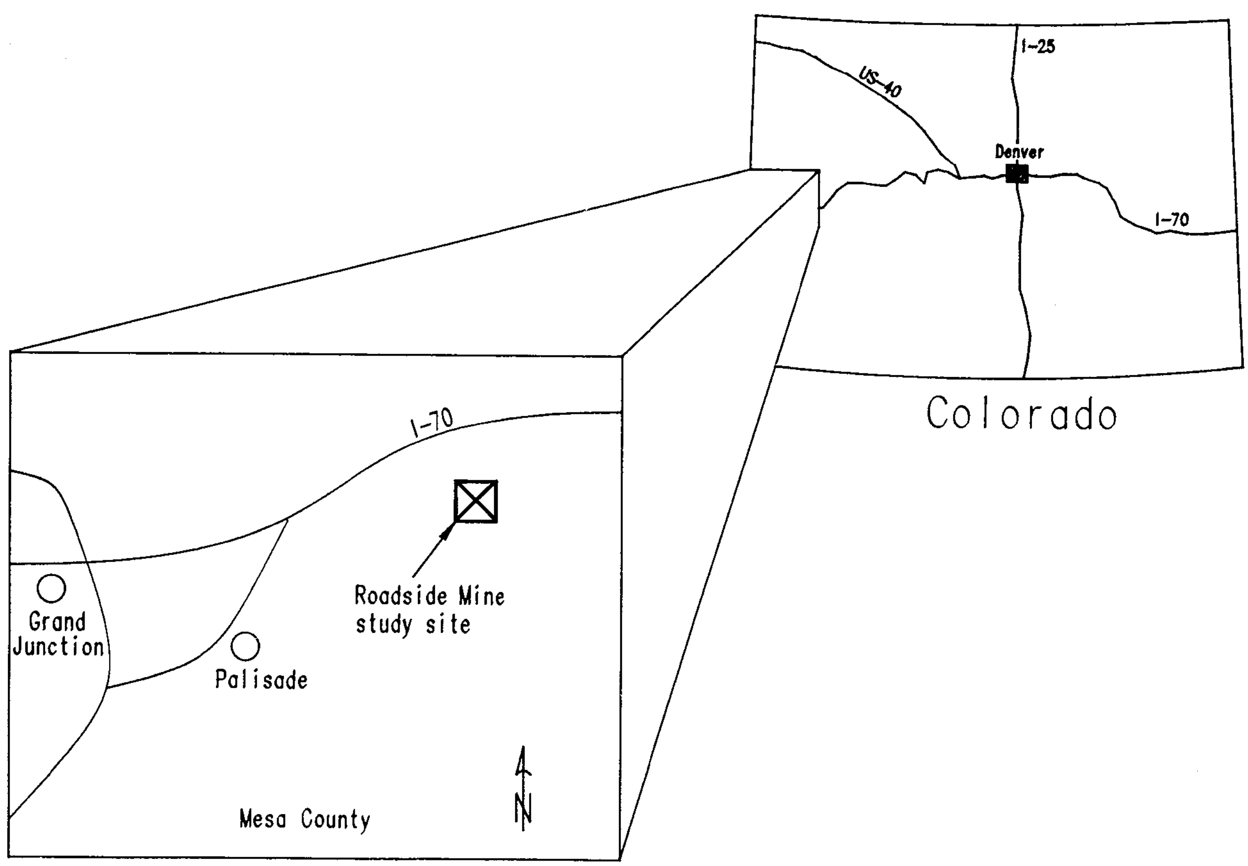

Figure 1.—Project location map.

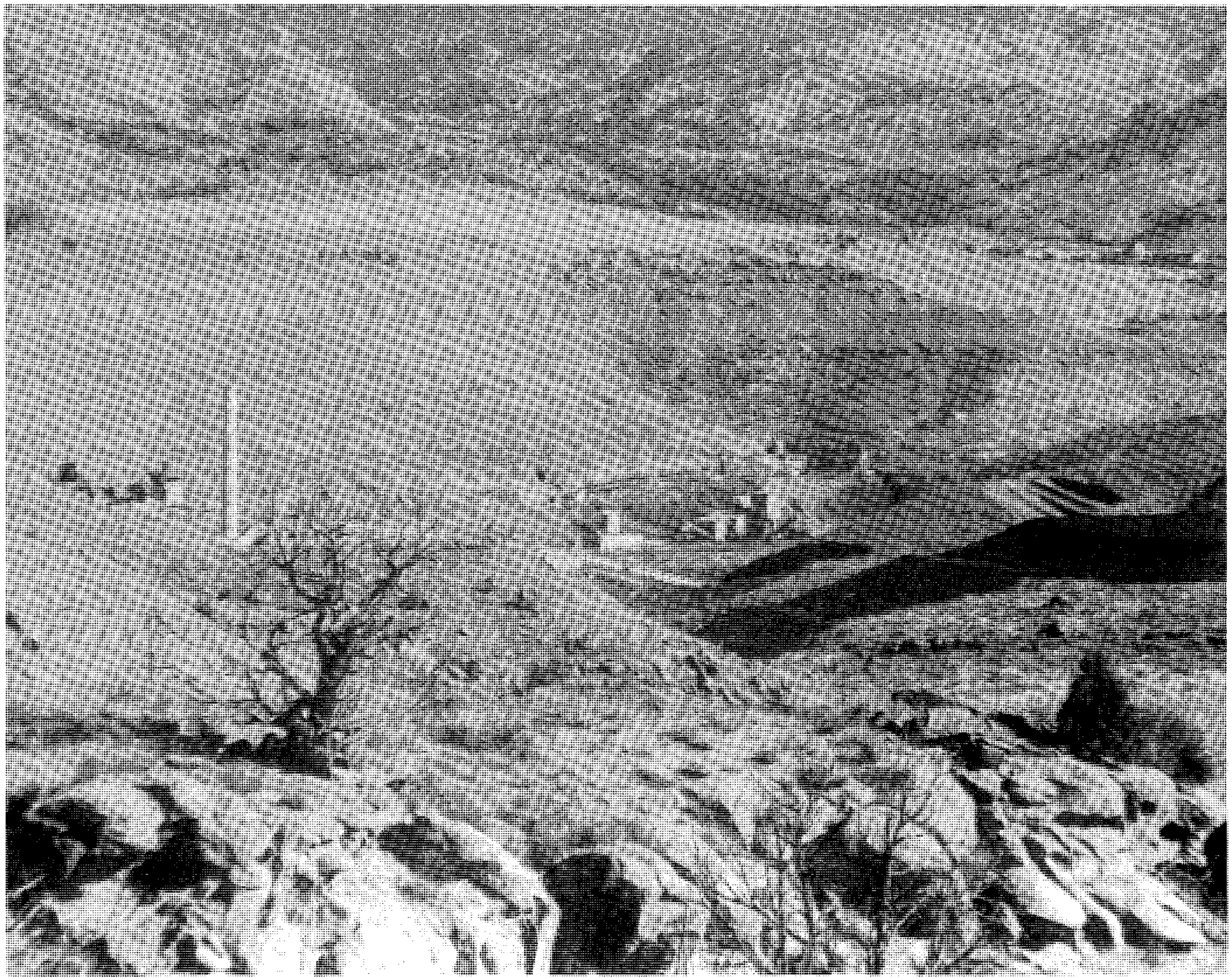

Figure 2.—Roadside Mine study site.

formation consists primarily of sandstones and shales that dip slightly 2° to 5° to the north-northeast and are the predominant features within the formation. Tabular basaltic lava flows occur in interbedded or capping sections of the formation and overlie most sections of the mine (*6*). The Cameo "B" Seam varies in thickness from 4 to 10 ft, averaging 6 ft, and is presently the only economically viable seam in the Mesaverde Group. Till, ranging from large boulders (greater than 5 ft in size) to fine sand, is prominent in the Cottonwood Creek Basin. No faults have been detected in the Roadside Mine or mapped in the study area.

MINE PLANS

Coal in the study areas was mined by the room-and-pillar method. Sections were developed with 20-ft-wide entries on 50- and 120-ft centers. After a section or subsection was developed, the 30- by 100-ft pillars were then retreat mined. During this process, the pillars were mined with continuous miners to approximately 10 by 100 ft and allowed to fail. Average pillar recovery was 75 pct.

Northwest Section

The mine plan for the northwest section is shown in figure 5. The study area overlay a room-and-pillar section approximately 2,000 by 1,500 ft. Five main entries were driven approximately due west. The area was then retreat mined from the northwest. Initially, the pillar dimensions were 30 by 100 ft on 50-ft centers. The pillars were then retreat mined to a width of approximately 20 ft. The L-shaped pillars near the entries were left for support of the entry. The barrier pillars in the entry system were

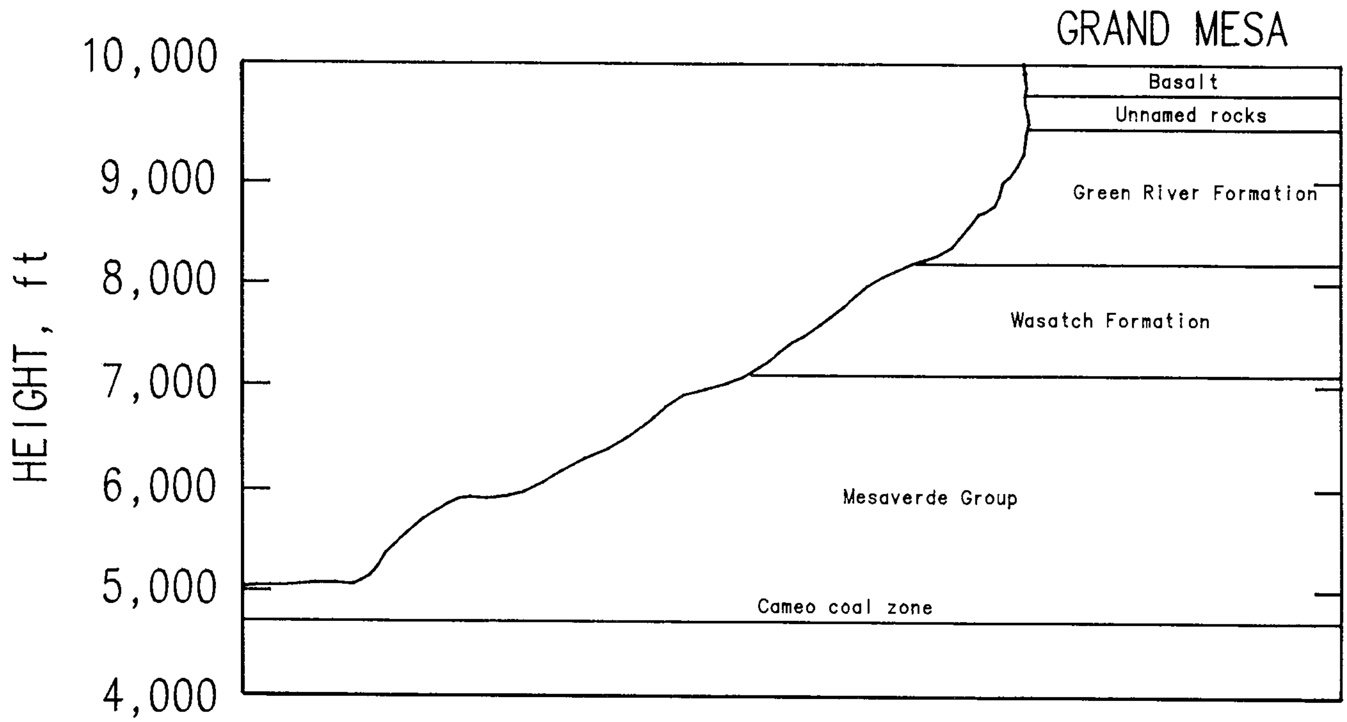

Figure 3.—Generalized overburden stratigraphy.

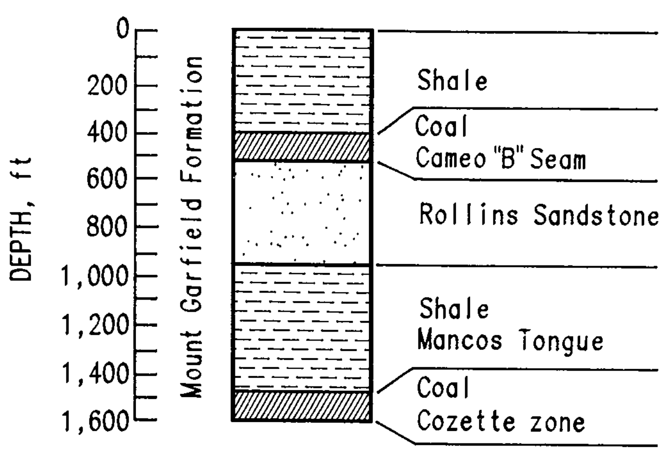

Figure 4.—Detailed overburden stratigraphy.

approximately 50 by 100 ft. The depth of cover over the northwest section ranged from 100 to 200 ft; minimum overburden occurred in the northeast corner. The seam dipped 2° to 5° on a strike of N 25° E, and was considered when calculating overburden depths. The mining height in this area was approximately 7 ft.

Southwest Section

The mine plan for the southwest section is shown in figure 6. The study area overlay a room-and-pillar section approximately 700 by 1,300 ft. The initial pillar dimensions were 40 by 100 ft on 60-ft centers. During development of the section, a subcrop was reached where weak sandstone strata and unconsolidated till were encountered in the roof and face. The till material ranged from large basalt boulders, greater than 5 ft in diam, to fine sand. The depth of cover over the section ranged from 50 to 200 ft. The minimum overburden occurred in the southwest corner. The seam was on the same dip and strike as the northwest section. The area was traversed by a 24-in-diam waterline and the main road to the Ute Water facility.

Third-West Section

The mine plan for the third-west section is shown in figure 7. The study area overlay two room-and-pillar sections separated by a barrier pillar. The barrier pillar was approximately 60 ft wide and 2,000 ft long. Each of the room-and-pillar sections averaged 500 by 2,000 ft. The

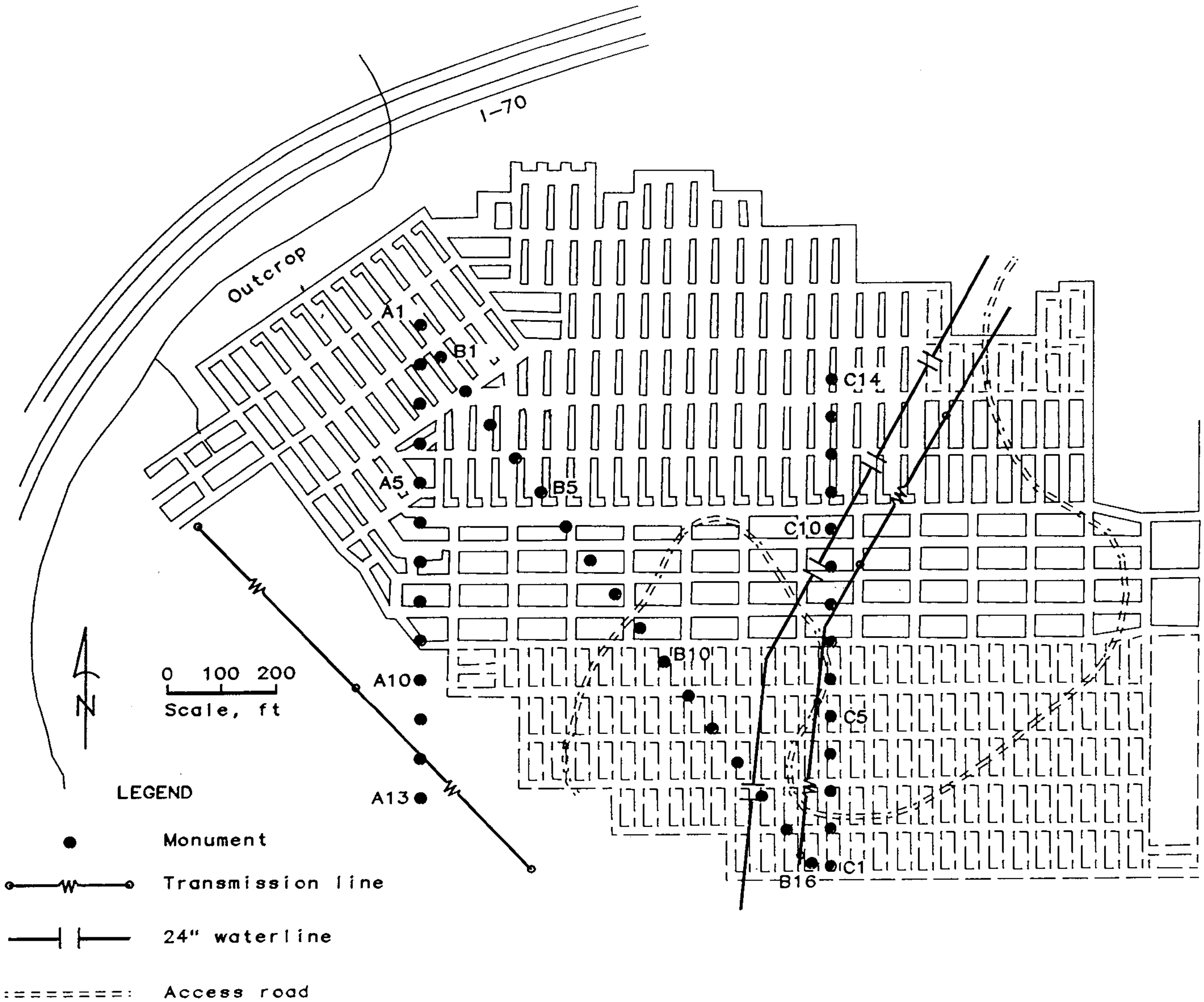

Figure 5.—Northwest section mine plan.

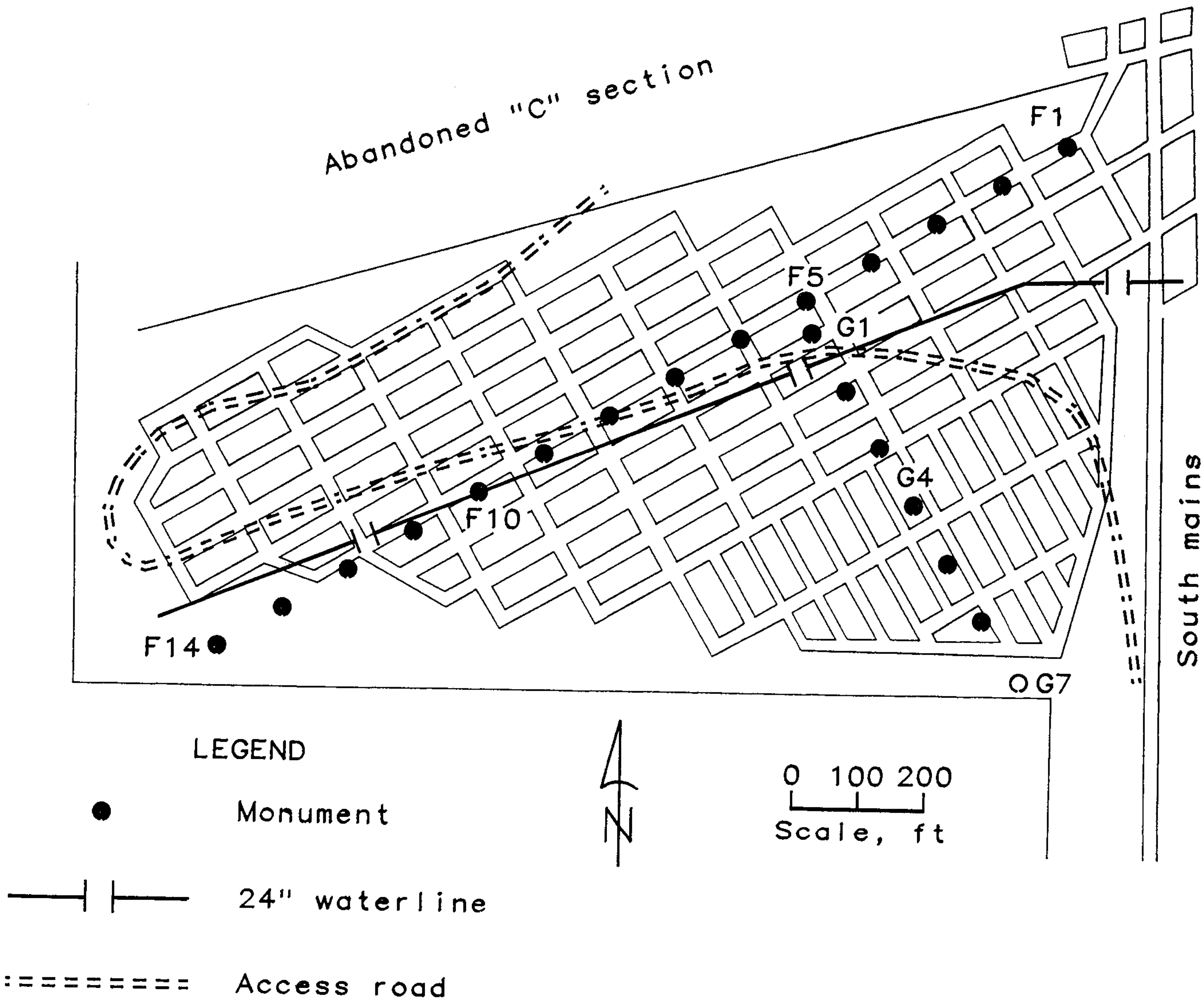

Figure 6.—Southwest section mine plan.

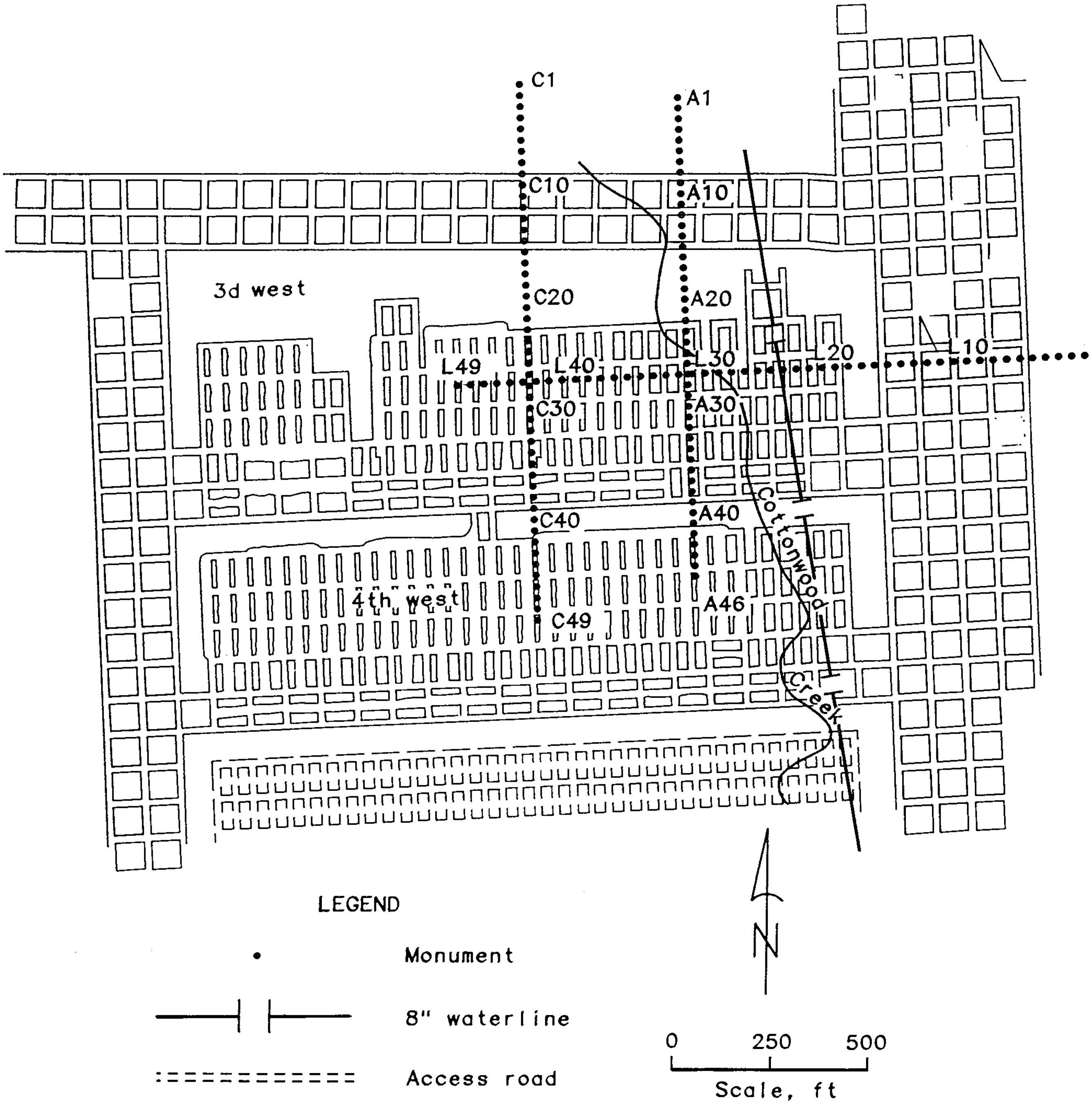

Figure 7.—Third-west mine plan.

initial pillar dimensions were 30 by 80 ft, and the pillars were retreat mined from west to east. The area was traversed by a City of Palisade waterline, service roads, utility lines, and Cottonwood Creek. Where the stream traversed the section, the streambed was approximately 25 ft wide. To prevent vertical deformation near Cottonwood Creek, a 10° angle of draw and barrier pillars were used to isolate the streambed from damage. Several rows of pillars were left in place directly below the stream to protect the stability of the stream. The depth of cover for the section ranged from 350 to 700 ft. The minimum overburden occurred in the northeast corner. This section included the major geological characteristics of both previous sections, but the amount of topographical relief in the area was somewhat greater.

SUBSIDENCE-MONITORING PROGRAM

Figures 5, 6, and 7 show the subsidence-monitoring networks located over the three study sites. The network for each site was designed to measure the maximum subsidence, the longitudinal subsidence profiles, and the rate that subsidence progressed over the sections. Major factors that affected collected subsidence data included survey accuracy and frequency, monument spacing, monument construction, and surveying instrumentation. The frequency and accuracy of surveys were affected by climatic and geographic conditions at the site, respectively.

MONUMENT SPACING AND CONSTRUCTION

The locations of the subsidence monuments were established on the basis of coordinates and mine maps supplied by Roadside Mine personnel. Both the underground and surface surveys were tied to the Colorado State Plane coordinate system, which allowed direct correlation between surface and underground positions.

The network layouts for the northwest and southwest sections were designed with monuments spaced at 100-ft intervals. Topography, vegetation, and localized soil conditions dictated the actual location of each monument; thus, actual spacing ranged from 90 to 100 ft. When surveyed, this spacing yielded a representative subsidence profile of these two sections. The third-west section was designed with monuments spaced at 25-ft intervals. The closer spacing was implemented to yield more detailed information over the Cottonwood Creek and to improve the evaluation of the angle of draw.

The survey monuments were 1-in-diam, 4- to 6-ft-long steel rods with machined points driven into the ground. Monuments were installed to a depth of 3 to 5 ft using a gas-powered pneumatic hammer or a sledge hammer. Approximately 6 in of each rod was left above the ground to accommodate the target used in the horizontal position surveys. Minimizing the height of the monuments above the ground decreased the error in the horizontal position that might have resulted from monuments tilting during subsidence. The 1-in-diam steel rods were easy to store, transport, and install, and provided extremely stable monitoring stations.

MONUMENT LOCATIONS

Northwest Section

Soil cover in this area ranged from a few feet to a depth of approximately 10 ft. Although the soil was moderately rocky, it was of adequate depth to permit the monuments to be installed with few problems. The only areas where monuments were difficult to install were along outcrops at the north end of this study area, where some monuments were moved a few feet to facilitate installation. In all cases, the monuments were driven to refusal, or until approximately 6 in of the rod remained above the surface. In no case was a monument omitted from a planned location because of the inability to drive it into rocky soil.

The network layout used for this site is shown in figure 5. It consisted of two north-south lines (A and C), and a diagonal B-line. This type of monitoring layout was used to give an overall picture of subsidence progression during mining. The diagonal line traversed the area with the least amount of overburden, with both ends of the line stopping near or on a rock outcrop. The rock outcrops, because of the extreme changes in their elevation and location, affected the ability to obtain angles of draw at this particular site.

Southwest Section

This section had similar topographic and geologic characteristics to the northwest section; however, it lay in a drainage basin. The monument locations are shown in figure 6. Rock outcrops were not a factor in the installation of these monuments. Two lines were installed over this section to monitor subsidence near a 24-in-diam waterline and the main road to the Ute Water facility.

Third-West Section

Geological characteristics of the third-west section were similar to both previous sections, with increased overburden over some areas. The section was traversed by Cottonwood Creek. Three monitoring lines were installed over the section. The network layout is shown in figure 7. The east-west L-line monitored the centerline of the panel, and the A- and C-lines provided subsidence information across the panel. The A-line was oriented to provide information regarding the effectiveness of the barrier pillars beneath Cottonwood Creek.

MONITORING PROCEDURES AND EQUIPMENT

The Roadside Mine subsidence monitoring program was designed primarily to measure vertical movement of the subsidence monuments. The initial and final monument elevations showing the subsidence profile were of prime importance. Another initial objective of the study was to determine the timing and rate of subsidence development. Because of a limited number of surveys, the actual subsidence rates were not evaluated.

Traverse surveys were used to position the monitoring network over the mine workings at predetermined locations and to monitor vertical and horizontal displacements. The traverse surveys were run using a total station geodimeter and reflecting prism assemblies (fig. 8). Horizontal and vertical angles and slope distances were measured to each subsidence monument from instrument stations with known coordinates. The elevations and coordinates of the instrument stations were determined from stable control points beyond the influence of mining, and a closed traverse survey was performed on all instrument stations and control points as part of each survey to ensure accuracy. The target unit for the traverse surveys (fig. 8) held a prism for distance measurement and a target for angle measurement and was clamped securely onto the subsidence monument and then surveyed. The interchangeable bottom clamp could be attached to circular monuments ranging in diameter from 9/16 to 1-1/2 in. If additional height was required for improved visibility, 1-ft aluminum extensions were attached between the clamp and the target.

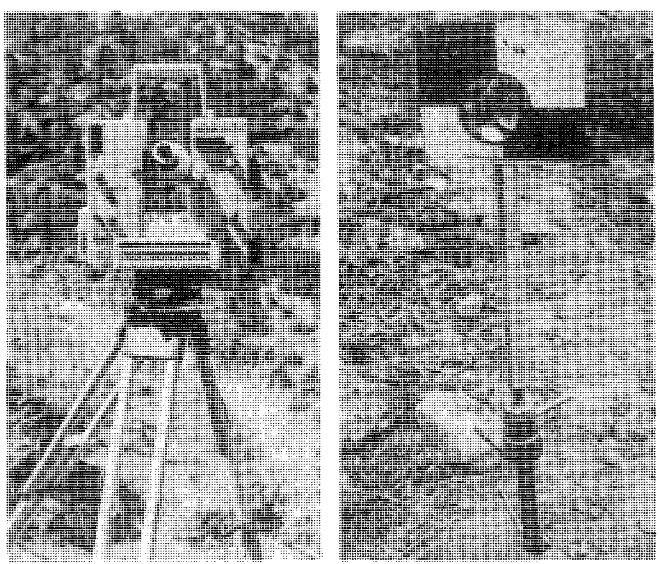

Figure 8.—Total station geodimeter and reflection prism assembly.

Third-order direct level surveys were used to monitor elevation in terrain with moderate relief. These surveys were performed using an automatic, self-leveling level and a level rod with 0.01-ft graduations. The accuracy of elevations from direct level surveys is greater than that from traverse surveys. Third-order level surveys have a maximum allowable closure error of ± 0.05 ft times the square root of the length of the level line in miles ($0.05\ \sqrt{mi}$), which resulted in a standard error calculated from several level surveys of 0.02 ft. The elevations computed from the traverse surveys yielded a standard error of 0.08 ft.

DATA PROCESSING

Following each traverse survey, field data were downloaded from the total station memory into computer files. Data from the total station geodimeter included station names, horizontal and vertical angles, slope distances, and target and instrument heights. The easting, northing, and elevation of each monument were then stored in a mass storage file; these data were filed by survey location, survey type, and date. Raw data from the level surveys were manually typed into the computer, and elevations for each subsidence monument were calculated and stored in the same mass storage file. A computer program calculated point elevations and closure errors and then adjusted the monument elevations accordingly. In this form, the information was readily accessed and used as input for programs that performed calculations such as coordinate and elevation differences between any two surveys. The data were also used to map monument locations and plot subsidence profiles. Several graphics software programs were used to generate subsidence profiles and maps with subsidence monument coordinates.

SUBSIDENCE RESULTS

NORTHWEST SECTION

The final subsidence profiles for the Northwest section are shown on figure 9. The figures show a baseline (zero line) averaged from two surveys performed in 1981, a profile from a level survey performed in 1985, and a profile from a level survey performed in 1991. The maximum subsidence measured in this section was approximately 3.0 ft located at station C6. This maximum subsidence value was approximately 40 pct of the mining height of 7 ft. The subsidence profiles (fig. 9) show a lack of subsidence above the chain pillars; it is apparent, therefore, that the chain pillars between the panels had not crushed. The shallow overburden in this section (200 ft) and the relatively flat topography had a minimum effect on the subsidence profiles. The angle of draw for this section was calculated from subsidence values taken from monument A2 through A6, B2 through B13, and C4 through C13 (where the monitoring network lines passed from mined panels to barrier pillars or chain pillars). The average angle of draw for these sections was 11° to 14°. The monument spacing of 100 ft adversely affected the calculation of the angle of draw because the distance between the monuments made choosing a specific point where subsidence ended a partially subjective process. The actual rate of subsidence was not obtained for this section because of a limited number of surveys.

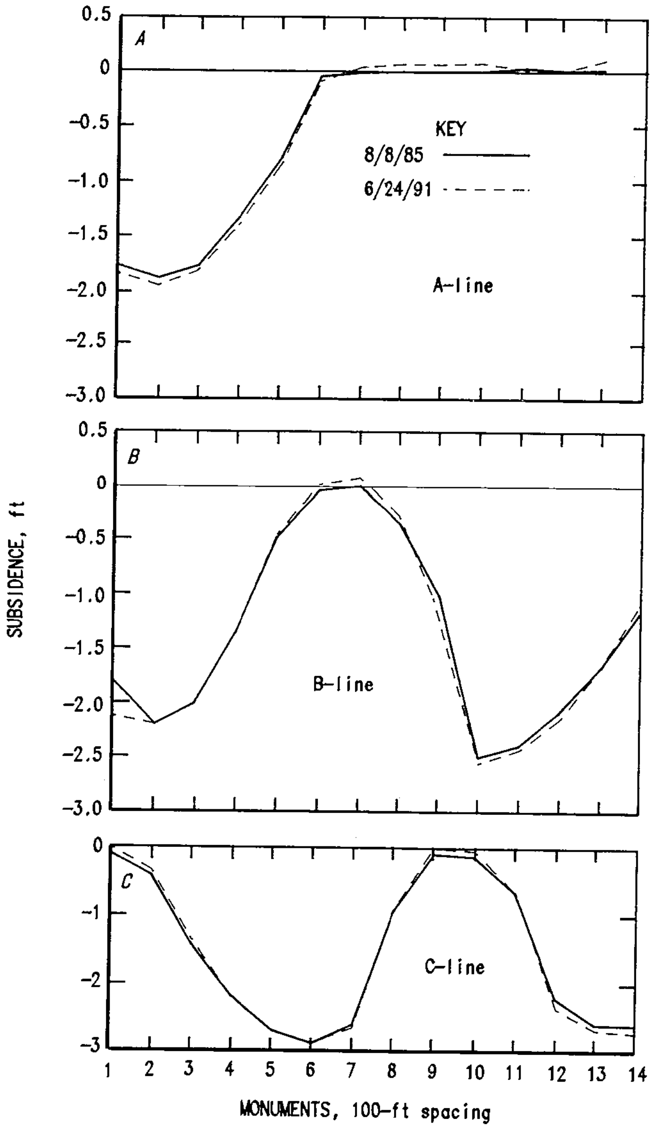

Figure 9.—Subsidence profiles for northwest section.

Figure 10 shows the locations of several tension cracks over the area that were mapped during the survey in 1985. Several cracks were apparent (fig. 11), with up to six parallel cracks appearing between monuments B5 and B6. These tension cracks ranged from approximately 1 to over 12 in wide in some locations, and varied in depth from 6 in to 1 ft. Observation of the affected area during the survey of June 1991 showed only one crack (fig. 12); this crack was approximately 1 to 2 ft wide and ranged in depth from 1 to 9 ft. The orientation of this crack was similar to the sets of cracks shown in figure 10, crossing the A-line between A5 and A6, and crossing the B-line between B5 and B6. The length of the crack was approximately 200 ft, with the deepest section in the middle of the length. The crack occurred in the tensile zone of the subsidence profiles for both the A- and B-monitoring lines. The subsidence profiles show no appreciable change from 1985 to 1991. The limited amount of vertical movement, with an increase in the width and depth of the crack, indicates that the crack may not have been affected by horizontal displacement. It is possible that erosion had acted as a catalyst to increase the depth and width over a period of 7 years. Erosion could have also "healed" the other smaller cracks that had appeared in 1985, but were not apparent in 1991.

SOUTHWEST SECTION

The subsidence profiles for the southwest section are shown in figure 13. The till material that was encountered in this section during development limited mining, and no significant subsidence occurred from 1981 to 1985 over the southwest section. The survey that was performed in June of 1991 also showed no appreciable subsidence. The

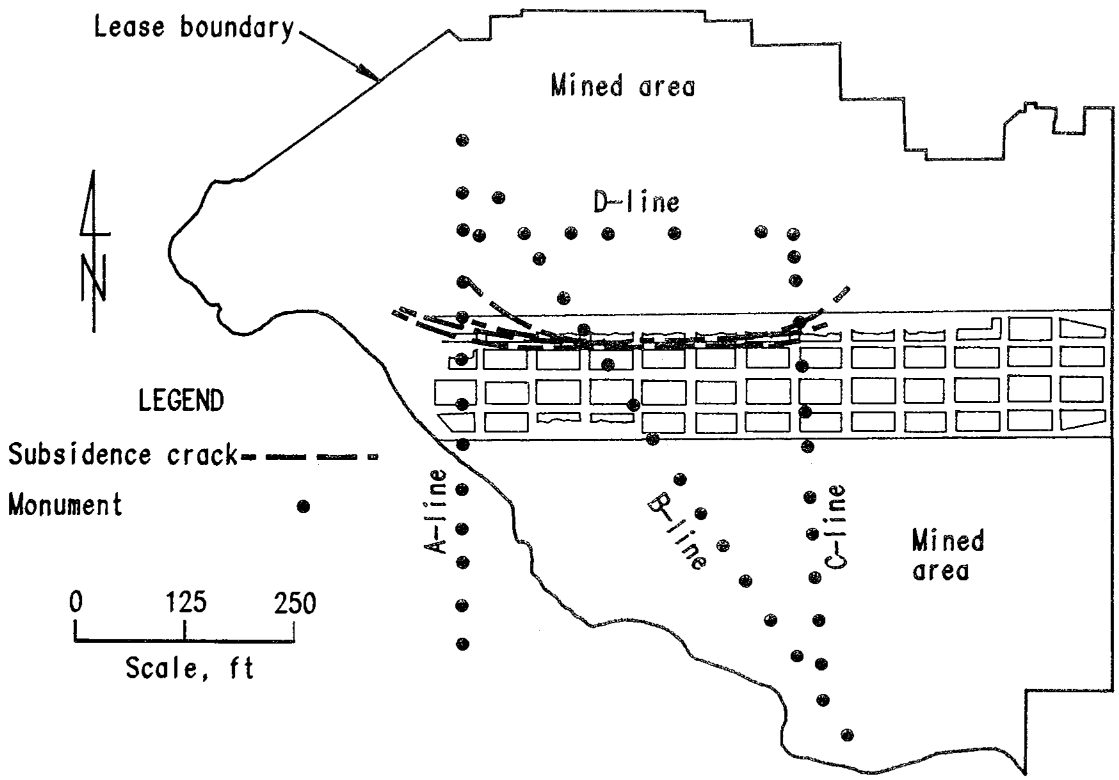

Figure 10.—Location of subsidence cracks, northwest section.

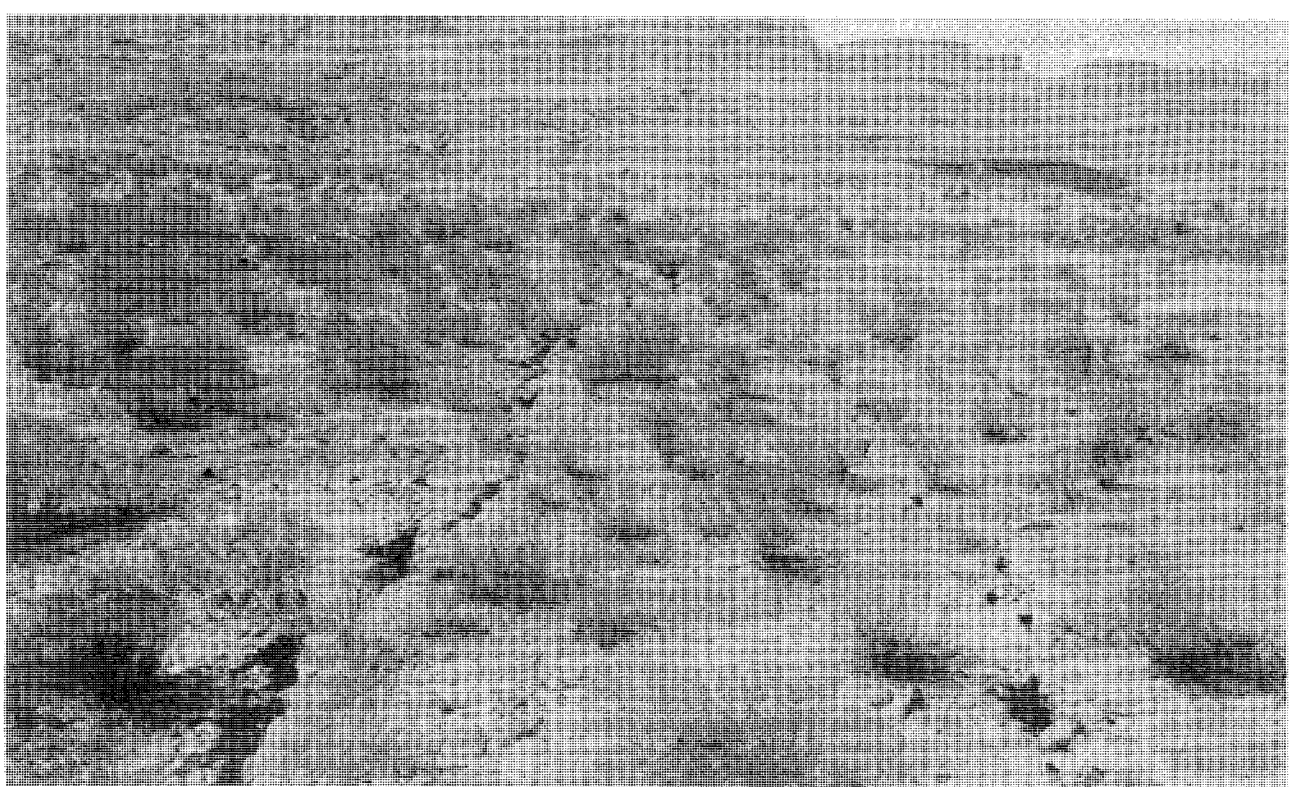

Figure 11.—Subsidence cracks located over northwest section, 1985 survey.

maximum amount of subsidence that occurred over the F-line during the period between 1981 and 1985 was 0.4 ft. The maximum amount of subsidence that occurred over the G-line during the same time period was also 0.4 ft. This is an expected result because retreat mining of this section was not completed.

THIRD-WEST SECTION

Subsidence profiles for the third-west section are shown in figure 14. As detailed in the mine plans, to prevent vertical deformation near Cottonwood Creek and to isolate the stream from damage, several pillars were left unmined beneath the streambed, providing a protective zone on the surface. The subsidence profile for the A-line (from the survey performed April 8, 1986) shows very little subsidence except those points that overlap onto the fourth-west panel, with a maximum subsidence value of 1.1 ft at station A43. The survey performed on April 8, 1986 was after

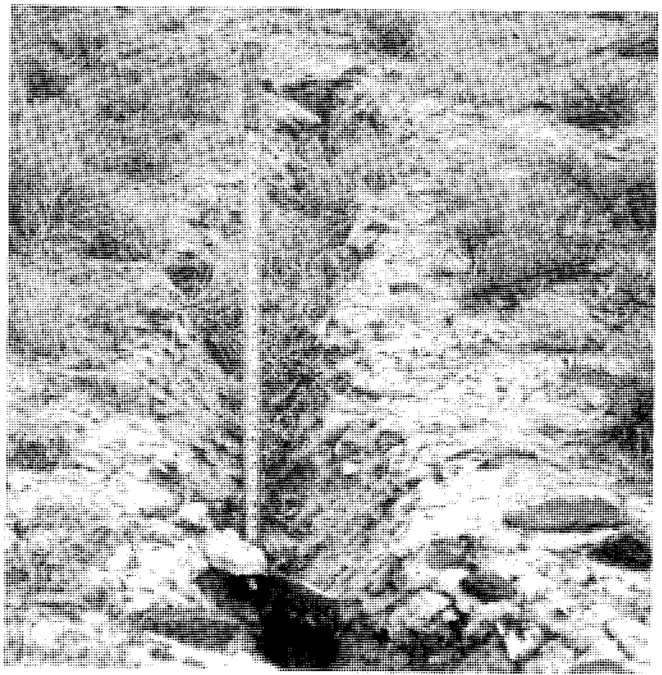

Figure 12.—Subsidence crack located over northwest section, 1991 survey.

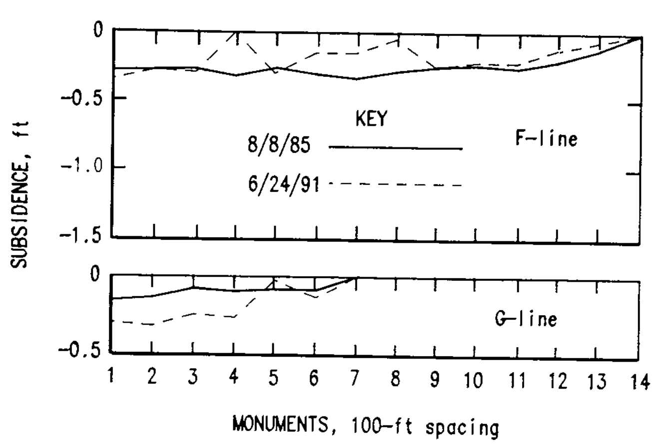

Figure 13.—Subsidence profiles for southwest section.

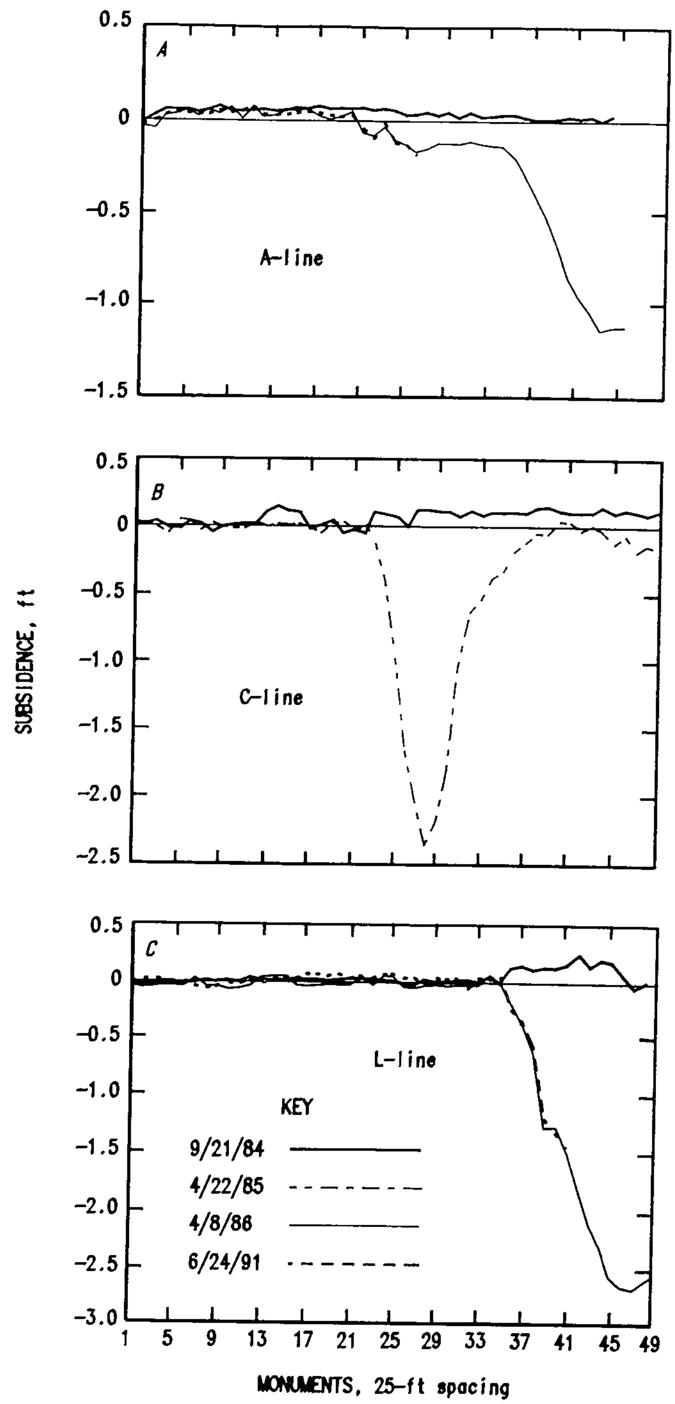

Figure 14.—Subsidence profiles for third-west section.

both the third- and fourth-west panels had been retreated. The average mining height in this area was 7 ft; the maximum subsidence was approximately 16 pct of the mining height. This lack of subsidence indicates that the support pillars that were left under Cottonwood Creek had prevented any major effects on the drainage pattern of the creek. The subsidence profiles for June 1991 show that no further subsidence had occurred in the creek area. The survey in June 1991 included only L1-L41 and A1-A26 because to survey the other monuments in this area required a trilateration survey as opposed to a facile level survey. No surface cracking, changes in drainage, or surface damage were noted either during the survey in 1986, or during the 1991 survey. The subsidence profile for the C-line is shown on figure 14. The maximum value for subsidence on this line as of April 22, 1985 was approximately 2.4 ft and occurred at station C27 prior to mining of the fourth-west panel. The maximum subsidence in this area was approximately 32 pct of the mining height. Some influence from the adjacent panel development was also prevalent in this profile toward the end of the C-line (C41-C49), which showed a subsidence value of 0.4 ft. Calculations regarding the angle of draw between the third- and fourth-west panels (using the C-line and A-line transverse profiles across the barrier pillar) yielded an average 8° to 11° angle of draw for this section. The fourth-west panel was mined during the later part of 1985.

The subsidence profile for the L-line is shown in figure 14. The maximum value for subsidence on this line was approximately 2.7 ft and occurred at station L47. The maximum subsidence for this line was 37 pct of the mining height. The lack of subsidence in the area around Cottonwood Creek (L31-L35) indicates that the support pillars had not failed. Directly below the stream, mining averaged approximately 50 pct extraction. The pillars west of L37 were retreat mined. The ability of the barrier pillars to protect the creek was apparent, since the subsidence profiles show little or no subsidence in the immediate area around Cottonwood Creek.

The purpose of the residual subsidence survey performed in June 1991 in the third-west section was to evaluate the long-term effectiveness of the barrier pillars below Cottonwood Creek. The level survey included A1-A26 and L1-L39. The results from the residual subsidence survey performed in 1991 are shown in figure 14. The elevations of the survey monuments had not changed substantially from the survey performed April 1986. The data from the survey performed in 1991 illustrate that the barrier pillars below Cottonwood Creek had not failed.

SUMMARY

The Bureau performed subsidence monitoring at the Roadside Mine from 1981 to 1985. A survey to evaluate residual subsidence at this site was performed in June 1991, and the results from this survey showed that no measurable residual subsidence had occurred in any of the three monitored sections (within the standard error of the instruments). Several structures (pipelines and utility lines), roads, and streams were above the mine. No physical damage to these structures or the stream was observed by Bureau personnel, nor was any type of utility service interrupted because of subsidence. Barrier pillars were used to reduce subsidence beneath these structures and minimize damage.

The maximum subsidence measured over the three sections was 3.0 ft, or 40 pct of the extraction height, and was located in the northwest section on the C- and B-lines of the monitoring networks. A shortage of surveys precluded evaluation of the timing between the immediate roof collapse, pillar crushing, pillar punching, overburden failure, and subsequent surface subsidence.

Surface cracks were observed in one area and were deemed to be tension cracks resulting from subsidence. Visual observation of the area affected by subsidence during the survey of June 1991 showed a crack approximately 1 to 2 ft wide and up to 9 ft deep. The length of the crack was approximately 200 ft, with the deepest section in the middle of the length. The tension crack appeared in an area of high tension on the surface, immediately above a panel edge. Erosion of this crack could have served to broaden and deepen it during the time frame between the last two surveys. The subsidence profiles showed no measurable change in elevations from 1984 to 1991. No other cracks were detected in other sections of the study area. The pillars below Cottonwood Creek were first-mined only, with no observable changes to the local drainage patterns. Overall, the physical effects on the surface were negligible except for the surface crack in the northwest section.

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