IMSRP VII

SUBSIDENCE INVESTIGATIONS OVER A HIGH-EXTRACTION RETREAT MINE IN WILLIAMSON COUNTY, ILLINOIS: FINAL REPORT

B. B. Mehnert, D. J. Van Roosendaal,
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Illinois Mine Subsidence Research Program

1994
IMSRP ~~VII~~ IX

cooperating agencies
ILLINOIS STATE GEOLOGICAL SURVEY
Illinois Department of Energy and Natural Resources
BUREAU OF MINES
United States Department of the Interior

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ILLINOIS STATE GEOLOGICAL SURVEY
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The **Illinois Mine Subsidence Research Program** (IMSRP) was established in 1985 to investigate methods and develop guidelines for underground mining operations that aim to maximize coal extraction yet preserve the productivity of prime farmland. The research program was initiated by the Illinois Coal Association and the Illinois Farm Bureau.

The Illinois State Geological Survey, a division of the Illinois Department of Energy and Natural Resources, directed the IMSRP. Participating research institutions included Southern Illinois University at Carbondale, the University of Illinois at Urbana–Champaign, Northern Illinois University, and the Illinois State Geological Survey. A 5-year Memorandum of Agreement, signed by the State of Illinois and the Bureau of Mines, U. S. Department of the Interior, ensured collaboration, cooperation, and financial support through 1991. Major funding was also provided by the Illinois Coal Development Board.

This publication is one in a series printed and distributed by the Illinois State Geological Survey as a service to the IMSRP.

Printed by authority of the State of Illinois/1994/800

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ABSTRACT

The effects of high-extraction retreat (HER) mining on the overburden were investigated using two instrument clusters placed over one HER panel in Williamson County, Illinois. The amount, extent, and location of fracturing in the bedrock were measured, and the effects of the fracturing on the local hydrogeology were examined. Instruments used included surface monuments, piezometers, extensometers, and two time-domain reflectometry cables. The Illinois State Geological Survey (ISGS) monitored the panel before, during, and after subsidence. This was the first time such information was collected over an HER operation in Illinois. This site is one of three investigated under the Illinois Mine Subsidence Research Program to study the effects of mining on the overburden.

INTRODUCTION

Scope and Purpose

High-extraction mining techniques are being used more frequently in Illinois to maximize coal-mining productivity and to decrease the cost of the delivered product. Underground coal extraction by these techniques causes immediate collapse of the overburden and subsidence of the ground surface. Farmland and water resources may be affected by surface subsidence. The Illinois Mine Subsidence Research Program (IMSRP) was created to address these concerns. This study is one of several projects performed under the IMSRP with funding from the U.S. Bureau of Mines, Illinois Department of Energy and Natural Resources Coal Development Board, and the Office of Surface Mining.

The purpose of this investigation was to study the effects of high-extraction retreat (HER) mining on the overburden. Two instrument clusters were installed over an HER panel to investigate the following: subsidence of the ground surface; amount, extent, and location of fracturing in the bedrock overburden; and hydrogeologic changes caused by bedrock deformations. Surface monuments, piezometers, extensometers, and two time-domain reflectometry cables were used to monitor overburden and ground surface response. The Illinois State Geological Survey (ISGS) monitored the panel before, during, and after subsidence. This was the first time such information was collected over an HER operation in Illinois.

This report summarizes the geotechnical monitoring program and the results of monitoring throughout a 3-year period. Unfortunately, the mining company did not complete the panel and only one-half of the instrumentation was undermined. The undermined instruments were located near the start of the panel.

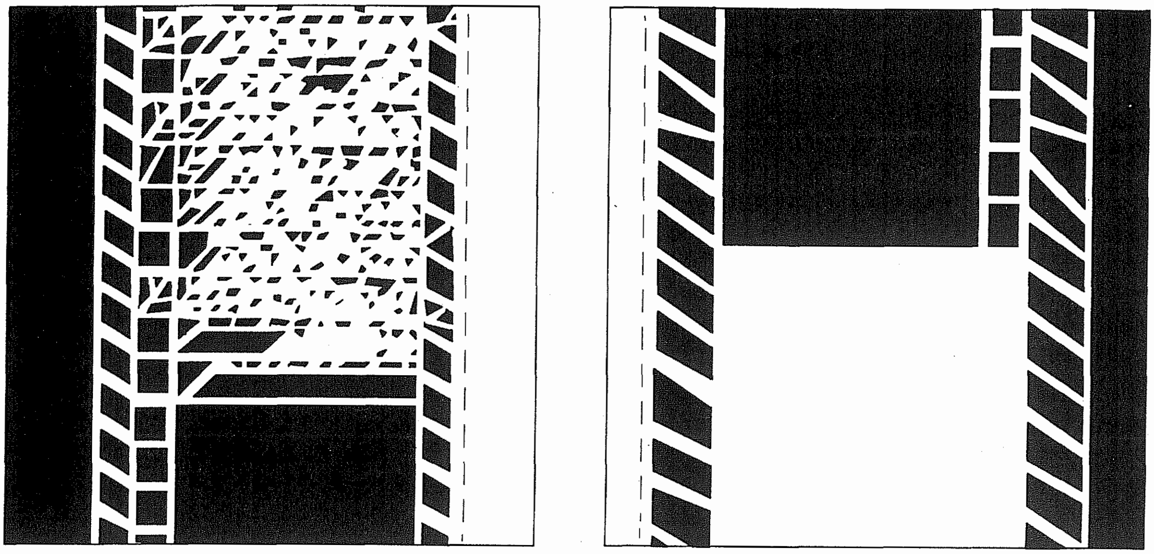
Background and Previous Studies

Natural resources affected by mine subsidence Illinois is the second largest producer of agricultural commodities and the fifth largest producer of coal in the United States. Problems sometimes occur in ensuring that both the farmland and the coal resources are used to their maximum potential. Subsidence-induced ground movements modify surface drainage, which may affect crop yields of the gently rolling farmland. Clearly, coal and farmland are valuable resources and important to the state's economy. Mine operators are required to manage the impacts of underground mining on near-surface hydrology and surface-drainage patterns.

Methods of mining Two high-extraction mining methods, HER and longwall, are used in Illinois; each produces immediate, planned subsidence. Figure 1 shows the configuration of the two high-extraction mining methods commonly used. These two methods differ in the amount of fracturing and hydrologic changes caused in the overburden and the amount of damage produced in surface structures.

High-extraction retreat methods are similar to room and pillar mining techniques except that pillars are removed on retreat. In this type of operation, small sections of the panel collapse and subside as they are extracted.The roof may stay up until several hundred feet have been mined out and then collapse. In contrast, the longwall method removes all the coal across a wide working face, which is temporarily supported by hydraulic shields. A double row of pillars separates the panels. The entryways of the pillars are used for ventilation and transportation. As the mine face advances, the overburden behind the shields is left unsupported and collapses into the void. Surface subsidence immediately follows this collapse.

Overburden fracturing Coe and Stowe (1984), Ming-Gao (1982), and Whitworth (1982) investigated the location and amount of fracturing in subsided bedrock over longwall operations in Ohio



high-extraction retreat

longwall

Figure 1 Two high-extraction techniques commonly used to remove coal. Both result in controlled surface subsidence.

(USA), Jiangsu Province (China), and South Staffordshire Coalfield (United Kingdom), respectively. Before the IMSRP efforts, Conroy (1980) performed the only study concerning fracturing above a high-extraction mining operation in Illinois. He grouted two time-domain reflectometry (TDR) cables into boreholes that extended from the ground surface into a 625-foot-deep longwall mine. Conroy found that the bedrock movements severed one of the cables within 100 to 150 feet of the surface.

Hydrogeologic effects Fracturing of the overburden may affect water-bearing formations by creating voids and increasing secondary permeability as found in the Appalachian Plateau of Pennsylvania (Booth 1986). In a study in England, Garritty (1982) suggested that fracturing of the bedrock up to the surface may hydrologically connect an aquifer or surface water body with the mine. While studying a mine roof in Illinois, Cartwright and Hunt (1978) observed localized, open, vertical joints that had been caused by faulting; they speculated that these joints could provide a direct passage for water from higher strata in the immediate roof. These fractures were discontinuous, however, and did not provide any hydrologic connection to the surface. In another study in Illinois, Nieto (1979) found that mines with faults showed no leakage, even though they were located about 600 feet under the Rend Lake reservoir. Similarly, subsequent studies in Illinois (Brutcher et al. 1990, Van Roosendaal et al. 1990, Booth and Spande 1990) have shown that discontinuous, localized fracturing caused by strains in the bedrock may occur without any hydrologic connections to the surface.

Before this study was initiated, the hydrogeologic effects of subsidence were investigated by several researchers (Coe and Stowe 1984, Duigon and Smigaj 1985, Garritty 1982, Owili-Eger 1983, Pennington et al. 1984, Sloan and Warner 1984). In studies of the Appalachian Plateau by Coe and Stowe (1984), Booth (1986), and Pennington et al. (1984), drops in water level were observed in wells that were undermined using the longwall method. Water levels partially or completely recovered, however, several months after being undermined by the longwall method (Owili-Eger 1983). Subsequent studies in Illinois by Pauvlik and Esling (1987), Brutcher et al. (1990), and Booth and Spande (1991) have also documented similar observations. Booth and Spande (1991) also determined that aquifer characteristics of an originally poor aquifer actually improved after mining.

Surface subsidence characteristics Planned subsidence is produced by both the HER and longwall methods of mining. Two types of surface subsidence profiles, static and dynamic, are produced during high-extraction mining (Kratzsch 1983). The static profile reflects the final changes in elevation after subsidence. Static profiles are generally measured transverse to the panel to show the final shape

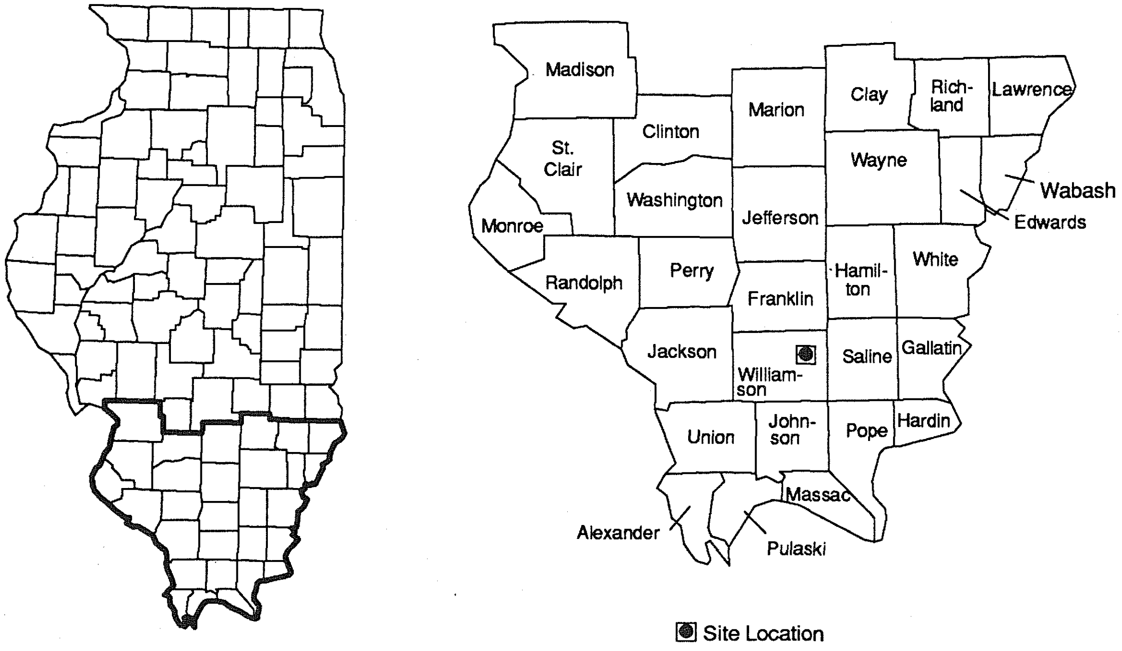


Figure 2 Approximate location of site in Williamson County, Illinois.

of the subsidence trough. Dynamic profiles are documented as surface subsidence occurs. For instance, longitudinal survey lines are used to document the dynamic traveling subsidence wave that develops on the ground surface behind the advancing mine face. Near the sides of the panels, the progression from dynamic to static subsidence is complex (Van Roosendaal et al. 1991).

Strain and slope characteristics of the two different profiles are unique and depend on the overburden properties and the rate of mining. Kratzsch (1983) states that a fast rate of advance in viscoelastic strata produces a flatter dynamic profile; strain and slope values are greatly reduced, as compared with those of the static profile. If the strata are fractured and loose, however, the dynamic profile becomes much more severe as mining-advance rates increase.

Physical Setting

Site selection Several factors were considered during the site selection process. First, an HER mine had to be available for study within a reasonable time frame. It was essential that instruments be installed well before the site was undermined so that site characterization and base-line data collection could take place. Next, the full cooperation of the mine operators and surface owners was required. Formal agreements with these parties were negotiated prior to initiation of work. Finally, the site had to be accessible and well suited for both instrument installation and long-term monitoring.

The above criteria were used to select an HER panel in northeastern Williamson County, Illinois. Figure 2 shows the approximate location of the mine panel about 2 miles east-southeast of the town of Pittsburg in the southwest quarter of Section 6, T9S, R4E, of the 3rd Principal Meridian (Pittsburg Quadrangle).

Physiography The study site is located in the Mount Vernon Hill Country physiographic division of Illinois (Leighton et al. 1948). The geomorphology of the area is characteristic of a maturely dissected, sandstone–shale plain of low relief mantled by thin (<40 feet) Illinoian drift. Restricted uplands and broad alluviated valleys occur along the larger streams.

Surface topography above the panel is gently rolling. The maximum relief is about 40 feet. Surface elevations range from about 480 to about 520 feet above mean sea level (msl) and slopes vary from less than 3% to more than 18%. The topography in the area is primarily bedrock controlled (Horberg 1950). Bedrock features are modified, however, by glacial action and somewhat subdued by a thin mantle of deeply eroded drift that covers the region (Leighton et al. 1948).

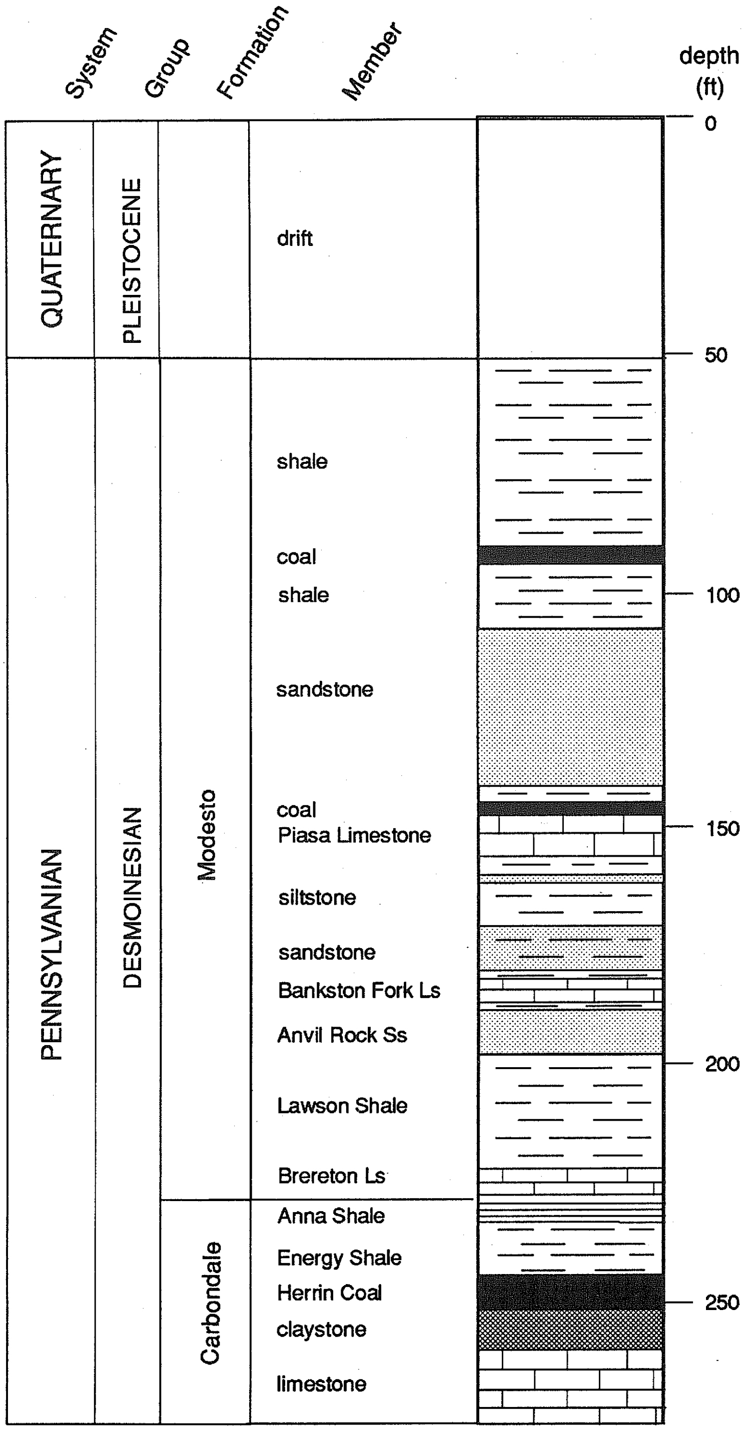


Figure 3 Generalized stratigraphic column of the Carbondale and Modesto Formations. The column was derived from one core log taken at the study site.

Dendritic drainage is predominantly bedrock-controlled in the vicinity of the panel site (MacClintock 1929). Upland areas are generally well drained, although some of the broad lowlands are poorly drained (Leighton et al. 1948). The surface above the panel is a well drained upland north of the watershed divide between the Big Muddy River Drainage Basin and the Saline River Drainage Basin to the east. The surface above the mine panel drains generally northwestward into Crab Orchard Creek.

Surficial geology The surficial geology at the study site consists of deeply eroded Illinoian till overlain by 3.3 to 4.6 feet of loess. Alluvial sand, silt, gravel, and clay are found in the bottomlands. Some lacustrine deposits are located downstream from the study area along Crab Orchard Creek. Outcrops of bedrock are rare and of limited extent; they are predominantly located low on the valley walls (MacClintock 1929). Glacial drift thickness may have substantial local variations, but as available borehole data indicate, it generally ranges from about 14 to 60 feet.

Soils found in the area include the Belknap silt loam, the Hickory-silt-loam-Ava-silt-loam complex, and the Ava silt loam (Feherenbacher and Odell 1959). The light-colored, acidic Belknap silt loam developed in the alluvium bottomlands where slopes are less than 1.5%. Belknap soils are characterized by poor drainage. The Hickory-silt-loam-Ava-silt-loam complex is found on slopes of 10% to 18% in loess and Illinoian till. It is developed under forest vegetation. The light-colored Hickory silt loam developed in Illinoian till on the lower, steeper parts of the slopes. Ava silt loam generally developed in 40 to 60 inches of loess over leached Illinoian till on gently sloping areas of the uplands and on relatively level, uneroded ridgetops. The Ava silt loam has a well developed fragipan (cemented layer) from 2 to 7 feet deep, which inhibits root penetration.

Bedrock stratigraphy and structure The bedrock units at the study site are the Carbondale and the Modesto Formations, which belong to the Pennsylvanian System of Illinois. Both formations are composed primarily of shales and siltstones (70–80%) along with fewer units of sandstone and limestone. A generalized regional stratigraphic column of parts of the Carbondale and Modesto Formations of the Pennsylvanian System in southern Illinois is shown in figure 3. In addition, table 1 summarizes the average thickness of overburden units and their ranges as derived from eight core logs of boreholes drilled within 1 mile of the study site.

The Cottage Grove Fault System is located 1.5 miles north of the site. The fault system consists of a right-lateral, strike-slip master fault and subsidiary, en echelon, high-angle normal faults (fig. 4). The Cottage Grove Fault is oriented northwest-southeast as a result of the orientation of the principal horizontal compressive stresses during the late Pennsylvanian to Early Permian Periods. The Cottage Grove Fault System is thought to have developed along a zone of weakness in the basement rocks at the time of general east-west compression that formed the Appalachian Mountains (Nelson and Krausse 1981). Contemporary stress measurements indicate the maximum horizontal stresses may be as much as three times the minimum horizontal and vertical stresses; the major stress field direction is east-northeast to west-southwest (Ingram and Molinda 1988, Nelson and Bauer 1987). The bedrock dips gently to the north at 25 to 100 feet per mile (Nieto 1979). Local dips of more than 15° were observed, however, in a coal mine operating in the Herrin Coal just north of the study site (Krausse et al. 1979). Mine workings affected by the Cottage Grove Fault System are oriented according to the pattern of faults encountered.

The immediate mine roof strata sequence contains Energy Shale distributed as an overbank deposit associated with the Walshville paleochannel, which is a clastic-filled channel that trends roughly north to south through southern Illinois about 20 miles to the west of the study site. The Walshville channel was, in part, contemporaneous with the deposition of the Herrin Coal and provided the Energy Shale, the youngest roof unit present here. Further details of the geology of the Walshville channel are found in Nelson (1979).

Drill-hole data and mine information indicate that the Energy Shale is typically 10 to 20 feet thick in the study area, placing the Anna Shale and Brereton Limestone out of bolting range. An unusual aspect of the roof sequence is the thick sandstone-rich, Anvil Rock Sandstone–Lawson Shale interval, which averages 37 feet in the area and includes a sandstone 7.3 feet thick in the west part of the panel.

The Herrin Coal Member is the seam mined at the site. It lies between 250 to 350 feet msl. Core logs indicate, however, that coal elevations vary from less than 240 feet to more than 390 feet msl within 1 mile of the site. The variation is due to the northward dip in strata and offsets of the coal seam caused by faulting. The thickness of the Herrin Coal varies between 5.5 to 6.5 feet, as measured in mines in the area, and probably averages around 6 feet near the study area (table 1).

Hydrogeology Local groundwater resources are limited and primarily used for domestic and household needs (Feherenbacher and Odell 1959). Surface water reservoirs, such as Crab Orchard Lake and other smaller manmade impoundments, supply water to the larger communities. Water for livestock, minor irrigation, and other farming purposes is usually obtained from small, natural or manmade ponds such as the one located at this site.

Table 1 Summary of overburden unit thickness and thickness ranges

Unit/interval	Thickness range (ft)	Average thickness* (ft)
Pleistocene (soil/till/drift)	14 – 60	37
Bedrock above Bankston Fork Ls	45 – 137	105
Bankston Fork Limestone	5 – 8	6.6
Anvil Rock Ss / Lawson Shale	32 – 45	37
Jamestown Coal / Conant Ls**	0.6 – 4	1.9
Brereton Limestone**	0.6 – 4.2	3.0
Anna Shale	2.6 – 6.7	3.5
Energy Shale**	8.2 – 19.5	15.3
Herrin Coal	5.6 – 6.2	6.0

* Where present; zero thickness is not averaged.

** Missing in either one or two drill holes.

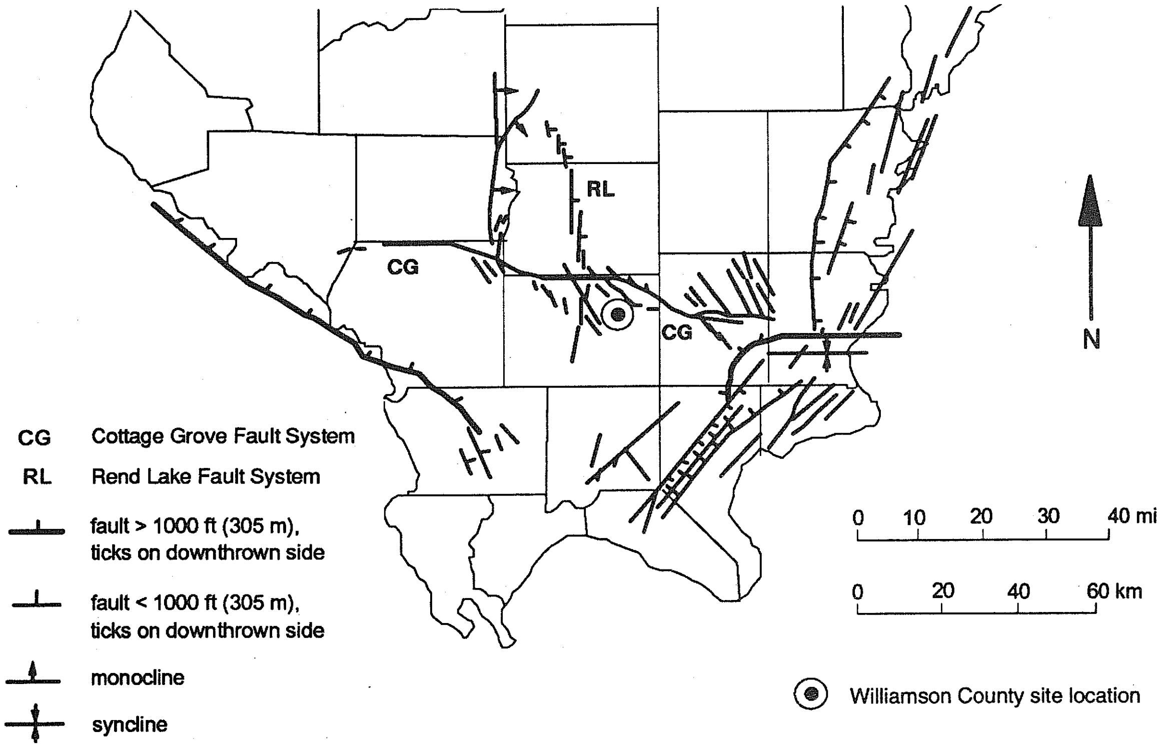


Figure 4 The Cottage Grove and other major fault systems of southern Illinois (after Nelson and Krausse 1981).

Groundwater is pumped from large diameter (2–5 feet) dug wells, which provide water for private and domestic purposes. These wells penetrate sand and gravel lenses that are in the glacial drift and usually directly overlie the bedrock surface at depths of as much as 60 feet (Pryor 1953). These lenses are as much as 12 feet thick. Sasman (1953) reported static water levels in the dug wells from about 5 to 35 feet below the surface and at pumping rates that varied from about 5 to 15 gallons per minute. This information concurs with water well data obtained from the ISGS and the Illinois State Water Survey (ISWS). Smaller diameter wells have also obtained groundwater from the glacial drift; however, yields were much lower than they were from the dug wells.

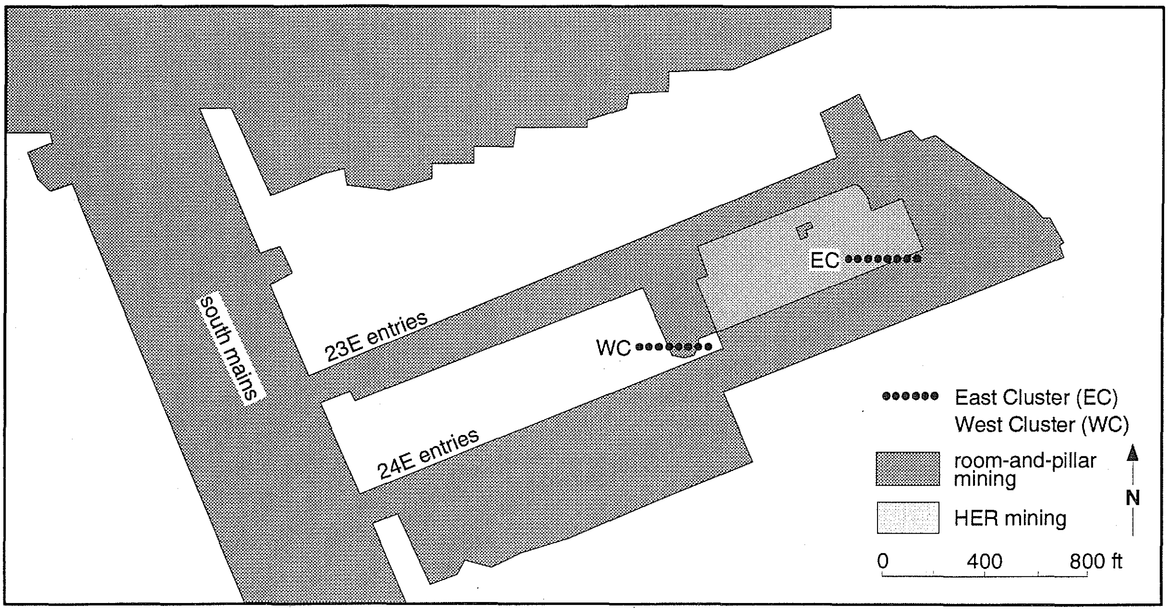


Figure 5 Partial mine map showing the monitored panel and adjacent workings.

Bedrock aquifers of the Pennsylvanian System in the study area are limited primarily to sandstone units; however, some fractured limestone aquifers were also reported (Pryor 1953). Static water levels in these wells ranged from about 10 feet to as much as 80 feet below ground surface.

Mine Description

The study site was situated over Panel 23 East of the Orient No. 4 Mine, which is operated by the Freeman United Coal Mining Company. Figure 5 shows the location of 23 East and adjacent workings. Mine plans called for a panel that is 2,300 feet long and 210 feet wide and has a seam 250 feet deep. The panel width was increased to 385 feet and the south edge of the panel was relocated northward during mining because of roof conditions. The operations at the mine were suspended on May 18, 1987, after the panel had progressed only 900 feet. Only the east cluster of instrumentation was undermined by the HER method. The west cluster was undermined by the room-and-pillar method only, but it is adjacent to the solid, unmined portion of the panel.

GEOTECHNICAL MONITORING PROGRAM

Introduction

The instrumentation for this study was selected to measure the geotechnical and hydrological effects of subsidence on the overburden. Engineers International (EI) of Westmont, Illinois, proposed an instrumentation plan that was reviewed and accepted by the U.S. Bureau of Mines, Twin Cities Research Center (USBM), and the ISGS. Representatives of the USBM let the contract to Engineers International to implement the instrumentation program and to conduct base-line surveys. Engineers International was responsible for installing most of the instruments including four bedrock and 11 drift piezometers, two multiple-position borehole extensometers (MPBXs), and 30 surface monuments (EI 1988). The ISGS, with assistance from Northwestern University, installed two time-domain reflectometry (TDR) cables, five tiltplates, four control monuments, survey turning points, and 14 additional rebar monuments to determine the static subsidence profile transverse to the panel.

The drilling program was conducted by the Soil and Rock Drilling Corporation of Bartlett, Illinois, under separate contracts. Engineers International installed the instruments in June 1986. The ISGS installed the tiltplates and additional survey monuments in March 1987.

Instrument layout Wyant Surveying Company of West Frankfort, Illinois, used mine coodinates to stake out the panel center line on the surface. The instrumentation layout shown in figure 6 was designed to measure two different responses of the overburden to mining of the panel by placing one instrument cluster near the beginning of the panel (east cluster) and one near the

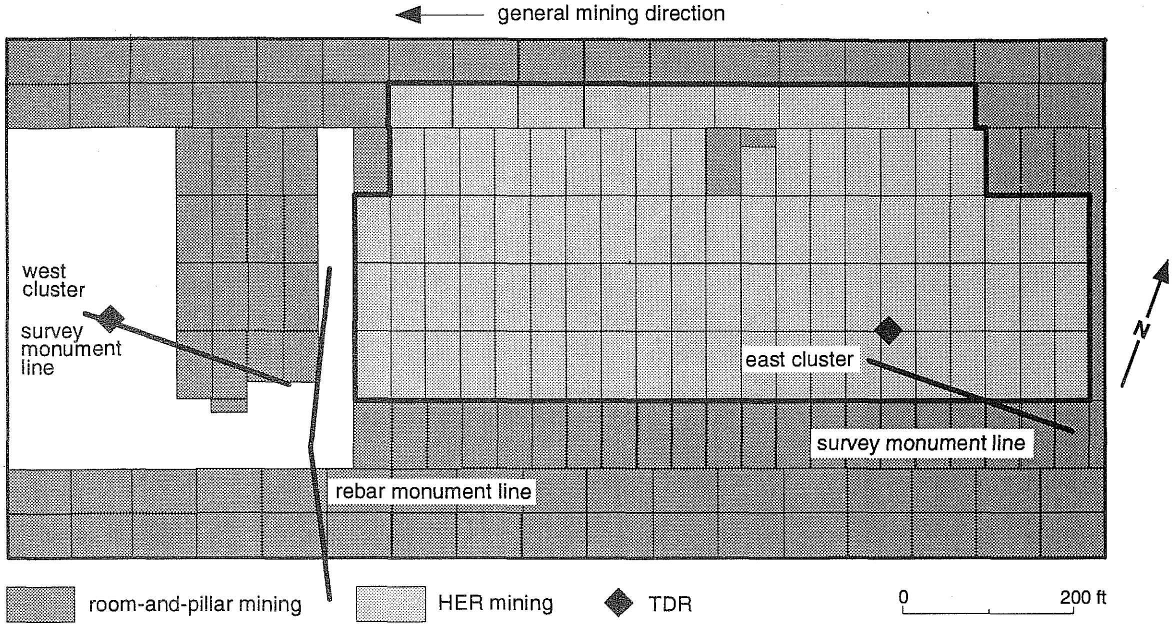


Figure 6 Instrumentation layout superimposed over the mine panel.

center (west cluster). The initial subsidence at the beginning of a high-extraction panel is usually sudden and extensive because the roof stays up until a critical span has been undermined. The subsequent subsidence that takes place shortly after roof support has been removed causes a dynamic subsidence wave behind the retreating face. The instrumentation in the west cluster was to monitor the effects of the dynamic subsidence wave.

Each instrument cluster consisted of a TDR cable, MPBX, one shallow (100 feet) bedrock observation well, and one deep (160–203 feet) bedrock observation well (figs. 7, 8). A line of surface monuments and drift piezometers extended from each instrument cluster; each line was oriented nearly east to west, perpendicular to the anticipated front of the subsidence wave. The west instrument cluster included additional rebar monuments, which were installed perpendicular to the panel center line to record the static profile over the edge of the panel. Additionally, five tiltplates were adjacent to successive east–west monuments. Two surface control monuments and two drift piezometers were placed well away (500 feet) from any undermined areas for both east and west clusters.

Mine operations Development and mining of Panel 23 East began in early 1987. Before mining, the company changed the panel dimensions, which placed the instrument clusters closer to the south side of the panel than was originally planned. The mine was abruptly closed shortly after pillar extraction had begun and before the face had reached the west instrument cluster. A company press release stated, "The mine company suspended operations due to economic conditions effective 12:01 a.m., Monday, May 18th, 1987." Although the mine company hoped to resume operations as soon as market conditions permitted, operations were not continued.

Surface Subsidence and Deformation Monitoring

Surveying *Monument design and installation* Two types of surface monuments were installed at the site. Frost-isolated monuments were anchored below the frost zone (fig. 9). The section of pipe that extended to the surface was surrounded by PVC pipe to isolate it from soil movements. Control monuments and long-term monitoring points were constructed in this manner. Simple rebar monuments, as shown in figure 9, were also used. Rebar monuments 3 feet in length were driven 2.5 feet into the ground as temporary monuments and turning points. The locations of surface monuments were selected on the basis of the mine layout. They were spaced 20 to 25 feet apart.

Surveying methods and frequency The ISGS began base-line monitoring in September 1986. Several level surveys were made with a WILD NA-2 as a check on the preliminary data received from Engineers International. A Lietz SET3 total station equipped with a SDR2 electronic notebook

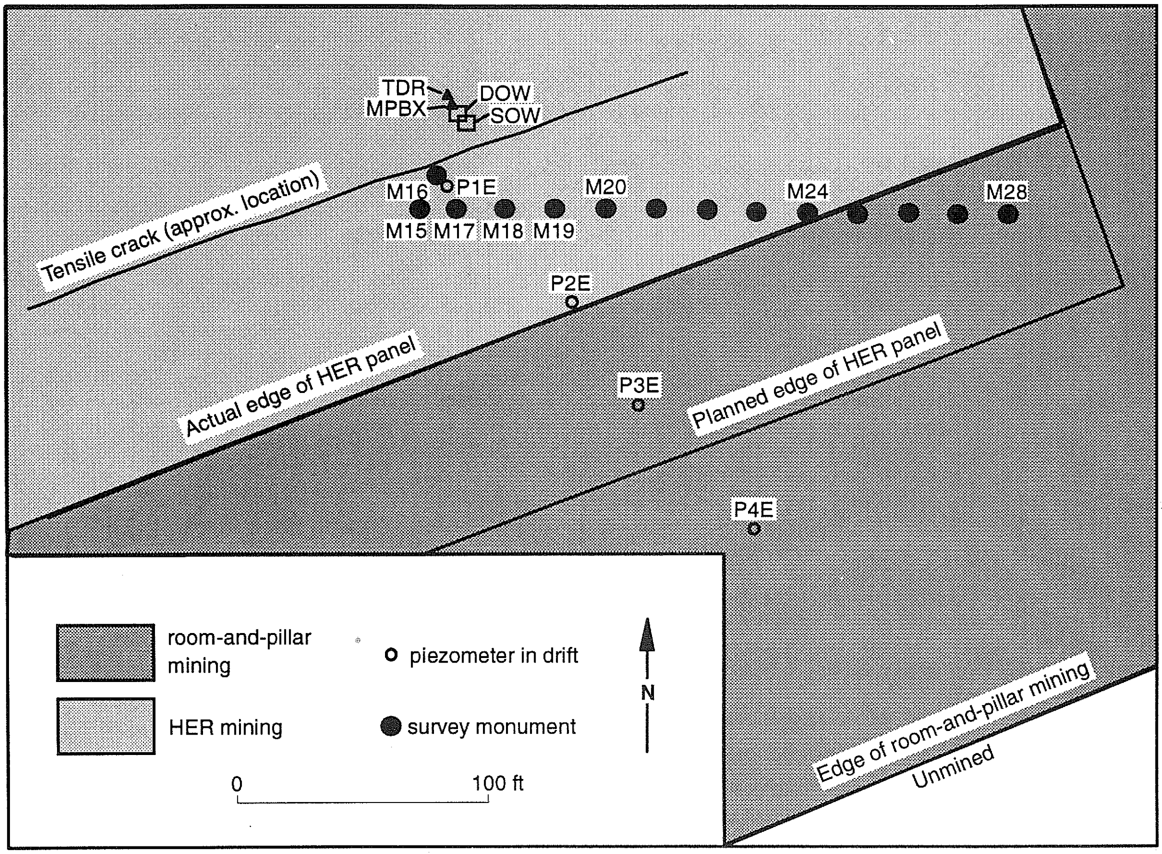


Figure 7 Schematic map of the east cluster instrument location and surface crack location.

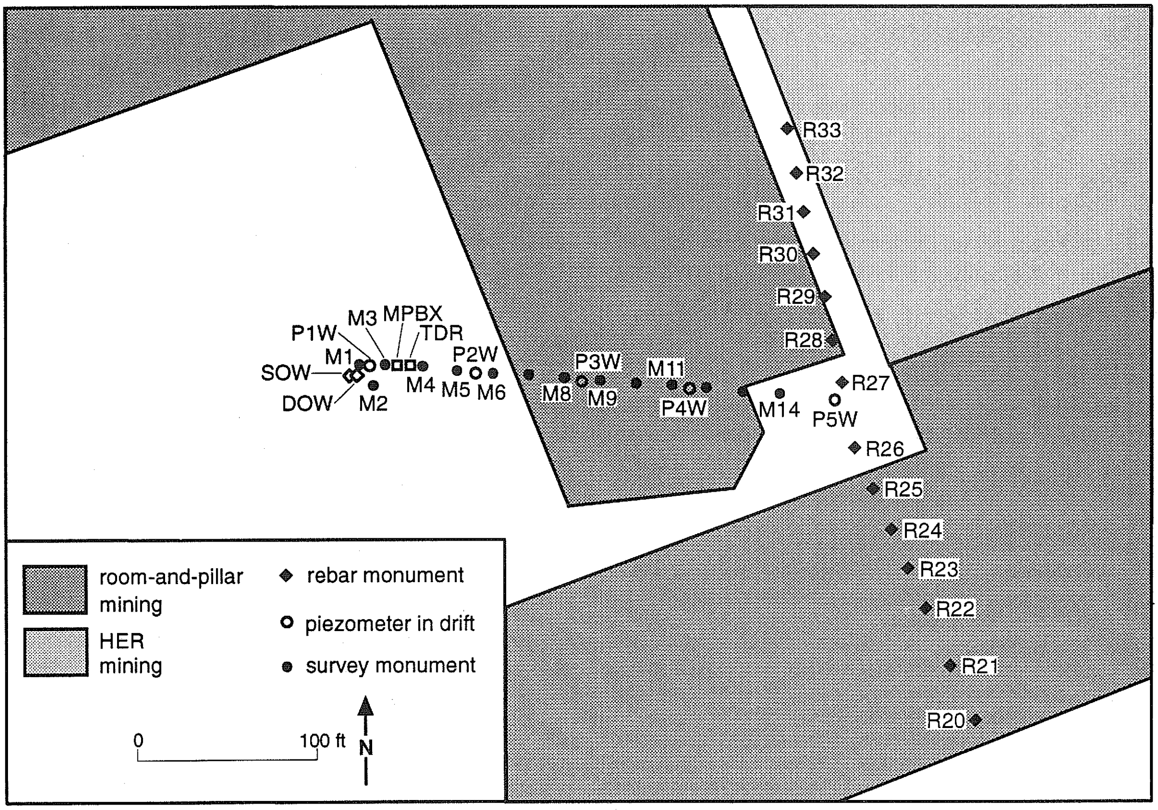


Figure 8 Schematic map of the west cluster instrument location.

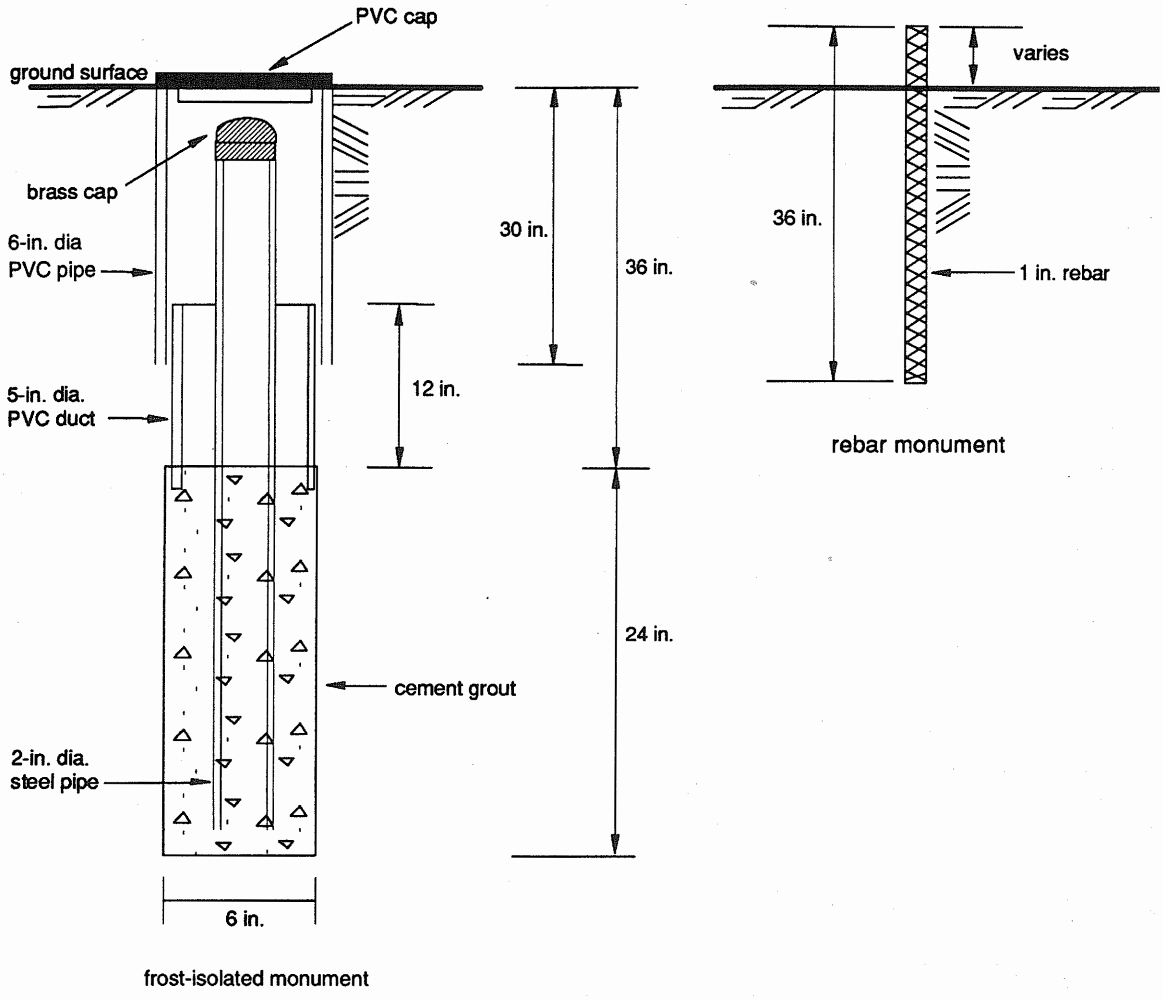


Figure 9 Frost-isolated monument and rebar monument design.

was used to set new control monuments for each instrument cluster. The west cluster instrument base line was set from ISGS control monuments during the period of April 2–30,1987.

Information provided by mine personnel was used to track the mining progress and to determine the frequency of monitoring. Monitoring surveys to document time-related effects were most frequent during the early, most active stage of subsidence. The east cluster survey monuments were monitored frequently for the first 8 days following the initial roof failure and steadily thereafter through the end of May 1987. The frequency of monitoring decreased with the rate of movement. Instruments were monitored about every 3 months through January 1988. Long-term monitoring continued to document residual movement of the overburden through December 1989.

The west cluster was not undermined by the HER method, although it was partially undermined by the room-and-pillar method. Monitoring of the west cluster survey monuments was performed to determine whether any changes were due to the approaching mine face.

Tiltplates Tiltplates installed in the west cluster were to be used to record changes in slope as the subsidence wave passed. Tiltplate installation is illustrated in figure 10. The plates were set into mortar beneath the frost zone (12–15 in.) and inside of 6-inch PVC casings with caps. The tiltplates were placed next to five frost-isolated monuments in the west cluster only. Unfortunately, the area did not subside.

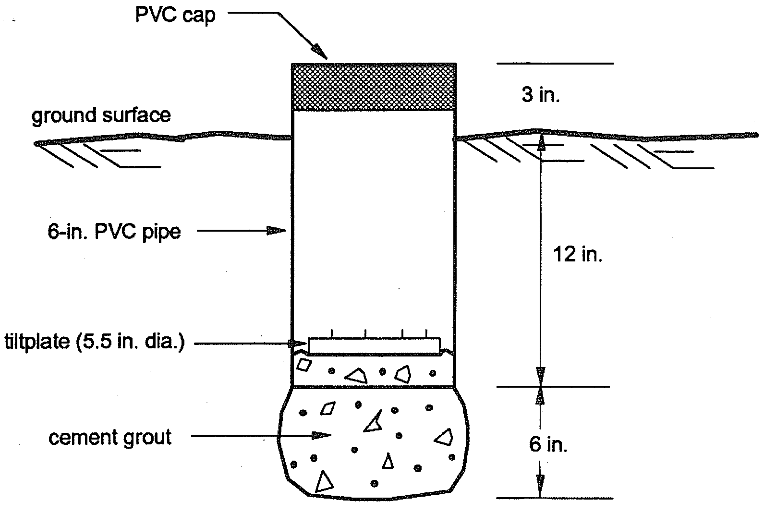


Figure 10 General tiltplate installation.

Overburden Characterization

Exploratory drilling A hole was drilled at a 10.5° angle from vertical, with a dip direction of S18.5°E near the center of the panel (west cluster). The coring was performed off-vertical so as to encounter any vertical joints in the formations. Core description, core recovery, fractures, and rock quality designation (RQD) were logged in the field by Engineers International. A stratigraphic section developed on the basis of the resulting depth-adjusted core log is presented in figure 3. The bedrock here is composed of Pennsylvanian-age siltstones and shales with approximately 49 feet of glacial deposits overlying it. The bedrock overburden is composed of approximately 54% shales, 11% siltstones, 23% sandstones, and 6% limestones; coals and claystones make up the remaining 6%. The geotechnical core log is presented in appendix A. The GeoTechnical Graphics System software (1991) was used to combine all the field logging notes into a presentable and legible core log.

Rock quality designation Rock quality designation (RQD) is a standard parameter for evaluating the degree of fracturing of a rock core. Rock quality designation is used as an index property to indicate rock-mass quality. The RQD value, expressed as a percent, is the quotient of the sum of the length of all core segments longer than 4 inches divided by the length of the core run. Fractures caused by drilling or handling are not included in the determination.

Fracture frequency Total fracture frequency per core run, in units of fractures per foot, is determined by counting the number of natural fractures per core run and dividing by the length of the core run. All natural discontinuities are counted, including fractures along weak bedding planes and joints. As with RQD, breaks caused by drilling and handling are not included in the determination.

Laboratory testing for intact rock properties Rock characterization was performed in the ISGS laboratory. Core samples were tested for unconfined compressive strength, modulus of elasticity, indirect tensile strength, specific gravity, shore hardness, and point-load index. The standards and suggested methods of the American Standard and Testing Materials (1988) and International Society for Rock Mechanics (1985) were followed. Results of all tests performed on the rock core are given in appendix A.

Unconfined strength and elastic modulus Samples were cut with a saw to near the allowable tolerance before they were lapped. Additional preparation of the sample consisted of lapping to a height-to-diameter ratio of 2 to 2.5 with a tolerance for nonparallelism of 0.001 inch (according to ASTM D 4543-85 1988). The 2:1 height-to-diameter ratio requirement was not always maintained, especially within a section of core that was quite fractured. Sample loading was under constant strain conditions, as allowed by ASTM D 2938-86 (1988). As recommended in Brown (1981), the sample ends were not capped.

The elastic modulus was obtained directly from the plot of “load versus deformation.” The elastic modulus represents the slope of the line tangent to the elastic portion of the stress/strain graph and at 50% of the ultimate compressive strength. The ultimate compressive strength was found by dividing the ultimate axial force by the area of core perpendicular to its axis, as suggested by the ISRM.

Indirect tensile strength Discs 1 inch thick were compressed diametrically between high modulus (steel) platens. The values of indirect tensile strength, σ_t, were calculated by the following equation (Brown 1981):

$$\sigma_t = \frac{2P}{\pi D t}$$

where P = axial load (lbs)
D = diameter (in.)
t = thickness (in.)

Axial point-load index The method suggested for the axial point-load index by the ISRM Commission on Testing Methods (1985) was used. Samples with a height-to-diameter ratio of 0.3 to 1.0 were tested. The samples were placed between two spherically truncated, conical platens of the standard geometry (60° cone). The load was steadily increased such that failure occurred within 10 to 60 seconds, and the failure load, P, was recorded. The point-load index was calculated using the following equation suggested by Broch and Franklin (1972):

$$I_s = \frac{P}{t^2}$$

where I_s = uncorrected point-load strength
P = axial load (lbs)
t = thickness

This equation does not take into account varying sample thicknesses, therefore a size correction is required. The size correction for the axial point-load index T_{500} of a rock specimen or sample is defined as the value that would have been measured by a diametral test with D = 50 mm (Brook 1980). The corrected axial point-load index is calculated by the following equation:

$$T_{500} = 211.47 \frac{P}{A^{0.75}}$$

where T_{500} = corrected point-load index (MPa)
P = load (kN)
A = diameter x thickness (mm^2)

Moisture content A center portion of each of the samples tested for unconfined strength was used for moisture content determination. Moisture content was calculated as a percentage of the dry weight of the sample as specified in ASTM D 2216-80 (1988).

Specific gravity The specific gravity of all samples was determined in accordance with ASTM D-1188-83 (1988). Samples were oven dried and coated with a polyurethane spray. The specific gravity for each sample was obtained by comparing its weight submerged in water to that in air.

Shore hardness A model D schleroscope, manufactured by Shore Instrument and Manufacturing Company, was used for hardness determination of compressive strength specimens. Each of the values in the summary tables is an average of the highest ten tests from a total of 20 tests performed on the lapped ends of the uniaxial compressive strength test specimen as described in Brown (1981).

Overburden Deformation Monitoring

Multiple-position borehole extensometer Two 6-anchor, multiple-position borehole extensometers (MPBXs) were installed at the site, as shown in figure 11. The anchors of each MPBX were grouted at depths of 50, 75, 100, 125, 150, and 175 feet below the ground surface. The extensometers mechanically monitor vertical overburden movements at each level. Anchor displacements are transmitted by the fiberglass rods to the surface, where movement of the rod tips is

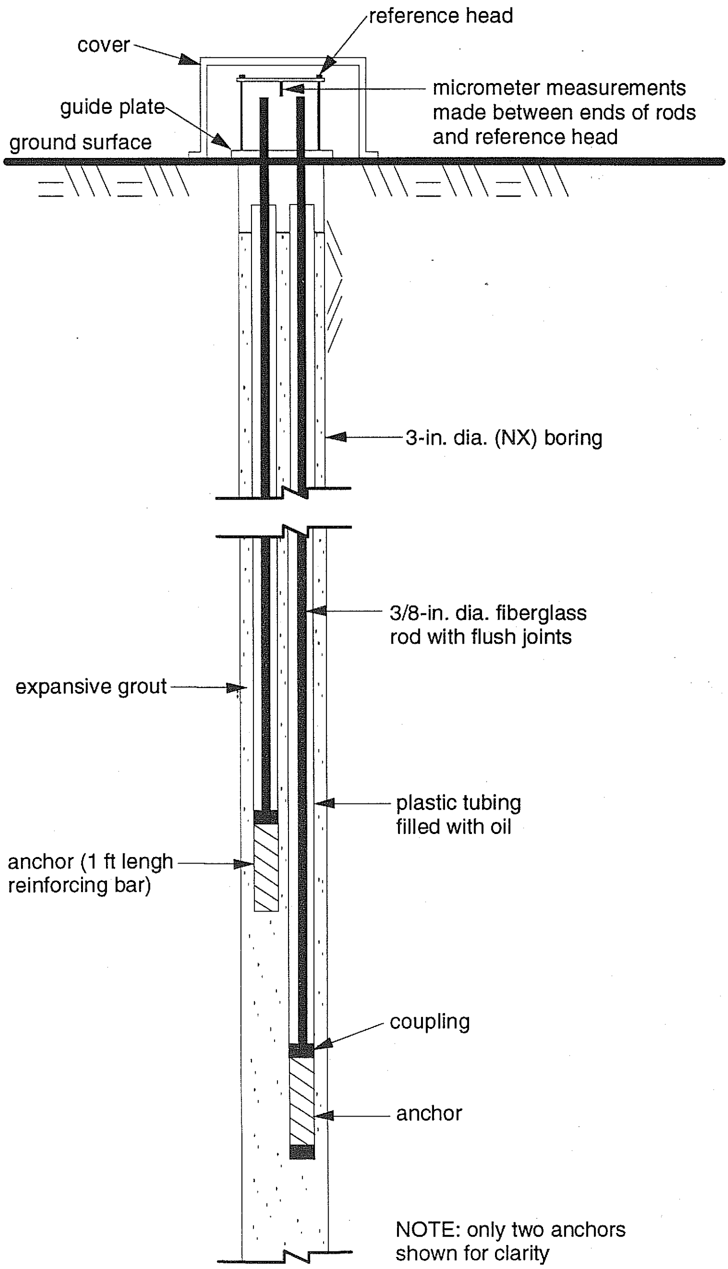


Figure 11 Multiple-position borehole extensometer installation.

measured relative to a reference plate. Displacements of the anchors relative to each other and to the reference plate indicate the magnitude and general depth interval of the vertical component of ground movements. Elevation control was maintained on the reference plates to establish absolute anchor movements. Appendix B contains the data collected for both the east and west cluster MPBX.

Time-domain reflectometry The time-domain reflectometry (TDR) technique was used to document fracture development caused by subsidence in the overburden. This technique was developed by the power and communications industries to locate breaks in transmission cables. A TDR tester sends ultra-fast rise time voltage pulses down the coaxial cable. Deformations in the cable reflect signals back to the tester. Reflections appear as a distinct signature versus distance on a cathode-ray tube (CRT) or strip-chart recorder. The cable is crimped every 20 feet to produce recognizable signals at known intervals on the cable, which increases the accuracy of distance measurements.

Researchers at Northwestern University (Dowding et al. 1988, 1989), determined the optimum cable size, bonding strength, and grout composition; they also characterized the signatures caused by different modes of deformation (e.g., tension versus shear).

A generalized TDR installation is shown in figure 12. One 0.5-inch-diameter unjacketed coaxial cable (Cablewave FXA 12-50) was installed at each instrument cluster. In the west cluster, a cable that was 269 feet long and extended through the Herrin Coal was grouted into the inclined borehole. The east cluster cable (256 feet long) was installed in a vertical borehole that did not penetrate the coal.

The TDR cable in the east cluster was designed with a weight or anchor of the type shown in figure 12. This anchor design works best with a braided cable and not the solid outer conductor type used on this project because the outer conductor splits when the cable is bent around the bolt. Therefore, a new design was implemented for the second cable in the west cluster. The new design consisted of placing the TDR cable through a 5-foot-long piece of black pipe with a cable clamp placed over the cable below the pipe, as shown in figure 13. Electrician's tape was wrapped around the clamp to smooth its profile and prevent snags during cable installation.

The entire cable was laid out on the ground and reference crimps were placed at intervals of 20 feet. Without reference crimps along the cable, location accuracy is on the order of 2% of the distance from the tester to the cable defect. Crimps at known distances allow for much more accurate defect locations. The reflected signal is attenuated as a function of distance along the cable. Therefore, a wider crimp, consisting of adjacent, individual plier crimps, is required at greater depths to produce the desired signal amplitude of 40 mρ. The grout had a 65% water-to-cement ratio by weight (7.6 gal/94 lb sack cement). High early strength Type III cement and 2% Intrusion-Aid (Intrusion-Prepakt, Inc.) were used, as recommended by Dowding et al. (1989). The grout was placed in the borehole up to the ground surface through the glacial material. The TDR installation and monitoring was part of an ongoing contract with the Office of Surface Mining to test the application of using TDR to monitor overburden fractures. Results of several studies using the TDR technique over both active and abandoned mines may be found in Bauer et al. (1991).

Hydrogeologic Investigations

The groundwater response to subsidence was monitored using two types of wells. Piezometers with 2-foot screens were used to document water levels in the drift material; the bedrock material was monitored using 20-foot screens in what is called here an observation well. Water level changes in the piezometers and observation wells reflect fluctuations in the piezometric head at the various screen depths.

Drift piezometers A total of 11 piezometers were installed. Five were placed in or near each instrumentation cluster, and one was located outside the area of anticipated subsidence. Alternating shallow and deep piezometers were installed in the drift to record the effect of the subsidence on piezometric levels in the unlithified glacial materials. The general design for both bedrock and drift piezometers is shown in figure 14. Screen depths ranged from about 15 to 50 feet, and the screen interval was 2 feet. The deep drift piezometers were set near the bedrock surface. Design specifications called for 2.5 feet of 1.0-inch screened PVC tubing surrounded by rounded river sand to a height of 5 feet above the screen. The sand was capped with a bentonite seal 2 feet thick, and the remaining borehole length was backfilled with a cement-bentonite grout. Small 1/2-inch riser tubing was used to reduce the response time to piezometric fluctuations. Piezometers were developed by pumping out all the fines before monitoring.

Bedrock observation wells Design specifications for the bedrock observation wells were identical to those for the drift piezometers except that the screened section was 20 feet long in order to increase the infiltration area. One shallow observation well and one deep observation well were installed in each instrument cluster. Screen depths of both east and west cluster shallow observation wells were from 80 to about 100 feet below the surface in a low hydraulic conductivity unit. The screen depth of the west cluster deep observation well was from 183 to 203 feet in the Anvil Rock Sandstone. The east cluster deep observation well screen was from 145 to 165 feet below the surface.

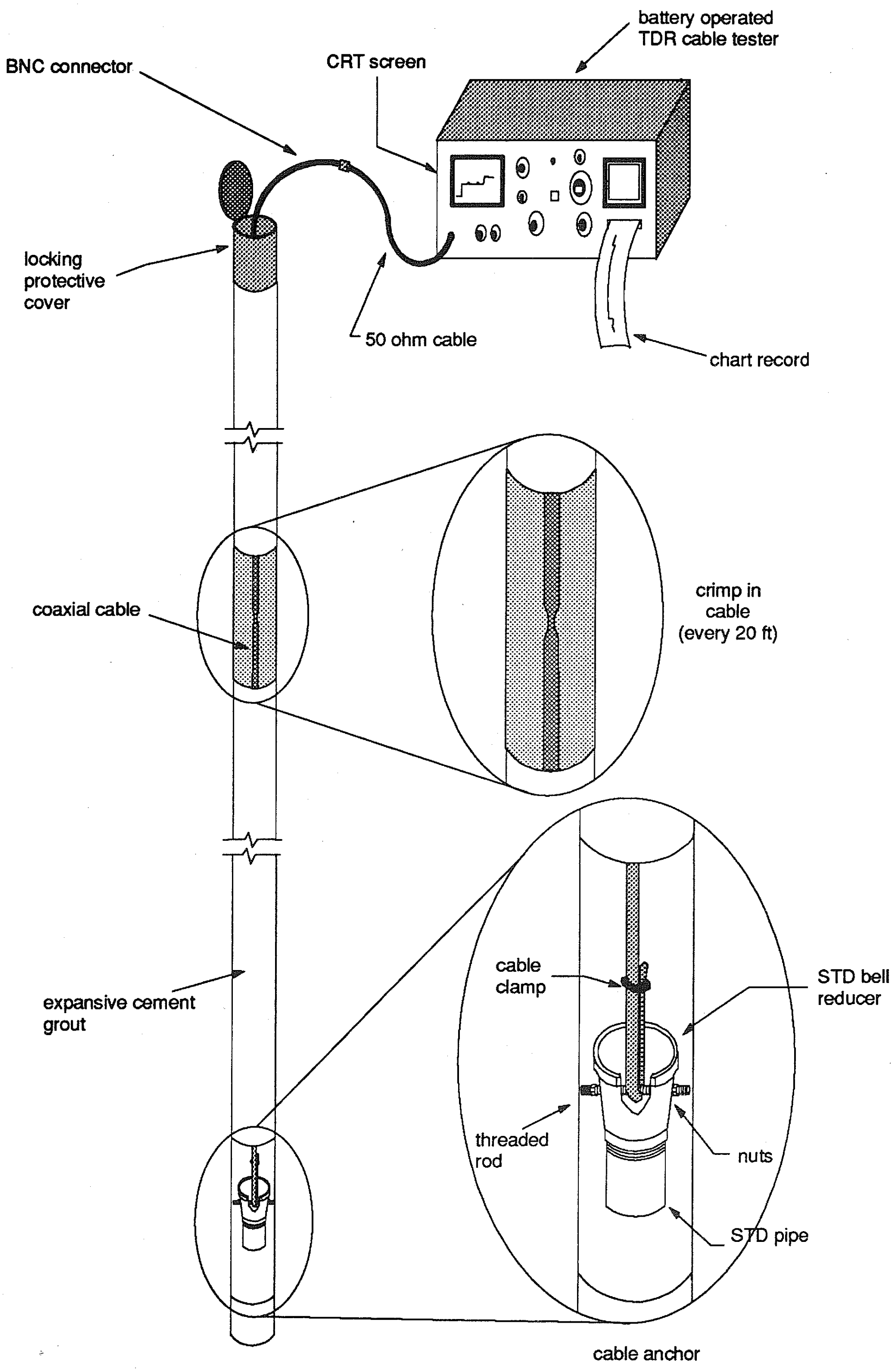


Figure 12 Schematic of original TDR installation.

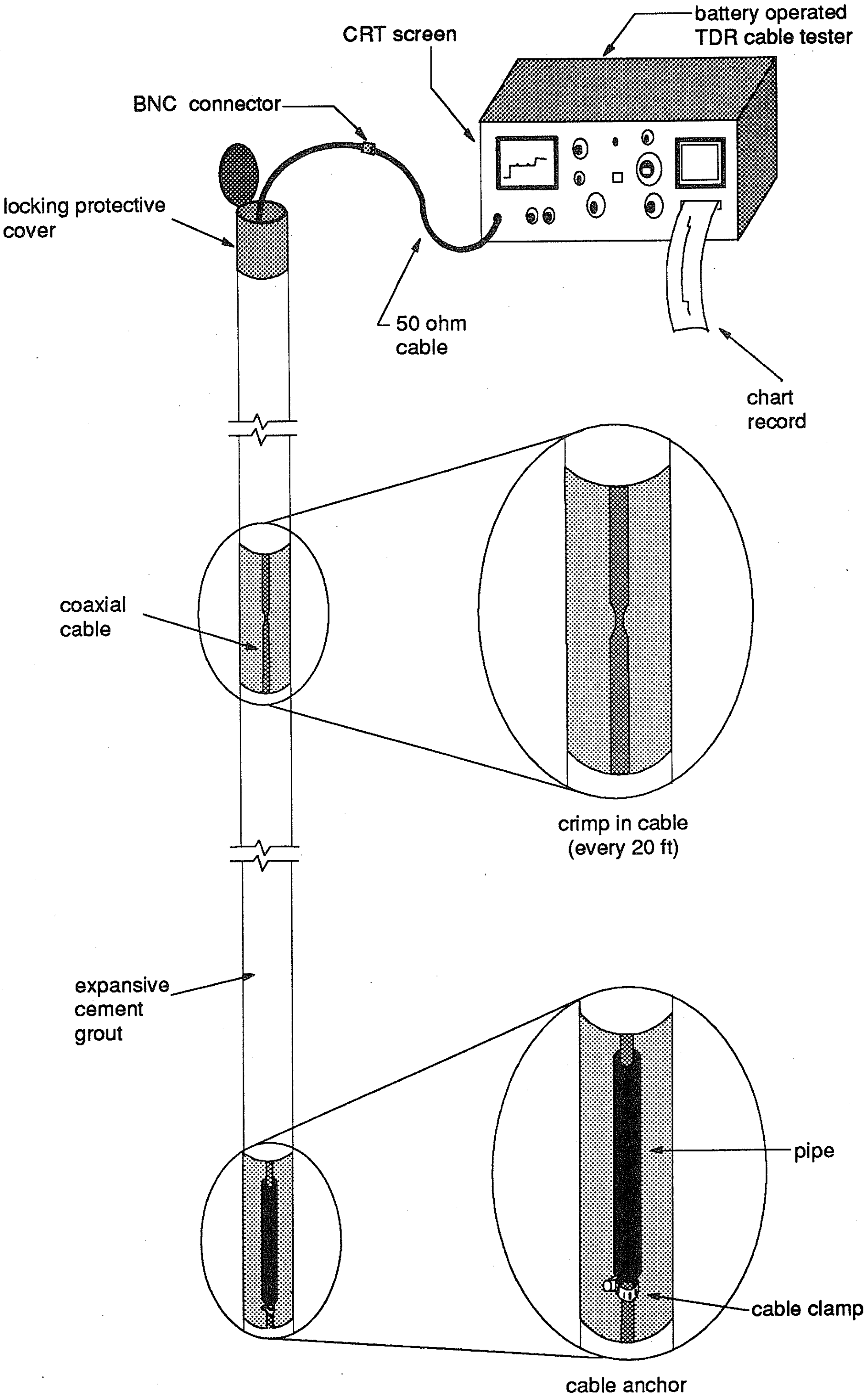


Figure 13 Schematic of TDR installation with revised cable anchor.

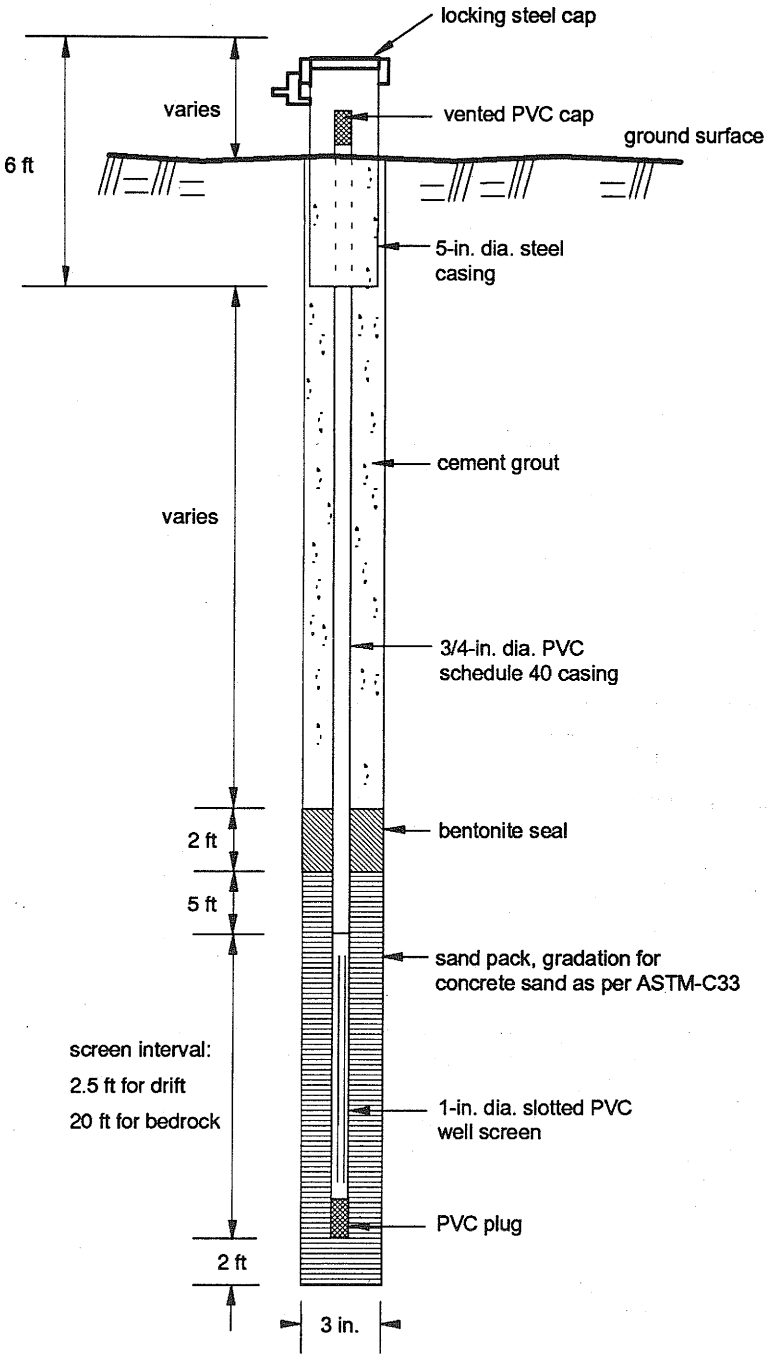


Figure 14 Schematic of piezometer and observation well installation.

MONITORING PROGRAM RESULTS

In September 1986, instrument monitoring commenced, excluding the TDR cables that were first read on June 20, 1986, by ISGS and Northwestern University research teams. Engineers International was responsible for collecting three sets of readings on all the instruments except the TDR cables, tiltplates, and rebar monuments. Wyant Surveying Company conducted the surveys and set vertical and horizontal controls on the instrumentation. The data were reduced and a draft base-line report was distributed by Engineers International in February 1987.

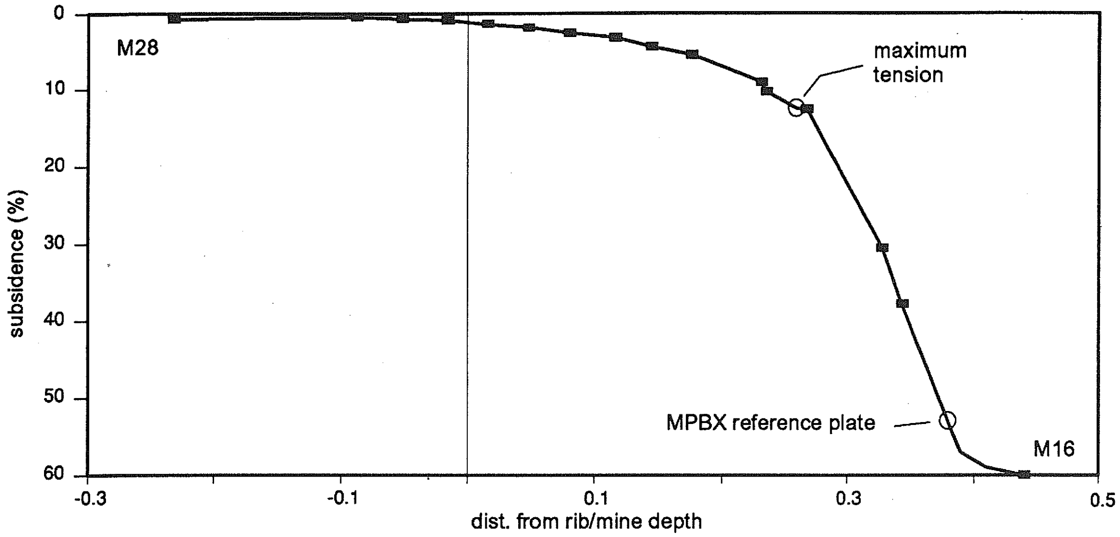


Figure 15 Subsidence profile characteristics of a longitudinal line for the east cluster area.

Survey coordinates and elevations for both the east and west cluster instrumentation may be found in appendix C.

The east cluster instrument readings from March 26–27, 1987, changed dramatically from those taken just 2 days earlier. These changes reflected the effects of subsidence on the overburden of what was probably an abrupt initial failure of the mine roof at the beginning of the panel.

At the west cluster, the MPBX, TDR, and tiltplates were unaffected by the mining. Some subsidence was detected, however, and piezometric changes were observed in the bedrock well. All the instruments were last monitored on September 25, 1987, after which only the drift and bedrock piezometers were read. Long-term monitoring of the west cluster instruments continued through October 1988. East cluster instruments were monitored through December 1989 to document water level recovery and any residual movement of the surface and overburden.

East Cluster

Surveying and subsidence characteristics Surface movements of the east cluster instrumentation were measured with a Lietz SET3 total station and recorded by an SDR2 electronic notebook. Subsidence was first detected at the east instrument cluster on March 26, 1987. Coordinates obtained for the monument points on March 26 did not match those of previous surveys, including one taken 2 days earlier. Also the grout apron around the MPBX was broken, and the casing apparently dropped about 0.4 foot relative to the ground surface. Subsequent readings of the MPBX, TDR cable, monuments, and drift and bedrock piezometers all registered changes, confirming the subsidence event.

The maximum elevation change determined by ISGS personnel was a drop of 3.16 feet at the MPBX as of January 12, 1988. The ground surface dropped approximately 2.7 feet at the MPBX, about 0.46 foot less than the casing, which was apparently pulled down into the disturbed drift by the anchor rod tubes. About 95% (on average) of the recorded subsidence occurred in the first 10 weeks following undermining. Appendix D contains the elevation changes for the east cluster instrumentation.

A surface crack up to 0.3 foot wide, located at the point of maximum tension, stretched in an arc from the east end of the panel westward through the east instrument cluster and beyond, roughly paralleling the edge of the mined-out area or panel rib (fig. 7). The crack was traced from a graben-like feature perpendicular to the center line at the east end of the panel. The crack opened to a maximum width of about 1 foot by April 16, 1987, when the pillaring sequence had advanced approximately 200 feet.

Although data were collected from the east cluster instrumentation, some subsidence characteristics could not be accurately determined because of the geometry of the instrumentation layout relative to

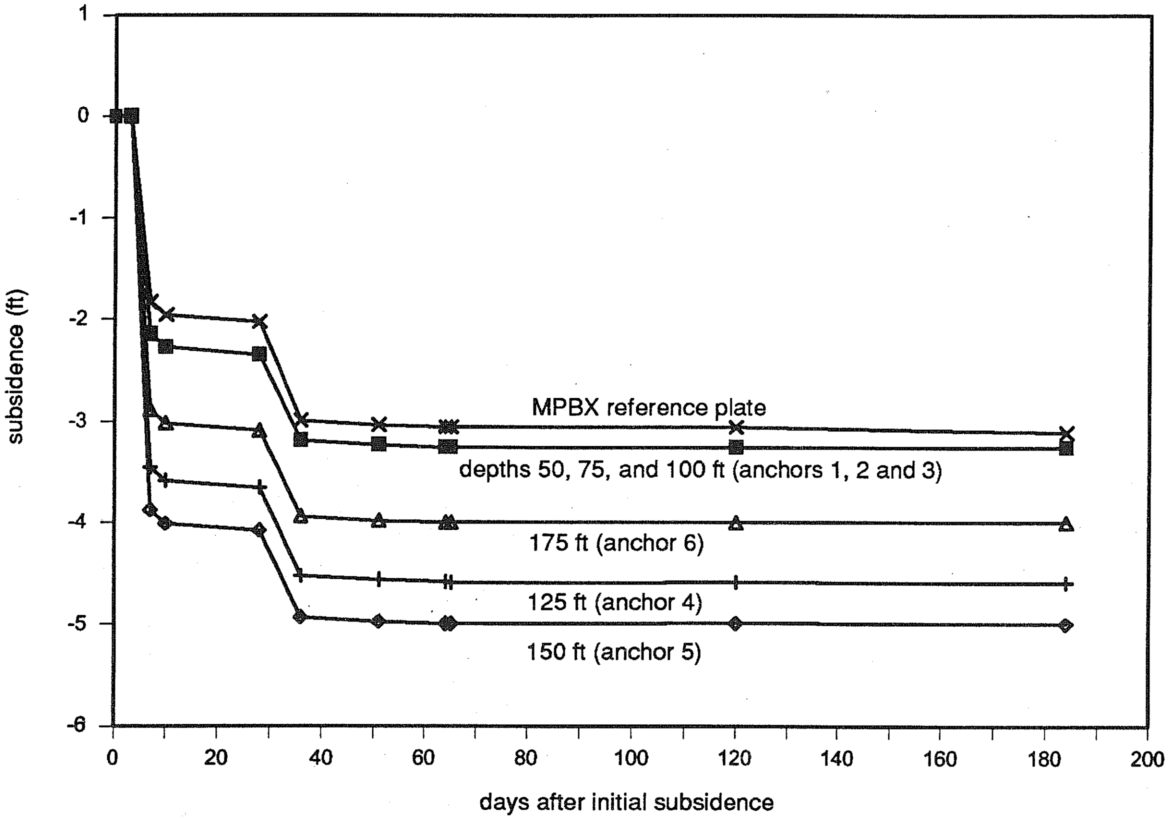


Figure 16 Vertical drop of each MPBX anchor for the east cluster.

the changed panel orientation and the irregular dimensions of the mined-out area near the east instrument cluster. No width to depth ratio (W/D) was well defined because the panel width increased from about 210 to 385 feet just north of the east cluster. The instruments were too close to the beginning of the panel to calculate the maximum percentage of subsidence (maximum subsidence/mining height), and the survey data from outside the panel rib were insufficient to accurately determine a representative angle of draw. The relationship between percentage of subsidence and the ratio of the distance to the panel edge versus mine depth is shown in figure 15. The data fall within the known range of values for HER mining in Illinois (Hunt 1980).

The only reference point that registered no consistent change along the east–west monument line was monument 28 (M28). The amount of subsidence of the monuments as of January 12, 1988, steadily increased from east to west to a maximum of 0.80 foot recorded at M16, just a few feet outside the surface crack; whereas, M28 subsided only 0.02 foot.

Maximum lateral movements of about 1 foot were recorded on the inside of the panel. The lateral movements were generally to the west and north, toward the mined-out void.

Overburden deformation monitoring

Multiple-position borehole extensometer Maximum subsidence recorded at the MPBX was about 3.16 feet. Differential vertical movements in the overburden were recorded by the MPBX (fig. 16). The MPBX indicated differential vertical movements at various depths from the ground surface to the bottom anchor. Anchor 6 (initial depth 175 feet) dropped 4.00 feet; anchor 5 (depth 150 feet) dropped 4.99 feet; anchor 4 (125 feet) dropped about 4.58 feet; anchors 1, 2, and 3 moved 3.26 feet; and the ground surface dropped about 2.7 feet. The anomalously small movement of anchor 6, as compared with the displacement of anchor 5, indicates that a large, abrupt movement between a depth of 150 and 175 feet broke the fiberglass rod-anchor assembly. No significant anchor movements were detected after May 1987, about 2 months after initiation of subsidence.

The lack of vertical movement or change in strain recorded by the MPBX after the initial failure indicates fracture openings that developed between the depths of 50 and 150 feet did not close significantly.

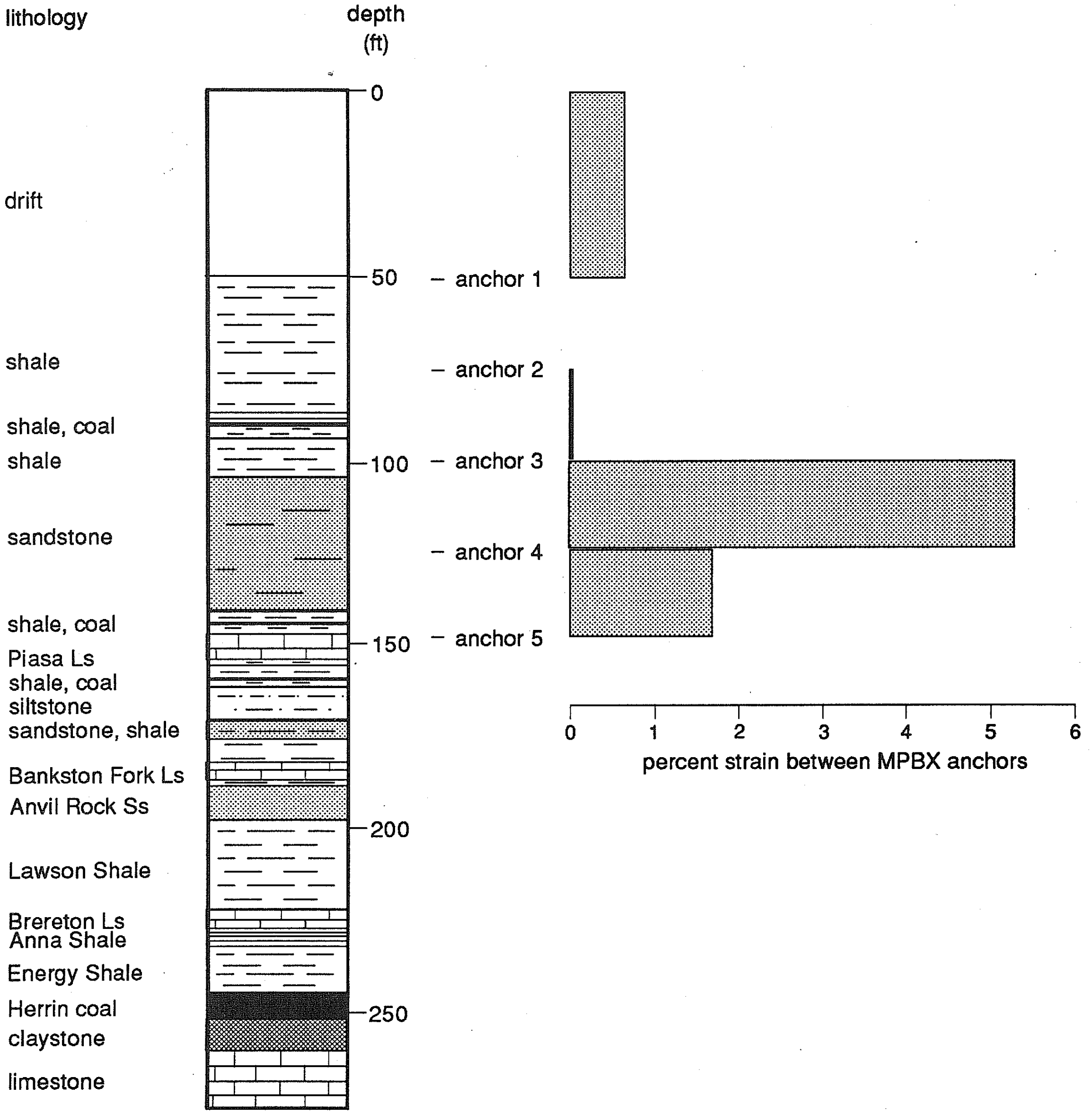


Figure 17 Amount of strain measured between MPBX anchors in relation to the stratigraphy.

Furthermore, the lack of differential movement indicated that subsequent subsidence was caused principally by closure of voids below the depth range monitored by the MPBX. A later, nearly uniform decrease of about 0.12 foot of all the rod readings was caused by closure of voids above anchor 1, as shown by the same downward movement of the surface monuments and reference head.

Strain within the overburden is shown in conjunction with the stratigraphy in figure 17. The nearly equal vertical movements of anchors 1, 2, and 3 indicate that the overburden from 50 to 100 feet beneath the surface moved largely as a mass. Some of the vertical differential movements in the overburden were associated with interfaces between materials of contrasting stiffness such as bedrock as opposed to drift. A massive sandstone of moderate strength (unconfined compressive strength of 5,000–6,400 psi) was encountered in the west cluster angled borehole core at a depth of 100 to 125 feet. Large vertical strains of 5.3% were detected between anchors 3 and 4, which spanned this interval. These large differential movements can be attributed to the sandstone being stiffer than the underlying material. Therefore, the sandstone acts as a beam and deflects less than the less rigid, underlying material.

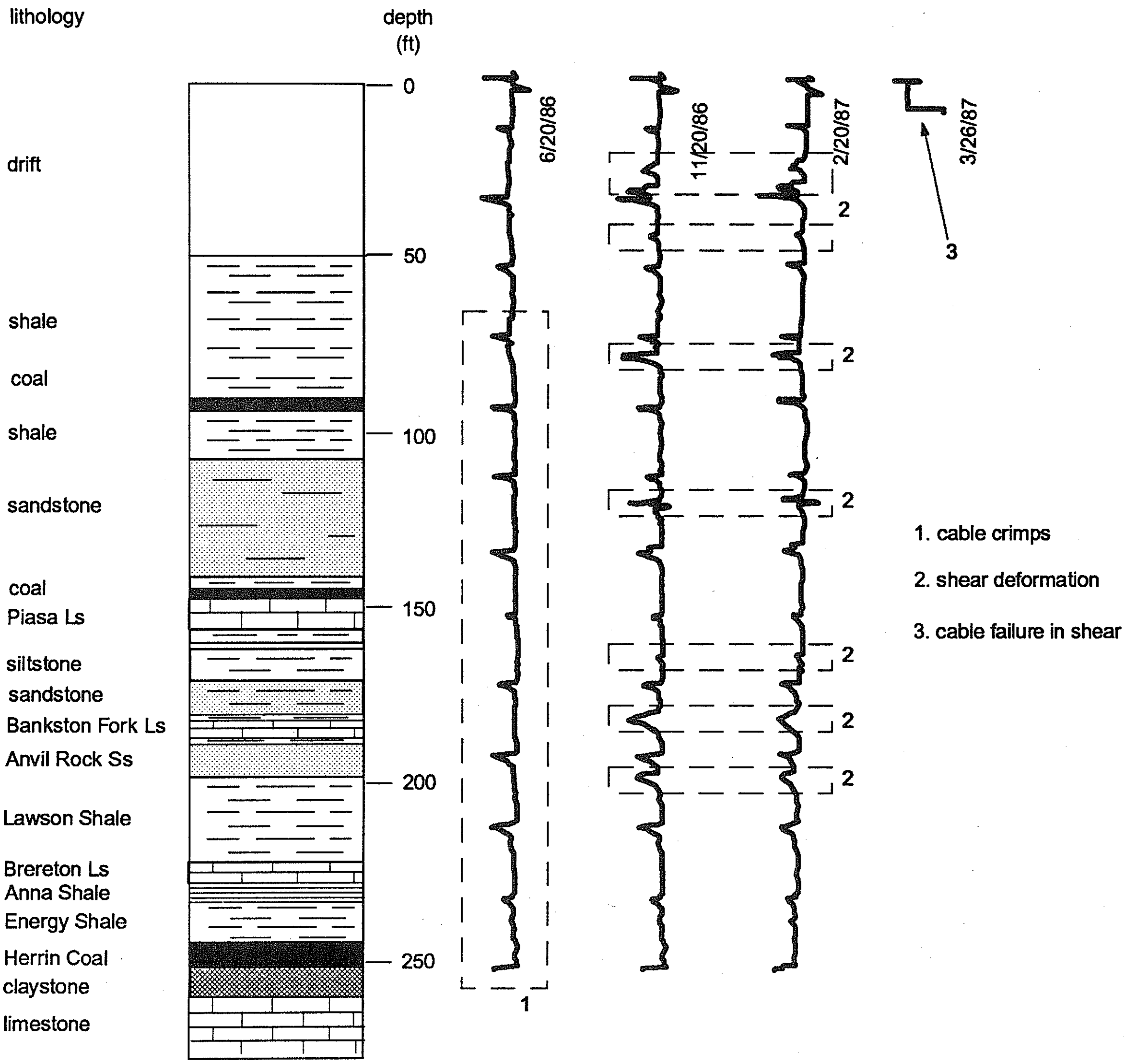


Figure 18 Deformation history of TDR cable at the east cluster.

Time-domain reflectometry The TDR cable at the east cluster was sheared and broken 8 feet below the ground surface during initial subsidence (fig. 18). After the shear was recorded, a pit was excavated so that a new piece of cable could be spliced to the top end of the grouted cable. The sheared cable was located near the base of the fragipan (cemented layer). The lower part of the cable had displaced 0.2 foot toward the mined-out area relative to the upper 8 feet of cable as shown in figure 19. The spliced TDR cable was read, and a second shear signal at a depth of approximately 38.5 feet was recorded. The shearing action that occurred near the sides of the panel was interpreted to result from differential lateral displacement at the bedrock and soil interface, which indicates that the drift deformed as a beam. Evidence of subsurface movements in the overburden is summarized in table 2.

Hydrogeologic investigations A prime objective of the study was to determine the effects of subsidence on the hydrogeology of the overburden at this site. Water levels in some drift and bedrock piezometers were affected by subsidence. The data collected, though inconclusive, indicate that subsidence impacted the groundwater regime for at least 1 year after mining.

Drift piezometers Data from a deep drift piezometer P1E (fig. 20) located near the panel edge show the subsidence event affected the groundwater in the drift materials. The water level in the piezometers at the east instrument cluster dropped from 497.39 feet msl to a dry condition at 489.41 feet msl, or

Table 2 Summary of subsurface overburden movements in the east cluster.

Instrument	Evidence	Interpretation of movement
TDR	cable shear at 8 feet	differential lateral displacement at base of fragipan
	cable shear at 38.5 feet	differential lateral displacement at drift/bedrock interface
Deep observation well	"plugged" at 28 feet	differential lateral displacement at drift/bedrock interface
Shallow observation well	"plugged" at 71 feet then "plugged" at 40 feet	shear offset in the bedrock
MPBX	anchor 1 drops about 0.23 feet more than reference plate	vertical differential movement in the upper 50 feet of overburden
	anchor 1, 2, and 3 all drop about 3.26 feet	vertical differential movement in the bedrock between 50 and 100 feet, which moved as a mass
	anchor 4 drops 4.58 feet	large vertical differential movement between 100 and 125 feet
	anchor 5 moves 4.99 feet	smaller vertical differential movement between 125 and 150 feet
	anomalous small movement of anchor 6	perhaps violent, large offset between 150 and 175 feet; broken rod

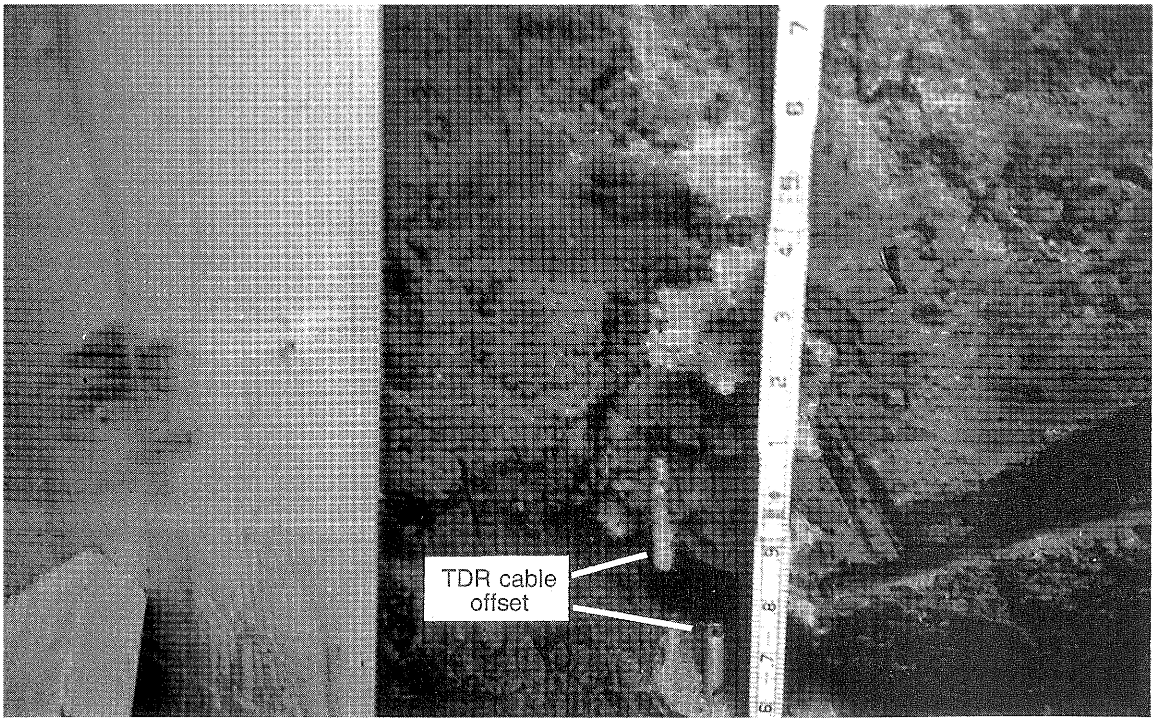


Figure 19 Photo of the east cluster TDR cable shows the lower part of the cable displaced 0.2 foot toward the mined-out area relative to the upper 8 feet of cable as a result of mining.

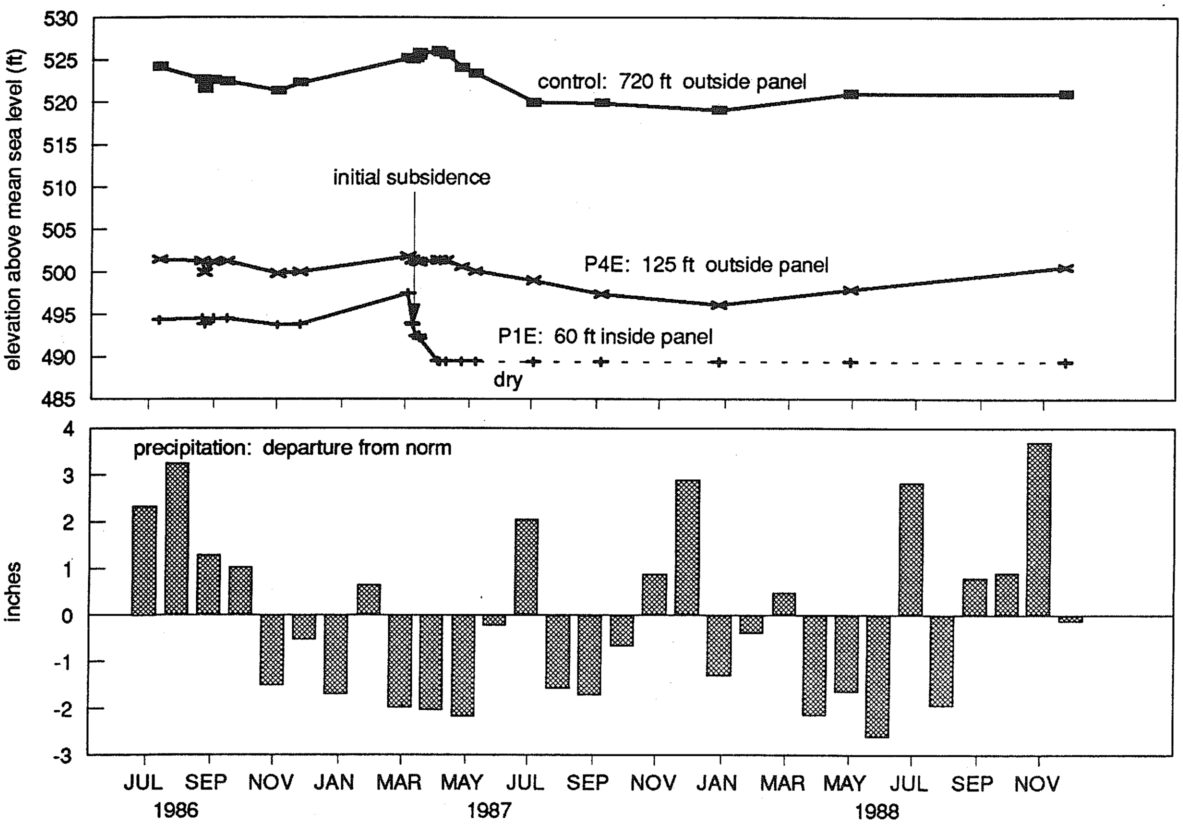


Figure 20 Piezometric response of the drift piezometers (east cluster) due to mining and precipitation.

about 8 feet over a 23-day period because of the subsidence event. The water level dropped, however, only 4.6 feet from the average elevation of about 494.0 feet msl for P1E (fig. 20). The control piezometer dropped 0.5 foot during the same period. The precipitation data shown in figure 20 were collected at a National Oceanic and Atmospheric Administration (NOAA) station located in Marion, Illinois, 8 miles west of the site. These data aid in distinguishing piezometric fluctuations caused by subsidence from those caused by variations in precipitation. The rise of the water levels in the three drift piezometers shown in figure 20 just prior to the subsidence event was probably caused by the high seasonal water table associated with the spring thaw and heavy rainfall (R. Darmody, University of Illinois, personal communication, 1987). The gradual fall and subsequent rise of the water levels in P4E and the control piezometer were similar, and they were probably caused by a precipitation deficit of about 6 inches in the first 7 months after subsidence, which was followed by a 4-inch surplus in the next 2 months. The sudden drop in the water level in P1E (deep piezometer) in late March 1987 was directly attributed to the subsidence event. P1E remained dry through December 1989.

Piezometers P2E and P3E were dry before and after subsidence and yielded no useful data. The apparently unaffected water level in P4E demonstrated that the zone of hydrogeologic influence of subsidence in the drift material was less than 125 feet outside the panel (fig. 20). Appendix E contains the precipitation data from the Marion Station and all water level data collected for the east and west cluster piezometers.

Bedrock observation wells The water levels in the east cluster bedrock wells stabilized by late November 1986, about 4 months prior to subsidence (fig. 21). The levels dropped more than 4 feet from February 3 to March 24, 1987. They apparently dropped because of dilation (due to fracturing) of the bedrock in response to changes in the in situ stress field as mining activity increased near the instrumentation. Wells in the west cluster detected similar, dilation-related, piezometric changes.

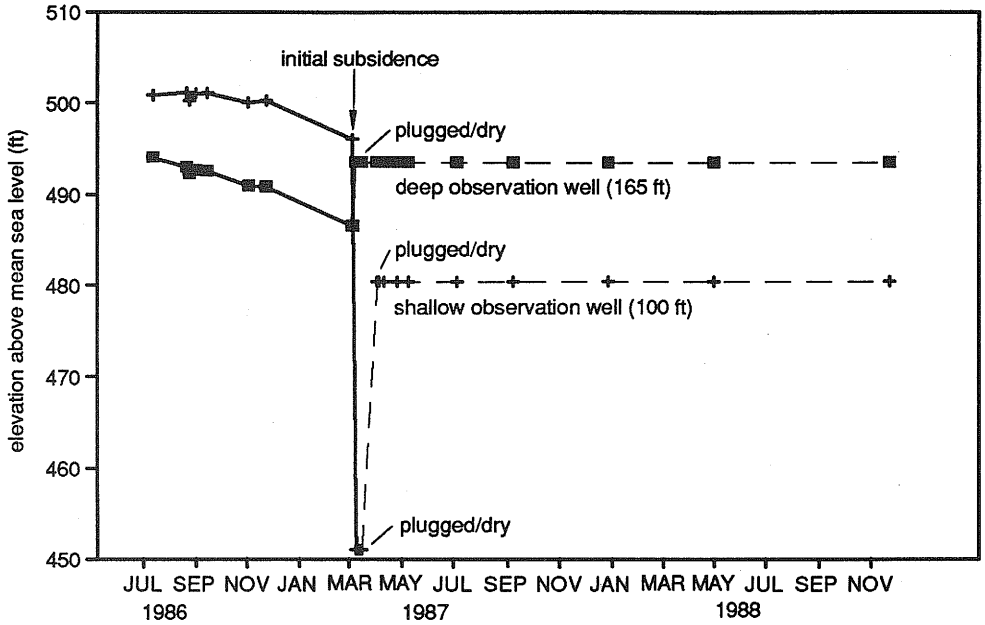


Figure 21 Piezometric response of the bedrock piezometers (east cluster).

Both the shallow and deep wells in the east cluster were obstructed in the initial subsidence event by movements in the overburden. The shallow well was plugged about 70 feet below the surface on March 26, 1987, about 43 feet below the water level recorded prior to subsidence just 2 days earlier. The shallow well was obstructed about 40 feet from the surface on April 16, 1987. The deep well was obstructed and dry at a depth of 28 feet after the initial failure. The sudden loss of water in the bedrock observation wells may be attributed in part to dilation of the bedrock caused by differential movements and fracturing. The fracturing in the bedrock increases the volume of the unit monitored, thereby decreasing the pressure head, as found in subsequent studies in Illinois by Van Roosendaal et al. (1990) and Booth and Spande (1991). The east instrument cluster bedrock wells maintained water levels below their initial readings (above the plugged depths) through the last readings in December 1989.

Subsidence affected the hydrogeology of the very low permeability materials of the bedrock over the mined-out area more significantly than that of the drift materials above. Both the bedrock wells and P1E were still dry more than 2 years after the initial failure.

West Cluster

The instrument and survey monument layout of the west cluster is shown in figure 8. Virtually all of the data collected from the west instrument cluster were base-line data. Base-line survey coordinates were established from ISGS control monuments during the period from April 2 to April 30, 1987. Base-line data for the MPBX, TDR, and drift and bedrock piezometers were established by numerous readings prior to April 30, 1987.

Surveying and subsidence characteristics Although the west cluster instrumentation was directly undermined by room-and-pillar mining only, pillar extraction stopped within 10 to 30 feet of part of the transverse monument line (fig. 8). Mining continued for 200 feet using the room-and-pillar mining technique. In July 1987, the maximum subsidence recorded at the west instrument cluster was about 0.13 foot at rebar monument R33, which was closest to the center line of the mined-out area. This monument was located 10 feet off the west edge of the pillar extraction. Unfortunately, all work ceased in the mine as of May 18, 1987. No additional subsidence has been measured at the west instrument cluster since September 1987. Measurements on the rebar monuments were only made with a total station, which produces less accurate elevation readings in comparison to using a level. Also, rebar monuments were short and not anchored or insulated from any freeze–thaw movements. Smaller movements that rapidly diminished westward from the caved face were recorded along the east–west monument line.

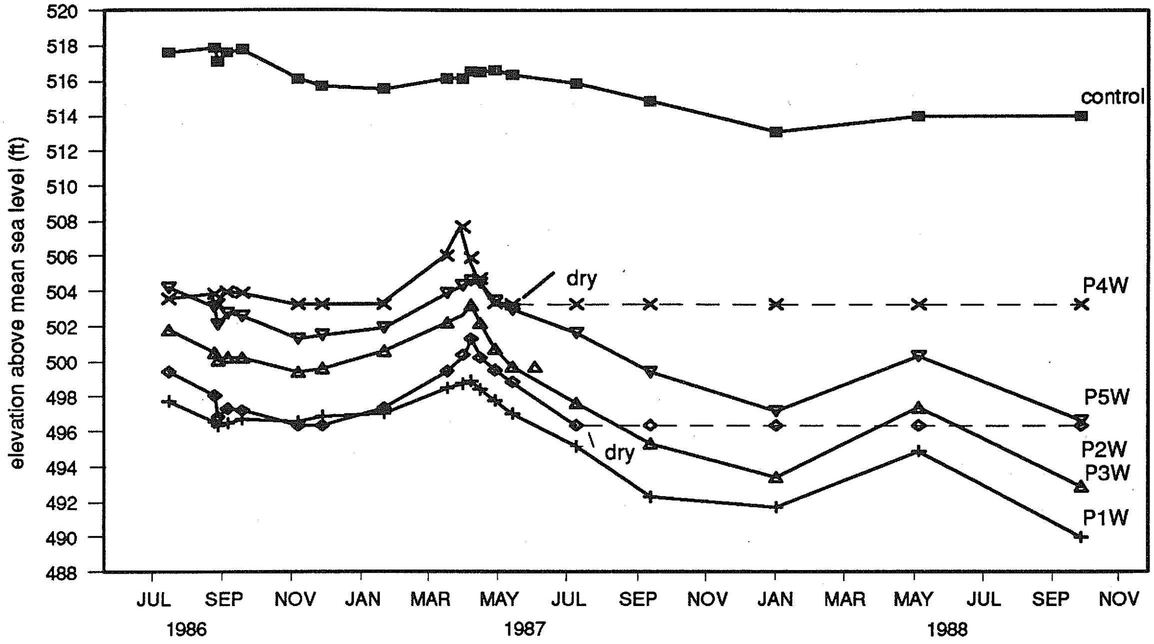


Figure 22 Piezometric response of the drift piezometers (west cluster).

Hydrogeologic investigations

Drift piezometers The water levels in drift piezometers P1W, P3W, and P5W (screens ranged from 15 to 50 feet below the surface), which were located along the side of a small draw, fluctuated in a manner somewhat similar to that of the shallow observation well in figure 22. However, the piezometric response of these piezometers, although exaggerated, compared more closely with that of the drift control piezometer, which was located on an interfluve and not affected by the mining. Water levels in the drift piezometers appeared to fluctuate more in response to precipitation (fig. 22), similar to the recorded levels in the piezometers in the east cluster.

Bedrock observation wells The water level in the shallow observation well fell about 13 feet from an average depth of 18.0 feet (late March 1987) to 29.6 feet (late September 1987) as shown in figure 23. The well water depth recovered to 18.8 feet by May 1988. The screen of the shallow well was 100 feet below the ground surface, under 50 feet of shale and 50 feet of drift. Piezometric pressures were probably not directly affected by variation in precipitation at this depth.

The screen of the deep observation well was about 50 feet above the coal seam at a depth of 203 feet. The water level in this well dropped approximately 26 feet during 15 months from a previously steady depth of around 37.5 feet (period 7/30/86 to 2/3/87) to about 63.3 feet (5/16/88). The water level fell 8 feet rather sharply from March to May 1987 during subsidence of the east cluster (fig. 22). The water dropped gradually and was apparently leveling off more than 25 feet below presubsidence readings by May 1988. Both the shallow and deep observation wells are about 300 feet from the caved face of the mine workings (fig. 8) and 75 feet from the entryways next to the panel. Solid coal is present on the other side of these entryways. Again, the piezometric pressure drop was apparently not affected by seasonal variations, but was more a function of the fracturing induced by the increased stress field around the mined-out area. This indicates that the mining activity affected the deep aquifer a horizontal distance of at least 300 feet from the caved face.

CONCLUSIONS

Although only one-half of the instruments were undermined by the high-extraction retreat method, some conclusions may be drawn from this site-specific study. The subsidence event affected the overburden at the Williamson County research site in several ways.

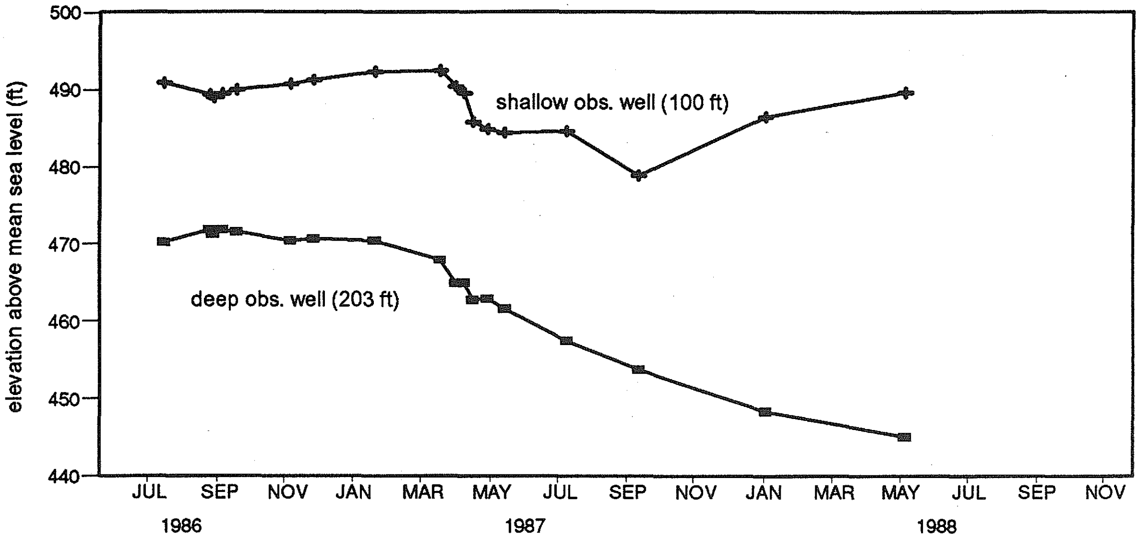


Figure 23 Piezometric response of the bedrock observation wells (west cluster).

1) Subsidence after the initial overburden failure (survey data) and a reconstructed subsidence profile line perpendicular to the edge of the mined-out area was similar to documented static profiles characteristic of high-extraction retreat subsidence in Illinois.

2) Only one drift piezometer was affected by mine subsidence. Drift piezometer P1E, which was screened just above the bedrock surface, showed a decline in water level as it was undermined. Other drift piezometers showed only fluctuations in the water level related to precipitation.

3) Bedrock observation wells in the east and west clusters responded to the mining activity by a sudden and gradual loss in piezometric pressures, respectively. The initial loss of head in the west cluster bedrock wells was probably caused by dilation of the rock (or microfracturing) in response to changes in the stress field around the mined-out area. The relatively rapid recovery of the shallow observation well as opposed to the slower recovery of the deep observation well indicates three possible explanations: the attenuation of the fracturing with distance from the caved face, more rapid recharge closer to the ground surface, and different aquifer characteristics at the two monitored levels. The latter may be the most probable explanation. Subsequent studies in Illinois (Van Roosendaal et al. 1991, Booth and Spande 1991) have shown that aquifer characteristics as well as lateral extent of the aquifer determine the recovery time after subsidence.

4) Drops in the water level in the bedrock wells of the west instrument cluster indicated that the mining activity affected the deep aquifer for a horizontal distance of at least 300 feet from the caved face.

5) The nearly equal vertical movements of anchors 1, 2, and 3 indicated that the overburden from 50 to 100 feet beneath the surface moved largely as a contiguous mass.

6) The lack of any further differential vertical movements in the overburden observed with the MPBX indicated that surface subsidence after the initial failure was caused primarily by closure of voids below a depth of 150 feet.

7) The break in the TDR cable and the obstruction of the bedrock wells in the east instrument cluster demonstrated the shearing action that occurs near the sides of the panel. This action is a result of differential lateral displacement of the soil and bedrock strata toward the center of the panel due to flexure of the units. Shear offsets were also observed in the piezometers when they were reclaimed.

8) Differential vertical and horizontal movements were associated with interfaces between material of contrasting strengths. These interfaces were located at the base of the fragipan, the drift/bedrock contact, and near the thick sandstone unit in the bedrock where the largest vertical strains were recorded.

RECOMMENDATIONS

The following are recommendations for performing a similar monitoring program.

1) The recovery time of the aquifer should be determined by monitoring on a more continuous basis than was done in this study. Groundwater fluctuations might also be correlated to surface strain if monitoring were more continuous.

2) The TDR weight/anchor design developed during this study is recommended. Use of a flexible bentonite fill in the glacial overburden in order to avoid cable shear failure in the glacial overburden or at the contact with the bedrock is also highly recommended.

3) An inclinometer installation is recommended to document lateral movements in the bedrock as the subsidence wave approaches and passes through the instrumented site.

4) Pre- and postsubsidence rock core should be compared to determine changes in fracture frequency and locations of increased shearing. The location of fractures would be useful in comparing any bedrock movements found using the inclinometer, MPBX, and TDR cables.

5) Glacial material should be sampled using standard split-spoon sampling; standard penetration tests (SPT) should be performed before and after subsidence.

6) One cored borehole should be geophysically logged before and after subsidence to measure differences in shear wave velocity as well as other rock mass properties.

7) All survey monuments, including the control or benchmark monuments, should be constructed alike. All vertical changes should be determined using a level instrument, which has a higher degree of accuracy than a total station instrument.

8) A series of packer tests should be conducted before and after subsidence to compare hydraulic conductivity.

ACKNOWLEDGMENTS

The Engineering Geology Section of the Illinois State Geological Survey in Champaign prepared this report under USBM Cooperative Agreement CO 267001, which was initiated under the Illinois Mine Subsidence Research Program. It was administered under the technical direction of the U.S. Bureau of Mines Twin Cities Research Center with Larry Powell acting as Technical Project Officer. Kent Charles and Jose Martinez were the contract administrators for the Bureau of Mines. This report is a summary of the work recently completed as part of the contract during the period from October 1, 1986, to September 30, 1992.

The authors acknowledge the partial funding provided by the Illinois Department of Energy and Natural Resources, the Illinois Coal Development Board, and the Office of Surface Mining. The authors also acknowledge the work of David F. Brutcher, Joseph (Jay) T. Kelleher, Christine E. Ovanic, and students from Northwestern University for their assistance in the field. Billy Anne Trent assisted with manuscript preparation, and Philip J. DeMaris provided several map figures. The authors also thank the land owner Sam Stotlar and the mining company for their assistance and cooperation. Paul B. DuMontelle, former director of the llinois Mine Subsidence Research Program, assisted in securing the research site.

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APPENDIXES

ILLINOIS STATE GEOLOGICAL SURVEY
ROCK MECHANICS LABORATORY
WILLIAMSON COUNTY -- HER MINE SITE
(PRE-SUBSIDENCE)

SAMPLE ID (DEPTH) (ft)	ROCK TYPE	qu (psi)	MODULUS (psi x 10^6)	MOISTURE CONTENT @qu (%)	AVERAGE AXIAL POINT LOAD INDEX (psi)	AVERAGE T500 (MPa)	AVERAGE INDIRECT TENSILE STRENGTH (psi)	SPECIFIC GRAVITY	SHORE HARDNESS
79.8	SH	7,294	0.61	2.72	**	**	**	2.50	27
80.7	SH	7,768	0.59	2.48	1,066	3.95	880	2.50	27
90.9	SH	7,668	0.79	3.29	1,132	3.19	638	2.35	33
138.9	SS	6,332	4.05	2.39	**	**	**	2.26	35
140.0	SS	5,351	1.19	2.44	879	3.46	423	2.26	27
152.3	LS	7,252	1.63	0.63	**	**	**	**	44
163.7	SLTST	8,401	0.82	0.90	1,200	5.11	702	2.47	48
164.8	SLTST	6,908	1.00	0.79	**	**	**	2.47	39
170.6	SS-SLTST	6,345	0.70	1.19	1,294	4.53	614	2.53	18
181.9	SLTST	3,873	0.57	1.66	877	2.94	472	2.58	18
190.5	LS	14,383	8.09	0.18	3,655	13.43	1,223	2.86	63
198.0	SS	7,544	1.13	1.44	956	3.76	605	2.44	35
221.6	SH	**	**	2.47	1,276	4.83	859	2.57	19
232.0	SH	**	**	3.12	505	2.65	659	2.04	46
238.0	SH	5,320	0.69	1.7	**	**	**	**	19
239.1	SH	**	**	**	614	3.16	576	2.54	22
241.3	SH	5,788	0.48	3.34	487	2.27	422	2.52	18

** No sample available.

SH = Shale
SS = Sandstone
SLTST = Siltstone
LS = Limestone

GEOLOGICAL BORING LOG: Pre-sub Core; 10° from vert; West Cluster		*Page 1 of 14*
PROJECT: IMSRP Williamson Cnty High-Extraction Retreat Site		SURF ELEV: 509.75 FT
LOCATION: NW¼, SW¼, S6, T9S, R4E, Williamson Cnty, IL		TOTAL DEPTH: 264.3 FT
LOGGED BY: E. Gefell, R. Bauer, T. Honeycutt	METHOD: NX-wireline core	DATE DRILLED: June 10-12, 1986

Depth (Feet)	Description	Lithology	Drilling Data	Core Recov (%) 25 50 75	RQD 25 50 75	Fractures per foot 1 2 3 4	RM Tests	Joints Log	Joints Description
0	GLACIAL TILL: less than 3 ft Loess overlying Illinosian till, some sandy zones, clayey at bottom								
5									
10									
15									
20									

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GEOLOGICAL BORING LOG: Pre-sub Core; 10° from vert; West Cluster

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PROJECT: IMSRP Williamson Cnty High-Extraction Retreat Site

SURF ELEV: 509.75 FT

LOCATION: NW¼, SW¼, S6, T9S, R4E, Williamson Cnty, IL

TOTAL DEPTH: 264.3 FT

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DATE DRILLED: June 10-12, 1986

Depth (Feet)	Description	Lithology	Drilling Data	Core Recov (%) 25 50 75	RQD 25 50 75	Fractures per foot 1 2 3 4	RM Tests	Joints Log	Joints Description
20									
25									
30									
35									
40									

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GEOLOGICAL BORING LOG: Pre-sub Core; 10° from vert; West Cluster

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PROJECT: IMSRP Williamson Cnty High-Extraction Retreat Site

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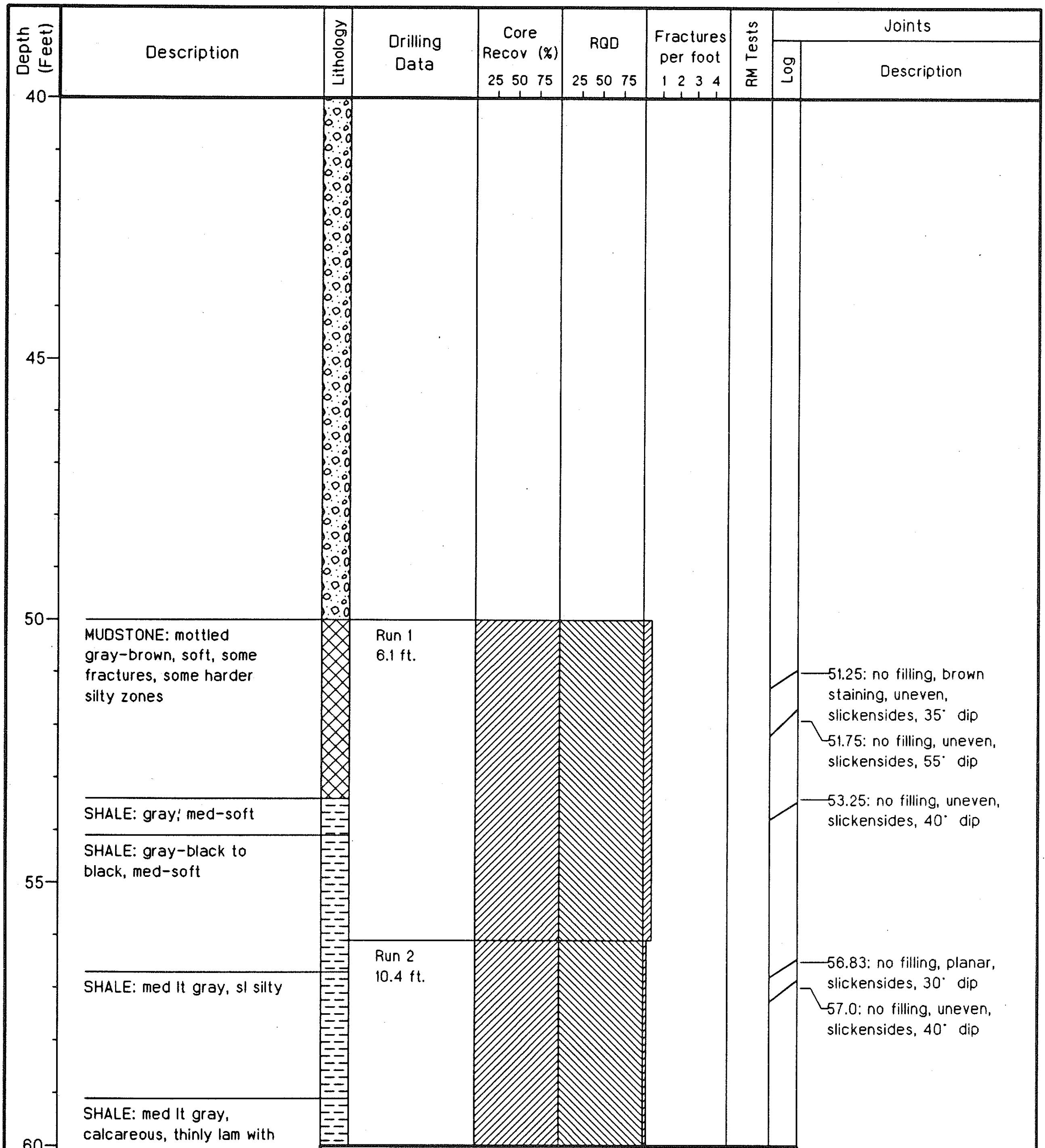

MUDSTONE: mottled gray-brown, soft, some fractures, some harder silty zones

SHALE: gray, med-soft

SHALE: gray-black to black, med-soft

SHALE: med lt gray, sl silty

SHALE: med lt gray, calcareous, thinly lam with siderite nodules, some silt

Run 1
6.1 ft.

Run 2
10.4 ft.

51.25: no filling, brown staining, uneven, slickensides, 35° dip

51.75: no filling, uneven, slickensides, 55° dip

53.25: no filling, uneven, slickensides, 40° dip

56.83: no filling, planar, slickensides, 30° dip

57.0: no filling, uneven, slickensides, 40° dip

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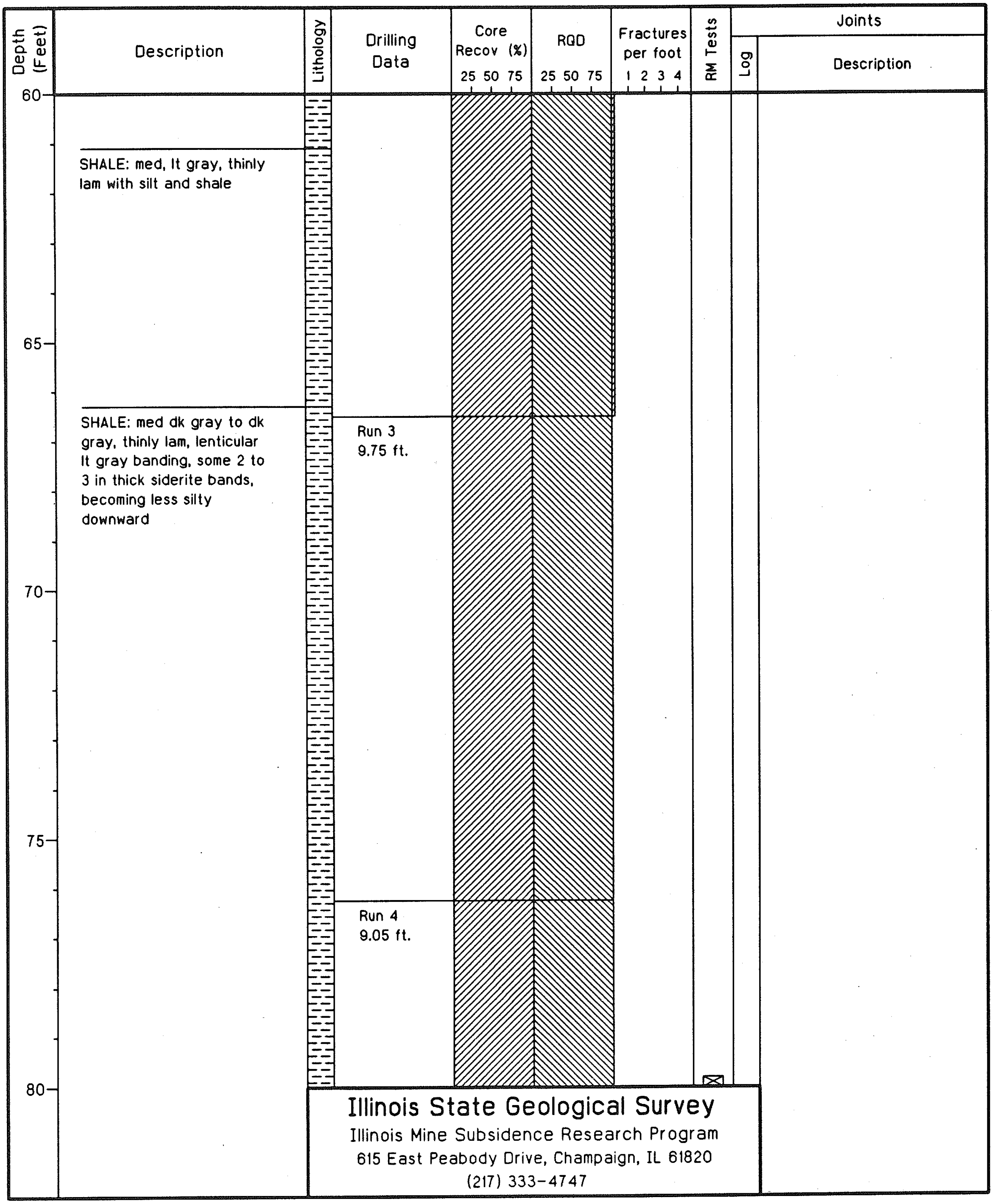
GEOLOGICAL BORING LOG: Pre-sub Core; 10° from vert; West Cluster	*Page 4 of 14*
PROJECT: IMSRP Williamson Cnty High-Extraction Retreat Site	SURF ELEV: 509.75 FT
LOCATION: NW¼, SW¼, S6, T9S, R4E, Williamson Cnty, IL	TOTAL DEPTH: 264.3 FT
LOGGED BY: E. Gefell, R. Bauer, T. Honeycutt METHOD: NX-wireline core	DATE DRILLED: June 10-12, 1986



SHALE: med, lt gray, thinly lam with silt and shale

SHALE: med dk gray to dk gray, thinly lam, lenticular lt gray banding, some 2 to 3 in thick siderite bands, becoming less silty downward

Run 3
9.75 ft.

Run 4
9.05 ft.

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GEOLOGICAL BORING LOG: Pre-sub Core; 10° from vert; West Cluster

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PROJECT: IMSRP Williamson Cnty High-Extraction Retreat Site

SURF ELEV: 509.75 FT

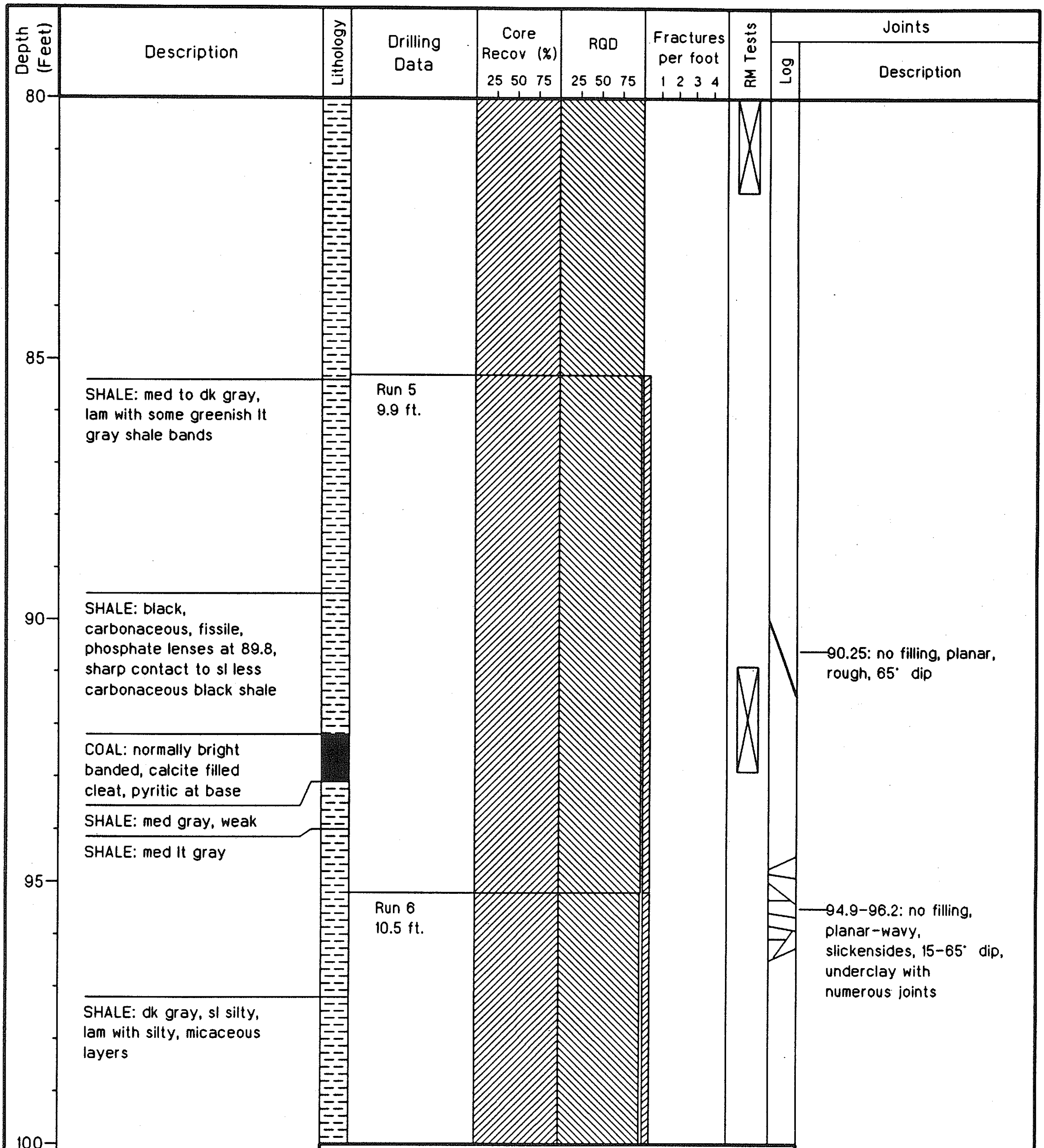
LOCATION: NW¼, SW¼, S6, T9S, R4E, Williamson Cnty, IL

TOTAL DEPTH: 264.3 FT

LOGGED BY: E. Gefell, R. Bauer, T. Honeycutt

METHOD: NX-wireline core

DATE DRILLED: June 10-12, 1986



SHALE: med to dk gray, lam with some greenish lt gray shale bands

Run 5
9.9 ft.

SHALE: black, carbonaceous, fissile, phosphate lenses at 89.8, sharp contact to sl less carbonaceous black shale

90.25: no filling, planar, rough, 65° dip

COAL: normally bright banded, calcite filled cleat, pyritic at base

SHALE: med gray, weak

SHALE: med lt gray

Run 6
10.5 ft.

94.9–96.2: no filling, planar-wavy, slickensides, 15-65° dip, underclay with numerous joints

SHALE: dk gray, sl silty, lam with silty, micaceous layers

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GEOLOGICAL BORING LOG: Pre-sub Core; 10° from vert; West Cluster		*Page 6 of 14*
PROJECT: IMSRP Williamson Cnty High-Extraction Retreat Site		SURF ELEV: 509.75 FT
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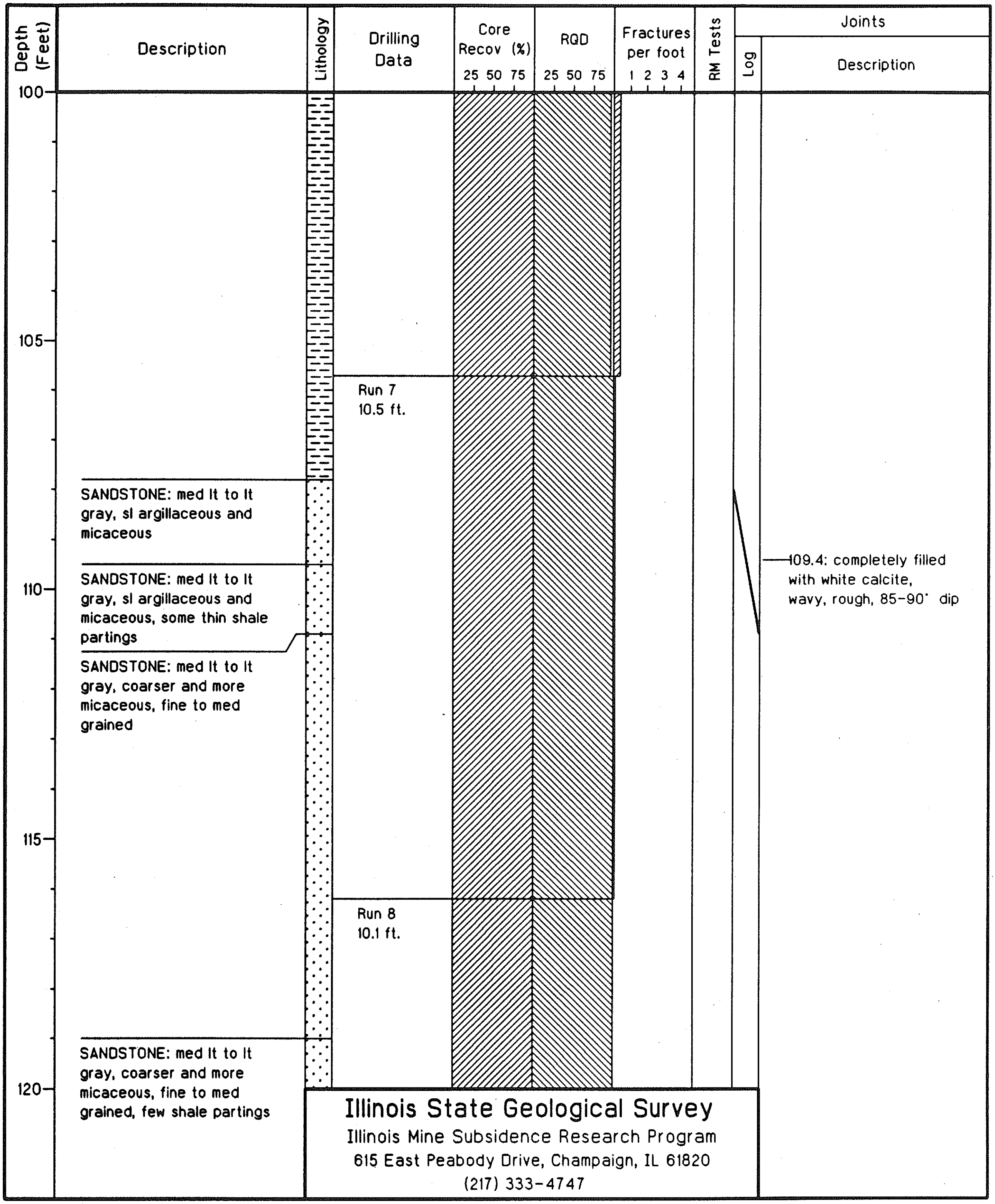

Run 7
10.5 ft.

Run 8
10.1 ft.

SANDSTONE: med lt to lt gray, sl argillaceous and micaceous

SANDSTONE: med lt to lt gray, sl argillaceous and micaceous, some thin shale partings

SANDSTONE: med lt to lt gray, coarser and more micaceous, fine to med grained

SANDSTONE: med lt to lt gray, coarser and more micaceous, fine to med grained, few shale partings

109.4: completely filled with white calcite, wavy, rough, 85-90° dip

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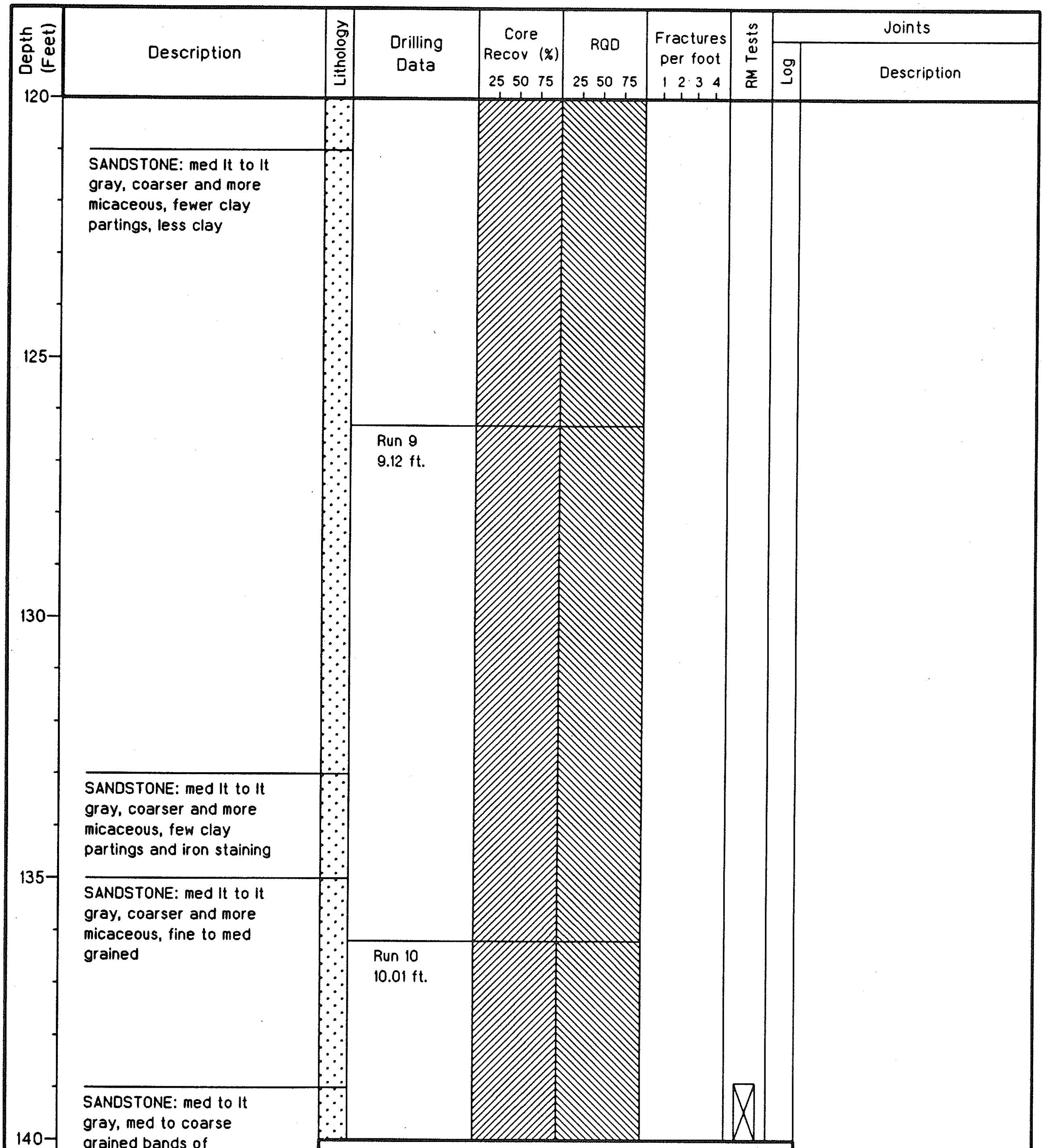
GEOLOGICAL BORING LOG: Pre-sub Core; 10° from vert; West Cluster		Page 7 of 14
PROJECT: IMSRP Williamson Cnty High-Extraction Retreat Site		SURF ELEV: 509.75 FT
LOCATION: NW¼, SW¼, S6, T9S, R4E, Williamson Cnty, IL		TOTAL DEPTH: 264.3 FT
LOGGED BY: E. Gefell, R. Bauer, T. Honeycutt	METHOD: NX-wireline core	DATE DRILLED: June 10-12, 1986



SANDSTONE: med lt to lt gray, coarser and more micaceous, fewer clay partings, less clay

SANDSTONE: med lt to lt gray, coarser and more micaceous, few clay partings and iron staining

SANDSTONE: med lt to lt gray, coarser and more micaceous, fine to med grained

SANDSTONE: med to lt gray, med to coarse grained bands of micaceous, carbonaceous material

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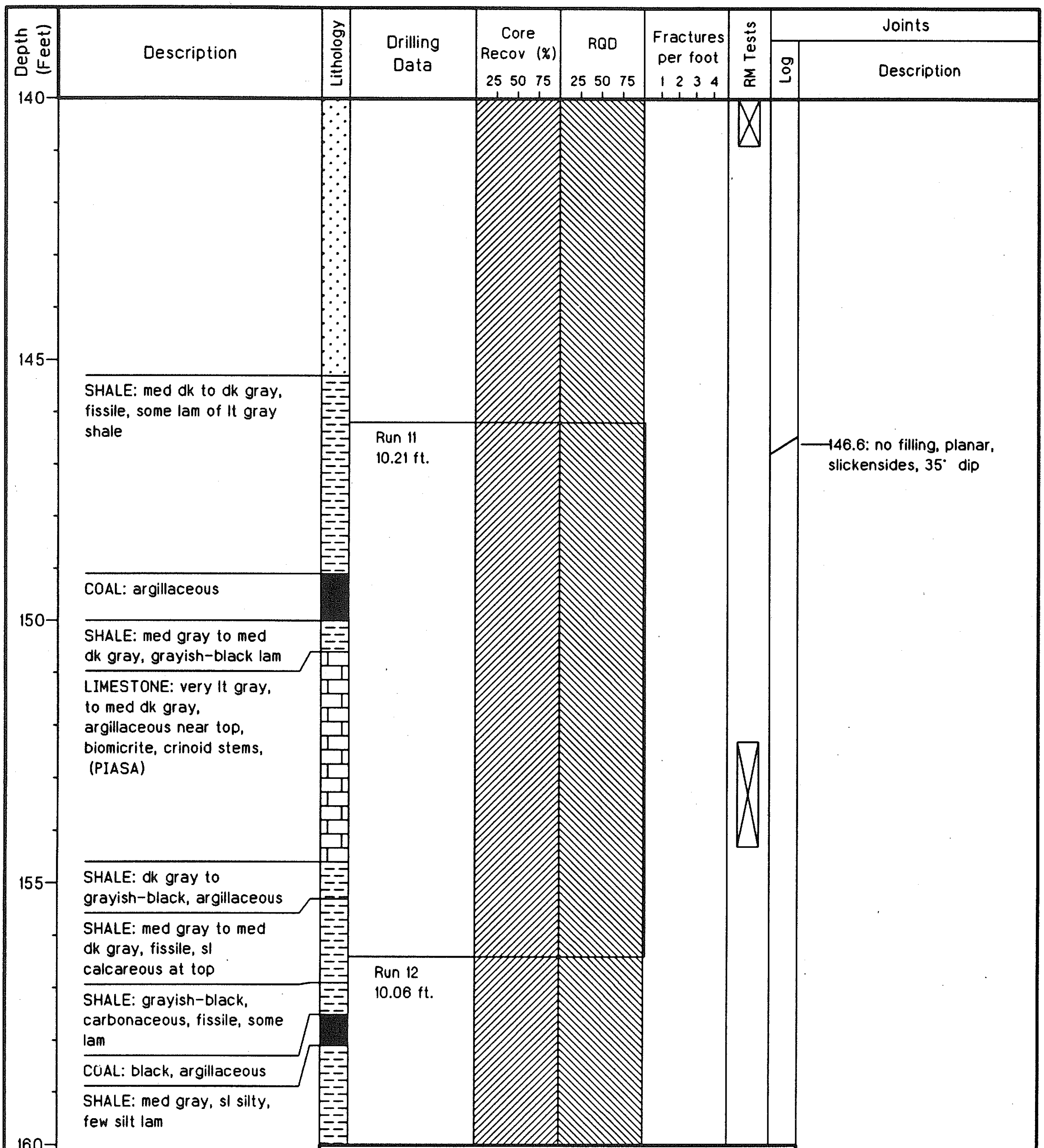
GEOLOGICAL BORING LOG: Pre-sub Core; 10° from vert; West Cluster | *Page 8 of 14*

PROJECT: IMSRP Williamson Cnty High-Extraction Retreat Site | SURF ELEV: 509.75 FT

LOCATION: NW¼, SW¼, S6, T9S, R4E, Williamson Cnty, IL | TOTAL DEPTH: 264.3 FT

LOGGED BY: E. Gefell, R. Bauer, T. Honeycutt | METHOD: NX-wireline core | DATE DRILLED: June 10-12, 1986



SHALE: med dk to dk gray, fissile, some lam of lt gray shale

COAL: argillaceous

SHALE: med gray to med dk gray, grayish-black lam

LIMESTONE: very lt gray, to med dk gray, argillaceous near top, biomicrite, crinoid stems, (PIASA)

SHALE: dk gray to grayish-black, argillaceous

SHALE: med gray to med dk gray, fissile, sl calcareous at top

SHALE: grayish-black, carbonaceous, fissile, some lam

COAL: black, argillaceous

SHALE: med gray, sl silty, few silt lam

Run 11
10.21 ft.

Run 12
10.06 ft.

146.6: no filling, planar, slickensides, 35° dip

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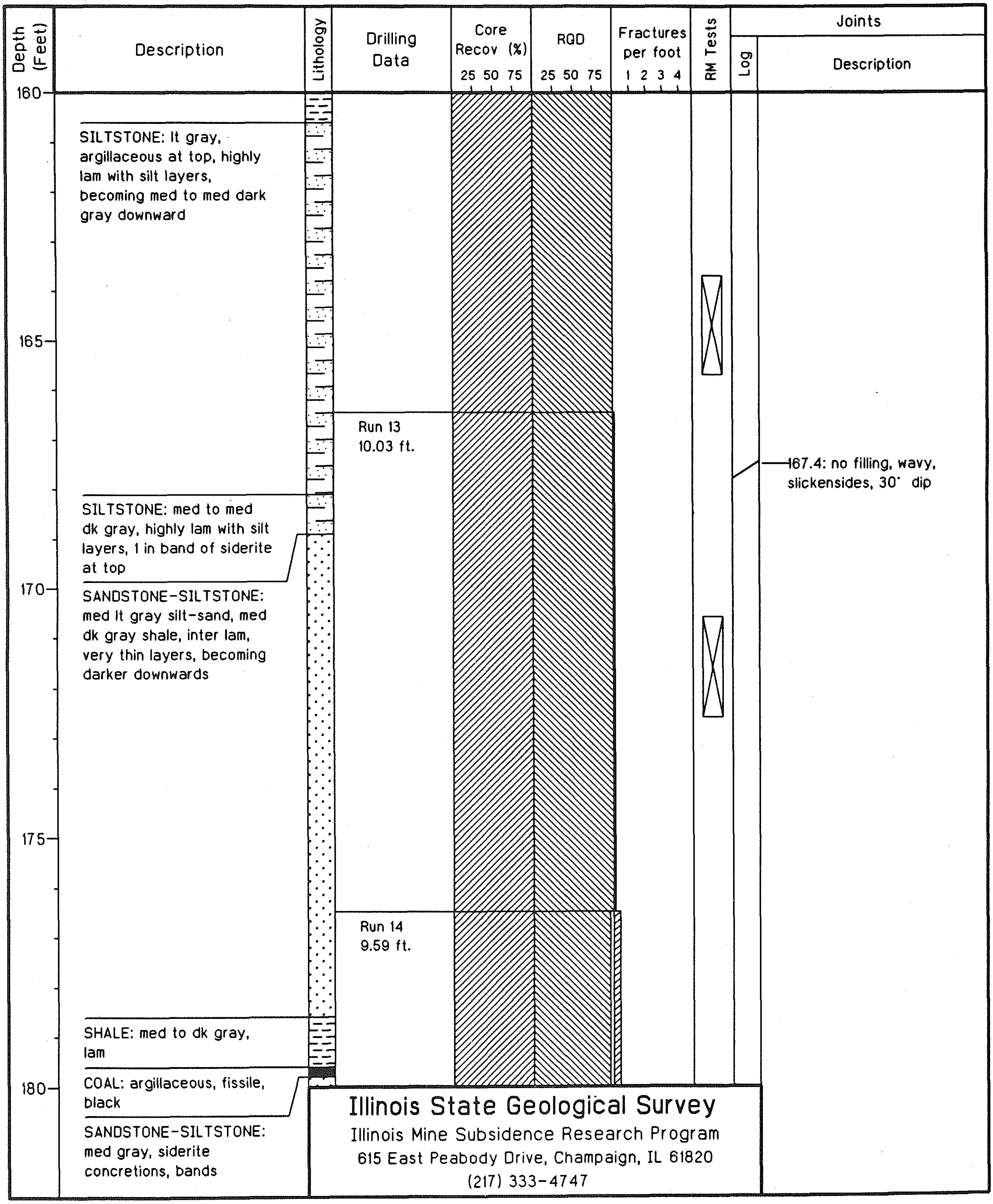
GEOLOGICAL BORING LOG: Pre-sub Core; 10° from vert; West Cluster	*Page 9 of 14*
PROJECT: IMSRP Williamson Cnty High-Extraction Retreat Site	SURF ELEV: 509.75 FT
LOCATION: NW¼, SW¼, S6, T9S, R4E, Williamson Cnty, IL	TOTAL DEPTH: 264.3 FT
LOGGED BY: E. Gefell, R. Bauer, T. Honeycutt · METHOD: NX-wireline core	DATE DRILLED: June 10-12, 1986



SILTSTONE: lt gray, argillaceous at top, highly lam with silt layers, becoming med to med dark gray downward

SILTSTONE: med to med dk gray, highly lam with silt layers, 1 in band of siderite at top

SANDSTONE-SILTSTONE: med lt gray silt-sand, med dk gray shale, inter lam, very thin layers, becoming darker downwards

SHALE: med to dk gray, lam

COAL: argillaceous, fissile, black

SANDSTONE-SILTSTONE: med gray, siderite concretions, bands

Run 13
10.03 ft.

Run 14
9.59 ft.

167.4: no filling, wavy, slickensides, 30° dip

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GEOLOGICAL BORING LOG: Pre-sub Core; 10° from vert; West Cluster

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TOTAL DEPTH: 264.3 FT

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METHOD: NX-wireline core

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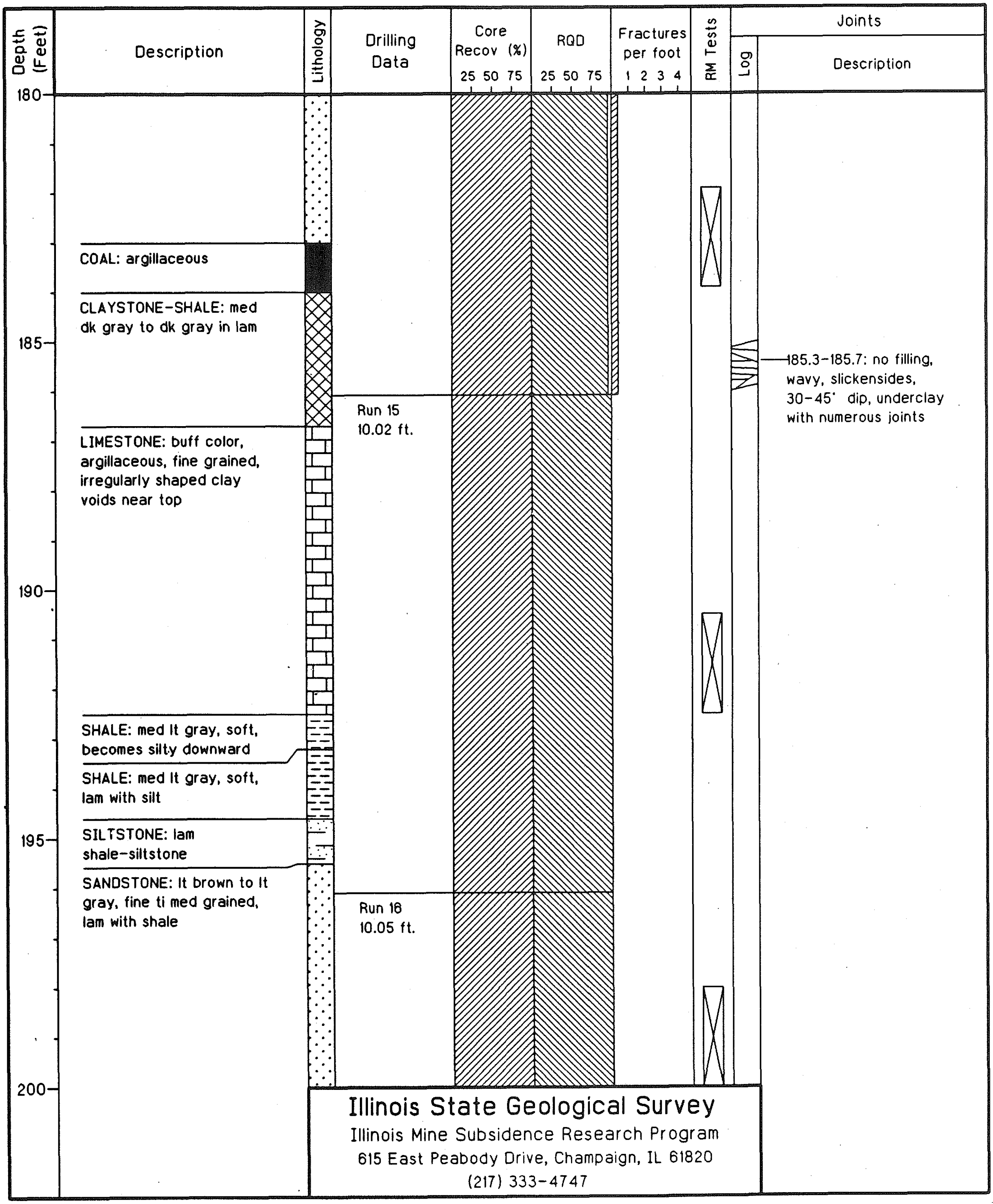

COAL: argillaceous

CLAYSTONE-SHALE: med dk gray to dk gray in lam

LIMESTONE: buff color, argillaceous, fine grained, irregularly shaped clay voids near top

SHALE: med lt gray, soft, becomes silty downward

SHALE: med lt gray, soft, lam with silt

SILTSTONE: lam shale-siltstone

SANDSTONE: lt brown to lt gray, fine ti med grained, lam with shale

Run 15
10.02 ft.

Run 16
10.05 ft.

185.3-185.7: no filling, wavy, slickensides, 30-45° dip, underclay with numerous joints

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GEOLOGICAL BORING LOG: Pre-sub Core; 10° from vert; West Cluster

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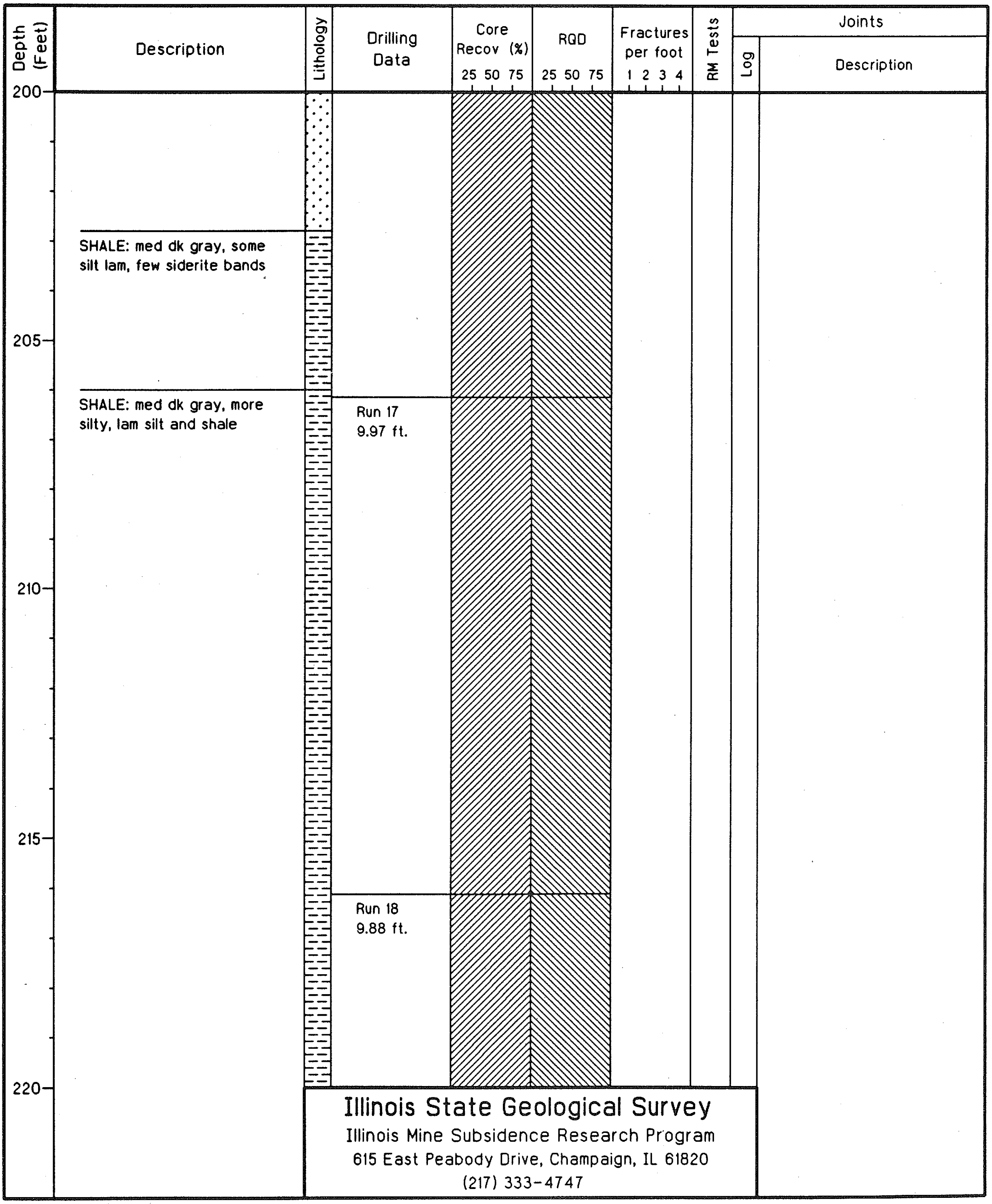

SHALE: med dk gray, some silt lam, few siderite bands

SHALE: med dk gray, more silty, lam silt and shale

Run 17
9.97 ft.

Run 18
9.88 ft.

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GEOLOGICAL BORING LOG: Pre-sub Core; 10˚ from vert; West Cluster | *Page 12 of 14*

PROJECT: IMSRP Williamson Cnty High-Extraction Retreat Site | SURF ELEV: 509.75 FT

LOCATION: NW¼, SW¼, S6, T9S, R4E, Williamson Cnty, IL | TOTAL DEPTH: 264.3 FT

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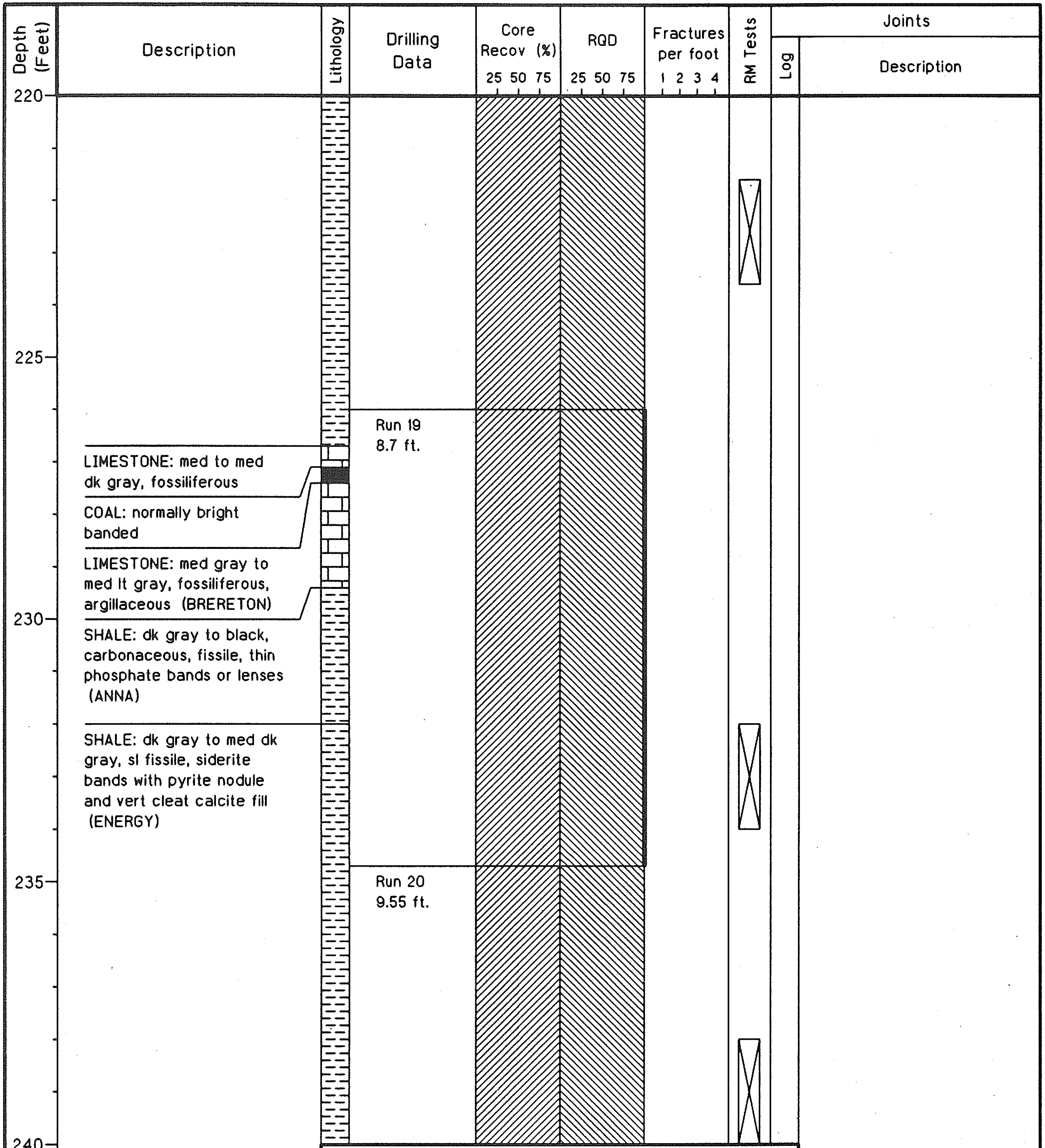

LIMESTONE: med to med dk gray, fossiliferous

COAL: normally bright banded

LIMESTONE: med gray to med lt gray, fossiliferous, argillaceous (BRERETON)

SHALE: dk gray to black, carbonaceous, fissile, thin phosphate bands or lenses (ANNA)

SHALE: dk gray to med dk gray, sl fissile, siderite bands with pyrite nodule and vert cleat calcite fill (ENERGY)

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GEOLOGICAL BORING LOG: Pre-sub Core; 10° from vert; West Cluster

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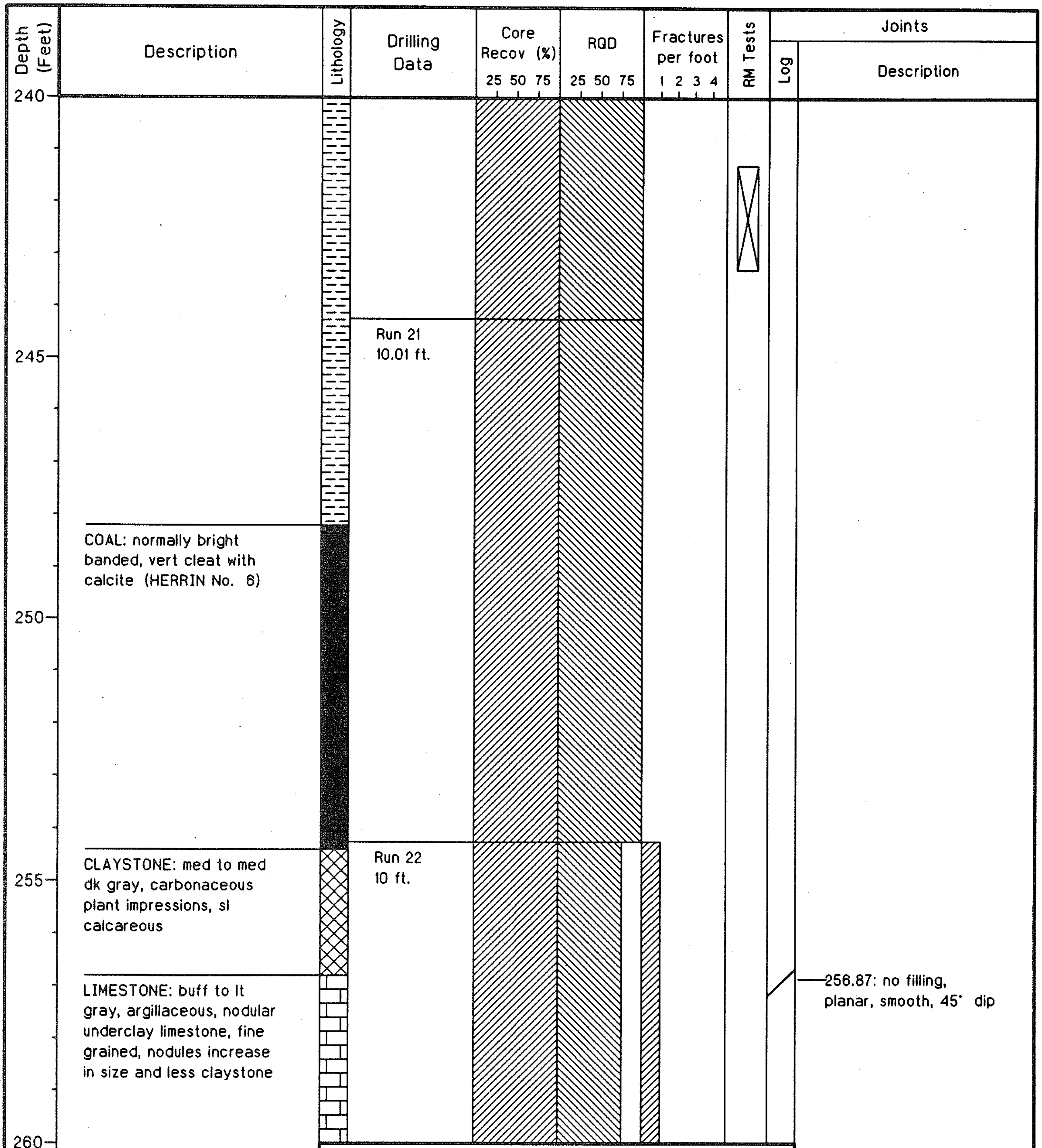
LOCATION: NW¼, SW¼, S6, T9S, R4E, Williamson Cnty, IL

TOTAL DEPTH: 264.3 FT

LOGGED BY: E. Gefell, R. Bauer, T. Honeycutt

METHOD: NX-wireline core

DATE DRILLED: June 10-12, 1986



Run 21
10.01 ft.

COAL: normally bright banded, vert cleat with calcite (HERRIN No. 6)

Run 22
10 ft.

CLAYSTONE: med to med dk gray, carbonaceous plant impressions, sl calcareous

LIMESTONE: buff to lt gray, argillaceous, nodular underclay limestone, fine grained, nodules increase in size and less claystone

256.87: no filling, planar, smooth, 45° dip

Illinois State Geological Survey
Illinois Mine Subsidence Research Program
615 East Peabody Drive, Champaign, IL 61820
(217) 333-4747

GEOLOGICAL BORING LOG: Pre-sub Core; 10˚ from vert; West Cluster

Page 14 of 14

PROJECT: IMSRP Williamson Cnty High-Extraction Retreat Site

SURF ELEV: 509.75 FT

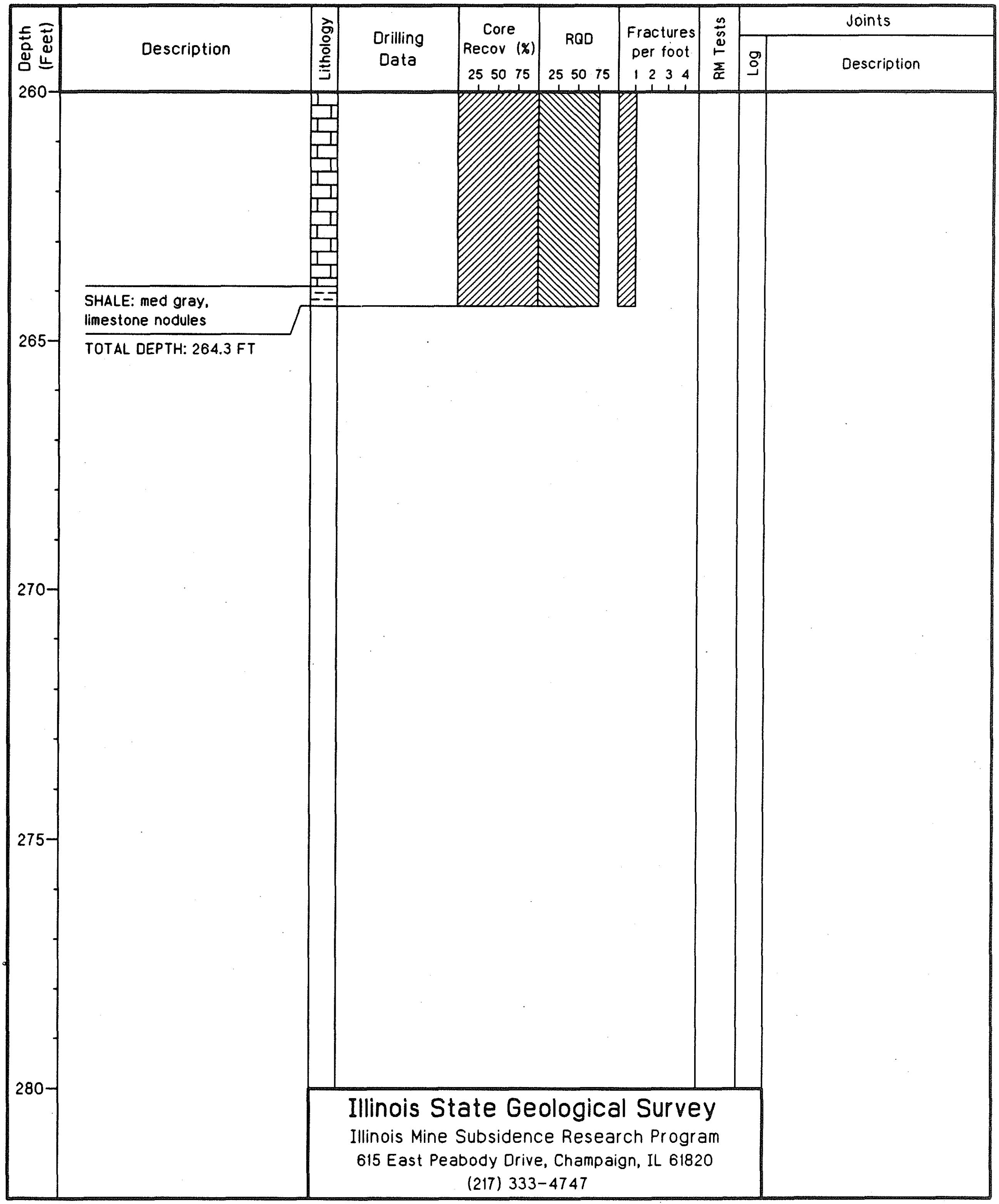
LOCATION: NW¼, SW¼, S6, T9S, R4E, Williamson Cnty, IL

TOTAL DEPTH: 264.3 FT

LOGGED BY: E. Gefell, R. Bauer, T. Honeycutt

METHOD: NX-wireline core

DATE DRILLED: June 10-12, 1986



Illinois State Geological Survey
Illinois Mine Subsidence Research Program
615 East Peabody Drive, Champaign, IL 61820
(217) 333-4747

APPENDIX B MPBX Readings and Calculations for Both Clusters

WILLIAMSON COUNTY
EAST CLUSTER MPBX READINGS
[in feet]

ROD #1
[length = 50 ft]

	DATE	ROD TIP READING	SURFACE ELEV	ANCHOR ELEV	TOTAL ANCHOR CHANGE
1986	SEPT 9	-0.080	523.050	472.970	---
	SEPT 20	-0.080	523.050	472.970	0.000
	DEC 10	-0.079	523.050	472.971	0.001
1987	FEB 2	-0.079	523.050	472.971	0.001
	MAR 24	-0.080	523.050	472.970	0.000
	MAR 27	-0.403	521.226	470.823	-2.147
	MAR 31	-0.401	521.098	470.697	-2.273
	APR 1	-0.400	521.098	470.698	-2.272
	APR 2	-0.400	521.098	470.698	-2.272
	APR 3	-0.403	521.025	470.622	-2.348
	APR 16	-0.287	521.025	470.738	-2.232
	APR 21	-0.280	520.056	469.776	-3.194
	APR 23	-0.279	520.056	469.777	-3.193
	APR 29	-0.278	520.011	469.733	-3.237
	MAY 14	-0.278	519.990	469.712	-3.258
	MAY 27	-0.278	519.990	469.712	-3.258
	MAY 28	-0.280	519.990	469.710	-3.260
	JULY 22	-0.280	519.937	469.657	-3.313
	SEPT 24	-0.280	519.926	469.646	-3.324
1988	JAN 12	-0.28	519.887	469.607	-3.364
	OCT 11	-0.274	519.887	469.613	-3.358
1989	APR 27	-0.2728	519.7776	469.505	-3.465

ROD #2
[length = 75 ft]

	DATE	ROD TIP READING	SURFACE ELEV	ANCHOR ELEV	TOTAL ANCHOR CHANGE
1986	SEPT 9	-0.081	523.050	447.969	---
	SEPT 20	-0.082	523.050	447.968	-0.001
	DEC 10	-0.081	523.050	447.969	0.000
1987	FEB 2	-0.081	523.050	447.969	0.000
	MAR 24	-0.082	523.050	447.968	-0.001
	MAR 27	-0.403	521.226	445.823	-2.146
	MAR 31	-0.400	521.098	445.698	-2.271
	APR 1	-0.400	521.098	445.698	-2.271
	APR 2	-0.400	521.098	445.698	-2.271
	APR 3	-0.403	521.025	445.622	-2.347
	APR 16	-0.289	521.025	445.736	-2.233
	APR 21	-0.284	520.056	444.772	-3.197
	APR 23	-0.280	520.056	444.776	-3.193
	APR 29	-0.280	520.011	444.731	-3.238
	MAY 14	-0.280	519.990	444.710	-3.259
	MAY 27	-0.282	519.990	444.708	-3.261
	MAY 28	-0.281	519.990	444.709	-3.260
	JULY 22	-0.285	519.937	444.652	-3.317
	SEPT 24	-0.283	519.926	444.643	-3.326
1988	JAN 12	-0.283	519.887	444.604	-3.365
	OCT 11	-0.279	519.887	444.608	-3.361
1989	APR 27	-0.2777	519.7776	444.500	-3.469

continued

WILLIAMSON COUNTY
EAST CLUSTER MPBX READINGS
[in feet]

ROD #3 [length = 100 ft]	DATE	ROD TIP READING	SURFACE ELEV	ANCHOR ELEV	TOTAL ANCHOR CHANGE
1986	SEPT 9	-0.077	523.050	422.973	---
	SEPT 20	-0.077	523.050	422.973	0.000
	DEC 10	-0.077	523.050	422.973	0.000
1987	FEB 2	-0.077	523.050	422.973	0.000
	MAR 24	-0.077	523.050	422.973	0.000
	MAR 27	-0.397	521.226	420.829	-2.144
	MAR 31	-0.396	521.098	420.702	-2.271
	APR 1	-0.396	521.098	420.702	-2.271
	APR 2	-0.396	521.098	420.702	-2.271
	APR 3	-0.397	521.025	420.628	-2.345
	APR 16	-0.287	521.025	420.738	-2.235
	APR 21	-0.285	520.056	419.771	-3.202
	APR 23	-0.282	520.056	419.774	-3.199
	APR 29	-0.281	520.011	419.730	-3.243
	MAY 14	-0.281	519.990	419.709	-3.264
	MAY 27	-0.280	519.990	419.710	-3.263
	MAY 28	-0.281	519.990	419.709	-3.264
	JULY 22	-0.287	519.937	419.650	-3.323
	SEPT 24	-0.286	519.926	419.640	-3.333
1988	JAN 12	-0.285	519.887	419.602	-3.371
	OCT 11	-0.281	519.887	419.606	-3.367
1989	APR 27	-0.2788	519.7776	419.499	-3.474

ROD #4 [length = 125 ft]	DATE	ROD TIP READING	SURFACE ELEV	ANCHOR ELEV	TOTAL ANCHOR CHANGE
1986	SEPT 9	-0.072	523.050	397.978	---
	SEPT 20	-0.073	523.050	397.977	-0.001
	DEC 10	-0.073	523.050	397.977	-0.001
1987	FEB 2	-0.074	523.050	397.976	-0.002
	MAR 24	-0.074	523.050	397.976	-0.002
	MAR 27	-1.698	521.226	394.528	-3.450
	MAR 31	-1.703	521.098	394.395	-3.583
	APR 1	-1.700	521.098	394.398	-3.580
	APR 2	-1.700	521.098	394.398	-3.580
	APR 3	-1.698	521.025	394.327	-3.651
	APR 16	-1.600	521.025	394.425	-3.553
	APR 21	-1.598	520.056	393.458	-4.520
	APR 23	-1.595	520.056	393.461	-4.517
	APR 29	-1.595	520.011	393.416	-4.562
	MAY 14	-1.594	519.990	393.396	-4.582
	MAY 27	-1.599	519.990	393.391	-4.587
	MAY 28	-1.595	519.990	393.395	-4.583
	JULY 22	-1.605	519.937	393.332	-4.646
	SEPT 24	-1.6	519.926	393.326	-4.652
1988	JAN 12	-1.605	519.887	393.282	-4.696
	OCT 11	-1.593	519.887	393.294	-4.684
1989	APR 27	-1.5885	519.7776	393.189	-4.789

continued

WILLIAMSON COUNTY
EAST CLUSTER MPBX READINGS
[in feet]

ROD #5 [length = 150 ft]	DATE	ROD TIP READING	SURFACE ELEV	ANCHOR ELEV	TOTAL ANCHOR CHANGE
1986	SEPT 9	-0.075	523.050	372.975	---
	SEPT 20	-0.075	523.050	372.975	0.000
	DEC 10	-0.076	523.050	372.974	-0.001
1987	FEB 2	-0.077	523.050	372.973	-0.002
	MAR 24	-0.077	523.050	372.973	-0.002
	MAR 27	-2.123	521.226	369.103	-3.872
	MAR 31	-2.130	521.098	368.968	-4.007
	APR 1	-2.127	521.098	368.971	-4.004
	APR 2	-2.128	521.098	368.970	-4.005
	APR 3	-2.123	521.025	368.902	-4.073
	APR 16	-2.008	521.025	369.017	-3.958
	APR 21	-2.010	520.056	368.046	-4.929
	APR 23	-2.004	520.056	368.052	-4.923
	APR 29	-2.008	520.011	368.003	-4.972
	MAY 14	-2.008	519.990	367.982	-4.993
	MAY 27	-2.008	519.990	367.982	-4.993
	MAY 28	-2.006	519.990	367.984	-4.991
	JULY 22	-2.012	519.937	367.925	-5.050
	SEPT 24	-2.009	519.926	367.917	-5.058
1988	JAN 12	-2.009	519.887	367.878	-5.097
	OCT 11	-2.001	519.887	367.886	-5.089
1989	APR 27	-1.9948	519.7776	367.783	-5.192

ROD #6 [length = 175 ft]	DATE	ROD TIP READING	SURFACE ELEV	ANCHOR ELEV	TOTAL ANCHOR CHANGE
1986	SEPT 9	-0.056	523.050	347.994	---
	SEPT 20	-0.056	523.050	347.994	0.000
	DEC 10	-0.055	523.050	347.995	0.001
1987	FEB 2	-0.056	523.050	347.994	0.000
	MAR 24	-0.057	523.050	347.993	-0.001
	MAR 27	-1.120	521.226	345.106	-2.888
	MAR 31	-1.122	521.098	344.976	-3.018
	APR 1	-1.120	521.098	344.978	-3.016
	APR 2	-1.123	521.098	344.975	-3.019
	APR 3	-1.120	521.025	344.905	-3.089
	APR 16	-0.998	521.025	345.027	-2.967
	APR 21	-0.996	520.056	344.060	-3.934
	APR 23	-0.995	520.056	344.061	-3.933
	APR 29	-0.995	520.011	344.016	-3.978
	MAY 14	-0.994	519.990	343.996	-3.998
	MAY 27	-0.993	519.990	343.997	-3.997
	MAY 28	-0.992	519.990	343.998	-3.996
	JULY 22	-0.995	519.937	343.942	-4.052
	SEPT 24	-0.995	519.926	343.931	-4.063
1988	JAN 12	-0.995	519.887	343.892	-4.102
	OCT 11	-0.989	519.887	343.898	-4.096
1989	APR 27	-0.9844	519.7776	343.793	-4.201

WILLIAMSON COUNTY
WEST CLUSTER MPBX READINGS

ROD #1
[length = 50 ft]

	DATE	ROD TIP READING	SURFACE ELEV	ANCHOR ELEV	TOTAL ANCHOR CHANGE
1986	SEPT 9	0.007	509.613	459.620	---
	SEPT 20	0.008	509.613	459.621	0.001
	DEC 11	0.006	509.613	459.619	-0.001
1987	FEB 2	0.004	509.613	459.617	-0.003
	APR 14	0.004	509.613	459.617	-0.003
	APR 22	0.002	509.613	459.615	-0.005
	APR 30	0.002	509.613	459.615	-0.005
	MAY 13	0.001	509.613	459.614	-0.006

ROD #2
[length = 75 ft]

	DATE	ROD TIP READING	SURFACE ELEV	ANCHOR ELEV	TOTAL ANCHOR CHANGE
1986	SEPT 9	0.050	509.613	434.663	---
	SEPT 20	0.050	509.613	434.663	0.000
	DEC 11	0.047	509.613	434.660	-0.003
1987	FEB 2	0.046	509.613	434.659	-0.004
	APR 14	0.046	509.613	434.659	-0.004
	APR 22	0.043	509.613	434.656	-0.007
	APR 30	0.045	509.613	434.658	-0.005
	MAY 13	0.046	509.613	434.659	-0.004

ROD #3
[length = 100 ft]

	DATE	ROD TIP READING	SURFACE ELEV	ANCHOR ELEV	TOTAL ANCHOR CHANGE
1986	SEPT 9	0.150	509.613	459.763	---
	SEPT 20	0.150	509.613	459.763	0.000
	DEC 11	0.149	509.613	459.762	-0.001
1987	FEB 2	0.149	509.613	459.762	-0.001
	APR 14	0.146	509.613	459.759	-0.004
	APR 22	0.146	509.613	459.759	-0.004
	APR 30	0.149	509.613	459.762	-0.001
	MAY 13	0.148	509.613	459.761	-0.002

ROD #4
[length = 125 ft]

	DATE	ROD TIP READING	SURFACE ELEV	ANCHOR ELEV	TOTAL ANCHOR CHANGE
1986	SEPT 9	0.170	509.613	434.783	---
	SEPT 20	0.170	509.613	434.783	0.000
	DEC 11	0.166	509.613	434.779	-0.004
1987	FEB 2	0.168	509.613	434.781	-0.002
	APR 14	0.161	509.613	434.774	-0.009
	APR 22	0.164	509.613	434.777	-0.006
	APR 30	0.165	509.613	434.778	-0.005
	MAY 13	0.164	509.613	434.777	-0.006

ROD #5
[length = 150 ft]

	DATE	ROD TIP READING	SURFACE ELEV	ANCHOR ELEV	TOTAL ANCHOR CHANGE
1986	SEPT 9	0.112	509.613	459.725	---
	SEPT 20	0.112	509.613	459.725	0.000
	DEC 11	0.109	509.613	459.722	-0.003
1987	FEB 2	0.110	509.613	459.723	-0.002
	APR 14	0.107	509.613	459.720	-0.005
	APR 22	0.109	509.613	459.722	-0.003
	APR 30	0.110	509.613	459.723	-0.002
	MAY 13	0.111	509.613	459.724	-0.001

ROD #6
[length = 175 ft]

	DATE	ROD TIP READING	SURFACE ELEV	ANCHOR ELEV	TOTAL ANCHOR CHANGE
1986	SEPT 9	0.083	509.613	434.696	---
	SEPT 20	0.083	509.613	434.696	0.000
	DEC 11	0.081	509.613	434.694	-0.002
1987	FEB 2	0.079	509.613	434.692	-0.004
	APR 14	0.078	509.613	434.691	-0.005
	APR 22	0.077	509.613	434.690	-0.006
	APR 30	0.079	509.613	434.692	-0.004
	MAY 13	0.079	509.613	434.692	-0.004

APPENDIX C Surveying Data

COORDINATES FOR THE EAST CLUSTER INSTRUMENTS & MONUMENTS

WILLIAMSON COUNTY

INSTRUMENT/ MONUMENT	NORTHINGS	EASTINGS	ELEVATIONS	DATE
MPBX	-4082.360	32160.930	523.330	E.I.*
	-4081.694	32161.258	521.226	3-27-87
	-4081.717	32161.170	521.025	4-03-87
	-4081.795	32160.475	520.056	4-21-87
	-4081.814	32160.443	520.011	4-29-87
	-4081.872	32160.379	519.990	5-14-86
	-4081.800	32160.423	519.937	7-22-87
	-4081.793	32160.509	519.926	9-24-87
	-4081.849	32160.437	519.887	1-12-88
TDR	-4078.330	32158.800	522.700	E.I.*
	-4077.734	32159.356	521.069	3-27-87
	-4077.769	32159.257	520.882	4-03-87
P5E (DOW)	-4087.080	32163.640	522.640	E.I.*
	-4086.507	32163.758	521.420	3-27-87
	-4086.492	32163.647	521.256	4-03-87
	-4086.346	32162.982	520.453	4-21-87
	-4086.369	32162.940	520.422	4-29-87
	-4086.422	32162.877	520.370	5-14-86
	-4086.345	32162.928	520.317	7-22-87
	-4086.336	32162.996	520.292	9-24-87
	-4086.385	32162.934	520.281	1-12-88
P6E (SOW)	-4090.960	32166.070	522.560	E.I.*
	-4090.425	32166.378	521.541	3-27-87
	-4090.396	32166.345	521.478	3-31-87
	-4090.367	32166.303	521.443	4-03-87
	--	--	520.812	4-21-87
	-4090.163	32165.651	520.778	4-23-87
	-4090.147	32165.617	520.761	4-29-87
	-4090.207	32165.569	520.729	5-14-87
	-4090.130	32165.612	520.683	7-22-87
	-4090.092	32165.671	520.673	9-24-87
	-4090.157	32165.617	520.651	1-12-88

INSTRUMENT/ MONUMENT	NORTHINGS	EASTINGS	ELEVATIONS	DATE
P1E	-4116.950	32158.930	522.490	E.I.*
	-4116.901	32159.175	522.256	3-27-87
	-4116.910	32159.173	522.235	3-31-87
	-4116.889	32159.152	522.204	4-03-87
	--	--	521.909	4-21-87
	-4116.681	32158.868	521.891	4-23-87
	-4116.666	32158.854	521.884	4-29-87
	-4116.714	32158.808	521.879	5-14-87
	-4116.655	32158.865	521.847	7-22-87
	-4116.655	32158.951	521.834	9-24-87
	-4116.685	32158.889	521.897	1-12-88
P2E	-4164.100	32209.080	515.770	E.I.*
	-4164.062	32209.242	515.716	3-27-87
	-4164.088	32209.234	515.701	3-31-87
	-4164.071	32209.209	515.693	4-03-87
	--	--	516.642	4-21-87
	-4164.073	32209.189	515.637	4-23-87
	-4164.067	32209.177	515.632	4-29-87
	-4164.099	32209.158	515.631	5-14-87
	-4164.065	32209.194	515.614	7-22-87
	-4164.073	32209.268	515.620	9-24-87
	-4164.100	32209.229	515.635	1-12-88
P3E	-4206.470	32235.230	515.620	E.I.*
	-4206.353	32235.411	515.627	3-27-87
	-4206.368	32235.415	515.614	3-31-87
	-4206.356	32235.397	515.610	4-03-87
	--	--	515.577	4-21-87
	-4206.367	32235.415	515.579	4-23-87
	-4206.371	32235.392	515.575	4-29-87
	-4206.383	32235.364	515.573	5-14-87
	-4206.635	32235.451	515.391	7-22-87
	-4206.591	32235.526	515.359	9-24-87
	-4206.610	32235.487	515.400	1-12-88
P4E	-4256.080	32281.650	513.590	E.I.*
	-4255.944	32281.714	513.654	3-27-87
	-4255.937	32281.720	513.642	3-31-87
	-4255.935	32281.714	513.639	4-03-87
	--	--	513.631	4-21-87
	-4255.943	32281.721	513.629	4-23-87
	-4255.952	32281.732	513.625	4-29-87
	-4255.955	32281.697	513.625	5-14-87
	-4255.929	32281.741	513.604	7-22-87
	-4255.934	32281.777	513.606	9-24-87
	-4255.973	32281.719	513.637	1-12-88

*EI BASELINE DATA FROM ENGINEERS INTERNATIONAL BASED ON 3 SURVEYS

COORDINATES FOR THE EAST CLUSTER INSTRUMENTS & MONUMENTS

WILLIAMSON COUNTY

INSTRUMENT/ MONUMENT	NORTHINGS	EASTINGS	ELEVATIONS	DATE
M-15	-4124.760	32148.680	522.480	E.I.*
	-4124.675	32148.789	522.332	3-27-87
	-4124.698	32148.781	522.323	3-31-87
	-4124.676	32148.746	522.288	4-03-87
	--	--	521.966	4-21-87
	-4124.467	32148.480	521.953	4-23-87
	-4124.451	32148.466	521.943	4-29-87
	-4124.508	32148.434	521.941	5-14-87
	-4124.455	32148.482	521.907	7-22-87
	-4124.456	32148.551	521.915	9-24-87
	-4124.492	32148.492	521.894	1-12-88
M-16	-4111.610	32156.190	522.280	E.I.*
	--	--	522.018	3-26-87
	-4111.324	32156.294	521.988	3-27-87
	-4111.331	32156.297	521.975	3-31-87
	-4111.303	32156.260	521.941	4-03-87
	--	--	521.560	4-21-87
	-4111.028	32155.831	521.547	4-23-87
	-4111.013	32155.805	521.539	4-29-87
	-4111.071	32155.770	521.535	5-14-87
	-4111.028	32155.834	521.505	7-22-87
	-4111.010	32155.898	521.510	9-24-87
	-4111.085	32155.842	521.487	1-12-88
M-17	-4124.930	32163.420	521.850	E.I.*
	-4124.761	32163.498	521.685	3-27-87
			521.681	3-31-87
	-4124.781	32163.430	521.632	4-03-87
	-4124.628	32163.264	521.428	4-21-87
M-18	-4124.820	32183.740	520.380	E.I.*
	--	--	520.219	3-26-87
	-4124.707	32183.734	520.217	3-27-87
	-4124.715	32183.732	520.208	3-31-87
	-4124.690	32183.700	520.189	4-03-87
	--	--	520.066	4-21-87
	-4124.638	32183.589	520.053	4-23-87
	-4124.628	32183.578	520.047	4-29-87
	-4124.682	32183.544	520.048	5-14-87
	-4124.644	32183.601	520.022	7-22-87
	-4124.636	32183.666	520.021	9-24-87
	-4124.685	32183.606	520.004	1-12-88

INSTRUMENT/ MONUMENT	NORTHINGS	EASTINGS	ELEVATIONS	DATE
M-19	-4125.090	32203.610	518.260	E.I.*
	--	--	518.109	3-26-87
	-4124.964	32203.542	518.107	3-27-87
	-4124.979	32203.535	518.099	3-31-87
	-4124.960	32203.499	518.083	4-03-87
	--	--	518.008	4-21-87
	-4124.940	32203.428	518.001	4-23-87
	-4124.933	32203.427	517.995	4-29-87
	-4124.973	32203.389	517.996	5-14-87
	-4124.923	32203.440	517.975	7-22-87
	-4124.929	32203.516	517.974	9-24-87
	-4124.984	32203.460	517.956	1-12-88
M-20	-4125.350	32223.610	515.850	E.I.*
	-4125.248	32223.517	515.731	3-27-87
	-4125.258	32223.507	515.723	3-31-87
	-4125.231	32223.482	515.714	4-03-87
	--	--	515.664	4-21-87
	-4125.238	32223.456	515.659	4-23-87
	-4125.223	32223.436	515.657	4-29-87
	-4125.274	32223.408	515.656	5-14-87
	-4125.234	32223.464	515.641	7-22-87
	-4125.223	32223.525	515.639	9-24-87
	-4125.283	32223.473	515.618	1-12-88
M-21	-4125.490	32243.370	513.570	E.I.*
	--	--	513.472	3-26-87
	-4125.392	32243.298	513.476	3-27-87
	-4125.414	32243.292	513.465	3-31-87
	-4125.392	32243.268	513.459	4-03-87
	--	--	513.424	4-21-87
	-4125.413	32243.254	513.419	4-23-87
	-4125.398	32243.247	513.415	4-29-87
	-4125.451	32243.211	513.416	5-14-87
	-4125.412	32243.263	513.402	7-22-87
	-4125.429	32243.332	513.405	9-24-87
	-4125.473	32243.272	513.387	1-12-88
M-22	-4125.800	32263.220	510.430	E.I.*
	-4125.719	32263.134	510.359	3-27-87
	-4125.732	32263.112	510.351	3-31-87
	-4125.701	32263.086	510.345	4-03-87
	--	--	510.315	4-21-87
	-4125.729	32263.085	510.318	4-23-87
	-4125.711	32263.083	510.312	4-29-87
	-4125.766	32263.039	510.314	5-14-87
				7-22-87
	-4125.755	32263.159	510.308	9-24-87
	-4125.803	32263.103	510.295	1-12-88

*EI BASELINE DATA FROM ENGINEERS INTERNATIONAL BASED ON 3 SURVEYS

COORDINATES FOR THE EAST CLUSTER INSTRUMENTS & MONUMENTS

WILLIAMSON COUNTY

INSTRUMENT/ MONUMENT	NORTHINGS	EASTINGS	ELEVATIONS	DATE
M-23	-4125.860	32283.090	508.130	E.I.*
	--	--	508.780	3-26-87
	-4125.791	32283.060	508.081	3-27-87
	-4125.805	32283.038	508.074	3-31-87
	-4125.768	32283.021	508.070	4-03-87
	--	--	508.052	4-21-87
	-4125.807	32283.014	508.050	4-23-87
	-4125.785	32283.026	508.044	4-29-87
	-4125.833	32282.977	508.047	5-14-87
	-4125.910	32283.394	508.030	7-22-87
	-4125.826	32283.089	508.030	9-24-87
	-4125.875	32283.030	508.030	1-12-88
M-24	-4126.210	32303.030	507.660	E.I.*
	-4126.142	32302.970	507.632	3-27-87
	-4126.156	32302.941	507.627	3-31-87
	-4126.116	32302.939	507.621	4-03-87
	--	--	507.609	4-21-87
	-4126.155	32302.934	507.611	4-23-87
	-4126.132	32302.942	507.604	4-29-87
	-4126.183	32302.887	507.608	5-14-87
	-4126.412	32303.345	507.592	7-22-87
	-4126.193	32303.051	507.583	9-24-87
	-4126.234	32302.934	507.595	1-12-88
M-25	-4126.600	32323.100	508.780	E.I.*
	--	--	508.750	3-26-87
	-4126.540	32323.042	508.757	3-27-87
	-4126.532	32323.027	508.752	3-31-87
	-4126.513	32323.014	508.747	4-03-87
	--	--	508.743	4-21-87
	-4126.551	32323.019	508.740	4-23-87
	-4126.538	32323.044	508.734	4-29-87
	-4126.578	32322.969	508.740	5-14-87
	-4126.963	32323.412	508.728	7-22-87
	-4126.590	32323.099	508.733	9-24-87
	-4126.629	32323.015	508.731	1-12-88
M-26			510.800	E.I.*
	-4126.771	32343.031	510.785	3-27-87
	-4126.771	32343.012	510.779	3-31-87
	-4126.742	32343.009	510.776	4-03-87
	--	--	510.779	4-21-87
	-4126.788	32343.008	510.771	4-23-87
	-4126.773	32343.031	510.768	4-29-87
	-4126.803	32342.961	510.772	5-14-87
	-4127.337	32343.385	510.763	7-22-87
	-4126.825	32343.101	510.766	9-24-87
	-4126.858	32343.005	510.763	1-12-88
M-27			512.730	E.I.*
	-4126.782	32363.184	512.735	3-27-87
	-4126.780	32363.176	512.731	3-31-87
	-4126.763	32363.163	512.723	4-03-87
	--	--	512.731	4-21-87
	-4126.807	32363.174	512.724	4-23-87
	-4126.795	32363.187	512.720	4-29-87
	-4126.826	32363.121	512.726	5-14-87
	-4127.502	32363.540	512.709	7-22-87
	-4126.849	32363.252	512.719	9-24-87
	-4126.878	32363.172	512.707	1-12-88
M-28			515.150	E.I.*
	-4126.927	32383.636	515.161	3-27-87
	-4126.923	32383.611	515.154	3-31-87
	-4126.901	32383.601	515.142	4-03-87
	--	--	515.156	4-21-87
	-4126.940	32383.622	515.155	4-23-87
	-4126.946	32383.632	515.148	4-29-87
	-4126.954	32383.565	515.154	5-14-87
	-4127.804	32383.981	515.137	7-22-87
	-4126.981	32383.697	515.150	9-24-87
	-4127.017	32383.613	515.134	1-12-88

*EI BASELINE DATA FROM ENGINEERS INTERNATIONAL BASED ON 3 SURVEYS

WILLIAMSON COUNTY
BASELINE SURVEY DATA
(WEST CLUSTER)

					AVERAGE		
INSTRUMENTS		NORTHINGS	EASTINGS	ELEVATIONS	NORTHINGS	EASTINGS	ELEVATIONS
MPBX	1	-4400.931	31327.936	509.607	-4400.922	31327.968	509.613
	2	-4400.979	31327.969	509.622			
	3	-4400.855	31327.998	509.609			
TDR	1	-4401.322	31337.176	510.743	-4401.310	31337.214	510.748
	2	-4401.366	31337.220	510.756			
	3	-4401.242	31337.245	510.744			
P7W (SOW)	1	-4406.115	31306.133	508.493	-4406.103	31306.167	508.498
	2	-4406.161	31306.178	508.507			
	3	-4406.033	31306.189	508.495			
P6W (DOW)	1	-4407.305	31301.968	508.418	-4407.294	31302.012	508.421
	2	-4407.356	31302.025	508.426			
	3	-4407.221	31302.044	508.419			
P1W	1	-4399.767	31312.301	508.101	-4399.756	31312.334	508.107
	2	-4399.820	31312.338	508.117			
	3	-4399.682	31312.364	508.103			
P2W	1	-4404.440	31372.781	512.574	-4404.430	31372.816	512.582
	2	-4404.472	31372.824	512.593			
	3	-4404.377	31372.844	512.578			
P3W	1	-4409.067	31432.058	515.470	-4409.049	31432.112	515.475
	2	-4409.094	31432.126	515.485			
	3	-4408.985	31432.151	515.470			
P4W	1	-4413.647	31492.212	518.190	-4413.619	31492.240	518.194
	2	-4413.653	31492.232	518.204			
	3	-4413.556	31492.276	518.188			
P5W	1	-4419.982	31572.062	519.580	-4419.966	31572.088	519.583
	2	-4420.005	31572.086	519.590			
	3	-4419.911	31572.117	519.578			

COORDINATES SURVEY DATE:

1 = 4/02/87
2 = 4/22/87
3 = 4/30/87

WILLIAMSON COUNTY
BASELINE SURVEY DATA
(WEST CLUSTER)

					AVERAGE		
MONUMENTS		NORTHINGS	EASTINGS	ELEVATIONS	NORTHINGS	EASTINGS	ELEVATIONS
M-1	1	-4399.444	31307.801	507.581	-4399.432	31307.836	507.588
	2	-4399.486	31307.843	507.597			
	3	-4399.365	31307.864	507.585			
M-2	2	-4412.836	31314.229	509.701	-4412.772	31314.244	509.689
	3	-4412.708	31314.258	509.677			
M-3	1	-4400.586	31322.597	509.351	-4400.578	31322.631	509.358
	2	-4400.636	31322.634	509.368			
	3	-4400.512	31322.661	509.354			
M-4	2	-4402.091	31342.757	511.001	-4402.033	31342.771	510.994
	3	-4401.974	31342.784	510.987			
M-5	1	-4403.770	31362.201	511.844	-4403.760	31362.239	511.853
	2	-4403.815	31362.241	511.864			
	3	-4403.696	31362.274	511.850			
M-6	2	-4405.380	31382.283	512.982	-4405.332	31382.295	512.974
	3	-4405.284	31382.306	512.966			
M-7	1	-4406.661	31402.282	514.455	-4406.648	31402.334	514.463
	2	-4406.696	31402.345	514.474			
	3	-4406.586	31402.375	514.460			
M-8	2	-4408.447	31422.288	515.088	-4408.393	31422.306	515.081
	3	-4408.338	31422.324	515.073			
M-9	1	-4409.915	31442.169	516.133	-4409.903	31442.216	516.137
	2	-4409.951	31442.221	516.147			
	3	-4409.842	31442.257	516.132			
M-10	2	-4411.492	31462.224	517.136	-4411.443	31462.244	517.130
	3	-4411.394	31462.264	517.123			
M-11	1	-4412.930	31482.150	517.894	-4412.906	31482.187	517.899
	2	-4412.943	31482.185	517.908			
	3	-4412.844	31482.226	517.895			
M-12	2	-4414.523	31502.067	518.405	-4414.473	31502.090	518.397
	3	-4414.422	31502.112	518.389			
M-13	1	-4415.991	31522.064	518.891	-4415.976	31522.089	518.896
	2	-4416.019	31522.082	518.906			
	3	-4415.918	31522.121	518.891			
M-14	2	-4417.583	31541.930	519.178	-4417.531	31541.950	519.173
	3	-4417.479	31541.970	519.167			

COORDINATES: 1 = 4-2-87 2 = 4-22-87 3 = 4-30-87

WILLIAMSON COUNTY
BASELINE SURVEY DATA
(WEST CLUSTER)

REBAR		NORTHINGS	EASTINGS	ELEVATIONS
R-20	1	-4604.042	31651.354	525.963
	2	-4603.997	31651.364	525.967
	AV	-4604.020	31651.359	525.965
R-21	1	-4572.285	31637.129	525.675
	2	-4572.227	31637.137	525.679
	AV	-4572.256	31637.133	525.677
R-22	1	-4539.861	31623.230	524.889
	2	-4539.791	31623.255	524.893
	AV	-4539.826	31623.243	524.891
R-23	1	-4516.929	31613.323	524.311
	2	-4516.860	31613.337	524.313
	AV	-4516.895	31613.330	524.312
R-24	1	-4494.103	31603.183	523.396
	2	-4494.025	31603.208	523.398
	AV	-4494.064	31603.196	523.397
R-25	1	-4471.102	31593.177	522.382
	2	-4471.025	31593.205	522.381
	AV	-4471.064	31593.191	522.382
R-26	1	-4448.043	31583.407	521.743
	2	-4447.955	31583.432	521.747
	AV	-4447.999	31583.420	521.745

REBAR		NORTHINGS	EASTINGS	ELEVATIONS
R-27	1	-4409.745	31575.681	519.237
	2	-4409.645	31575.722	519.223
	AV	-4409.695	31575.702	519.230
R-28	1	-4385.242	31570.481	518.628
	2	-4385.145	31570.526	518.611
	AV	-4385.194	31570.504	518.620
R-29	1	-4360.643	31565.412	517.325
	2	-4360.536	31565.460	517.309
	AV	-4360.590	31565.436	517.317
R-30	1	-4336.333	31560.441	516.985
	2	-4336.236	31560.491	516.964
	AV	-4336.285	31560.466	516.975
R-31	1	-4312.024	31555.494	516.979
	2	-4311.924	31555.546	516.956
	AV	-4311.974	31555.520	516.968
R-32	1	-4288.821	31550.679	516.650
	2	-4288.718	31550.731	516.627
	AV	-4288.770	31550.705	516.639
R-33	1	-4263.271	31545.544	515.807
	2	-4263.170	31545.607	515.782
	AV	-4263.221	31545.576	515.795

1 = 4-22-87
2 = 4-30-87

APPENDIX D Elevation Changes due to Subsidence

WILLIAMSON COUNTY
ELEVATIONAL CHANGES DUE TO SUBSIDENCE
EAST CLUSTER INSTRUMENTS

INSTRUMENT	DATE	ELEVATION (FT)	SUBSIDENCE (FT)
MPBX	E.I.*	523.050	--
	3-27-87	521.226	-1.824
	4-03-87	521.098	-1.952
	4-21-87	521.025	-2.025
	4-23-87	520.056	-2.994
	4-29-87	520.011	-3.039
	5-14-87	519.990	-3.060
	7-22-87	519.937	-3.113
	9-24-87	519.926	-3.124
	1-12-88	519.887	-3.163
TDR	E.I.*	522.700	--
	3-27-87	521.069	-1.631
	3-31-87	520.951	-1.749
	4-03-87	520.882	-1.818
P5E (DOW)	E.I.*	522.640	--
	3-27-87	521.420	-1.220
	3-31-87	521.323	-1.317
	4-03-87	521.256	-1.384
	4-21-87	520.453	-2.187
	4-29-87	520.422	-2.218
	5-14-87	520.370	-2.270
	7-22-87	520.317	-2.323
	9-24-87	520.292	-2.348
	1-12-88	520.281	-2.359
P6E (SOW)	E.I.*	522.560	--
	3-27-87	521.541	-1.019
	3-31-87	521.478	-1.082
	4-03-87	521.443	-1.117
	4-21-87	520.778	-1.782
	4-29-87	520.761	-1.799
	5-14-87	520.729	-1.831
	7-22-87	520.683	-1.877
	9-24-87	520.673	-1.887
	1-12-88	520.651	-1.909

INSTRUMENT	DATE	ELEVATION (FT)	SUBSIDENCE (FT)
P1E	E.I.*	522.490	--
	3-27-87	522.256	-0.234
	3-31-87	522.235	-0.255
	4-03-87	522.204	-0.286
	4-21-87	521.909	-0.581
	4-23-87	521.891	-0.599
	4-29-87	521.884	-0.606
	5-14-87	521.879	-0.611
	7-22-87	521.847	-0.643
	9-24-87	521.834	-0.656
	1-12-88	521.897	-0.593
P2E	E.I.*	515.770	--
	3-27-87	515.716	-0.054
	3-31-87	515.701	-0.069
	4-03-87	515.693	-0.077
	4-21-87	515.642	-0.128
	4-23-87	515.637	-0.133
	4-29-87	515.632	-0.138
	5-14-87	515.631	-0.139
	7-22-87	515.614	-0.156
	9-24-87	515.620	-0.150
	1-12-88	515.635	-0.135
P3E	E.I.*	515.620	--
	3-27-87	515.627	0.007
	3-31-87	515.614	-0.006
	4-03-87	515.610	-0.010
	4-21-87	515.577	-0.043
	4-23-87	515.579	-0.041
	4-29-87	515.575	-0.045
	5-14-87	515.573	-0.047
	7-22-87	515.391	-0.229
	9-24-87	515.359	-0.261
	1-12-88	515.400	-0.220
P4E	E.I.*	513.590	--
	3-27-87	513.654	0.064
	3-31-87	513.642	0.052
	4-03-87	513.639	0.049
	4-21-87	513.631	0.041
	4-23-87	513.629	0.039
	4-29-87	513.625	0.035
	5-14-87	513.625	0.035
	7-22-87	513.606	0.016
	9-24-87	513.606	0.016
	1-12-88	513.637	0.047

*EI BASELINE DATA FROM ENGINEERS INTERNATIONAL BASED ON 3 SURVEYS

WILLIAMSON COUNTY
ELEVATIONAL CHANGES DUE TO SUBSIDENCE
EAST CLUSTER MONUMENTS

MONUMENT	DATE	ELEVATION (FT)	SUBSIDENCE (FT)	MONUMENT	DATE	ELEVATION (FT)	SUBSIDENCE (FT)
M-15	E.I.*	522.480	–	M-19	E.I.*	518.260	--
	3-27-87	522.332	-0.148		3-27-87	518.107	-0.153
	3-31-87	522.323	-0.157		3-31-87	518.099	-0.161
	4-03-87	522.288	-0.192		4-03-87	518.083	-0.177
	4-21-87	521.966	-0.514		4-21-87	518.008	-0.252
	4-23-87	521.953	-0.527		4-23-87	518.001	-0.259
	4-29-87	521.943	-0.537		4-29-87	517.995	-0.265
	5-14-87	521.941	-0.539		5-14-87	517.996	-0.264
	7-22-87	521.907	-0.573		7-22-87	517.975	-0.285
	9-24-87	521.915	-0.565		9-24-87	517.974	-0.286
	1-12-87	521.894	-0.586		1-12-88	517.956	-0.304
M-16	E.I.*	522.280	--	M-20	E.I.*	515.850	--
	3-27-87	521.988	-0.292		3-27-87	515.731	-0.119
	3-31-87	521.975	-0.305		3-31-87	515.723	-0.127
	4-03-87	521.941	-0.339		4-03-87	515.714	-0.136
	4-21-87	521.560	-0.720		4-21-87	515.664	-0.186
	4-23-87	521.547	-0.733		4-23-87	515.659	-0.191
	4-29-87	521.539	-0.741		4-29-87	515.657	-0.193
	5-14-87	521.535	-0.745		5-14-87	515.656	-0.194
	7-22-87	521.505	-0.775		7-22-87	515.641	-0.209
	9-24-87	521.510	-0.770		9-24-87	515.639	-0.211
	1-12-87	521.487	-0.793		1-12-88	515.618	
M-17	E.I.*	521.850	--	M-21	E.I.*	513.570	--
	3-27-87	521.685	-0.165		3-27-87	513.476	-0.094
	3-31-87	521.681	-0.169		3-31-87	513.465	-0.105
	4-03-87	521.632	-0.218		4-03-87	513.459	-0.111
	4-21-87	521.428	-0.422		4-21-87	513.424	-0.146
					4-23-87	513.419	-0.151
					4-29-87	513.415	-0.155
					5-14-87	513.416	-0.154
					7-22-87	513.402	-0.168
					9-24-87	513.405	-0.165
					1-12-88	513.387	
M-18	E.I.*	520.380	--	M-22	E.I.*	510.430	--
	3-27-87	520.217	-0.163		3-27-87	510.359	-0.071
	3-31-87	520.208	-0.172		3-31-87	510.351	-0.079
	4-03-87	520.189	-0.191		4-03-87	510.345	-0.085
	4-21-87	520.066	-0.314		4-21-87	510.315	-0.115
	4-23-87	520.053	-0.327		4-23-87	510.318	-0.112
	4-29-87	520.047	-0.333		4-29-87	510.312	-0.118
	5-14-87	520.048	-0.332		5-14-87	510.314	-0.116
	7-22-87	520.022	-0.358		9-24-87	510.308	-0.122
	9-24-87	520.021	-0.359		1-12-88	510.295	-0.135
	1-12-88	520.004	-0.376				

*EI BASELINE DATA FROM ENGINEERS INTERNATIONAL BASED ON 3 SURVEYS

WILLIAMSON COUNTY
ELEVATIONAL CHANGES DUE TO SUBSIDENCE
EAST CLUSTER MONUMENTS

MONUMENT	DATE	ELEVATION (FT)	SUBSIDENCE (FT)
M-23	E.I.*	508.130	--
	3-27-87	508.081	-0.049
	3-31-87	508.074	-0.056
	4-03-87	508.070	-0.060
	4-21-87	508.052	-0.078
	4-23-87	508.050	-0.080
	4-29-87	508.044	-0.086
	5-14-87	508.047	-0.083
	7-22-87	508.030	-0.100
	9-24-87	508.030	-0.100
	1-12-88	508.030	-0.100
M-24	E.I.*	507.660	--
	3-27-87	507.632	-0.028
	3-31-87	507.627	-0.033
	4-03-87	507.621	-0.039
	4-21-87	507.609	-0.051
	4-23-87	507.611	-0.049
	4-29-87	507.604	-0.056
	5-14-87	507.608	-0.052
	7-22-87	507.592	-0.068
	9-24-87	507.583	-0.077
	1-12-88	507.595	-0.065
M-25	E.I.*	508.780	--
	3-27-87	508.757	-0.023
	3-31-87	508.752	-0.028
	4-03-87	508.747	-0.033
	4-21-87	508.743	-0.037
	4-23-87	508.740	-0.040
	4-29-87	508.734	-0.046
	5-14-87	508.740	-0.040
	7-22-87	508.728	-0.052
	9-24-87	508.733	-0.047
	1-12-88	508.731	-0.049

MONUMENT	DATE	ELEVATION (FT)	SUBSIDENCE (FT)
M-26	E.I.*	510.800	--
	3-27-87	510.785	-0.015
	3-31-87	510.779	-0.021
	4-03-87	510.776	-0.024
	4-21-87	510.779	-0.021
	4-23-87	510.771	-0.029
	4-29-87	510.768	-0.032
	5-14-87	510.772	-0.028
	7-22-87	510.763	-0.037
	9-24-87	510.766	-0.034
	1-12-88	510.763	-0.037
M-27	E.I.*	512.730	--
	3-27-87	512.735	0.005
	3-31-87	512.731	0.001
	4-03-87	512.723	-0.007
	4-21-87	512.731	0.001
	4-23-87	512.724	-0.006
	4-29-87	512.720	-0.010
	5-14-87	512.726	-0.004
	7-22-87	512.709	-0.021
	9-24-87	512.719	-0.011
	1-12-88	512.707	-0.023
M-28	E.I.*	515.150	--
	3-27-87	515.161	0.011
	3-31-87	515.154	0.004
	4-03-87	515.142	-0.008
	4-21-87	515.156	0.006
	4-23-87	515.155	0.005
	4-29-87	515.148	-0.002
	5-14-87	515.154	0.004
	7-22-87-	515.137	-0.013
	9-24-87	515.150	0.000
	1-12-88	515.134	-0.016

*EI BASELINE DATA FROM ENGINEERS INTERNATIONAL BASED ON 3 SURVEYS

WILLIAMSON COUNTY
ELEVATION CHANGES DUE TO SUBSIDENCE
(WEST CLUSTER INSTRUMENTS)

INSTRUMENT	DATE	ELEVATION (FT)	CHANGE (FT)
MPBX	BASE	509.613	---
	5-13-87	509.616	0.003
	7-23-87	509.601	-0.012
TDR	BASE	510.748	---
	5-13-87	510.748	0.000
	7-23-87	510.729	-0.019
P7W (SOW)	BASE	508.498	---
	5-13-87	508.501	0.003
	7-23-87	508.461	-0.037
P6W (DOW)	BASE	508.421	---
	5-13-87	508.424	0.003
	7-23-87	508.384	-0.037

INSTRUMENT	DATE	ELEVATION (FT)	CHANGE (FT)
P1W	BASE	508.107	---
	5-13-87	508.106	-0.001
	7-23-87	508.069	-0.038
P2W	BASE	512.582	---
	5-13-87	512.577	-0.005
	7-23-87	512.534	-0.048
P3W	BASE	515.475	---
	5-13-87	515.472	-0.003
	7-23-87	515.455	-0.020
P4W	BASE	518.194	---
	5-13-87	518.188	-0.006
	7-23-87	518.161	-0.033
P5W	BASE	519.583	---
	5-13-87	519.564	-0.019
	7-23-87	519.568	-0.015

WILLIAMSON COUNTY
ELEVATION CHANGES DUE TO SUBSIDENCE
(WEST CLUSTER MONUMENTS)

MONUMENT	DATE	ELEVATION (FT)	CHANGE (FT)
M-1	BASE	507.588	---
	5-13-87	507.593	0.005
	7-23-87	507.574	-0.014
M-2	BASE	509.689	---
	5-13-87	509.697	0.008
	7-23-87	509.675	-0.014
M-3	BASE	509.358	---
	5-13-87	509.362	0.004
	7-23-87	509.340	-0.018
M-4	BASE	510.994	---
	5-13-87	510.991	-0.003
	7-23-87	510.976	-0.018
M-5	BASE	511.853	---
	5-13-87	511.855	0.002
	7-23-87	511.838	-0.015
M-6	BASE	512.974	---
	5-13-87	512.969	-0.005
	7-23-87	512.953	-0.021
M-7	BASE	514.463	---
	5-13-87	514.460	-0.003
	7-23-87	514.441	-0.022

MONUMENT	DATE	ELEVATION (FT)	CHANGE (FT)
M-8	BASE	515.081	---
	5-13-87	515.075	-0.006
	7-23-87	515.058	-0.023
M-9	BASE	516.137	---
	5-13-87	516.134	-0.003
	7-23-87	516.120	-0.017
M-10	BASE	517.130	---
	5-13-87	517.124	-0.006
	7-23-87	517.107	-0.023
M-11	BASE	517.899	---
	5-13-87	517.893	-0.006
	7-23-87	517.874	-0.025
M-12	BASE	518.397	---
	5-13-87	518.388	-0.009
	7-23-87	518.362	-0.035
M-13	BASE	518.896	---
	5-13-87	518.889	-0.007
	7-23-87	518.862	-0.034
M-14	BASE	519.173	---
	5-13-87	519.158	-0.015
	7-23-87	519.150	-0.023

WILLIAMSON COUNTY
ELEVATION CHANGES DUE TO SUBSIDENCE
(WEST CLUSTER INSTRUMENTS)

REBAR	DATE	ELEVATION (FT)	CHANGE (FT)
R-20	BASE	525.965	---
	5-13-87	525.968	0.003
	7-23-87	---	---
R-21	BASE	525.677	---
	5-13-87	525.678	0.001
	7-23-87	525.669	-0.008
R-22	BASE	524.891	---
	5-13-87	524.890	-0.001
	7-23-87	---	---
R-23	BASE	524.312	---
	5-13-87	524.312	0.000
	7-23-87	524.289	-0.023
R-24	BASE	523.397	---
	5-13-87	523.395	-0.002
	7-23-87	---	---
R-25	BASE	522.382	---
	5-13-87	522.379	-0.003
	7-23-87	522.356	-0.026
R-26	BASE	521.745	---
	5-13-87	521.739	-0.006
	7-23-87	521.704	-0.041

REBAR	DATE	ELEVATION (FT)	CHANGE (FT)
R-27	BASE	519.230	---
	5-13-87	519.196	-0.034
	7-23-87	519.192	-0.038
	9-25-87	519.193	-0.037
R-28	BASE	518.620	---
	5-13-87	518.580	-0.040
	7-23-87	518.578	-0.042
	9-25-87	518.579	-0.041
R-29	BASE	517.312	---
	5-13-87	517.266	-0.046
	7-23-87	517.251	-0.061
	9-25-87	517.251	-0.061
R-30	BASE	516.975	---
	5-13-87	516.915	-0.060
	7-23-87	516.901	-0.074
	9-25-87	516.912	-0.063
R-31	BASE	516.968	---
	5-13-87	516.889	-0.079
	7-23-87	516.866	-0.102
	9-25-87	516.871	-0.097
R-32	BASE	516.639	---
	5-13-87	516.538	-0.101
	7-23-87	516.524	-0.115
	9-25-87	516.526	-0.113
R-33	BASE	515.795	---
	5-13-87	515.680	-0.115
	7-23-87	515.657	-0.138
	9-25-87	515.666	-0.129

APPENDIX E Water Level Readings and Precipitation Data

ILLINOIS MINE SUBSIDENCE RESEARCH PROGRAM
WILLIAMSON COUNTY SITE

PIEZOMETERS IN THE EAST INSTRUMENT CLUSTER
WATER LEVEL READINGS

			GLACIAL DRIFT WELLS					BEDROCK WELLS	
	WELL DESIGNATION		Con E	P1E	P2E	P3E	P4E	P5E (DOW)	P6E (SOW)
TOP OF WELL	ELEVATION (FT)		535.54	522.49	515.77	515.62	513.59	522.56	512.00
	WELL DEPTH (FT)		17.25	32.50	16.45	17.00	21.85	165.00	99.80
YEAR	DATE	TIME	DEPTH TO WATER LEVEL (FT)						
1986	July 31		11.40	28.20	DRY	DRY	12.20	28.50	21.80
	Sept 9		12.85	28.00	15.80	DRY	12.40	29.60	21.50
	Sept 12		14.00	28.70	DRY	DRY	13.70	30.30	22.40
	Sept 20		12.95	28.05	15.80	16.15	12.45	29.90	21.60
	Oct 3		13.10	28.00	15.85	16.15	12.40	30.00	21.55
	Nov 20		14.20	28.80	DRY	DRY	13.85	31.60	22.65
	Dec 11		---	28.75	DRY	DRY	13.65	31.75	22.40
1987	Feb 2		12.20	28.70	DRY	DRY	13.30	31.90	21.90
	Mar 23		10.29	25.10	DRY	16.60	11.85	36.00	26.64
	Mar 24		---	---	---	---	---	36.15	26.69
			"SUBSIDENCE EVENT"						
	Mar 26		10.31	31.37	DRY	DRY	12.30	28.00 *	70.35*
	Mar 27	12:30	10.44	28.42	DRY	DRY	12.25	28.00 *	70.35*
		4:30	10.43	28.54	DRY	DRY	---	28.00 *	70.35*
	Mar 30	5:20	---	29.89	DRY	DRY	12.45	"	"
	Apr 1	11:00	10.28	29.82	DRY	DRY	12.26	"	"
	Apr 2	11:50	10.39	30.10	DRY	DRY	12.42	"	"
	Apr 3	11:10	---	30.15	DRY	DRY	12.54	"	"
		3:30	---	30.10	DRY	DRY	12.50	"	"
	Apr 16	8:30	9.78	DRY	DRY	16.64	12.33	"	"
	Apr 21	3:00	9.49	DRY	DRY	DRY	12.27	"	40.00*
	Apr 23	11:30	9.60	DRY	DRY	DRY	12.25	"	"
	Apr 29	2:00	9.90	DRY	DRY	DRY	12.28	"	"
	May 14		11.44	DRY	DRY	DRY	13.07	"	"
	May 27		12.12	DRY	DRY	DRY	13.55	"	"
	July 22		15.57	DRY	DRY	DRY	14.65	"	"
	Sept 24		16.32	DRY	DRY	DRY	16.28	"	"
1988	Jan 12		16.50	DRY	DRY	DRY	17.52	"	"
	May 16		14.55	DRY	DRY	DRY	15.70	"	"
	Oct 11		---	DRY	DRY	DRY	16.55	"	"
1989	Dec 6		17	DRY	DRY	DRY	14.5	"	"

* Denotes well is blocked and dry at this depth.

ILLINOIS MINE SUBSIDENCE RESEARCH PROGRAM
WILLIAMSON COUNTY SITE

WATER LEVEL ELEVATIONS
(EAST INSTRUMENT CLUSTER)

		GLACIAL DRIFT WELLS					BEDROCK WELLS	
WELL DESIGNATION		Con E	P1E	P2E	P3E	P4E	P5E (DOW)	P6E (SOW)
WELL DEPTH (FT)		17.25	32.50	16.45	17.00	21.85	165.00	99.80
YEAR	DATE	WATER LEVEL ELEVATIONS (FT)						
1986	July 31	524.14	494.29	d-499.32	d-498.62	501.45	494.06	500.84
	Sept 9	522.69	494.49	499.97	d-498.62	501.25	492.96	501.14
	Sept 12	521.54	493.79	d-499.32	d-498.62	499.95	492.26	500.24
	Sept 20	522.59	494.44	499.97	499.47	501.20	492.66	501.04
	Oct 3	522.44	494.49	499.92	499.47	501.25	492.56	501.09
	Nov 20	521.34	493.69	d-499.32	d-498.62	499.80	490.96	499.99
	Dec 11	---	493.74	d-499.32	d-498.62	500.00	490.81	500.24
1987	Feb 2	523.34	493.79	d-499.32	d-498.62	500.35	490.66	500.74
	Mar 23	525.25	497.39	d-499.32	499.02	501.80	486.56	496.00
	Mar 24	---	---	---	---	---	---	---
		"SUBSIDENCE EVENT"						
	Mar 26	525.23	---	---	---	---	---	---
	Mar 27	525.10	493.84	d-499.27	d-498.63	501.40	*493.54	*451.07
	Mar 27	525.11	493.72	d-499.27	d-498.63	---	"	"
	Mar 31	---	492.35	d-499.25	d-498.61	501.19	"	"
	Apr 1	525.26	492.42	d-499.25	d-498.61	501.38	"	"
	Apr 2	525.15	492.14	d-499.25	d-498.61	501.22	"	"
	Apr 3	---	492.05	d-499.24	d-498.61	501.10	"	"
	Apr 3	---	492.10	d-499.24	d-498.61	501.14	"	"
	Apr 16	525.76	489.70	d-499.19	498.97	501.31	"	"
	Apr 21	526.05	d-489.41	d-499.19	d-498.58	501.36	"	*480.45
	Apr 23	525.94	d-489.39	d-499.19	d-498.58	501.38	"	"
	Apr 29	525.64	d-489.38	d-499.18	d-498.58	501.35	"	"
	May 14	524.10	d-489.38	d-499.18	d-498.57	500.56	"	"
	May 27	523.42	d-489.38	d-499.18	d-498.57	500.08	"	"
	July 22	519.97	d-489.35	d-499.16	d-498.57	498.98	"	"
	Sept 24	519.22	d-489.33	d-498.91	d-498.34	497.33	"	"
1988	Jan 12	519.04	d-489.33	d-498.91	d-498.34	496.09	"	"
	May 16	520.99	d-489.33	d-498.91	d-498.34	497.91	"	"
1989	Dec 6	---	d-489.33	d-498.91	d-498.34	497.06	"	"

d- Denotes well is dry
* Denotes well is blocked and dry at this elevation

ILLINOIS MINE SUBSIDENCE RESEARCH PROGRAM
WILLIAMSON COUNTY SITE

PIEZOMETERS IN THE WEST INSTRUMENT CLUSTER

			GLACIAL DRIFT WELLS						BEDROCK WELLS	
	WELL DESIGNATION		Con W	P1W	P2W	P3W	P4W	P5W	P6W (DOW)	P7W (SOW)
TOP OF WELL	ELEVATION (FT)		536.59	508.11	512.58	515.48	518.19	519.58	508.39	508.45
	WELL DEPTH (FT)		28.90	29.55	16.25	49.80	14.95	30.50	203.10	100.00
YEAR	DATE	TIME	DEPTH TO WATER LEVEL (FT)							
1986	July 31		19.00	10.40	13.20	13.70	14.65	15.40	38.20	17.65
	Sept 9		18.75	11.60	14.55	15.00	14.35	16.50	36.55	19.15
	Sept 12		19.50	11.80	15.75	15.45	DRY	17.50	37.10	19.50
	Sept 20		19.00	11.65	15.30	15.25	14.25	16.85	36.55	19.00
	Oct 3		18.83	11.42	15.40	15.30	14.30	17.00	36.81	18.50
	Nov 20		20.50	11.55	DRY	16.10	DRY	18.30	37.95	17.75
	Dec 11		20.90	11.25	DRY	15.90	DRY	18.10	37.75	17.25
1987	Feb 3		21.05	11.10	15.25	14.90	DRY	17.67	37.97	16.20
	Apr 1		20.47	9.65	13.15	13.27	12.19	15.73	40.45	16.05
	Apr 15		20.05	9.41	12.23	12.87	10.55	15.30	43.45	18.12
	Apr 22		20.10	9.25	11.31	12.28	12.30	15.01	43.40	18.98
	Apr 30		20.00	9.72	12.41	13.31	13.51	15.14	45.60	22.67
	May 13		20.13	10.36	13.11	14.77	14.88	16.15	45.49	23.65
	May 28		20.25	11.12	13.78	15.82	DRY	16.64	46.78	24.08
	July 22		20.75	12.98	DRY	17.87	DRY	17.98	50.95	23.88
	Sept 24		21.76	15.86	DRY	20.19	DRY	20.24	54.65	29.58
1988	Jan 13		23.50	16.45	DRY	22.10	DRY	22.43	60.07	22.00
	May 16		22.61	13.24	DRY	18.10	DRY	19.30	63.32	18.81
	Oct 6		23.22	18.15	15.62	22.62	DRY	22.97		

ILLINOIS MINE SUBSIDENCE RESEARCH PROGRAM
WILLIAMSON COUNTY SITE

WATER LEVEL ELEVATIONS
(WEST INSTRUMENT CLUSTER)

		GLACIAL DRIFT WELLS						BEDROCK	
WELL DESIGNATION		Con W	P1W	P2W	P3W	P4W	P5W	P6W (DOW)	P7W (SOW)
WELL DEPTH (FT)		28.90	29.55	16.25	49.80	14.95	30.50	203.10	100.00
YEAR	DATE	WATER LEVEL ELEVATIONS (FT)							
1986	July 31	517.59	497.71	499.38	501.78	503.54	504.18	470.19	490.80
	Sept 9	517.84	496.51	498.03	500.48	503.84	503.08	471.84	489.30
	Sept 12	517.09	496.31	496.83	500.03	d-503.24	502.08	471.29	488.95
	Sept 20	517.59	496.46	497.28	500.23	503.94	502.73	471.84	489.45
	Oct 3	517.76	496.69	497.18	500.18	503.89	502.58	471.58	489.95
	Nov 20	516.09	496.56	d-496.33	499.38	d-503.24	501.28	470.44	490.70
	Dec 11	515.69	496.86	d-496.33	499.58	d-503.24	501.48	470.64	491.20
1987	Feb 3	515.54	497.01	497.33	500.58	d-503.24	501.91	470.42	492.25
	Apr 1	516.12	498.46	499.43	502.21	506.00	503.85	467.94	492.40
	Apr 15	516.54	498.70	500.35	502.61	507.64	504.28	464.94	490.33
	Apr 22	516.49	498.86	501.27	503.20	505.89	504.57	464.99	489.47
	Apr 30	516.59	498.39	500.17	502.17	504.68	504.44	462.79	485.78
	May 13	516.46	497.75	499.47	500.71	503.31	503.43	462.90	484.80
	May 28	516.34	496.99	498.80	499.66	DRY	502.94	461.61	484.37
	July 22	515.84	495.13	DRY	497.61	DRY	501.60	457.44	484.57
	Sept 24	514.83	492.25	DRY	495.29	DRY	499.34	453.74	478.87
1988	Jan 13	513.09	491.66	DRY	493.38	DRY	497.15	448.32	486.45
	May 16	513.98	494.87	DRY	497.38	DRY	500.28	445.07	489.64
	Oct 6	513.98	489.96	496.96	492.86	DRY	496.61		

ILLINOIS MINE SUBSIDENCE RESEARCH PROGRAM

WILLIAMSON COUNTY SITE
*** PRECIPITATION DATA FROM MARION STATION***

TOTAL AND DEPARTURE FROM NORMAL PRECIPITATION
FROM JUL 1986 - DEC 1988

*** FOR GRAPHING: DEPARTURE FROM NORM VS. MONTH ***

YEAR	MONTH	DEPARTURE FROM NORM * NOAA (in)	TOTAL (in)
1986	JUL	2.35	5.96
	AUG	3.26	6.76
	SEP	1.29	4.34
	OCT	1.04	3.23
	NOV	-1.51	2.13
	DEC	-0.53	2.78
1987	JAN	-1.69	1.11
	FEB	0.65	3.72
	MAR	-1.99	2.73
	APR	-2.04	2.06
	MAY	-2.18	1.81
	JUN	-0.23	3.57
	JUL	2.05	5.66
	AUG	-1.58	1.92
	SEP	-1.71	1.34
	OCT	-0.67	1.52
	NOV	0.88	4.52
	DEC	2.90	6.21
1988	JAN	-1.31	1.49
	FEB	-0.39	2.68
	MAR	0.49	5.21
	APR	-2.14	1.96
	MAY	-1.64	2.35
	JUN	-2.62	1.18
	JUL	2.83	6.44
	AUG	-1.94	1.56
	SEP	0.80	3.85
	OCT	0.91	3.10
	NOV	3.70	7.34
	DEC	-0.13	3.18