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CHARACTERIZATION OF SUBSIDENCE OVER LONGWALL MINING PANELS - ROCKY MOUNTAIN COAL PROVINCE

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N O T I C E

This report was completed under a contract to the U.S. Department of Energy (DOE). Responsibility for the program to which the report relates has recently been transferred to the Bureau of Mines, U.S. Department of the Interior, and the report is made public under a Bureau cover. Inquiries concerning the report should be directed to the Bureau.

The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies or recommendations of the Interior Department's Bureau of Mines or of the U.S. Government.

FORWARD

This report was prepared for the Department of Energy (DOE) by Woodward-Clyde Consultants (WCC), Western Region, San Francisco, California under DOE Contract No. DE-AC22-80PC30117. The contract was initiated and administered by the Pittsburgh Energy Technology Center with technical direction by the Carbondale Mining Technology Center. Mr. D. R. Williams was the DOE Contract Specialist, Mr. Robert W. Stephan replaced Mr. W. Eichfield who was the DOE Project Manager, and Ms. M. Harthill was the DOE Program Manager. This report is a summary of the work recently completed during the period September 1980 to September 1982. It was submitted by Woodward-Clyde on September 19, 1982.

The authors wish to acknowledge the cooperation and assistance of Mr. W. Boies, Chief Mining Engineer, CF&I Steel Corporation, Mr. T. Augustine, General Mine Superintendent, Mr. J. Snow, Allen Mine Superintendent, the mining engineers, foremen and miners of the Allen Mine.

Principal-in-Charge for Woodward-Clyde was Dr. Ulrich Luscher and the Project Manager was John E. O'Rourke. Project Engineer was Kevin O'Connor and Assistant Project Engineer was Pamela H. Rey. Staff Engineers were Mark Milani and Chuck Burgin, and Brett O'Rourke served as a Field Technician. Professor John Abel, Colorado School of Mines, was a project consultant. Drafting was done by Dante Tolosa, and technical typing by Cheri King.

EXECUTIVE SUMMARY

This report describes a Department of Energy (DOE) sponsored study for the characterization of subsidence over longwall mining panels in a coal field of the Rocky Mountain Coal Province. Site selection, instrument installation, initial data acquisition and preliminary data analysis was performed by Woodward-Clyde Consultants. Responsibility for continued data acquisition and analysis has been assumed by the U. S. Bureau of Mines (USBM). The objective in preparing this report was to document all work accomplished up to the end of contract work in May of 1982 and to provide a basis for continued data acquisition.

Site selection criteria required that two adjacent longwall mining panels be available for surface, subsurface and mine-level monitoring. Scheduling for the mining of the proposed panels had to be compatible with the time available for the study. Two mines were located which satisfied these general criteria, and final site selection was made on the basis of more detailed criteria such as topography, logistics, mining conditions, and owner interest. The Allen Mine, located in Weston, Colorado was selected as the site for this study. The average panel width was 425 feet with 500 to 1000 feet of relatively flat lying overburden.

A preliminary instrumentation plan was tailored to site conditions in April 1981. Plan review meetings were held with DOE and an agreed plan conforming to contract specifications and available budget was ready for implementation in June 1981. Surface, subsurface, and mine level installation of the instruments selected for this study was conducted from May to October 1981.

Ninety-three survey monuments were installed to monitor vertical and horizontal displacements of points on the ground surface along and perpendicular to the centerline of the longwall panels. Two automatic-recording strainmeters were installed to characterize dynamic strains along the centerline of one panel and the development of permanent strain over the panel ribside. In order to characterize the nature of strata separation and shearing which occurs in the overburden, inclinometer-extensometers were installed over the ribs of both panels, and rod extensometers were installed along the centerline of one panel. In order to better insure that the important subsurface vertical displacements would be successfully monitored, a redundant system utilizing Time Domain Reflectometry was also installed.

The mine level instrumentation layout was designed to characterize stress redistribution and displacement phenomena that accompany longwall mining and which are basic to the eventual development of subsidence above the panel. A total of eighteen stressmeters were installed to monitor stress redistribution in the pillars adjacent to one panel and in the floor beneath the panel. Roof-floor convergence was investigated by installing ten convergence stations. Rod extensometers were installed in the roof and floor to monitor discrete strata separation. An attempt was made to characterize initial stress conditions using an undercoring technique at ten locations in the roof and ribs.

Monitoring trips for data acquisition were scheduled on the basis of longwall face location with respect to the instrumentation. After baseline data initialization was completed in October of 1981, monitoring trips were made in January, March, and May of 1982. In June of 1982, the Allen Mine was shut down indefinitely and the longwall face had been advanced to within 200 feet of the

most heavily instrumented location. The Woodward-Clyde Consultants contract was terminated in May of 1982 due to budgetary decreases and reorganization of DOE and continued monitoring of the Allen Mine instrumentation will be performed by the U.S. Bureau of Mines.

At the time that this project was terminated, one of the longwall panels had been converted to room and pillar mining, and the face of the second panel had only advanced past the first of two major instrumentation locations. Consequently, only a limited amount of data was collected and only a preliminary analysis of these data was possible.

The stressmeters installed in one chain pillar not only showed the development of abutment pressure 200 feet in front of the face, but also suggested the development of a 15 foot wide distressed zone around the pillar with an inner confined core. Roof-floor convergence was initiated about 400 feet in front of the face and the total convergence of 2.72 inches was approximately 2.5 times greater than that indicated by the extensometer data. The thickness of strata generating convergence must therefore be greater than the deepest extensometer anchors located 32 feet up into the roof and 21 feet down into the floor. The overburden appears to subside as a relatively coherent rock mass with overburden displacements being initiated about 500 feet in front of the face; however, significant displacement of the surface was only detected at survey monuments within 200 feet of the longwall face. The onset of greatest movement at mine level and within the overburden began when the face was within 150 feet of an instrumented location, but this increased rate of movement did not begin on the surface until a survey point was undermined.

The largest vertical displacement recorded on the surface was 3.13 feet and the largest horizontal displacement was 0.91 feet. Greater displacements are considered likely so that an assessment of maximum subsidence was not valid. It appears that topography has a strong influence on horizontal displacement so no attempt should be made to evaluate horizontal strains until data is obtained from the automatic-recording strainmeters. The average mined height was 76.4 inches, so the maximum subsidence is on the order of 49 percent of the mined height.

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1.0 INTRODUCTION

One of the major energy resources of the United States is its large coal reserves. In the past, the economic climate for this resource promoted the use of low extraction mining methods. These methods tended to minimize immediate surface subsidence damage, but sterilized or rendered inaccessible for future mining upwards of 50 percent of the available resource in a seam. Today, rising coal prices and increasing demands for coal productivity, coupled with a national concern for conservation of coal resources, have generated considerable interest in high extraction mining methods such as longwalling. A major constraint to adoption of high extraction mining methods in some mining districts, however, has been a fear of the consequences of the associated subsidence. This fear has been perpetuated, in part, by a continuing inability to adequately predict either the characteristics of the subsidence or its impact on the surface environment. Although European coal producing countries have had some notable successes, particularly in the United Kingdom, with development of empirical subsidence prediction techniques based on a large body of field data, no such body of data exists in the United States. Since the geologic conditions of the major coal fields in the United States are substantially different from the European cases, the use of the foreign prediction techniques is probably inappropriate to conditions here. A relevant data base for developing subsidence prediction techniques in the United States is needed, and since the geologic conditions differ between the major coal fields in this county, representative subsidence characterization data are needed for each field. The Department of Energy (DOE) has, over recent years, organized and sponsored a systematic collection and analysis of subsidence characterization data in the major coal mining areas. This report describes a DOE sponsored study for the characterization of subsidence over longwall mining panels in a

coal field of the Rocky Mountain Coal Province. The field data obtained and analyzed during this study, together with the results from the other coal provinces, contributes toward: (1) the near term development of an empirical subsidence prediction capability, and (2) the long term goal for development of analytical methods of subsidence prediction.

2.0 PREPARATIONS FOR FIELD OPERATIONS

2.1 SITE SELECTION

An initial review of reported Western longwall activity in the fall of 1980 showed 11 mines currently using or planning the use of longwall mining equipment. Most of the operational longwalls were at depths of over 1000 feet and ranged up to a 2500-foot depth. Project criteria required that two adjacent longwall mining panels be available for surface, subsurface and mine-level monitoring. Longwall mining was to be the main or at least a typical mining method used at the mine and the panels chosen for the work were to be typical extraction panels in the regular mining sequence. Scheduling for the mining of the proposed panels had to be compatible with the time available for the study.

These general criteria focused attention on two candidate mines that expressed a willingness to participate in the study. The two mines were visited and studied with respect to a set of detailed criteria aimed at selection of a candidate mine with the highest probability of meeting study objectives within the study time and budget constraints. The detailed site selection criteria are shown in Table 2.1. Both the candidate mines were rated in terms of these criteria. Some of the criteria leading to the slightly higher total score and more favorable evaluation for the selected candidate, the Allen Mine, are shown in Table 2.2.

The Allen Mine is located 30 miles due west of Trinidad, Colorado and 11 miles north of the New Mexico border (Figure 2.1). Elevation of the surface is between 7400 and 8500 feet, and the coal seam in the study panels lies at depths of 500 to 1000 feet beneath hilly topography. Maximum snow depth of about 1 foot was expected at the site, and snow cover lasts only short periods, a definite advantage for

TABLE 2.1
SITE SELECTION CRITERIA

| SELECTION CRITERIA | WEIGHTING FACTOR | 3 (DESIRABLE) | RATING 2 | 1 (UNDESIRABLE) |
|--------------------|------------------|--|----------|--|
| TOPOGRAPHY | 2 | flat, low vegetation, little surface water, little surface activity | | rugged, mountainous, tall vegetation, swampy lakes, much traffic and other surface activity |
| LOGISTICS | 2 | facilities close (motels, restaurants, rental cars, airport, highway, suppliers), good surface access, good underground access (drift mine best), services available (power, water, air), experienced drilling contractors close to major city | | facilities farther than about 30 miles, surface access requires road building or foot travel only, underground access through shaft, services must be installed, experienced drilling contractors unavailable, far from major city |
| MINING | 1 | longwall operation well-established, good production rates, typical panel size, and panels adjacent | | longwall operation recently started, marginal production rates, atypical panel size and panels not adjacent |
| OWNER INTERACTION | 3 | operator's interest in data is high, no problem foreseen with carrying out a cooperative agreement, willing to provide on-site office facilities (or field office trailer space), surface owned by mine, mine surveyors available | | operator's interest in data is marginal, problems foreseen with carrying out a cooperative agreement, field office facilities not available, surface is privately owned, mine surveyors not available |

INTERMEDIATE BETWEEN 1 AND 3

TABLE 2.1
SITE SELECTION CRITERIA (CONT)

| SELECTION CRITERIA | WEIGHTING FACTOR | 3 (DESIRABLE) | RATING 2 | 1 (UNDESIRABLE) |
|------------------------------|------------------|--|-------------|---|
| OVERBURDEN | 3 | less than 600 ft, stable borehole walls, consistent and known geology, simple structure | | thicker than 1200 ft (approximate limit of instrumentation experience), boreholes require casing, complex/variable geology not mapped, steeply dipping strata, highly faulted and jointed |
| COAL SEAM | 2 | more than 6-ft thick, thicker than overburden thickness divided by 100, competent immediate roof | | less than 5-ft thick, less than overburden thickness divided by 100, poor immediate roof conditions |
| CLIMATE | 2 | low precipitation, moderate temperatures, minimal wind, little snow | | heavy precipitation, extreme high/low temperatures, frequent high winds, heavy snow accumulation |
| TIMING | 3 | scheduling compatible with program plan and cooperate commitment firm | | scheduling not consistent with program plan or indefinite |
| INTERMEDIATE BETWEEN 1 AND 3 | | | | |

TABLE 2.2
ALLEN MINE, WESTON, COLORADO

OWNER: CF&I Steel Corporation
LOCATION: Near Trinidad, Colorado

Topography

- steep hills and valleys
- heavily vegetated north slopes, sparser south-facing slopes
- surface triangulation net
- portal surface elevation approximately 7400 ft

Logistics

- Pueblo is 2 hours away, Denver is 4 hours away
- comprehensive facilities in Trinidad, 30 miles from mine
- mine can provide parking, water, electricity for site trailer
- 2-WD access to surface (under dry weather conditions)
- slope access to mine
- water haulage required for surface drilling

Mining

- production is 1 million tons/year
- relatively ungassy
- two adjacent panels being mined, next planned panels not adjacent or of typical length
- dip of coal seam is less than 1°
- mining thickness is 6 ft
- mine can provide underground transportation, repairs, compressed air
- chock-supported longwall panels
- chiefly electric power

TABLE 2.2
ALLEN MINE, WESTON, COLORADO (CONT)

OWNER: CF&I Steel Corporation
LOCATION: Near Trinidad, Colorado

Owner Interaction

- four to five engineers, also do survey work
- enthusiastic about study
- mine provides safety training course approximately every six weeks
- CF&I leases surface, requires OSM permit for surface work
- contact William Boies, CF&I, Pueblo

Overburden

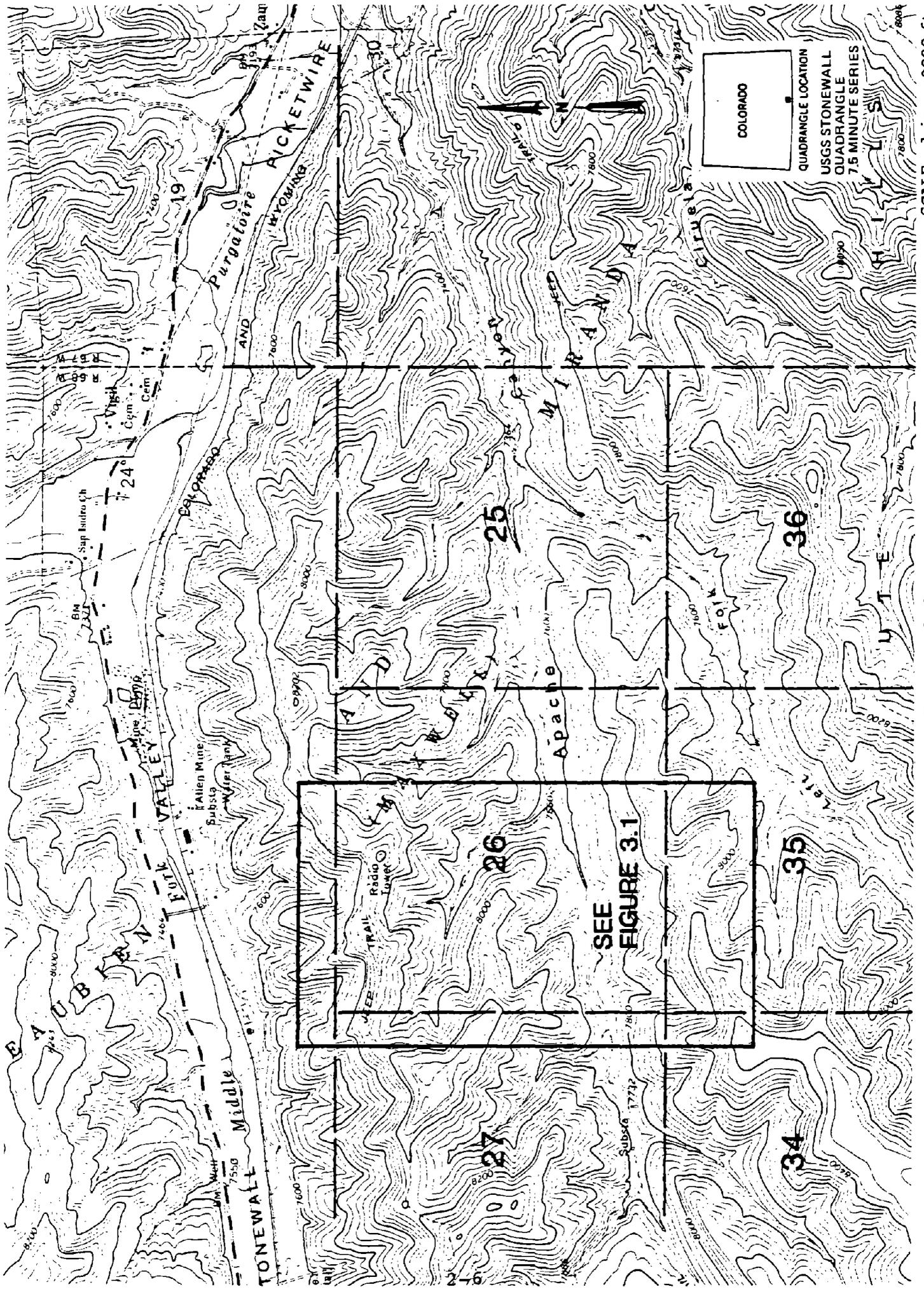
- 700 to 1000 ft over panels
- strata relatively flat-lying
- slickensided carbonaceous shale in immediate roof causes ground control problems and mining delays
- another coal seam (4 to 5 ft thick) is located 12 to 15 ft above mined seam

Coal Seam

- flat, relatively consistent thickness
- seam is 7 ft thick; 6 ft is mined, leaving 10 in. of roof coal
- deep overburden, but within experience of instrumentation

Climate

- dry, sunny, maximum 8100 ft surface elevation over study area
- little snow in winter, about 1 ft maximum
- does not prevent surface access



SCALE: 1 in. = 2000 ft

FIGURE 2.1

S I T E M A P

winter installation and monitoring work on the surface. The panels were of moderate length, just over 3150 ft, and average width, 425 ft. A negative factor was that the proposed two panels were already being mined. At the time of the site visit in January, 1981, one panel was mined about 1000 ft and the other was just started. The rate of face advance was as high as 200-ft/month, although interception of a fault system involved difficult driving through sandstone and associated chock stability problems, resulting in very slow progress in the previous 6-month period. It was anticipated that the mining schedule would leave at least 1000 to 1200 ft to be mined in the lead panel, and more than 2000 ft in the lagging panel by the end of the period of instrumentation installation. Consequently, there were expected to be sufficient unmined lengths to get good definition of longitudinal and transverse subsidence profiles for both panels. It was also a consideration that earlier subsidence data was available from the York Canyon Mine, located to the south of Allen Mine, near Raton, New Mexico, as a result of a subsidence study conducted by the Colorado School of Mines. The two sets of data may demonstrate that a regional approach to subsidence prediction is possible for this Western coal field.

2.2 MINE DESCRIPTION

Coal mined at the Allen Mine lies within the upper Cretaceous- Tertiary Raton formation, a heterogeneous sequence of lenticular argillaceous sandstone, siltstones, shales and coal. Lithologic types are highly variable both laterally and vertically with correlations being best established by the coal seams. Bedrock geology in the mine area is limited to the Tertiary Poison Canyon and Raton formations. The Poison Canyon formation intermittently tops the hills in the mine vicinity. The Allen Mine lies on the

west flank of the Raton basin, an asymmetrical north-south trending structural basin (Jackson, 1981).

The Apache seam is present above the Allen seam throughout the entire mine area. This rider seam varies from about 4 1/2 to 6 ft thick. The interval between the rider and main seams dictates roof conditions in the Allen Mine. When the interval is less than 8 ft, roof is difficult to control; over 8 ft, it is manageable. The width of the separation between the two seams generally increases to the east. In one drillhole above the second panel, the Allen seam was intercepted 18 ft below the Apache seam.

The immediate roof over the Allen seam is an incompetent carbonaceous shale. Above the Apache seam, the strata are fairly competent. The mine floor is a competent shale except when wet. In addition to the adverse roof conditions in the Allen Mine, faults and top and bottom rolls sometimes make mining difficult (Jackson, 1981). The chronically bad roof conditions caused longwall mining to be introduced in the Allen Mine about 10 years ago.

The present longwall mining method for the 6-ft mining height in the 7-ft thick Allen seam uses 500 ton, four-leg chocks. At the start of this project, two longwall systems were in operation. The longwall system in Panel No. 1 is equipped with an Eickhoff EDW 170 double-drum shearer and an Eickhoff 30-mm single-stranded face conveyor and stage loader. Roof support at the face was by 113 Gullick-Dobson chocks on 51-in. centers. All equipment operated on 480 volt AC except for the 1000 volt shearer. The longwall system in Panel 2 included an Anderson Mavor AB-16, 51-in. diameter single drum shearer, a 30-mm single strand Eickhoff face conveyor, a Mavor-Colson stage loader and 94 Hemscheidt chocks.

The double drum shearer mined the full seam in a single pass cut from tailgate to headgate. Chocks were advanced as soon as possible after the shearer passed because of the weak roof conditions.

The single drum shearer in the adjacent Panel 2 makes two cuts. The top was cut first from headgate to tailgate and the chocks advanced to support the roof. After the return bottom cut was made, the conveyor was advanced. A full cut was 30 inches deep. The single drum shearer could not reach into the tailgate, necessitating mining this coal web by hand.

Heavy ground conditions were evident ahead of the face in the tailgates of both panels. Forward abutment pressure in the tailgates was estimated to occur about 50 to 70 ft ahead of the longwall face, and cribs were installed ahead of any indications of abutment pressure as the face advanced. Roof support was achieved by placing a single line of cribs beneath the 6-in. steel H-beams previously installed across the tailgate entry and supported by wooden posts during panel development. The crib line was on the side of the entry away from the panel rib. This support system had the proper yield under abutment loads to allow roof deformation and floor heave to occur without breaking the roof or choking off the tailgate, as had previously occurred when a central line of cribs, and alternately a double line of cribs, was installed.

2.3 INSTRUMENTATION PLAN

A preliminary instrumentation plan was tailored to site conditions in April 1981. Several plan review meetings were held with DOE and an agreed plan conforming to contract specifications and available budget was ready for implementation in June, 1981. The agreed plan for types of

instruments and measurements, the area location in the panel, and the readout location is shown in Table 2.3. Actual numbers of the individual types of instruments later installed are also shown in Table 2.3, and in some cases differ from the original planned quantities.

2.4 COOPERATIVE AGREEMENT AND PERMITTING

Before any site work commenced, a Cooperative Agreement was drawn up between the mine owner, CF&I Steel Corporation, and Woodward-Clyde Consultants (WCC). The Cooperative Agreement described the work to be done at the mine, the rights, contributions, and liabilities of the respective parties to the agreement, and the insurance requirements to be met by WCC.

Concurrent with processing of the Cooperative Agreement in May, 1981, a Notice of Intent to Drill was sent for review to the Mined Land Reclamation (MLR) Division of the Colorado Department of Natural Resources, and under MLR direction this document was also filed with the Las Animas County Planning and Land Use Office in Trinidad, Colorado. This document generally described the objectives of the subsidence project, the work on access roads and drilling that needed to be done on the surface overlying the mine, and the reclamation measures that would be done by WCC to restore the surface. Since the mine operators owned long term leases of the surface land, there were no problems in securing access and permission to do the clearing, access road construction, and deep drilling that was necessary, as might occur if there were several private owners of surface land with whom to negotiate.

2.5 SUBCONTRACTOR AND EQUIPMENT SELECTION

Requests for Quotation (RFQ) were sent to qualified parties for three principal categories of proposed subcontract work

TABLE 2.3
INSTRUMENTATION PLAN

| INSTRUMENT TYPE | INSTALLED PANEL 1 | INSTALLED PANEL 2 | MEASUREMENT | LOCATION OF READOUT | LAYOUT |
|--|-------------------|--------------------------------|---|---------------------|--|
| Survey Points | 42 | 51 | Vertical and horizontal displacements and strain | Surface | Entire panel and adjacent areas |
| Automatic Recording, Horizontal Strainmeters | | 12 | Traveling horizontal strain | Surface | Panel center and ribsides |
| Deep Hole SLEX | 1 - 580 ft | 1 - 560 ft | Overburden strata vertical and horizontal displacements | Surface | Panel ribsides |
| 6-Point Deep Hole Extensometers (REX) | | 2 - 850 ft & 600 ft | Overburden strata vertical displacements | Surface | Panel center |
| Observation Wells | | 2 SLEX holes | Ground water level and quality | Surface | Panel ribsides |
| 4-Point Roof Extensometers | | 2 - 50 ft deep | Roof strata separation | Mine entry | Headgate entry roof |
| 2-Point Floor Extensometers | | 2 - 20 ft deep | Floor strata separation | Mine entry | Headgate entry floor |
| Tape Extensometer Convergence Stations | | 10 | Convergence | Mine entry | Headgate entry |
| Floor Stressmeters | | 4 - vertical | Floor stress | Mine entry | Under panel |
| Pillar Stressmeters | | 6 - vertical 8 - horizontal | Pillar stress | Mine crosscut | Pillars |
| Absolute Stress Measurement | | 10 | Surface stress at rib or roof | Mine entries | Pillars, panel and headgate entry roof |

including: (1) deep hole drilling from the surface, (2) underground drilling in the mine and (3) geodetic surveys at the surface. The RFQ's were sent out in April, 1981. Quotations were reviewed by WCC and recommendations for subcontract awards were made to DOE. By June, 1981, the following subcontracts were approved by DOE and were issued by WCC:

| <u>Subcontract Category</u> | <u>Subcontractor</u> |
|-----------------------------|---------------------------------------|
| (1) Deep Hole Drilling | Longyear Company |
| (2) Underground Drilling | Earth Exploration Drilling of Utah |
| (3) Geodetic Surveys | Benchmark Control Services. |

Instrumentation judged best able to meet monitoring specifications, available budget, special project needs and site conditions, was procured directly by WCC from experienced manufacturers of such equipment.

3.0 FIELD OPERATIONS AND INSTALLATIONS

Surface, subsurface and underground installation of the instruments selected for this project was conducted from May to October, 1981. Consideration of budgetary concerns and the fact that Panel 1 was expected to be completed by the end of 1981 lead to the decision to concentrate the instrumentation on Panel 2, as shown on Figures 3.1, 3.2, and 3.3. The instrumentation plan involved positioning the underground instruments vertically below the overburden instruments, in order to investigate relationships between the underground, overburden and surface response to mining. Two general areas were instrumented, with most of the instrumentation concentrated at the second location so that experience at the first section could be used to optimize data acquisition at the second.

3.1 SURFACE INSTALLATIONS

Ninety-three survey monuments were installed to determine the following characteristics of surface subsidence troughs over the two longwall panels: angle of draw, maximum subsidence, maximum horizontal strain, and the transition point (between compressive and tensile strain near the panel ribsides). Two automatic-recording strainmeters were installed in order to characterize the horizontal surface strain wave traveling ahead of a longwall face (Schmechel, et al., 1979) and to accurately measure horizontal surface strains near a panel ribside.

3.1.1 Survey Network

Survey points for horizontal and vertical surface displacement monitoring and horizontal strainmeter anchor points were laid out and installed by Benchmark Control Services along the centerlines of both panels and also across both

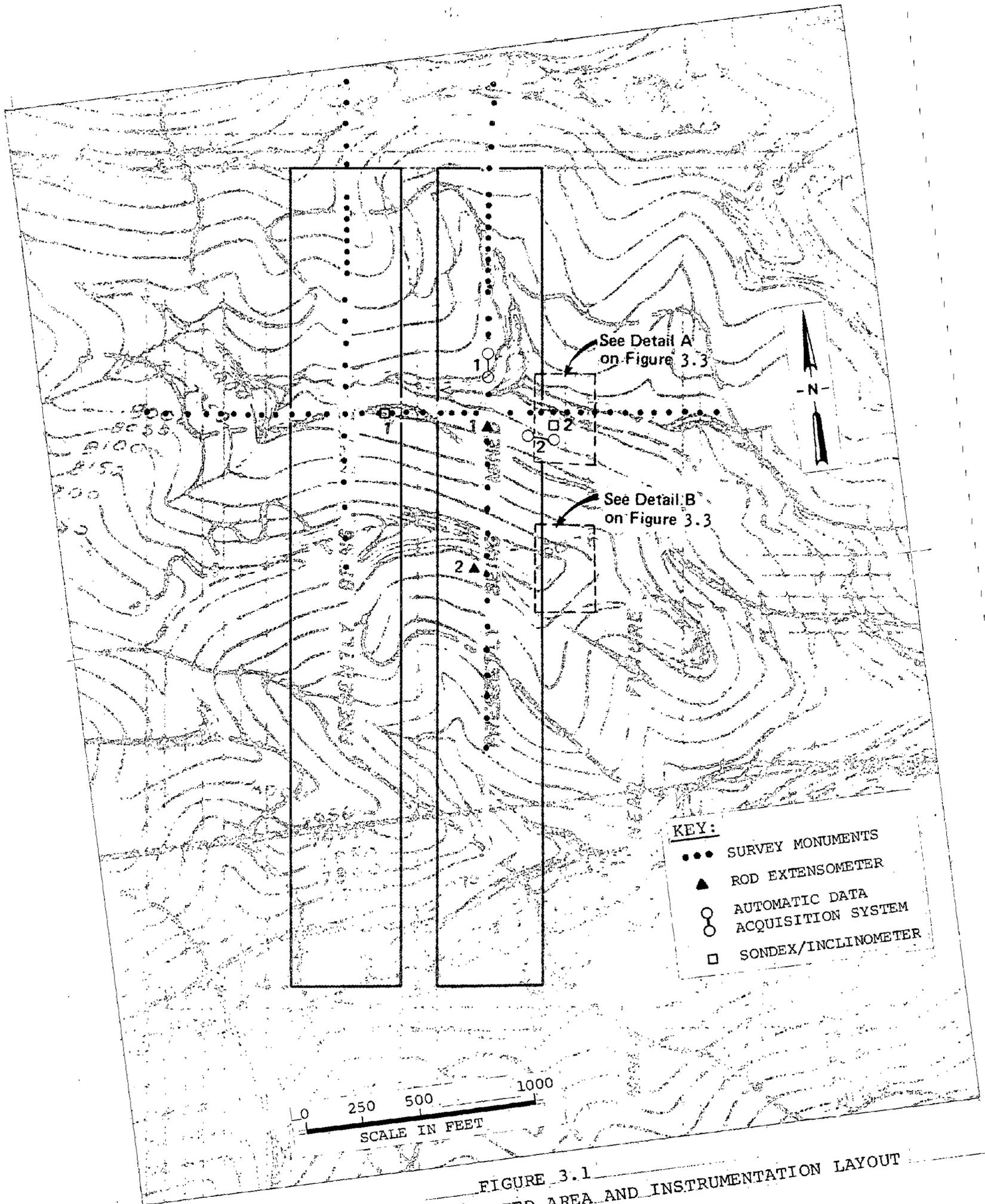


FIGURE 3.1
TOPOGRAPHY OF INSTRUMENTED AREA AND INSTRUMENTATION LAYOUT



panels. The survey lines extend a distance of 700 ft or $0.7D$ where D is the depth to seam, past the barrier pillar at the end of the panel and the same distance past the panel ribsides in the direction perpendicular to the panel centerline. This layout permits measurement of the angle of draw up to a limit of 35 degrees.

Spacing between monuments varied from 50 feet ($0.05D$) over the ribsides and ends of the panels, where detailed vertical and horizontal surface subsidence characterization is required, to 100 ft ($0.1D$) in the mid-portions of the panels, where uniform subsidence displacements corresponding to the center of the subsidence trough were expected. The range from $0.05D$ to $0.1D$ is consistent for this overburden with the suggestion based on current monitoring practice that the range should be between 25 ft or $0.05D$, whichever is greater, and 200 feet or $0.2D$, whichever is less (O'Rourke, et al., 1977). The maximum spacing, $0.1D$, used at the Allen Mine is one-half the recommended spacing, $0.2D$. This close spacing was chosen to provide additional information for assessing the effects of topography on the angle of draw and displacement of a point. The investigation of topographic effects follows Gentry and Abel's (1978) observation that greater horizontal movement occurred when the direction of mining was in a downslope direction than when it was in an upslope direction at the York Canyon Mine.

The benchmarks for the survey are two U. S. Coast and Geodetic Surveys benchmarks located 1.4 miles away from the project area. The coordinates of these benchmarks were checked by Benchmark Control Services by trigonometric leveling, and a favorable check between the benchmarks was obtained.

Monuments consisted of 2-in. diameter, 6-ft long iron pipes driven into 1-ft diameter, 4-ft long holes. A 3-in. diameter, flat brass disk was set on the 2-in. iron pipe and the hole

was backfilled with Type II Portland Cement and sand-concrete (Figure 3.4). In areas where rock was encountered at a depth of less than 4 ft, the pipe was driven as far as possible and the hole was widened before backfilling with concrete to provide maximum stability for the monument. This survey monument design has been successfully used by Benchmark Control Services for a number of precision surveys in the vicinity of the study area (i.e., southern Colorado).

Benchmark Control Services cleared lines, set temporary points and concrete monuments, and completed the baseline survey by August 11, 1981. The initial survey elevations were found to differ from the 1 in. = 500 ft scale topographic map in general use for this area by as much as 50 ft for a given monument. In order to procure a detailed and accurate base topographic map for subsidence characterization, Benchmark Control Services plotted and scribed a 1 in. = 100 ft scale, 2-ft contour interval topographic map on the basis of aerial photographs (flown in conjunction with other work) on October 19, 1981.

3.1.2 Automatic Data Acquisition System (ADAS): Strainmeters

Two strainmeter assemblies consisting of six 20-ft strainmeters in series (Figure 3.5) were installed along the centerline and across one ribside of Panel 2. These assemblies are designated ADAS-1 and ADAS-2. ADAS-1 was installed along the centerline of Panel 2 in order to provide a continuous record of traveling strain development as the face of Panel 2 passed beneath these stations.

ADAS-2 was located across one ribside of Panel 2 in the areas of expected maximum tensile and compressive strain, in order to monitor development of permanent strains as the face passes. The distance from the panel centerline to the

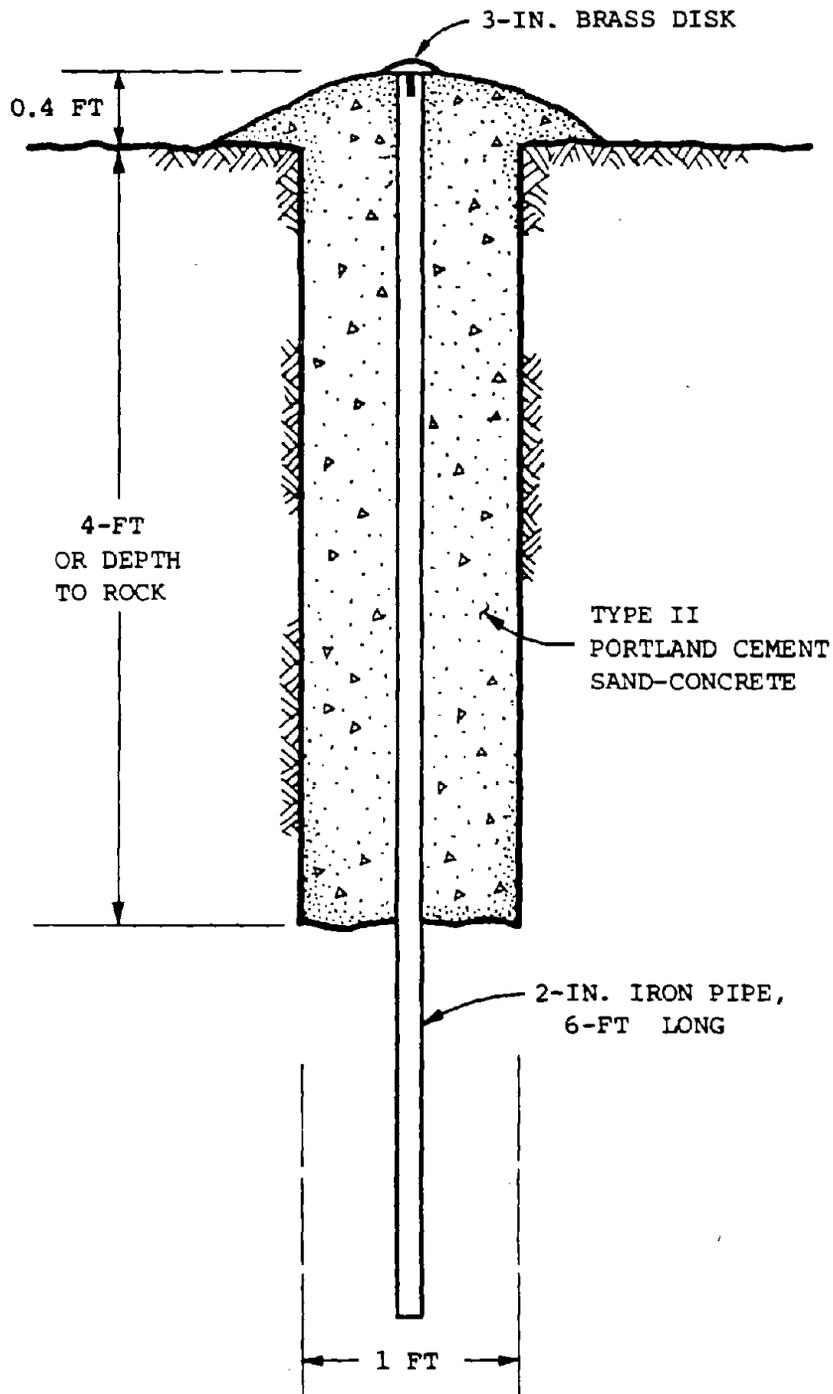
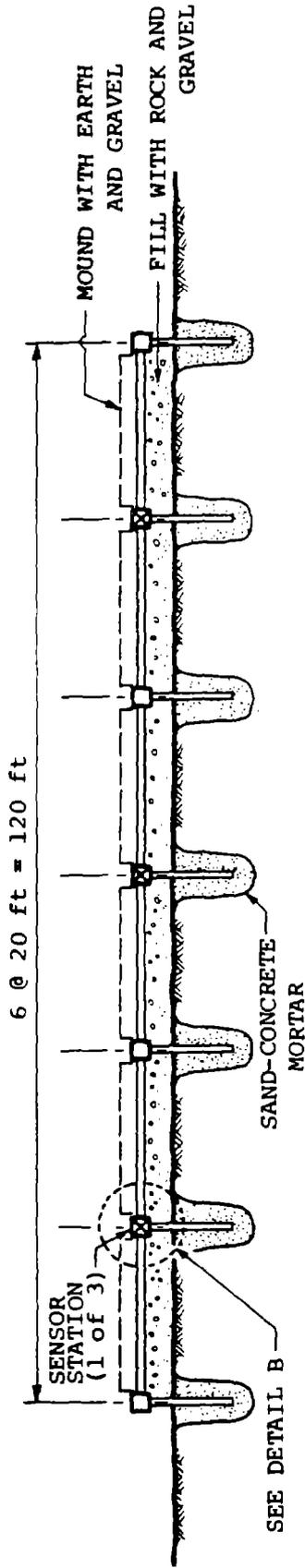
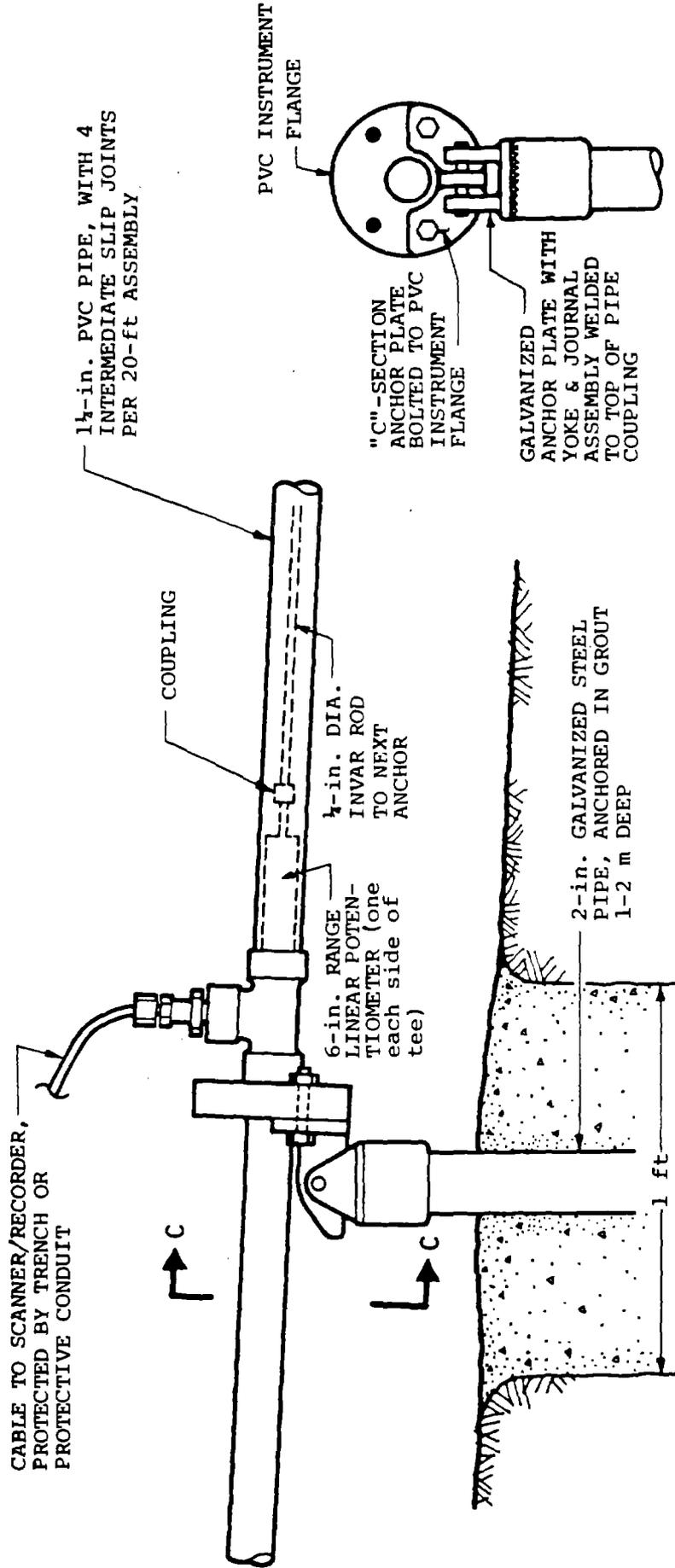


FIGURE 3.4
SURFACE SURVEY MONUMENT



ELEVATION OF ADAS



DETAIL B

SECTION C-C

FIGURE 3.5
 DETAILS OF AUTOMATIC DATA ACQUISITION SYSTEM (ADAS) STRAINMETERS

surface locations expected to experience maximum compressive and tensile strains was determined on the basis of a strain contour map similar to the National Coal Board (1976) graph for predicting strain profiles. For depths ranging from 600 to 800 ft, it was estimated that the distance from centerline toward the ribside to the surface points experiencing maximum strain would range from 132 to 208 ft. Consequently, the six strainmeters comprising ADAS-2 were installed between the interval from 110 and 230 ft from the centerline of Panel 2.

The anchor points for the two strainmeter assemblies consisted of 2-in. diameter, 5 1/2-ft long galvanized steel pipes threaded at the top and installed every 20 ft in 6-in. to 2-ft deep, 120-ft long trenches by Benchmark Control Services by the method used for survey monument installation. To anchor the smooth steel pipe to the ground, 6-in. long crossbars were installed in holes drilled in the steel pipe. The steel pipe extended an average of 6 inches above the ground surface, facilitating assembly of the strainmeters but necessitating measures to shield the strainmeters from temperature changes.

Twelve SINCO strainmeters (Figure 3.5), of 20-ft gauge length were assembled and installed by WCC engineers at the site according to SINCO specifications. The PVC pipe was not filled with oil, which is an optional specification for long-term protection of buried installations. The sensing element of these strainmeters is a linear potentiometer with a 6-in. range. The double sensor assemblies contain two linear potentiometers and were installed at every other anchor point. A 1/4-in. diameter invar rod connects the potentiometer shaft to the anchor point and is enclosed within 1 1/4-in. PVC pipe. The potentiometers were calibrated in the SINCO plant and in the field office after

shipment. The potentiometers were set by adjustment of the extension rod with respect to the jam nut at the anchor end of the assembly. Initial settings were made by connecting a SINCO extensometer hand-held readout to the five-conductor cable, enclosed within 1/2-inch polyethylene tubing extending from each double sensor assembly. After setting the potentiometers, the cables were uncoiled and collected at a terminal box where they were connected to a SINCO Extensometer Scanner/Recorder with Expander Box using environmentally-sealed multi-pin connectors (Figure 3.6).

Initial settings for the linear potentiometers were determined by using unpublished empirical curves based on York Canyon results for maximum horizontal strain as a function of the panel width to depth ratio. It was estimated that extension over a 20-ft gauge length would be 2.25 in. and compression 1.53 in. The linear potentiometers have a range of 6 in. so they were set to allow 4 in. extension and 2 in. compression.

As mentioned above, the steel anchor pipes extended about 6 in. above the ground surface so that measures had to be taken not only to shield the strainmeters from temperature effects but also to minimize the potential for vandalism. In order to allow drainage, 3/8-in. pea gravel was laid to a depth of 2 in. in the strainmeter trenches. Flake-board cribs were then constructed along the sides of the trenches, and rocks were piled to fill the gap between the PVC housing of the strainmeters and the gravel layer. Gravel was then placed to cover the strainmeter assemblies, and it was in turn covered with earth to further isolate the strainmeters from temperature effects. The main body of each strainmeter was covered to a depth of 6 in. while the anchor and sensor posts were left exposed to allow surveying of each point during subsequent monitoring sessions.

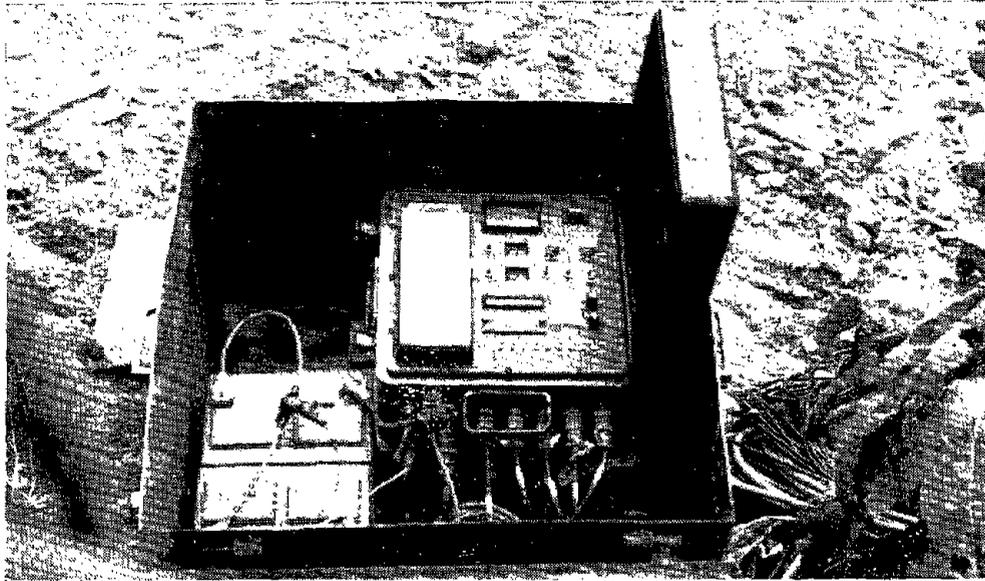


FIGURE 3.6

ADAS SCANNER/RECORDER

3.2 OVERBURDEN INSTRUMENTATION

In order to characterize the nature of strata separation and shearing which occurs in the overburden as the subsidence trough developed, inclinometer-extensometers were installed over the ribs of both panels and rod extensometers were installed along the centerline of one panel. In order to insure that at least subsurface vertical displacements would be successfully monitored, a redundant system utilizing Time-Domain Reflectometry was also installed.

The inclinometer-extensometers can provide a continuous profile of subsurface displacements but the rod extensometers can only be used to monitor the vertical displacements of discrete, selected strata. To aid in finalizing the rod extensometer design, as well as developing a more complete description of the overburden, borehole geophysics was run in each drill hole in conjunction with the maintenance of drilling records and logs of cuttings.

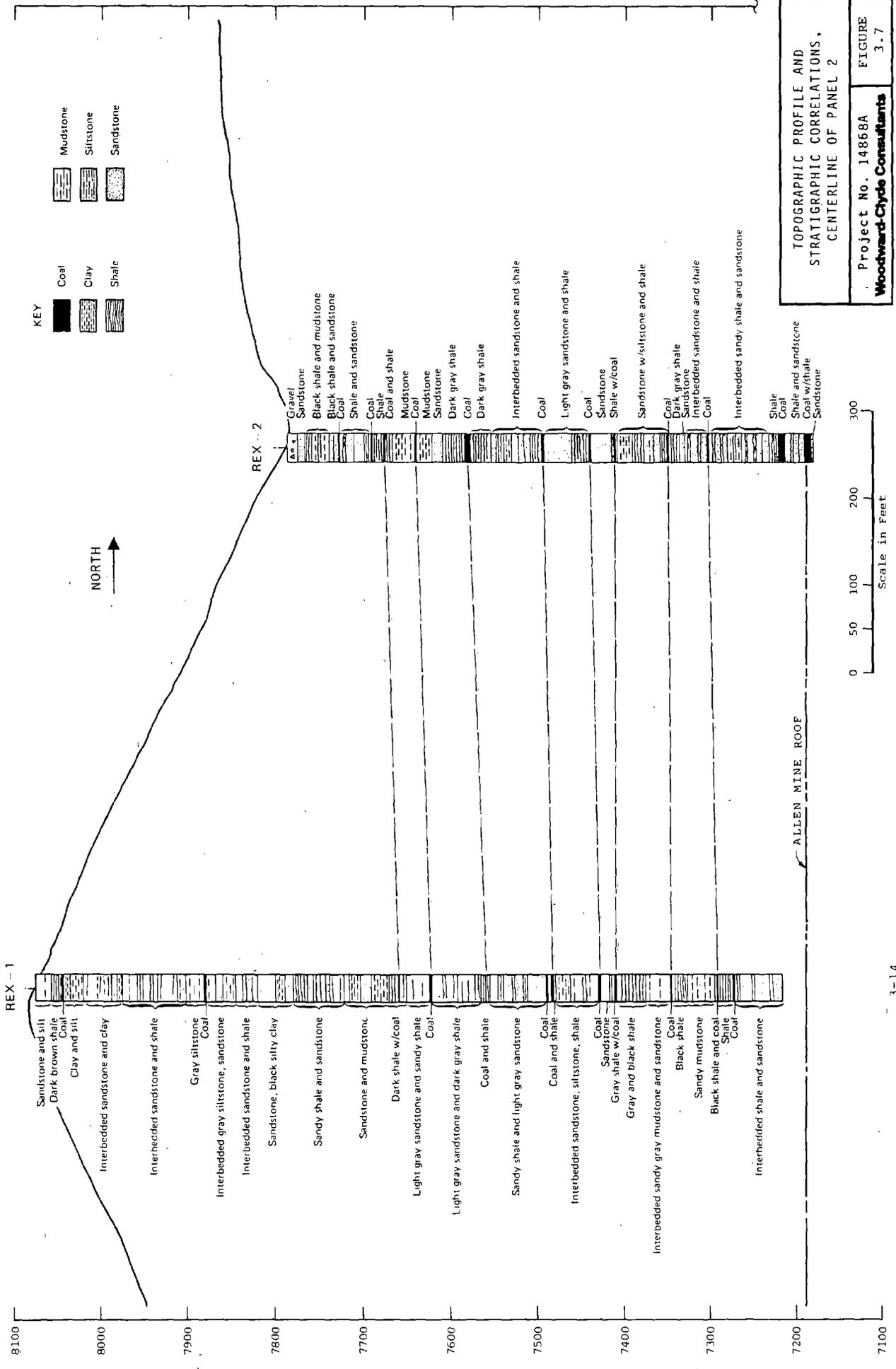
3.2.1 Borehole Logging and Geophysics

Four 8-in. diameter holes were drilled by Longyear Company using a Longyear CP-8 Portadrill, tricone rock bits and water with a polymer foam additive. Steel casing was installed to a depth of 20 ft in each hole to ensure hole stability during drilling. During the course of drilling the rod extensometer holes a record was maintained of the time required to drill every 5 ft and a sample of cuttings was obtained at least once every 10 ft or whenever there was a noticeable change in drilling rate. It was not possible to maintain these records when drilling the two inclinometer-extensometer holes. Cuttings were logged according to the method described by Compton (1962) without correction for the circulation time from bit to surface.

Blue Ox Logging of Raton, New Mexico, conducted geophysical surveys in each of the four deep holes. Resistivity, gamma and gamma-gamma logs were obtained in each of the rod extensometer holes prior to instrument installation. In the case of the inclinometer-extensometer holes, however, the surveys were made after the casings were installed, and lithologic logs for these holes were developed by comparing the geophysical surveys with those of the rod extensometer holes. As may be seen on Figures 3.7 and 3.8, strata between the correlated coals vary from shales to sandstones, and are not consistent across the area. The coals provide good stratigraphic correlations, however, and may be used as marker beds for classifying the logs in terms of "strong" and "weak" rock types. Consideration of the complete boring logs yields the percentage of shales, mudstones and sandstones tabulated in Table 3.1. The drilling rate is an indication of relative rock competence, and was considered when designing the lengths of the rod extensometers to assure that the anchors were located in competent strata. Figures 3.9 through 3.12 show the lithologic logs for all four holes and the drilling rates as a function of depth.

3.2.2 Time Domain Reflectometry (TDR)

For the measurement of progressive upward migration of strata extension, bed separation or rock caving from mine level to the surface, the principle of time domain reflectometry was implemented. A voltage step is sent out along a cable and reflected back to show discontinuities in the cable. The time required for the reflected signal to be returned is proportional to the cable length, so the depth of the discontinuities can be determined. As mining progresses and the bed separation or caving develops, progressive cable breakage may be monitored.

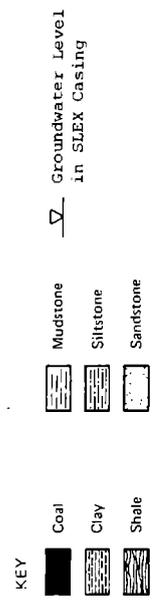
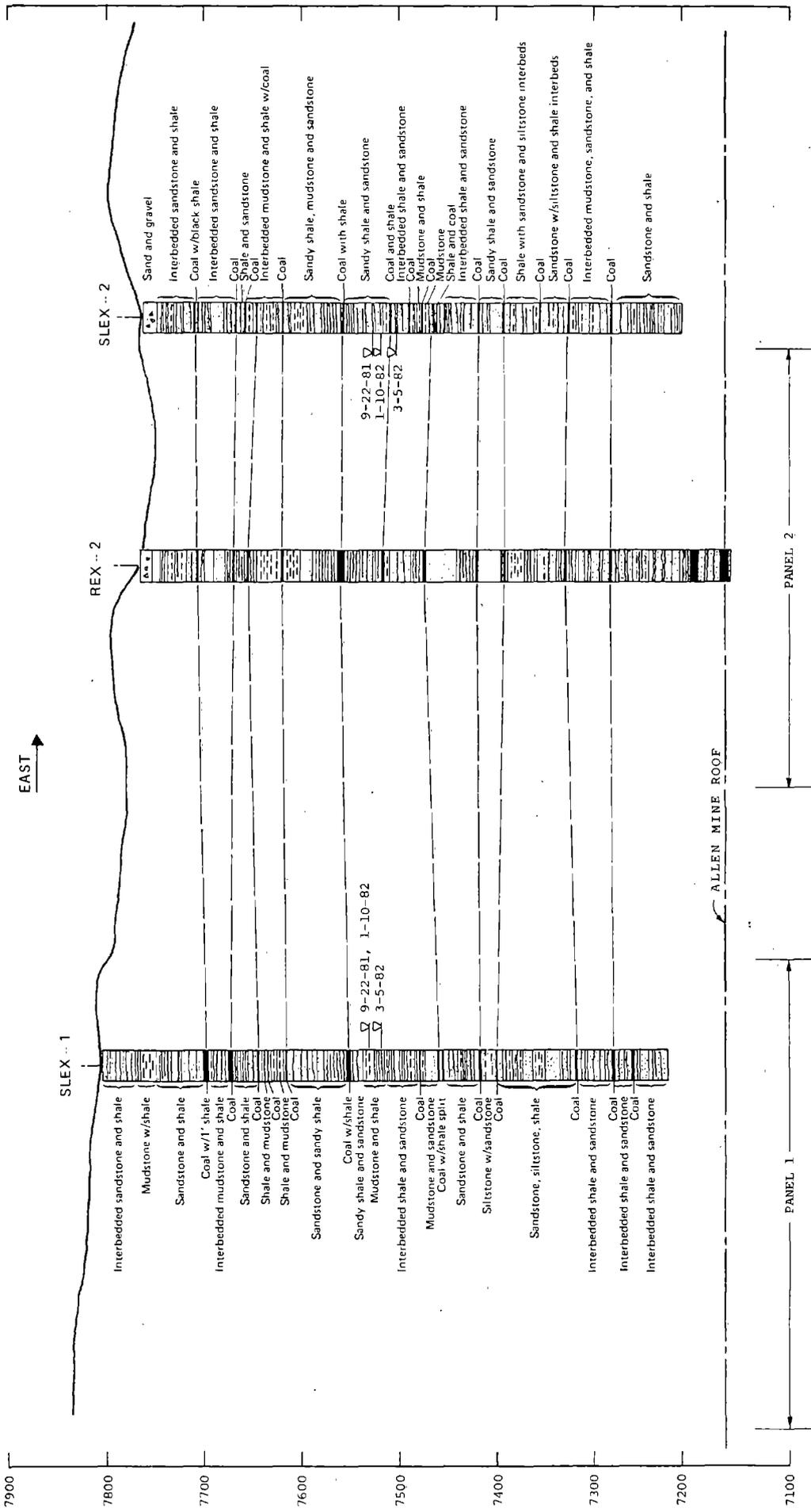


TOPOGRAPHIC PROFILE AND STRATIGRAPHIC CORRELATIONS, CENTERLINE OF PANEL 2

Project No. 14868A

Woodward-Clyde Consultants

FIGURE 3-7



TOPOGRAPHIC PROFILE AND STRATIGRAPHIC CORRELATIONS, ACROSS PANELS 1 AND 2

Project No. 14868A

Woodward-Clyde Consultants

FIGURE 3.8

TABLE 3.1
LITHOLOGIC COMPOSITION OF OVERBURDEN

| LITHOLOGIC TYPE | DRILLHOLE | | | | MEAN PERCENT |
|----------------------|-----------|--------|-------|-------|--------------|
| | SLEX-1 | SLEX-2 | REX-1 | REX-2 | |
| Sandstone | 36 | 32 | 45 | 50 | 41 |
| Siltstone & Mudstone | 41 | 47 | 36 | 35 | 39 |
| Shale | 17 | 15 | 12 | 11 | 14 |
| Coal | 6 | 6 | 7 | 4 | 6 |

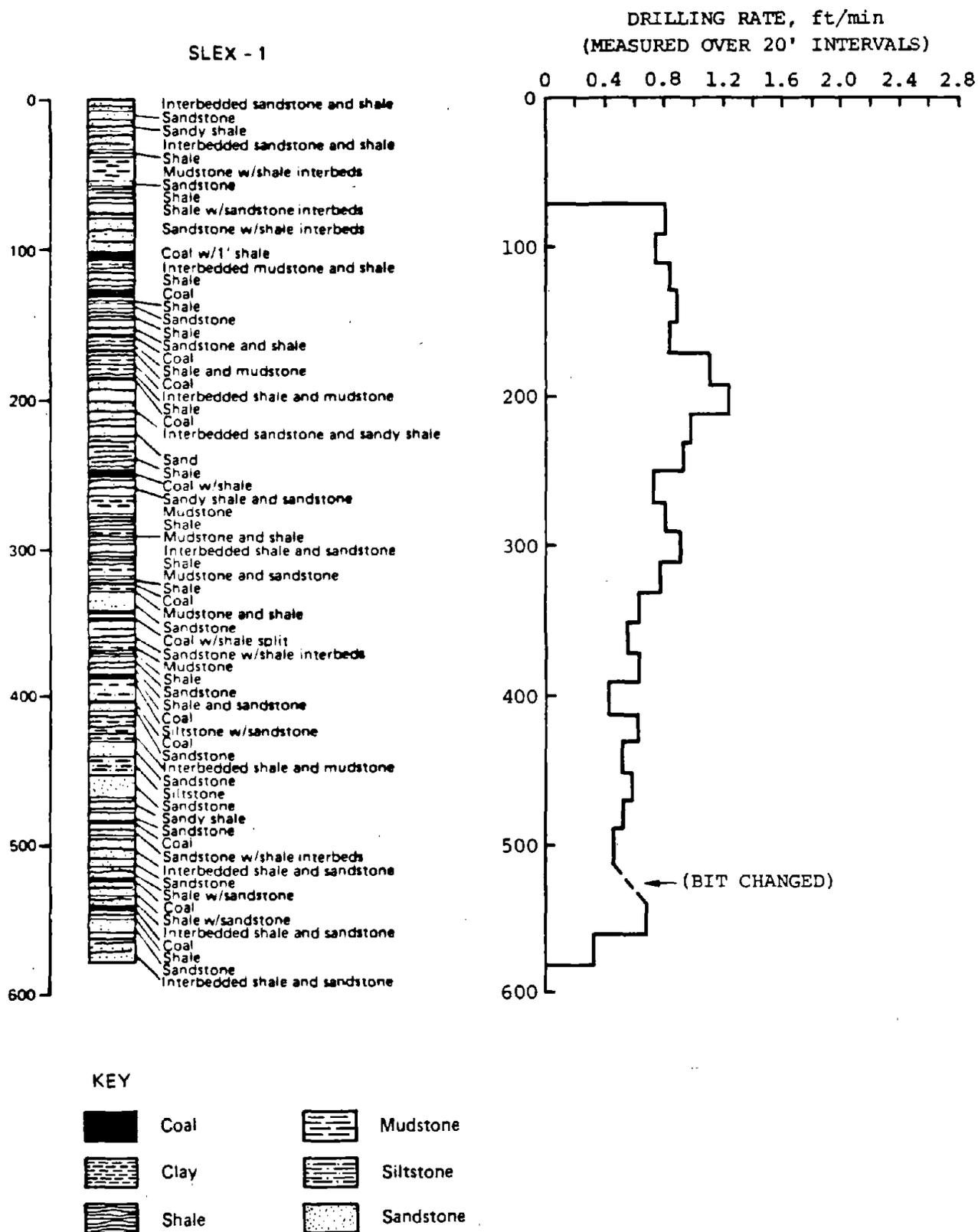
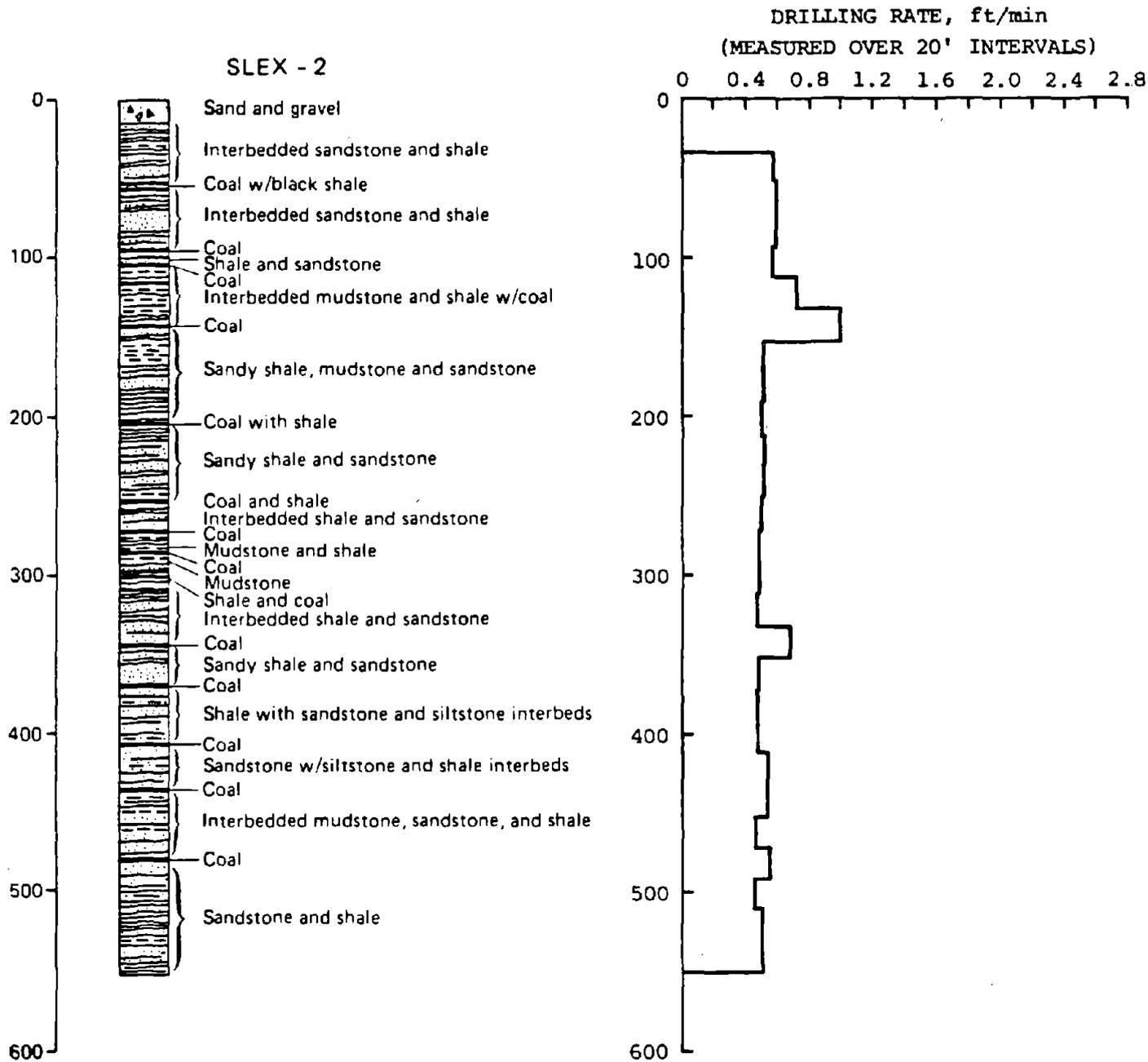
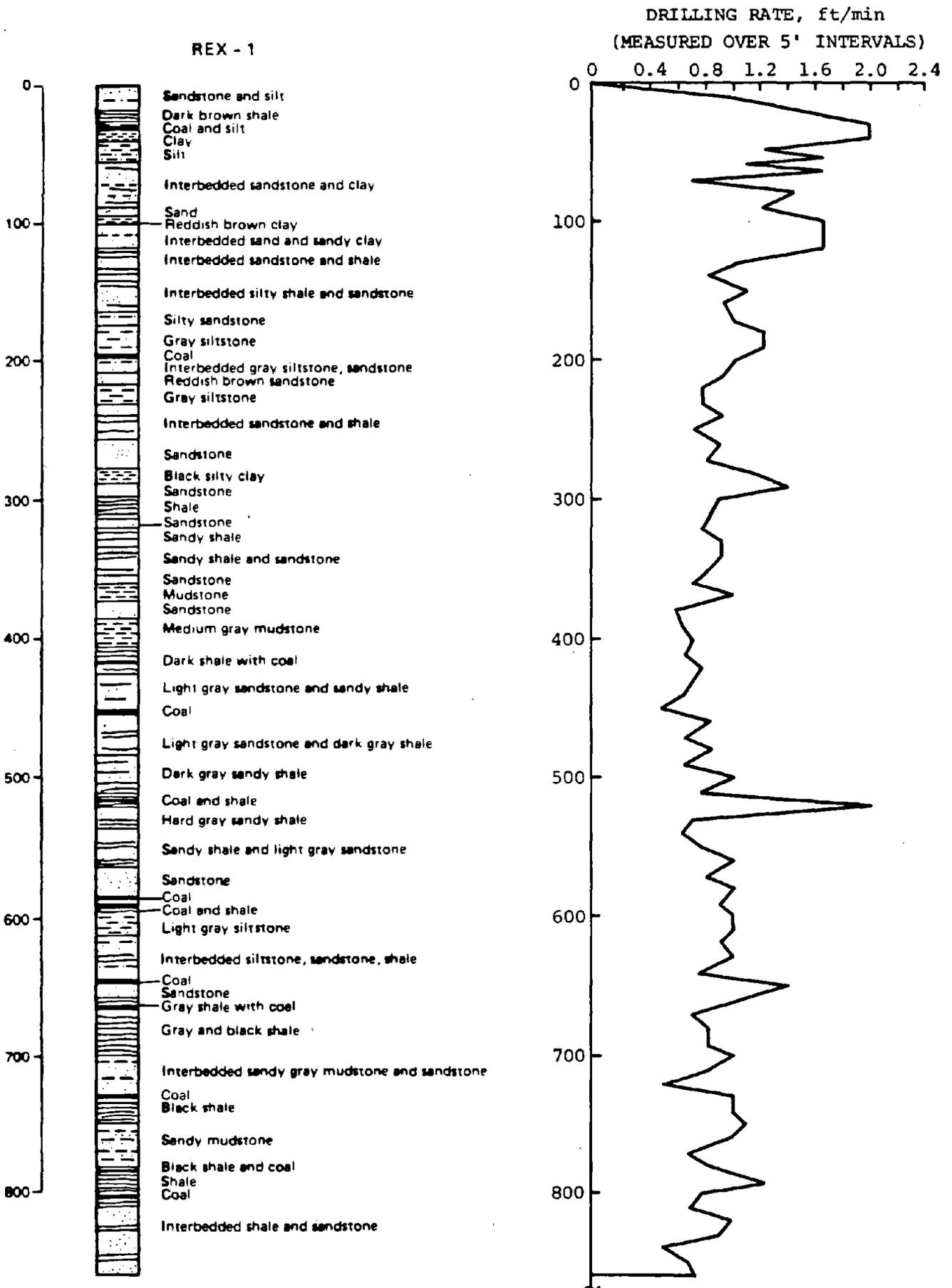


FIGURE 3.9
SLEX-1 GEOLOGIC LOG AND DRILLING RATE



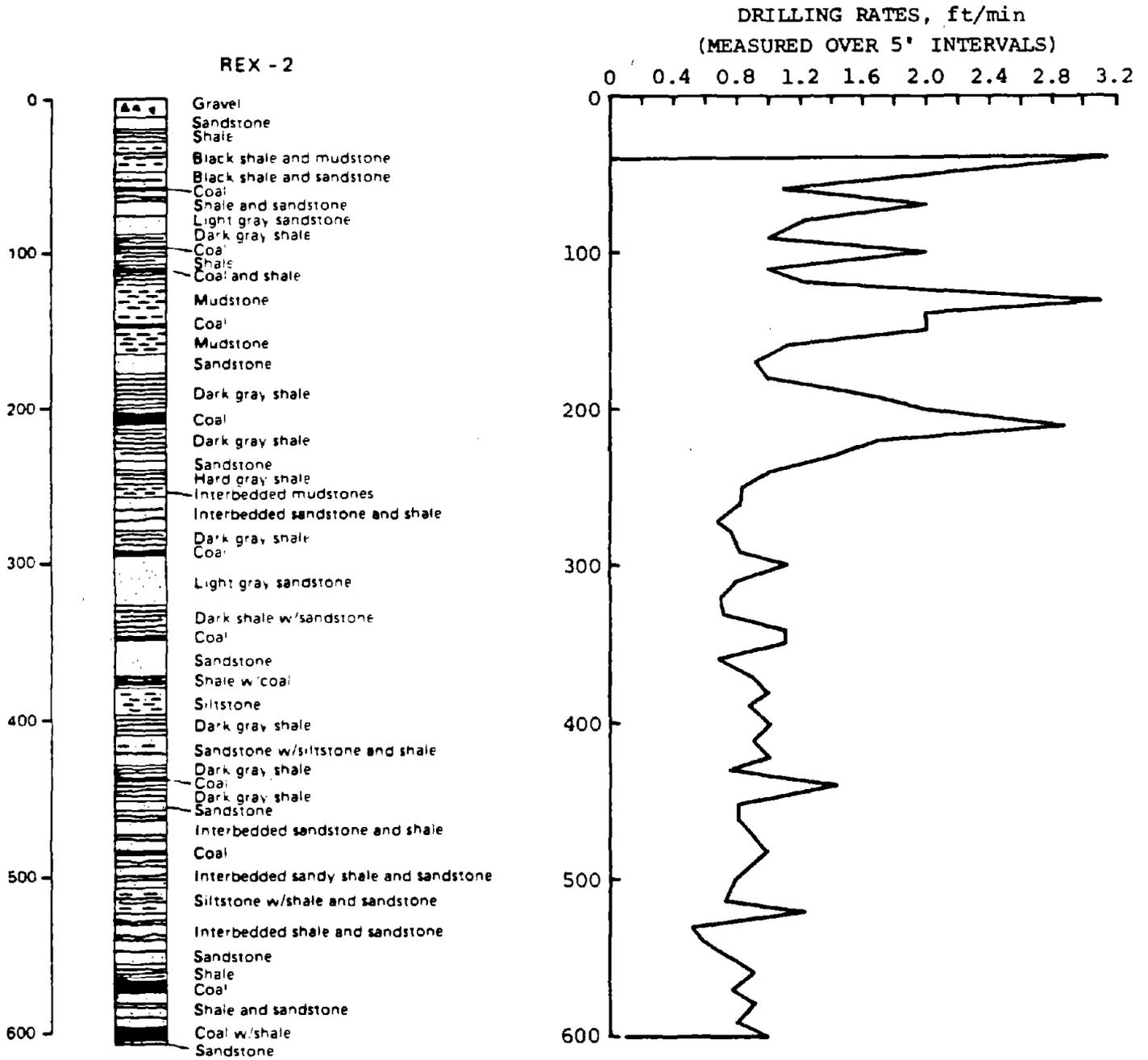
NOTE: See KEY on Figure 3.9.

FIGURE 3.10
SLEX-2 GEOLOGIC LOG AND DRILLING RATE



NOTE: See KEY on Figure 3.9.

FIGURE 3.11
REX-1 GEOLOGIC LOG AND DRILLING RATE
3-19



NOTE: See KEY on Figure 3.9.

FIGURE 3.12
REX-2 GEOLOGIC LOG AND DRILLING RATE

This installation consisted of a 0.405-in. diameter cable which was crimped at 10-ft intervals. As described below, it was installed simultaneously with the inclinometer-extensometers and rod extensometers. When the installation in each hole was completed, excess cable was cut off and a UHF connector was attached to the end of the cable so that it could be attached to a Tektronix TDR cable tester.

3.2.3 Inclinometer-Extensometers (SLEX)

This installation consisted of an inner, grooved-plastic inclinometer casing and an outer, corrugated plastic Sondex extensometer casing (Figure 3.13). The outer casing is rigid in the radial direction to resist horizontal strata pressures, and very flexible in the axial direction in order to comply with vertical strata deformation. Metal rings are fixed on its outer surface at 10-ft intervals.

The two SLEX holes were located along the transverse survey line. SLEX-1 was drilled 130 ft from the centerline of Panel 1 toward the ribside while SLEX-2 was drilled over the ribside of Panel 2 (Figure 3.2).

Installation of the SLEX casing began with the setting of the 3.5-in. outside diameter corrugated plastic Sondex casing in a steel boot designed for lowering casings into the hole. Lowering of the 20-ft lengths of Sondex casing was controlled by means of nylon ropes attached at two points to the steel boot. The 2.75-in. O. D., 10-ft long ABS plastic inclinometer casing was pre-assembled into 20-ft lengths and was installed inside the 20-ft lengths of Sondex casing. The coaxial cable was attached to the steel boot and fed into the hole as the Sondex casing was lowered. The TDR cable was taped to the Sondex casing for temporary support of the cable. The cable was crimped with a crimping tool at

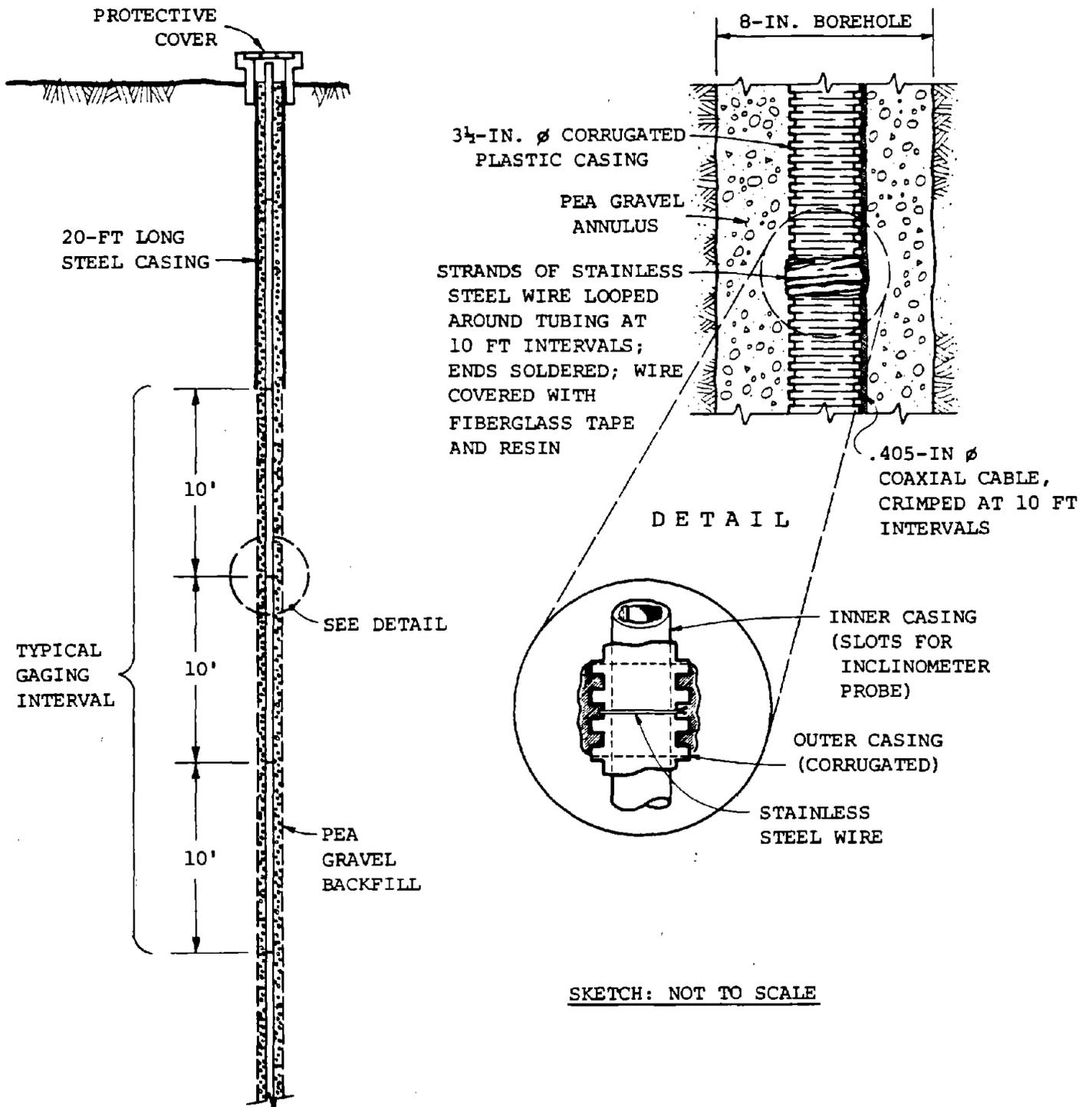


FIGURE 3.13
 COMBINED BOREHOLE INSTALLATION FOR SLOPE
 INDICATOR AND EXTENSOMETER (SLEX)

the same general locations as the Sondex rings in order to provide calibration checks when testing the cable. Sondex casing couplings consisted of longitudinally-split, 1-ft lengths of casing which were bound around the Sondex casing with banding straps and seals. The inclinometer casing sections have a reduced outside diameter at each end which seats in a 6-in. long coupling in a square-shoulder, flush joint. The coupling joint is cemented and pop-riveted. The internal grooves in each casing length are aligned with the aid of a spring-loaded aligning tool. The aligning tool was extracted by pulling it up in the grooves of the upper 20-ft length of casing. Removal of the tool occasionally required force, possibly resulting in the carving of new internal grooves for short lengths.

Holes were drilled in the casings for SLEX-2 to allow ground water inflow. The decision to monitor SLEX-2 as a water observation well was made when water in the SLEX-1 hole was measured at a depth of about 250 ft. Eight 5/32-in. diameter holes were drilled in each 20-ft section of Sondex casing and three 1/4-in. diameter holes were drilled in each 10-ft length of inclinometer casing.

Following casing installation, the annulus between the Sondex casing and the hole was backfilled using minus 3/8-in. pea gravel. The pea gravel contained a small percentage of plus 3/8-in. material. Approximately 7-1/2 cubic yards were installed in SLEX-1, and 7 cubic yards in SLEX-2, compared to the estimated 6.4 cubic yards required for SLEX-1 and 6.0 cubic yards for SLEX-2. The gravel was installed in lifts of 1 cubic yard which was estimated to fill the annular space along 100 ft of hole. The depth to gravel was sounded after each lift with a weighted rope to check that no voids were created by bridging of the gravel between the borehole walls and the casing. The higher than estimated gravel take in both holes indicates that the existence of voids is unlikely.

The top 2 ft of the annulus in SLEX-2 was packed with bentonite pellets to seal the hole from surface water infiltration. This hole was used as a water observation well. Valve covers, like those used by water utilities, completed the surface installation of the SLEX holes (Figure 3.13). SLEX-1 extended to a depth of 580 feet and SLEX-2 to a depth of 548-feet, both about 50 feet above the Allen seam.

3.2.4 Surface Rod Extensometers (REX)

Two six-point rod extensometers were installed over the centerline of Panel 2 in 8-in. diameter holes drilled by Longyear Company. The first rod extensometer assembly to be undermined was designated REX-1, and the second, located 600 ft north of REX-1 on the transverse surveying line between SLEX-1 and SLEX-2, was designated REX-2 (Figure 3.2). The rod extensometers were located over the center of the panel in order to measure differential strata extension, bed separation and possible caving which occurs as vertical displacement progresses from mine level to the surface. While the rod extensometers provide fewer monitoring points than the Sondex sensing rings, the Interfels REX equipment is of more robust construction and design. The REX installations can only monitor vertical displacement at the subsidence trough center, and are a reference check for Sondex measurements near the panel rib. The REX equipment was installed to provide vertical displacement data in the event that the SLEX assemblies failed due to lateral shearing of the plastic casings (Wade and Conroy, 1980, WCC, 1982).

Lithologic logs developed on the basis of cutting logs and borehole geophysics logs provided the basis for determining rod anchor depths in the 600-ft (REX-2) and 860-ft (REX-1) deep holes (Table 3.2). An attempt was made to position the anchors in competent strata, where a reliable grout bond

between the anchor and the rock may be sustained throughout the period of active overburden response to subsidence. The location of the rod extensometer anchors with respect to lithology is shown on Figures 3.14 and 3.15.

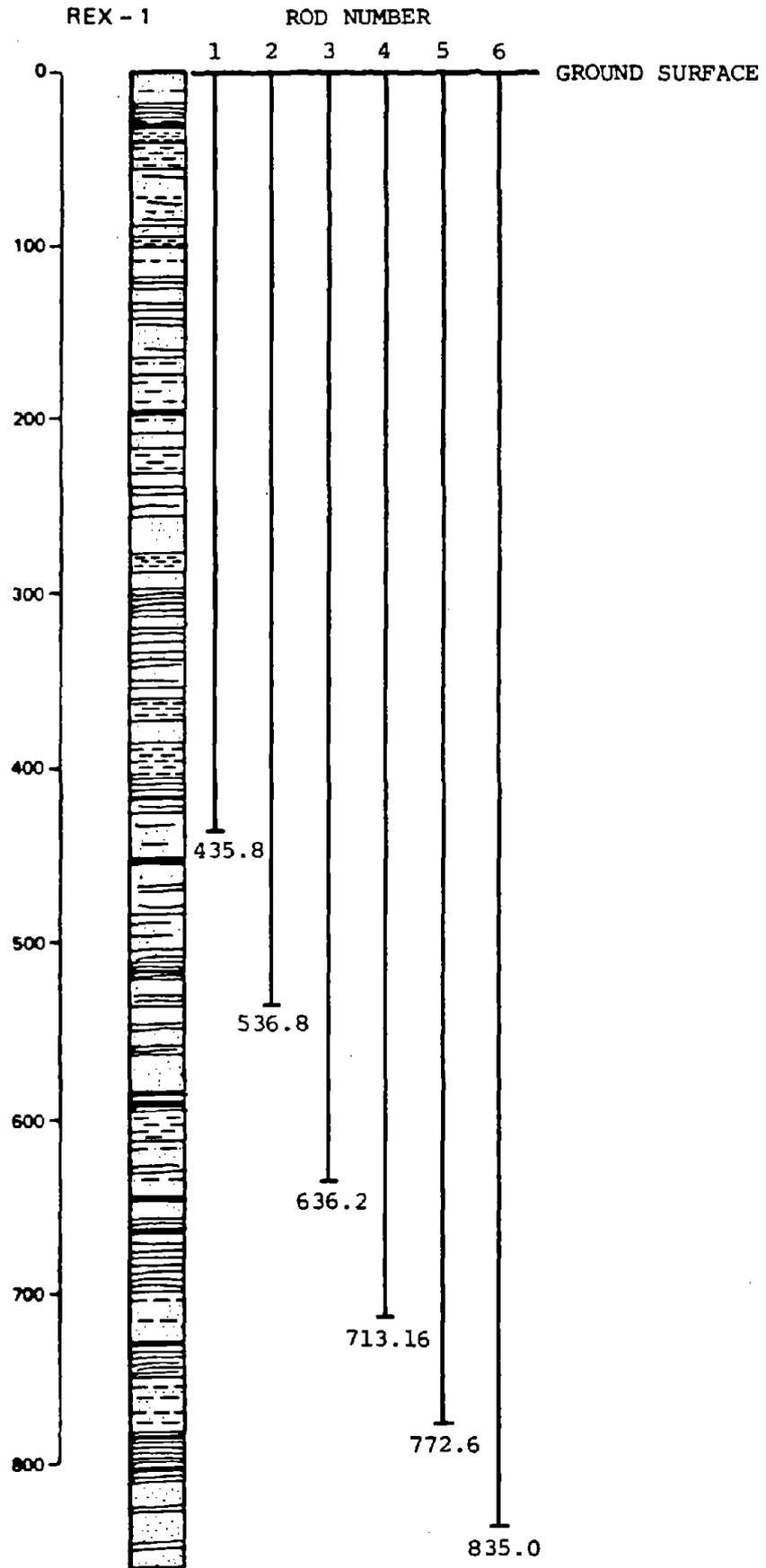
The rod extensometer equipment consists of 3/8- and 3/4-inch diameter galvanized steel pipe in 20-ft lengths. The smaller pipe was used for the three shallowest anchors in each hole while the larger pipe was used for the three deepest anchors. The hollow extensometer anchors are shown on Figure 3.16 a. The rods above the anchors were sheathed in plastic casing to isolate them from the grout which was used to bind the anchors to the surrounding rock and prevent bowing of the pipe in the hole. The six rods and casings were installed simultaneously to avoid jamming or intertwining of the rods. The TDR coaxial cable was attached to the deepest rod at 20-ft intervals using nylon cable ties so that it would extend the full length of each hole. Splices in this cable were required at some points.

During installation, water was pumped into the space between the protective plastic casing and the rods to compensate partially for pressures developed on the casing during grouting. Water was also circulated through the three deepest rods to ensure that the rods would remain open for grouting. Grouting records are shown in Table 3.3. A water/cement ratio of 1:1 (ft³ water:sack) was used, and all grout mixes were sampled.

REX-2 was grouted between July 18 and 21, 1981, first through the deepest rod (No. 6). After the grout level rose above the deepest large diameter rod, a finishing 2-in. diameter tremie hose was introduced into the hole but could only be lowered 14 ft into the hole. A total of 126 cubic ft of grout was pumped into REX-2, although calculations indicated that 166 cubic ft was required, showing the

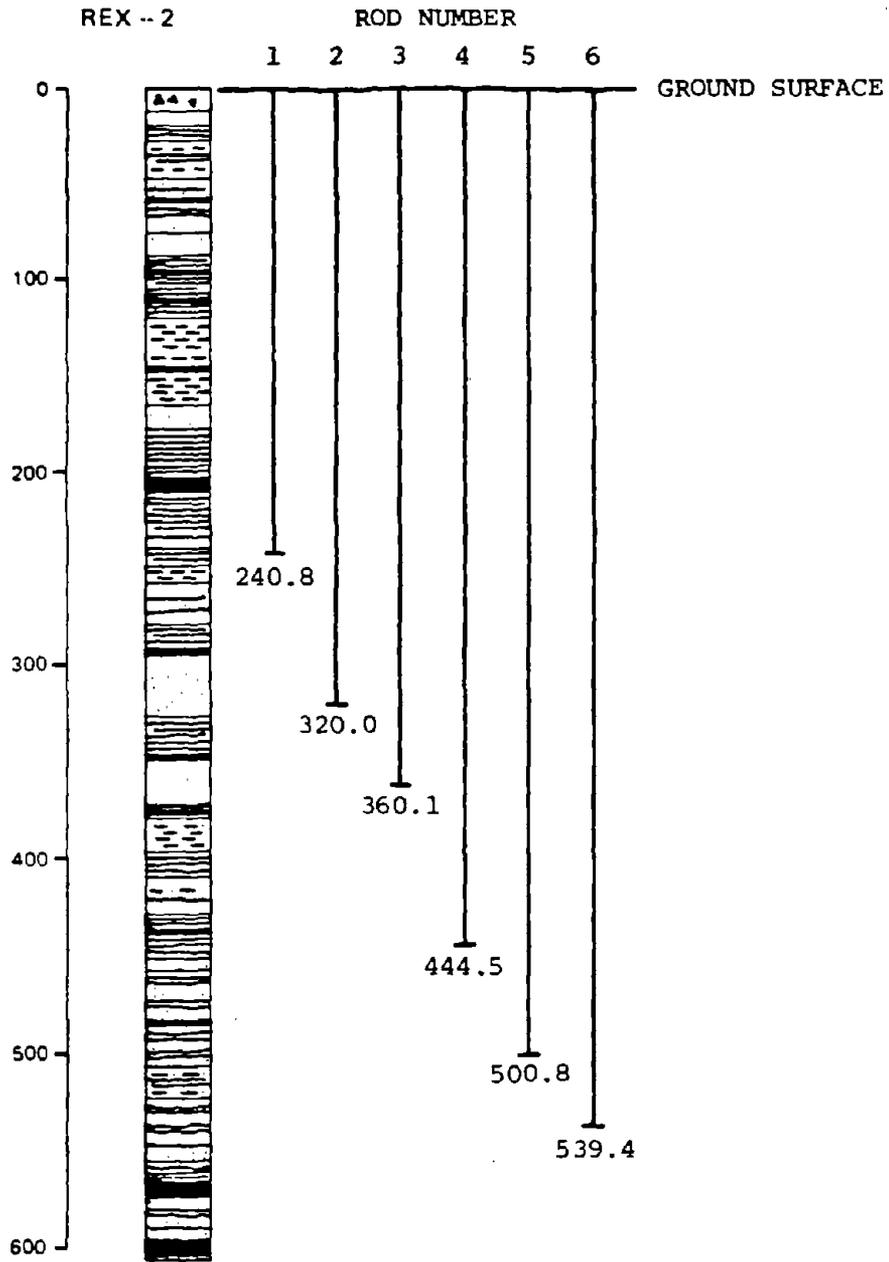
TABLE 3.2
DEEP HOLE EXTENSOMETER ROD LENGTHS

| ROD EXTENSOMETER | ROD NUMBER | DEPTH OF ANCHOR (FT) |
|---------------------|---------------|----------------------|
| REX-1 | 1 | 435.8 |
| | 2 | 536.8 |
| | 3 | 636.2 |
| | 4 | 713.2 |
| | 5 | 772.6 |
| | 6 | 835 |
| REX-2 | 1 | 241.6 |
| | 2 | 321 |
| | 3 | 360 |
| | 4 | 445 |
| | 5 | 500 |
| | 6 | 538 |



NOTE: See KEY on Figure 3.9.

FIGURE 3.14
REX-1 ANCHOR LOCATIONS AND ROD LENGTHS

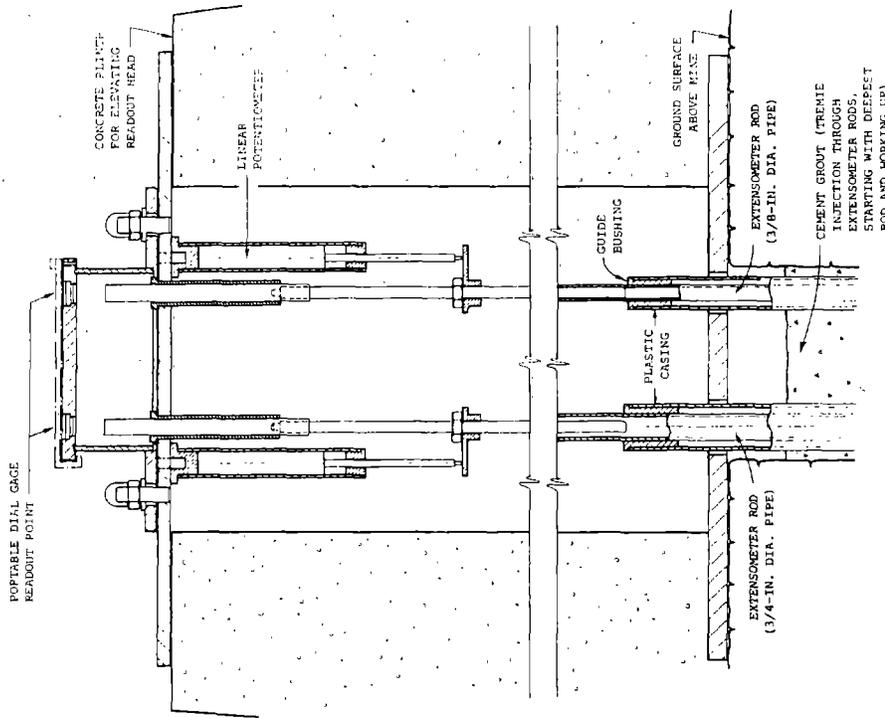


NOTE: See KEY on Figure 3.9.

FIGURE 3.15
REX-2 ANCHOR LOCATIONS AND ROD LENGTHS



a) PHOTOGRAPH: DEEP ROD EXTENSOMETER ANCHORS



b) SECTION: ROD EXTENSOMETER SURFACE ASSEMBLY



c) PHOTOGRAPH: ROD EXTENSOMETER SURFACE ASSEMBLY

FIGURE 3.16
DEEP HOLE ROD EXTENSOMETER (REX)

TABLE 3.3
DEEP HOLE EXTENSOMETER GROUTING RECORD

EXTENSOMETER: REX-1

| DATE | LIFT NO. | SAMPLE NO. | GROUT MIX | | GROUTING PRESSURE (PSI) | VOLUME (CU FT) | TIME | GROUTING ROD NO. | COMMENTS |
|---------|----------|------------|----------------|------------------|-------------------------|----------------|-----------|------------------|---|
| | | | BAGS OF CEMENT | GALLONS OF WATER | | | | | |
| 7/18/81 | 1 | 1 | 22 | 160 | 200-250 | 22 | 1610-1620 | 6 | |
| | 2 | 2 | 17 | 160 | 200-300 | 21 | 1643-1651 | 6 | |
| | 3 | 3 | 22 | 160 | 200-500 | 22 | 1717-1726 | 6 | Rod No. 4 grouted (no circulation possible) |
| 7/19/81 | 4 | 4 | 22 | 160 | 0 | 20 | 0846-0905 | 2 in. hose | Water + grout from Rod no. 1 |
| | 5 | 5 | 22 | 160 | 0 | 22 | 0945-1057 | 2 in. hose | |
| | 6 | 6 | 22 | 160 | 0 | 14 | 1320-1405 | 2 in. hose | Grout at depth of 17 ft |
| 7/21/81 | 7 | | 5 | 35 | | 5 | 1758 | Poured in hole | Grout at top of hole |
| 7/22/81 | 8 | -- | 22 | 160 | 200-300 | 22 | 1115-1128 | 6 | |
| | 9 | 9 | 22 | 160 | 200-250 | 22 | 1150-1205 | 5 | |
| | 10 | 10 | 22 | 160 | 200-250 | 22 | 1228-1241 | 4 | |

TABLE 3.3
DEEP HOLE EXTENSOMETER GROUTING RECORD (CONT)

EXTENSOMETER: REX-2

| DATE | LIFT NO. | SAMPLE NO. | GROUT MIX | | GROUTING PRESSURE (PSI) | VOLUME (CU FT) | TIME | GROUTING ROD NO. | COMMENTS |
|---------|----------|------------|----------------|------------------|-------------------------|----------------|---------------------------|--|-------------------|
| | | | BAGS OF CEMENT | GALLONS OF WATER | | | | | |
| 7/22/81 | 11 | 11 | 22 | 160 | 250-300 | 22 | 1820-1829 | 316 ft long 3/4-in. pipe | |
| | 12 | 12 | 22 | 160 | 250-300 | 22 | 1853-1904 | 316 ft long 3/4-in. pipe | |
| | 13 | 13 | 22 | 160 | 250-300 | 22 | 1927-1938 | 316 ft long 3/4-in. pipe | Rod No. 1 open |
| 7/23/81 | 14 | 14 | 22 | 160 | 200-300 | 22 | 1110-1120 | 316 ft long 3/4-in. pipe | |
| | 15 | 15 | 22 | 160 | 250-300 | 22 | 1140-1150 | 316 ft long 3/4-in. pipe | |
| | 16 | 16 | 10 | 80 | 200-300 | 10 | 1200-1205 | 316 ft long 3/4-in. pipe | |
| 17 | 17 | 22 | 160 | 300-350 | 22 | 1602-1609 | 156 ft of 3/4-in. pipe | | |
| 18 | 18 | 22 | 160 | 100-200 | 22 | 1627-1635 | 156 ft of 3/4-in. pipe | | |
| 19 | 19 | 21 | 160 | 200-250 | 21 | 1654-1705 | 156 ft of 3/4-in. pipe | | |
| 20 | 20 | 12 | 120 | 200 | 15 | 1715-1721 | 156 ft of 3/4-in. pipe | No fluid return; all rods grouted | |

effects of not being able to get a tremie base deep enough into the hole to ensure a continuous grout backfill to the surface.

REX-1 was grouted through each of the three deepest rods and through a 320-ft length of 3/4-in. steel pipe which was pulled out of the hole as grouting proceeded. Grouting was done in four sessions from June 22 to 23, 1981. The grouting program was stopped when 266 cubic ft, compared to the predicted requirement of 230 cubic ft, of grout had been pumped into the hole, circulation of water through rod No. 1 was still possible, and there was no return of grout in the 156-ft long grout rod. Loss of grout through a discontinuity intercepting the borehole was considered the most plausible explanation for the high grout take. Despite the indications that the hole was not filled with grout, the rods only settled approximately 2 in. when support brackets that had been holding them during grouting were removed. This movement was probably a result of bowing of the rods extending above the grouted portion of the hole to the surface. Sounding of the grout was not possible because of the number of rods in the hole.

Completion of the REX installations involved construction of 4-ft high concrete pedestals, as shown on Figure 3.16 b. REX-2 rods were outfitted with Interfels linear potentiometers as shown on Figure 3.16 c. In order to allow operation of the linear potentiometers with the SINCO scanner/recorder (Figure 3.6), SINCO personnel added extra resistors to the Interfels junction box. The 4-in. range linear potentiometers were first connected to an Interfels junction box from which a multi-conductor cable was extended to the SINCO ADAS scanner/recorder.

3.2.5 Groundwater Samples

As mentioned above, the SLEX-2 installation was adapted for use as a groundwater monitoring well while the SLEX-1 installation unintentionally functioned as a monitoring well due to leaks in the SLEX casing. It was initially intended to use these installations for monitoring not only groundwater levels but also groundwater quality. However, the costs required to carry out a rigorous water quality sampling program were not justified because there was no actual aquifer in the overburden. Consequently, it was decided that only gross changes in a few index properties, such as TDS and pH could be monitored.

3.3 MINE LEVEL INSTRUMENTATION

The underground instrumentation plan shown on Figure 3.3 was designed to characterize stress redistribution and displacement phenomena that accompany longwall mining and are basic to the eventual development of subsidence above the panel. Two general areas located 600 feet apart, corresponding to principal instrumentation areas on the surface, were instrumented underground. A total of 18 stressmeters were installed to monitor stress redistribution in the pillars and floor of Panel 2. Roof-floor convergence was investigated by installing ten convergence stations. Roof and floor extensometers were installed at two locations to monitor discrete strata separation. An absolute stress measurement technique was employed at ten sites with the aim of characterizing the initial stress condition in the instrumented areas.

Most of the underground instrumentation was installed in rotary, diamond-drilled holes drilled by Earth Exploration of Utah using a CP-8 drill. Compressed air and water lines leading to the longwall face were tapped for use with the drill, and a special line from the 4160 volt power source

was provided by the mine. Underground drilling and installation was performed from August to September, 1981, in the headgate entries of Panel 2.

Following completion of underground instrumentation installation, the mine surveyors surveyed the locations of all instruments using a Zeiss TH 43 theodolite and a 300-ft steel tape.

3.3.1 Drill Hole and Roof Support Documentation

In connection with site characterization tasks, Woodward-Clyde engineers mapped roof support and roof falls along the instrumented headgate areas of Panel 2 during the course of instrument installation. The type of support used gives a general indication of the stability of the ground, and may have a localized impact on the absolute value or the rate of development of stresses and strains (and therefore the caving behavior) as undermining progresses. Support types included steel H-beams on timber posts and wooden spacers in the more heavily-supported areas and roof bolts, steel mesh and straps in the more stable areas.

At the time of mapping, the area surrounding the first instrumented section, between 18+00 and 14+00, was extensively supported by H-beams on timber posts and wooden spacers. At the second location, between 14+00 and 4+00, the support was significantly less substantial, consisting chiefly of rock bolts, with a few H-beams and wooden spacers used in roof fall areas. The support density decreased markedly at the north end of the panel, as sandstone was intercepted in the roof. Roof falls, ranging from small falls to one extending to 8 ft above the mine roof at 12+50, were mapped throughout the area, and will be discussed in Section 5.1.2.

Drilling conditions were documented during drilling of the roof and floor rod extensometer holes and are shown on Figure 3.17 for the holes drilled at the first location. Conditions encountered during the drilling of these holes are representative of conditions encountered at the second location. The roof strata and coal seams were easily drilled. Drilling in the floor was hampered by the existence of hard strata at a variable depth beneath the immediate mine floor. The existence of the hard strata made drilling of subhorizontal stressmeter holes under the mine panel particularly difficult, and the measures adopted for completing these holes will be described in the following stressmeter discussion.

Other drilling difficulties were encountered during initial horizontal drilling of the 3-in. diameter stressmeter holes, and a 2-in. diameter hole was used for most of the pillar stressmeter holes.

During drilling of the subhorizontal floor holes at the first location water flowed out of fractures in the mine floor up to 20 ft away from the holes and circulation of drilling water was lost.

3.3.2 Stressmeters

Preliminary testing for the use of grouted hydraulic borehole pressure cells indicated that expansive grout would not generate a pre-stress pressure on a cell due to voids forming in the grout around the cell. It was therefore decided to install ten Irad vibrating stressmeters, Model VBS-1 (Figure 3.18), at each instrumentation section. The stressmeter records changes in the resonant frequency of a highly tensioned steel wire clamped diametrically across the gage which reflects changes in stress acting in the direction of the wire. One pillar adjacent to the longwall panel in each section was instrumented with three vertically-oriented

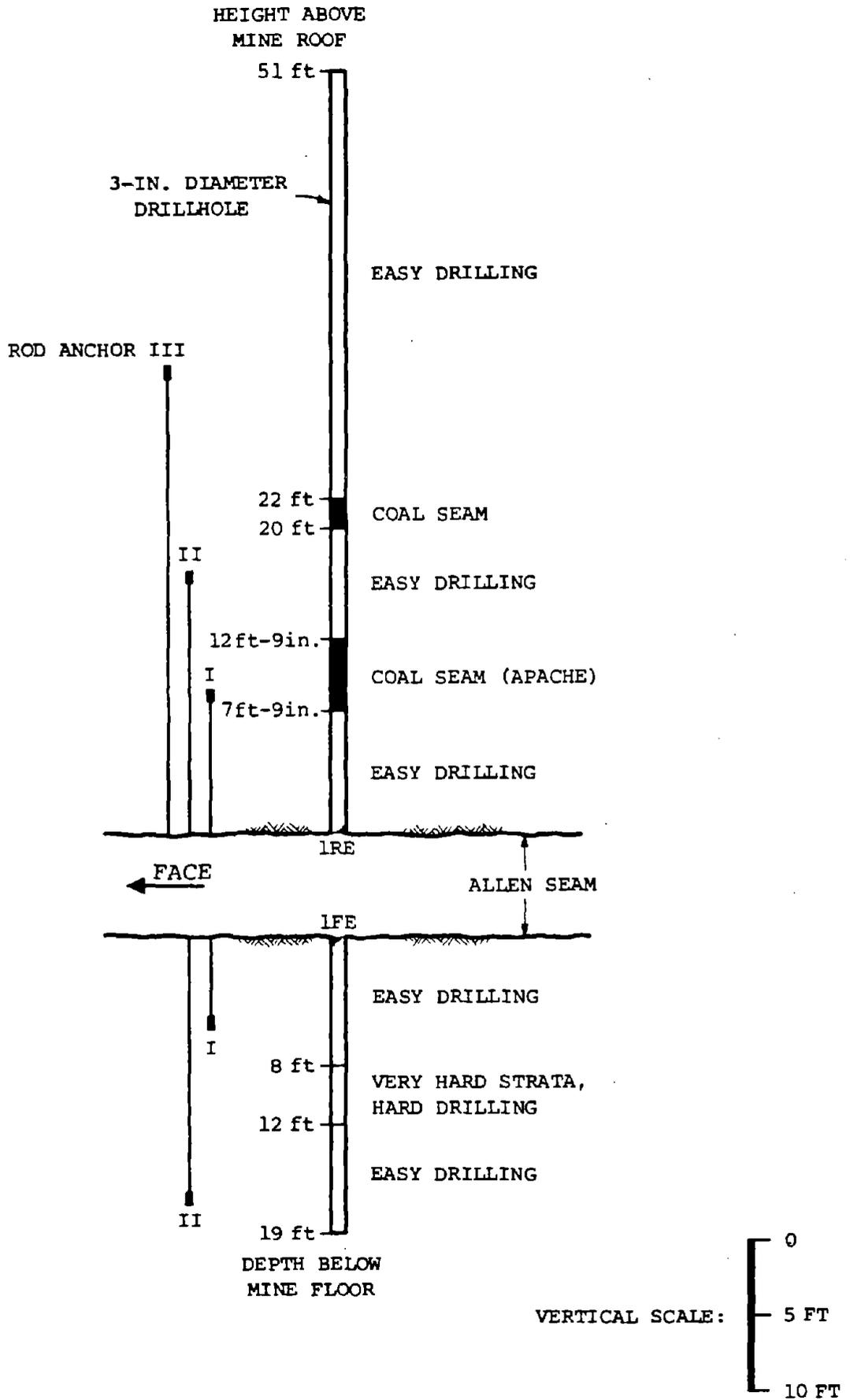
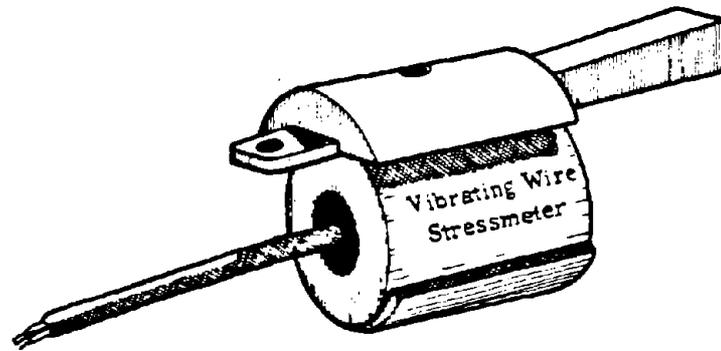
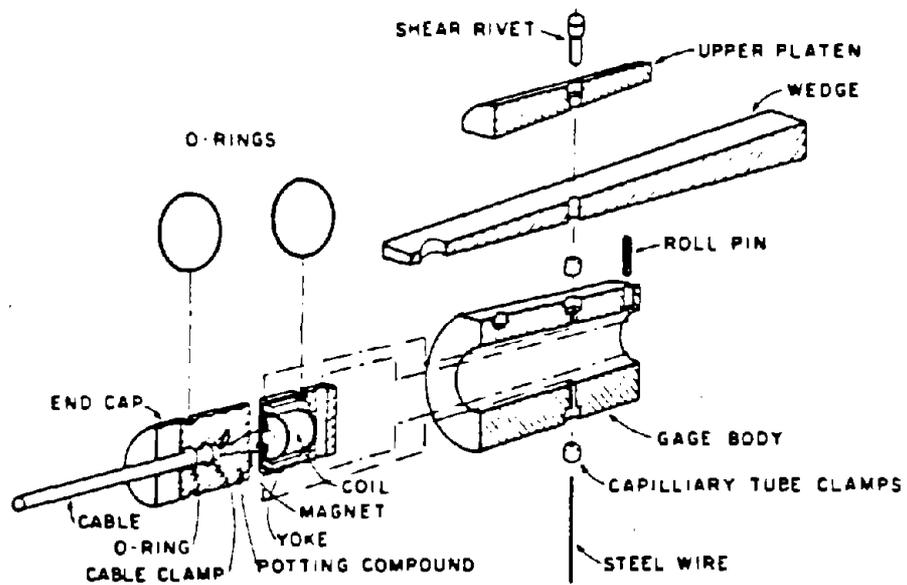


FIGURE 3.17

DRILLHOLE CONDITIONS AND ROD ANCHOR LOCATIONS, 1RE AND 1FE



a) GAGE READY FOR INSTALLATION IN 1.5-in. DIAMETER DRILLHOLE



b) EXPLODED VIEW OF GAGE COMPONENTS

FIGURE 3.18
STRESSMETER DETAILS

stressmeters at depths of 10, 20, and 40 ft, and four horizontally oriented stressmeters at depths of 10 and 20 ft into the pillar. Three other stressmeters were planned for installation beneath the panel in holes drilled at an angle of 5 degrees below horizontal, for the purpose of monitoring changes in stress in the longwall panel floor as mining progressed. The stressmeters were equipped with enough cable to allow remote monitoring 200 ft from the installations. This arrangement allowed recording of stress redistribution within the pillar and under the panel before, during, and after the face passed the instrumented pillar. This stressmeter layout was designed to provide insight into the load transfer mechanism acting on the pillars and panel, a function of both face location and location within the pillar. In the case of the floor stressmeters, the long lead wires were intended to permit remote monitoring of goaf loads as caving occurs behind the face.

Holes for stressmeter installation were diamond drilled in pillars to a depth about 2 ft short of the total hole depth. At the first location, 3-in. diameter holes were drilled. Drilling difficulty at this location resulted in the decision to use 2-in. holes at the second location. The holes were then extended 3 ft deeper with a 1-1/2-in. diameter bit. Stressmeters were installed using the Irad hydraulic setting tool and setting rods fabricated into 10-ft lengths from surplus larger diameter surface rod extensometer pipes (Figure 3.15). The Irad installation procedure was followed, and included preloading the stressmeter 100 to 200 units above the initial reading. The setting was accomplished by hydraulically pulling the wedge in between the gage and the upper platen. The vertical stressmeters were installed such that the vibrating wire was maintained in a vertical position. The horizontal stressmeters were turned clockwise through a 90 degree angle prior to preloading in order to position the vibrating wire for measurement of horizontal stress changes.

Drilling of the 2-in. diameter holes and installation of the stressmeters in pillars was straightforward and efficient. Because the shale floor and underlying strata were difficult to drill, however, only two subhorizontal floor holes were drilled to depths of 40 and 120 ft at the first location. These holes were drilled at an angle of about 10 degrees from horizontal through the pillar, in order to provide better stabilization of the drill steel. This configuration is indicated on Figures 3.3 and 3.19. At the second location, all three planned holes (40, 120, and 200 ft deep) were drilled directly into the floor, as shown on Figure 3.3. Stressmeter installation in the floor holes was successful in all except one drilled hole. Two attempts were made to install a stressmeter in the 200-ft deep hole at the second instrumentation location. In both cases the stressmeter was preloaded, but would not release from the setting tool, as proven by the fact the stressmeter without the wedge was pulled out with the setting tool. After the loss of the last two available wedges in this way, further attempts to install a stressmeter in this hole were abandoned. The reasons for failure of installation in this 200-ft hole were thought to be two-fold. One, the hole was not stable and tended to squeeze in on the installation rods, requiring forceful advance of the rods. The second explanation is related to the fact that the rods should move out of the hole when the hydraulic pressure is released, indicating disengagement of the setting tools from the stressmeter. During installation of stressmeters to depths greater than 40 ft, this characteristic movement was not observed because the steel installation rods were too heavy and the ground too confining for the hydraulic setting tool to move the rods.

Leads from the stressmeters were connected to a junction box and then to an Irad Datalogger connected to two 12-volt batteries in parallel, in order to allow remote monitoring on a regular basis (Figure 3.20).

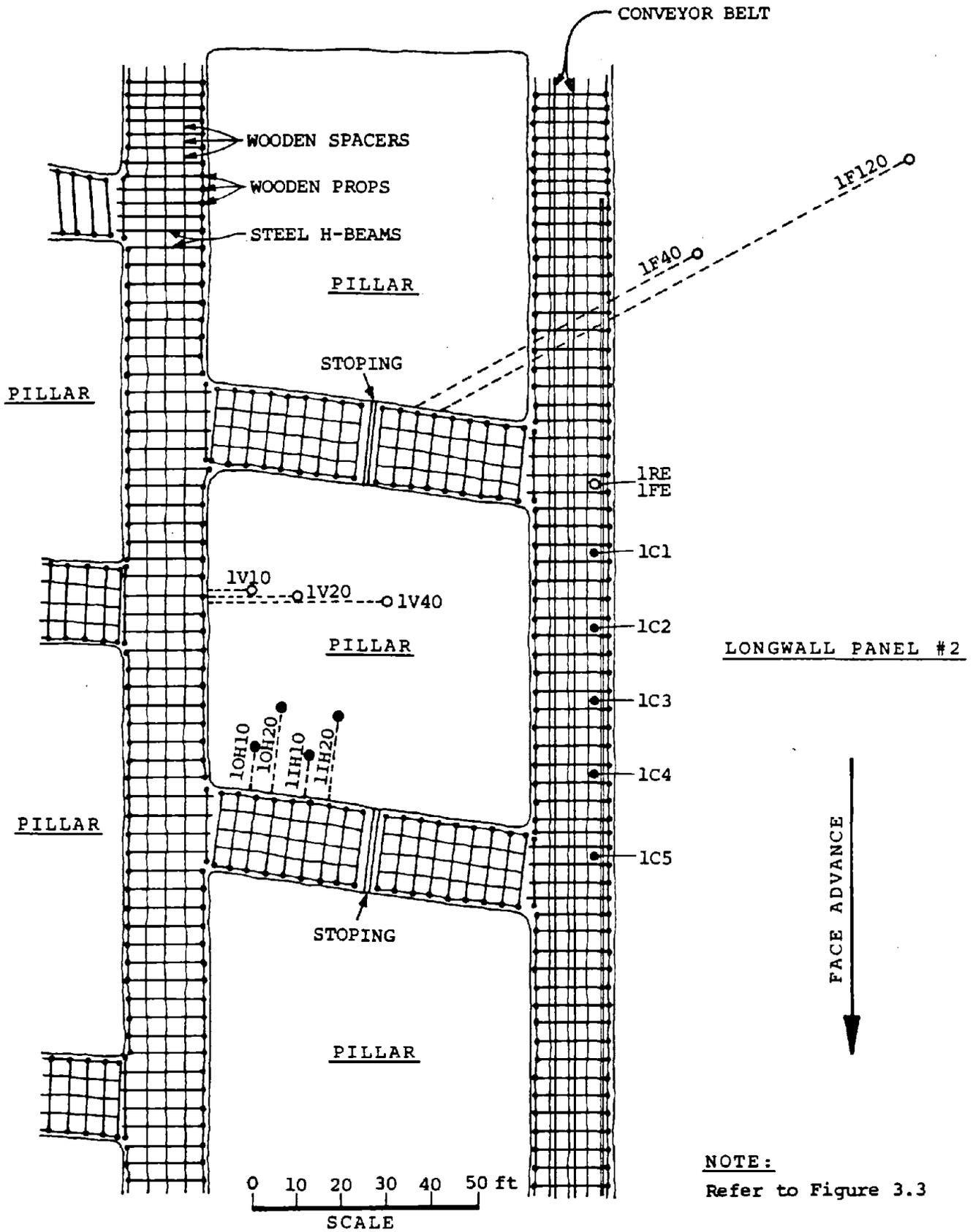


FIGURE 3.19
MINE LEVEL INSTRUMENTATION AT LOCATION 1

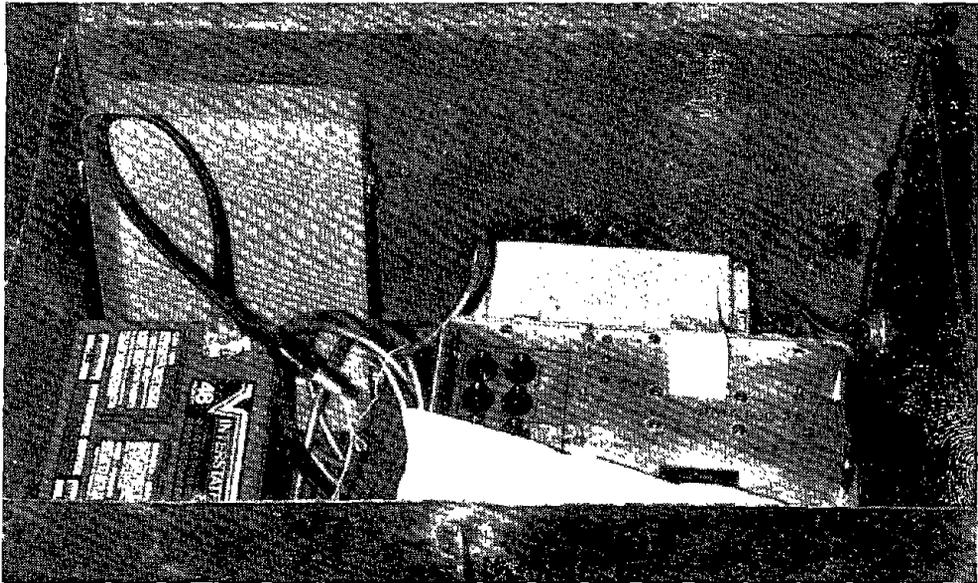


FIGURE 3.20

VIBRATING WIRE STRESSMETER DATALOGGER

3.3.3 Roof and Floor Extensometers

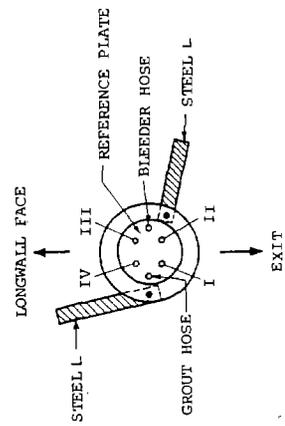
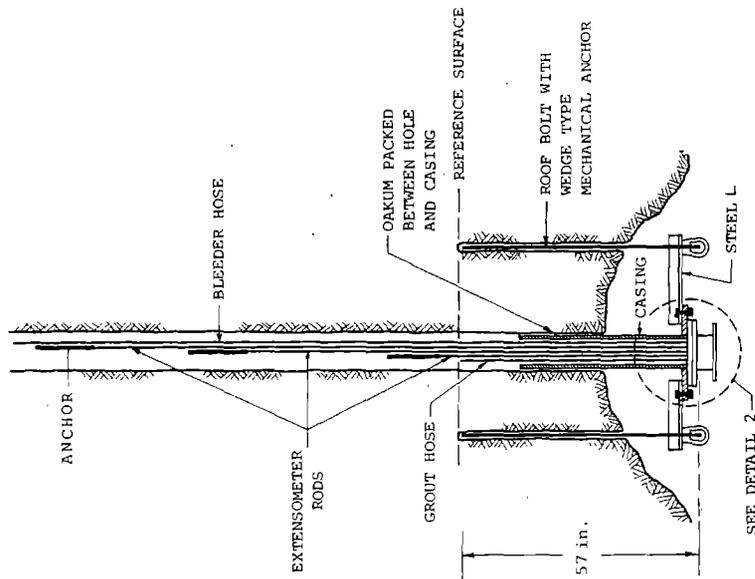
An Interfels roof and floor extensometer assembly was installed in the headgate entry at both instrumentation locations. The purpose of the four-point roof extensometer was to measure any separation of strata overlying the coal seam as the face approached. The roof extensometers were installed to a distance of 50 ft above the coal seam, for a height of approximately eight times the mined seam thickness (Table 3.4). The two-point floor extensometers were installed to a depth of 20 ft in order to detect floor heave which may occur as mining proceeds. While the optimum location for monitoring discrete strata movement independent of pillar effects would be the middle of the headgate entry, this was not possible as a conveyor belt occupied the middle of this entry.

The Interfels rod extensometer assemblies are shown on Figure 3.21. Drilling of the 3-in. diameter holes for the extensometers involved moving the CP-8 drill beneath the conveyor belt to a position immediately adjacent to the panel. Three-in. diameter holes were drilled for all extensometers except the floor hole at the first location, where hard strata was encountered at a depth of 8 ft (Figure 3.17). A 2-in. bit was used to drill the remainder of that hole, to a depth of 19 ft. The roof spalled during drilling of the roof hole, necessitating support of the extensometer head plate by roof bolts and casing, as shown on Figure 3.21 a.

The Interfels steel rods, 0.4 in. in diameter, were installed inside the plastic tubing to prevent grouting of the rods. As shown on Figure 3.21 b, the two-position locking socket at the anchor allowed removal of the rods for length adjustment if necessary. Along with the rods, one length of the black protective plastic pipe was installed as

TABLE 3.4
MINE LEVEL EXTENSOMETER ROD LENGTHS

| ROD EXTENSOMETER | ROD NUMBER | DEPTH OF ANCHOR (FT) |
|------------------|---------------|-------------------------|
| 1 RE | I | 9.3 |
| | II | 17.4 |
| | III | 32.1 |
| 1 FE | I | 5.8 |
| | II | 17.6 |
| 2 FE | I | 9.4 |
| | II | 12.7 |
| | III | 30.8 |
| | IV | 47.2 |
| 2 FE | I | 5.1 |
| | II | 21.1 |

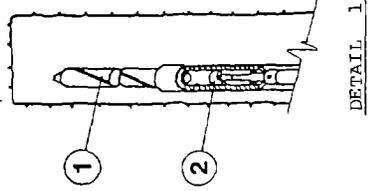


ORIENTATION

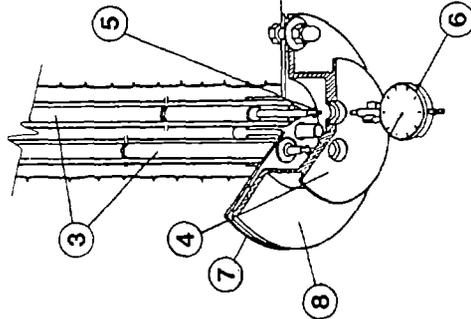
a) SCHEMATIC SECTION

LEGEND:

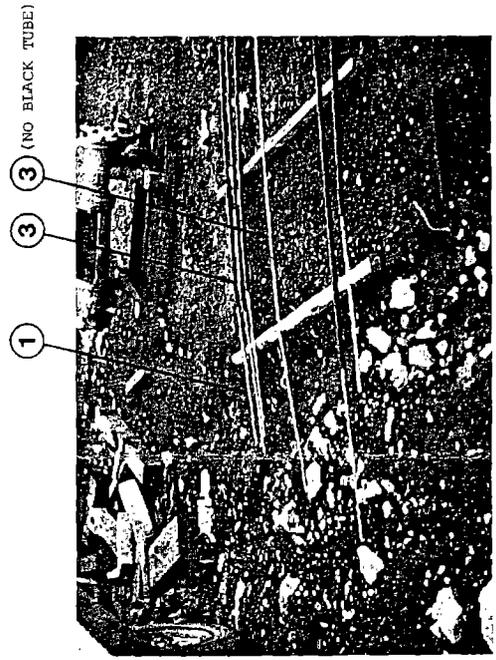
- 1 Ribbed steel anchor, fixed by grout injection
- 2 Anchor cone with measuring and calibrating notch for functional control
- 3 Extension rods in plastic protective tube, with lock mandril at anchor end, and with sensor bar at head end
- 4 Extensometer head with rod guides and rock bolts for fixation at borehole mouth
- 5 Sensor bar and dial gauge bar; recess for placing dial gauge or electrical sensor
- 6 Dial gauge with dial gauge bar
- 7 Inner cover plate
- 8 Outer measuring plate



DETAIL 1



DETAIL 2



c) PHOTOGRAPH: ROD EXTENSOMETER ANCHORS

FIGURE 3.21
MINE LEVEL INTERFELS ROD EXTENSOMETER

a grout hose and one length was installed as a bleed line through extra holes in the Interfels steel plate (Figure 3.21 a). The floor installations were recessed and covered with a steel plate to prevent damage during mining operations.

Grout for the underground extensometers holes was mixed in 2 to 3 gallon batches, with water cement ratios of 1.5:1, and approximately 10 ounces of an expansive agent (SIKA Intraplant-N) per batch. The grout plan consisted of one day of grouting for each floor extensometer and two days for each roof extensometer. The first batch of grout in the roof was used to seal the casing in place and allowed to set overnight before grouting the rest of the hole. Grouting records are shown in Table 3.5.

Grouting of the first roof extensometer installation (1RE) was performed through a 5-ft grout hose. After pumping the calculated amount of grout on the second day of grouting, grout was observed to leak from fractures 10 ft away from the extensometer hole, although no grout was returned through the bleeder hose. Grouting was ceased then performed for two more days through the bleeder hose until leakage of grout was observed in roof fractures. On the fourth day of grouting, a grout leak was observed along the deepest rod. Installation of this rod had required splicing of two pieces of the black protective tubing because of imperfections inside this tubing. Removal of the rod for examination resulted in return of the grout, indicating that the splice in the black protective tubing at a depth of 15 feet had broken and the hole was filled with grout to that depth. In order to assure that the next longest anchor would be grouted, the black protective tubing for the longest rod (Rod IV) was then used as a grout tube. An amount of grout estimated to fill the hole (10 gallons) was

TABLE 3.5
MINE LEVEL EXTENSOMETER GROUTING RECORD

| EXTENSOMETER: <u>1FE</u> | | | | | | |
|---|-----|---------|----------------|------------|--------------|--|
| DATE | MIX | WATER | TYPE II CEMENT | INTRAPLAST | COMMENTS | |
| 8-26-82 | 1 | 2½ gal | 30 lb | 15¼ oz | | |
| 8-26-82 | 2 | 3 gal | 40 lb | 15¼ oz | Sample taken | |
| EXTENSOMETER: <u>1RE</u> | | | | | | |
| DATE | MIX | WATER | TYPE II CEMENT | INTRAPLAST | COMMENTS | |
| 8/27/81 | | 2½ gal | 25 lb | 10 oz | | |
| 8/31/81 | 1 | 2½ gal | 30 lb | 10 oz | | "Plug" of grout placed in bottom of hole |
| 8/31/81 | 2 | 2½ gal | 20-30 lb | 10 oz | | |
| 8/31/81 | 3 | 2½ gal | 20-30 lb | 10 oz | | |
| 8/31/81 | 4 | 2½ gal | 20-30 lb | 10 oz | | |
| 8/31/81 | 5 | 2½ gal | 20-30 lb | 10 oz | | |
| 8/31/81 | 6 | 2½ gal | 20-30 lb | 10 oz | | |
| 8/31/81 | 7 | 2½ gal | 20-30 lb | 10 oz | | |
| 8/31/81 | 8 | 2½ gal | 20-30 lb | 10 oz | | |
| 8/31/81 | 9 | 2½ gal | 20-30 lb | 10 oz | | Grout coming out of fractures in roof 10 feet from hole; no grout returned from bleed hose |
| Note: grout injected through grout hose | | | | | | |
| 9/1/81 | 10 | 2½ gal | 15-20 lb | 10 oz | | |
| 9/1/81 | 11 | 2½ gal | 15-20 lb | 10 oz | | |
| 9/1/81 | 12 | 2½ gal | 10-15 lb | | | No Intraplast-N available; water coming out of fracture in roof 10 ft from hole |
| 9/2/81 | 13 | 2-3 gal | 15-20 lb | | | Sample taken |
| 9/2/81 | 14 | 2-3 gal | 15-20 lb | | | |
| 9/2/81 | 15 | 2-3 gal | 15-20 lb | | | |
| 9/2/81 | 16 | 2-3 gal | 15-20 lb | | | |
| 9/2/81 | 17 | 2-3 gal | 15-20 lb | | | |
| 9/2/81 | 18 | 2-3 gal | 15-20 lb | | | Note: grout injected through bleed hose |

TABLE 3.5
MINE LEVEL EXTENSOMETER GROUTING RECORD (CONT)

| EXTENSOMETER: <u>2FE</u> | | | | | |
|---|-----|--------|-------------------|------------|---|
| DATE | MIX | WATER | TYPE II CEMENT | INTRAPLAST | COMMENTS |
| 9/8/81 | 19 | 2½ gal | 15-20 lb | | |
| 9/8/81 | 20 | 2½ gal | 15-20 lb | | |
| 9/8/81 | 21 | 2½ gal | 15-20 lb | | |
| 9/8/81 | 22 | 2½ gal | 15-20 lb | | Grout came out bleed hose |
| Note: grout injected through No. 4 plastic tube | | | | | |
| 9/24/81 | 1 | 2½ gal | 20 lb | 20 oz | |
| 9/24/81 | 2 | 3 gal | 25 lb | 20 oz | |
| 9/24/81 | 3 | 3 gal | 25 lb | 20 oz | Grout returned at top of hole |
| 9/28/81 | | | | | Grouted at 20 ft depths; rich grout plug placed at 8 ft |
| 9/29/81 | | | | | Replacement for rod No. 1 installed and grouted with about 1 gal rich grout |
| 10/01/81 | | | | | Level of grout in hole about 2 in. below plate |
| EXTENSOMETER: <u>2RE</u> | | | | | |
| DATE | MIX | WATER | TYPE II CEMENT | INTRAPLAST | COMMENTS |
| 9/28/81 | 1 | 2 gal | 25 lb | 10 oz | |
| 9/29/81 | 2 | 2 gal | 20 lb | 20 oz | |
| 9/29/81 | 3 | 2 gal | 15-20 lb | 10 oz | Sample taken |
| 9/29/81 | 4 | 2½ gal | 15-20 lb | 10 oz | |
| 9/29/81 | 5 | 3 gal | 15 lb | 10 oz | |
| 9/29/81 | 6 | 3 gal | 15 lb | 10 oz | |
| 9/29/81 | 7 | 2 gal | 15 lb | 10 oz | |
| 9/29/81 | 8 | 3½ gal | 20 lb | 10 oz | Grout returned in bleed hose after pumping ¼ gallon |

pumped and return through the bleed hose occurred, indicating that open fracturing in the first 15 ft of hole had caused the loss of grout pumped previously.

Grouting of the second floor extensometer installation (2FE) proceeded successfully the first day, showing a return at the top of the hole after pumping three batches. Four days later, it was discovered that the grout had dropped to a depth of 20 ft in the 21-ft deep hole indicating that there were fractures in the floor at a depth of 20 ft. The deep anchor was grouted in place but the shallow anchor was lost in the hole when tested. A 1-gallon batch of rich grout was poured over a wadded paper plug at a depth of 8 ft. A short rod was installed when the cemented plug had cured and the hole was successfully grouted with a rich mix, resulting in a grout level 2 in. below the reference plate.

3.3.4 Convergence Measurements

Ten convergence stations were established, along the head-gate entry at 20-ft intervals (Figure 3.3). These reference points were installed in order to develop a relationship between roof to floor convergence and face advance as well as extensometer measurements, and surface subsidence measurements.

Woodward-Clyde engineers drilled 1-in diameter holes to a depth of 2 ft in the roof and 1 ft in the floor with a mine-owned, pneumatic stoper drill. A mechanical roof bolter was used to install 3/4-in. rebar in the holes with Celtite epoxy cartridges. The rebar lengths had been tapped to allow mounting of SINCO reference points (Figure 3.22). Reference points were epoxied into the floor rebar installations and the area surrounding the point was grouted in order to prevent damage to the points. The roof rebar installations were fitted with a removable bolt, to preclude

removal of the steel balls between monitoring sessions and allow replacement of the steel balls whenever a set of measurements was taken.

3.3.5 Absolute Stress Measurement

Department of Energy reviewers of the instrumentation plan originally submitted for this project requested that a determination of in-situ stresses be made for the instrumented mine. Since the overcoring technique, a proven but expensive technique for stress determination, was not included in the project budget, a surface stress relief technique (U. S. Bureau of Mines, 1981) was applied at ten locations. This undercoring technique involves measurement of surface displacements around a 6-in. hole which are transformed to stresses existing on the measurement surface according to rock mechanics theory. In a continuous, isotropic, elastic medium, the stresses on three orthogonal surfaces may be transformed to in-situ regional stresses.

Ten locations on the roof and ribs in the vicinity of the instrumented areas were selected (Figure 3.3) for application of this method. A steel template and 3/8-in. diameter stainless steel reference pins were fabricated as specified by the U. S. Bureau of Mines (USBM) (Figure 3.23). The template was used to mark rosette pin locations and the 6-in. diameter hole at the selected locations. Pin holes were drilled with an electric hand drill and a 1/2-in. diameter masonry bit, to a depth of 1/2 in., and the reference pins set with a paste epoxy, PC-7. The distances between the pins across three diameters were measured with a 10-in. Whittemore gauge. Three diameters were distinguished by three marks at three reference pins (dash, circle, cross), and these three diameters are referred to as AA', BB', and CC'. The diameters were measured several times prior to

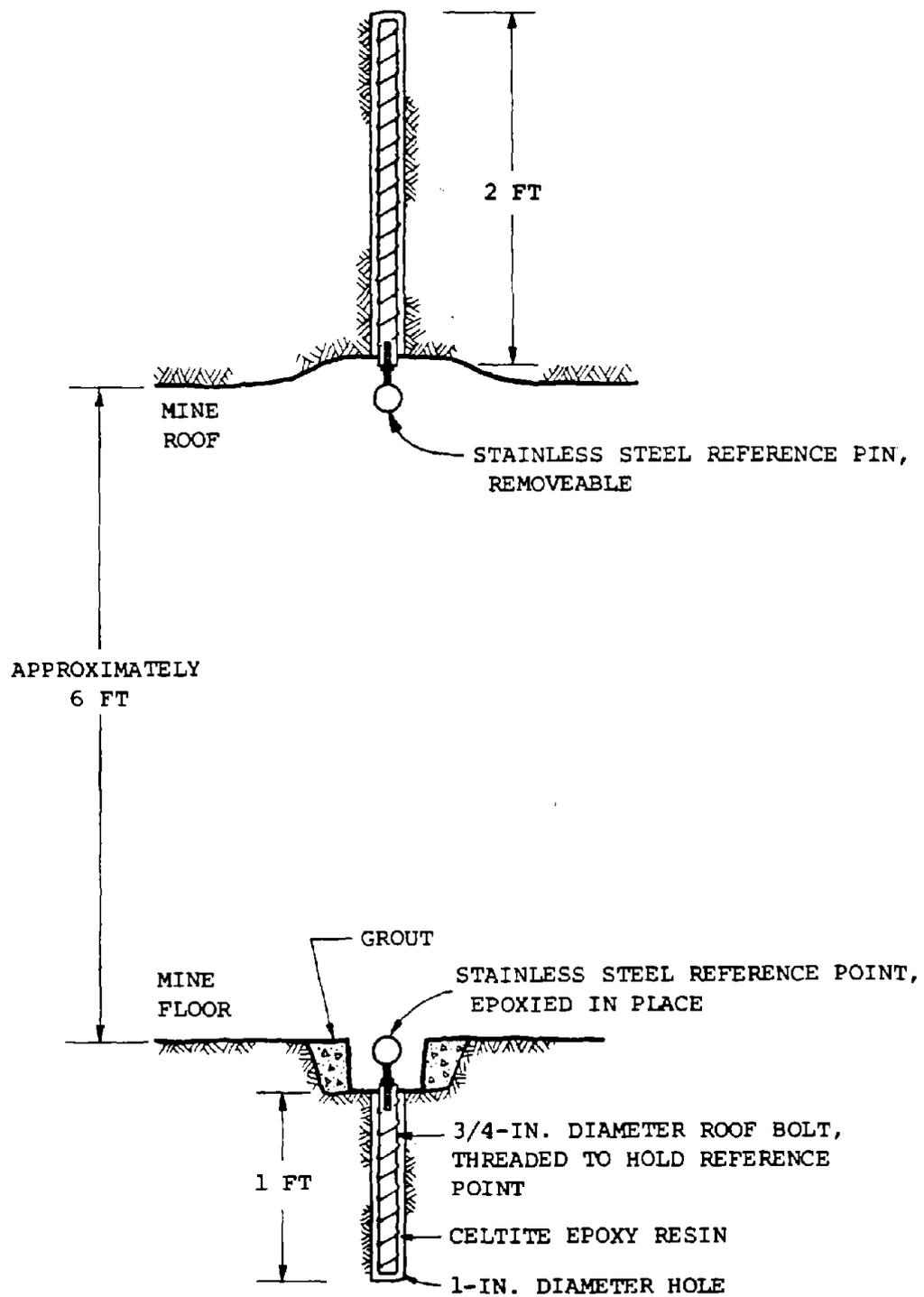
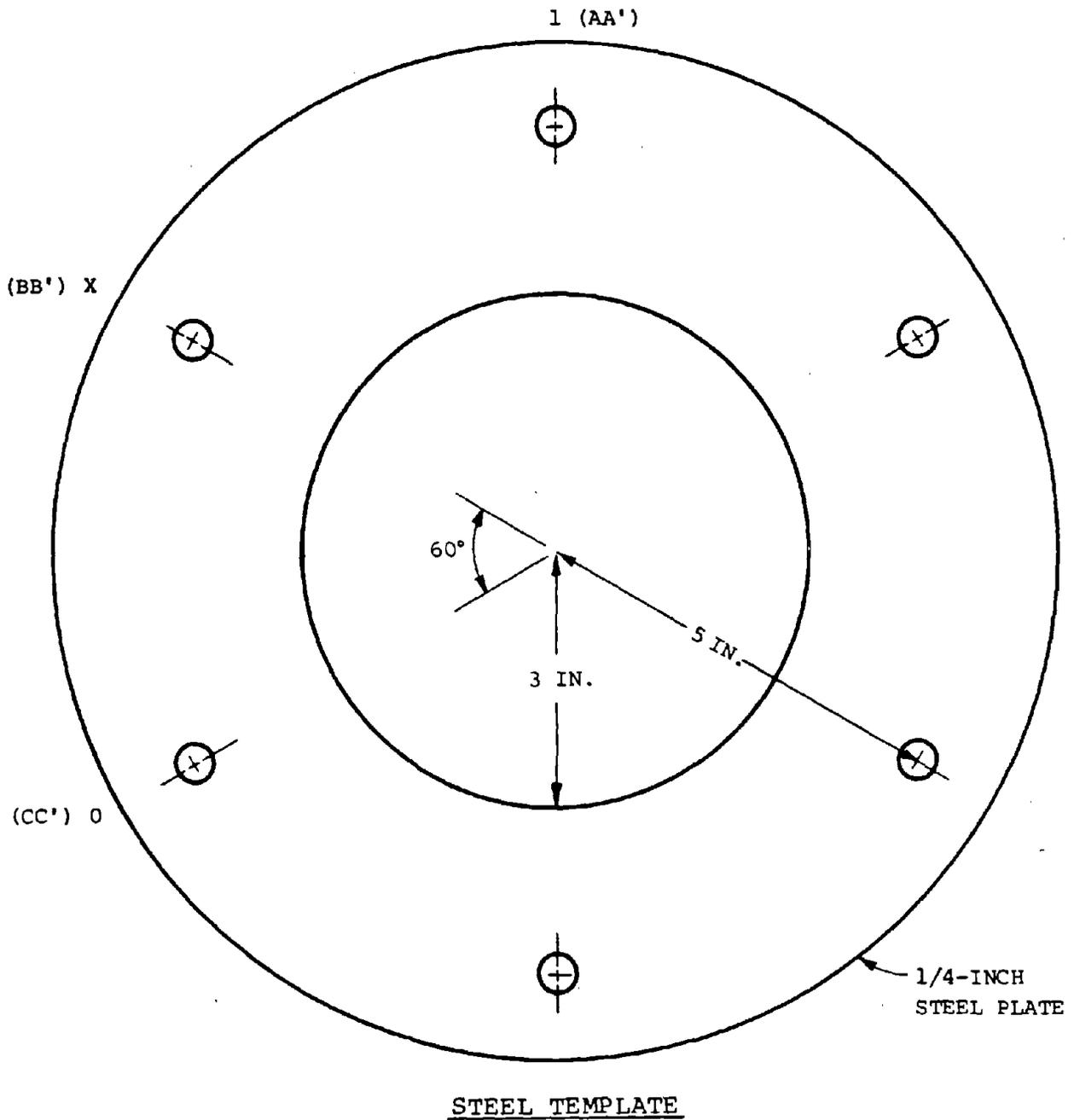
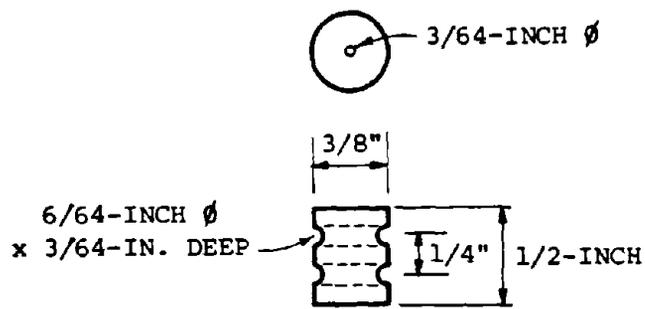


FIGURE 3.22
 ROOF-FLOOR CONVERGENCE STATION IN MINE ENTRY



STEEL TEMPLATE



STAINLESS STEEL REFERENCE PIN

FIGURE 3.23
ABSOLUTE STRESS MEASUREMENT TEMPLATE AND PINS

coring of the 6-in. hole, and these values were averaged to be used as initial diameters for calculation purposes. Mine engineers at the coal mine surveyed the stress relief locations including the bearing of the AA' diameter.

The 6-in. hole was drilled at the first five locations (1AS1-1AS5) using water circulation. No core was retrieved, and only two of these five locations were successfully drilled. In the other three cases, a reference pin came loose during drilling. The second set of five measurements was air drilled and core was retrieved at three of the sites. Reference pins fell out during drilling at the other two locations.

Measurement of the diameter at the five successful locations were continued after drilling, to investigate the change in diameter as a function of time. Results of this test are discussed in a later section.

4.0 DATA ACQUISITION METHODOLOGY

Monitoring trips for data acquisition were scheduled on the basis of location of the face with respect to the instrumented areas. Monitoring trips were planned to occur before, during and after the face passed each instrumented section, and after mining of the panel was complete. The purpose of visiting the site prior to face advance past an instrumented area was to collect data from manually-operated instruments and to increase the monitoring frequency of the automatic data recorders so that an adequately continuous profile of stress and strain development was obtained during face approach. As the face reached the first instrumented area, data from manually read instruments situated underground was acquired while the instruments were still safely accessible. Following advance past the instrumented area, manually-read surface and overburden instruments were monitored to allow investigation of the rate of surface and overburden response to mining, and the underground data acquisition system was moved to the second location. Coordination of data acquisition efforts with face advance involved frequent contact with mine personnel. The monitoring trips planned and completed are shown on Figure 4.1. In order to allow correlation of underground, overburden and surface instrument data, the measurements were made within as short a time period as possible. As can be seen from Figure 4.1, monitoring continued until the face was located almost 200 ft past the first instrumented section at which time this project was transferred to the U. S. Bureau of Mines.

4.1 SURFACE MOVEMENTS

Surface surveys and regular automatic recording of the surface strainmeters provided documentation of surface movements occurring as a result of mining between August, 1981, and May, 1982.

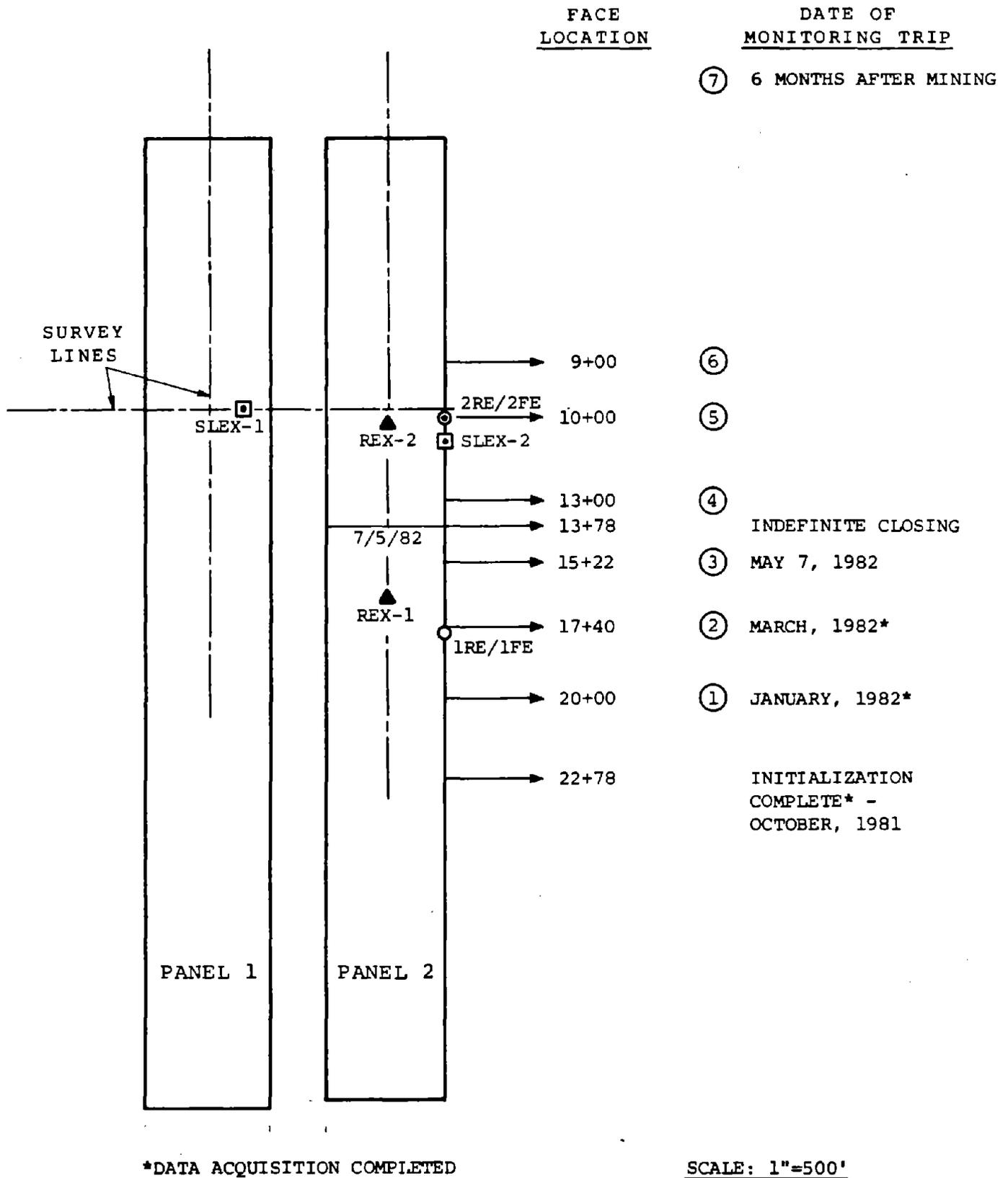


FIGURE 4.1
SCHEDULE OF MONITORING TRIPS

4.1.1 Surface Displacements

A total of four surface surveys were completed by the surveying subcontractor, Benchmark Control Services, prior to May 7, 1982. The initial survey was conducted on August 2, 1981. Surveys were then completed in conjunction with the January and March monitoring trips. A final survey under this contract was completed in May.

In order to monitor vertical displacements of the surface survey points, level surveys were conducted using a Wild NA-2 self-leveling level and a Lovar steel second order survey rod. Horizontal displacements of the survey points were monitored by the comparison of horizontal electronic distance measurement (EDM) surveys performed with a Wild T-2 Universal Theodolite an AGA Model 14-A Geodimeter and a Retroray prism.

The vertical and horizontal coordinates of the rod extensometer pedestals, the inclinometer casing and ADAS the strainmeter anchors were obtained along with those of the other survey points. The elevations of the rod extensometer base and of the top of the inclinometer casing were essential to the data reduction process of the subsurface instrumentation. The survey data for the ADAS anchors was used to determine the slope distance and therefore the gauge length for each strainmeter.

4.1.2 Surface Strains

The surface strainmeters are precision electrical instruments which can be read remotely from a central point by means of portable indicators or by automatic data logging monitors. The surface strainmeters were connected to the SINCO scanner/recorder (Figure 3.6), a multi-channel acquisition system which operates on internal rechargeable

batteries connected to two 12-volt batteries connected in parallel. During the period between September 29, 1982, and May 8, 1982, the scanner was set to record linear potentiometer readings every four days. Only one reading was made between September 29, 1982 and January 9, 1982, as the result of a blown fuse which occurred after the initialization phase was completed. The fuse was replaced and the batteries were recharged and installed on rubber mats during the January, 1982, monitoring trip. Thereafter the scanner recorder operated on a four-day basis until May 8, 1982, at which time the voltage was too low to allow operation of the recorder. It was discovered that, as a consequence of operation at low voltage, the scanner had minor damage and had to be returned to SINCO for repair.

Monitoring of the strainmeter readings involves no direct operator skill, as the stressmeters are read automatically and they cannot be adjusted after installation. Careful maintenance of the scanner/recorder system is essential to the acquisition of high quality data.

4.2 OVERBURDEN MOVEMENTS

Overburden movements were monitored by means of the rod extensometers, the Sondex/inclinometer assemblies and the TDR cables. Vertical movements were measured by measuring the location of the rod extensometers with respect to the reference plate and by locating the depths of metallic Sondex rings below the surface. The horizontal displacement of the inclinometer casing is measured to determine the lateral overburden movement as a function of depth. A cable tester was used to measure the length of the TDR cable, and hence the height of bed separation or caving above the mine roof.

4.2.1 Rod Extensometer Measurement

Movements of rod anchors are measured as changes in the distance between the rod measuring studs and the cover plate mounted on the concrete pedestals and cemented in place. A metric dial gauge was used to measure the distance between the top of the rod and the reference plate (Figure 3.16). The reading for a calibration jig was made first, and then subtracted from the rod reading to obtain the relative rod location. The same calibration jig was used for all readings. In order to provide a check on the readings and give an indication of movements, a mechanic's scale graduated in sixty-fourths of an inch was also read. When the rods subsided below or heaved above the plate such that the range of the dial gage was exceeded, the mechanic's scale provides the only quantitative measure of the rod location and therefore of the cumulative anchor movement.

The rods could be reset when the movement exceeded the dial gage range of 50 mm. Whenever the rods were reset, two sets of readings were made, before and after the change. The linear potentiometers used for continuous recording at REX-2 were reset at the same time as the rods, in order to allow continuous recording during subsidence and to prevent damage to the linear potentiometers during heave. Because the footings for the concrete pedestals were poured on the ground surface, the pedestals experienced frost heave and thaw settlement during the course of the 1981/82 winter. Both rod extensometer assemblies were adjusted to allow recording during this freeze/thaw period.

The change in elevation of the reference head must be known at the time the rod measurements are made, to allow calculation of anchor movement from the relative anchor/surface measurement. The elevations of REX-1 and REX-2 were obtained during the course of each monitoring survey.

Rod extensometer measurements were made during WCC monitoring visits and occasionally by Allen Mine engineers. The SINCO scanner/recorder was set to record every 4 days throughout the period of WCC contract work. On May 7, 1982, the face was located 500 ft away from REX-2. As the face approaches the instrumented area and displacement changes begin to accelerate, a shorter recording interval is warranted.

4.2.2 Sondex Measurements

The measurement of the location of the Sondex rings was made by lowering an induction probe into the hole (Figure 4.2) and measuring the depth of the probe whenever a signal was emitted from the Sondex indicator. The Sondex probe consists of a radio frequency oscillator and detector circuit. The metal rings reduce the efficiency of the rf oscillator whenever the Sondex probe passes through the center of one of these rings. The detector provides a signal to drive the meter and buzzer contained within the cable reel.

The depth to the rings was determined by measuring between the top of the cable mark closest to the top of the casing, by means of a carpenter's rule (Figure 4.3). The change in vertical position of the rings was determined by correcting for the change in elevation of the top of the casing.

The accuracy of this instrument is primarily limited by the skill of the operators in measuring the probe depth with the carpenter's scale and in determining the peak signal. Sondex measurements were made by WCC engineers during monitoring visits. Inclinator measurements were made at the same time to allow complete analysis of all movement.

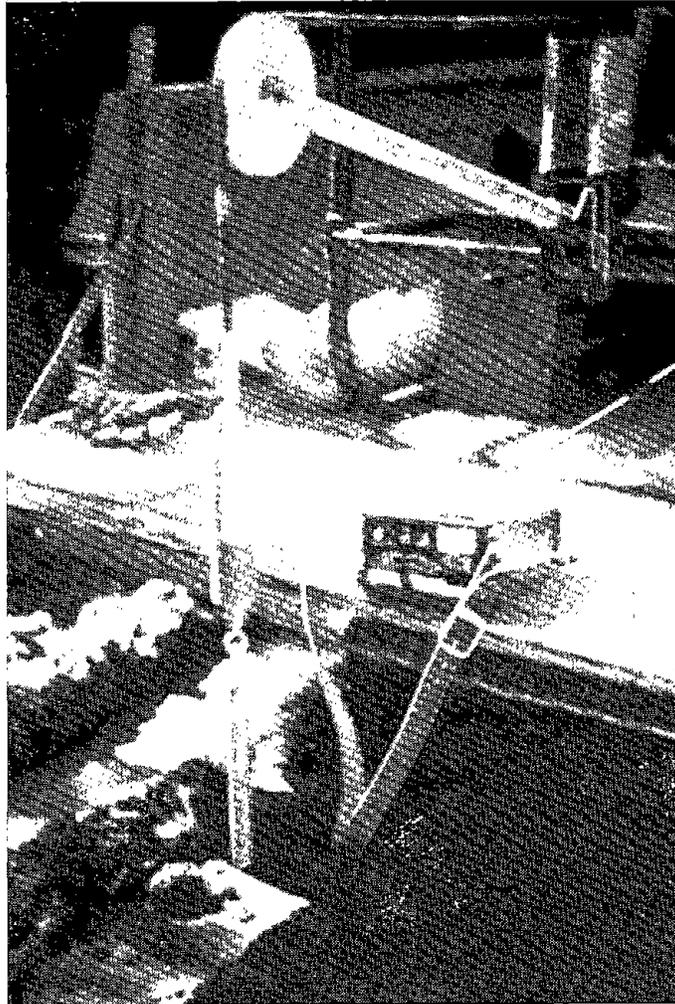


FIGURE 4.2

SONDEX PROBE AND READOUT

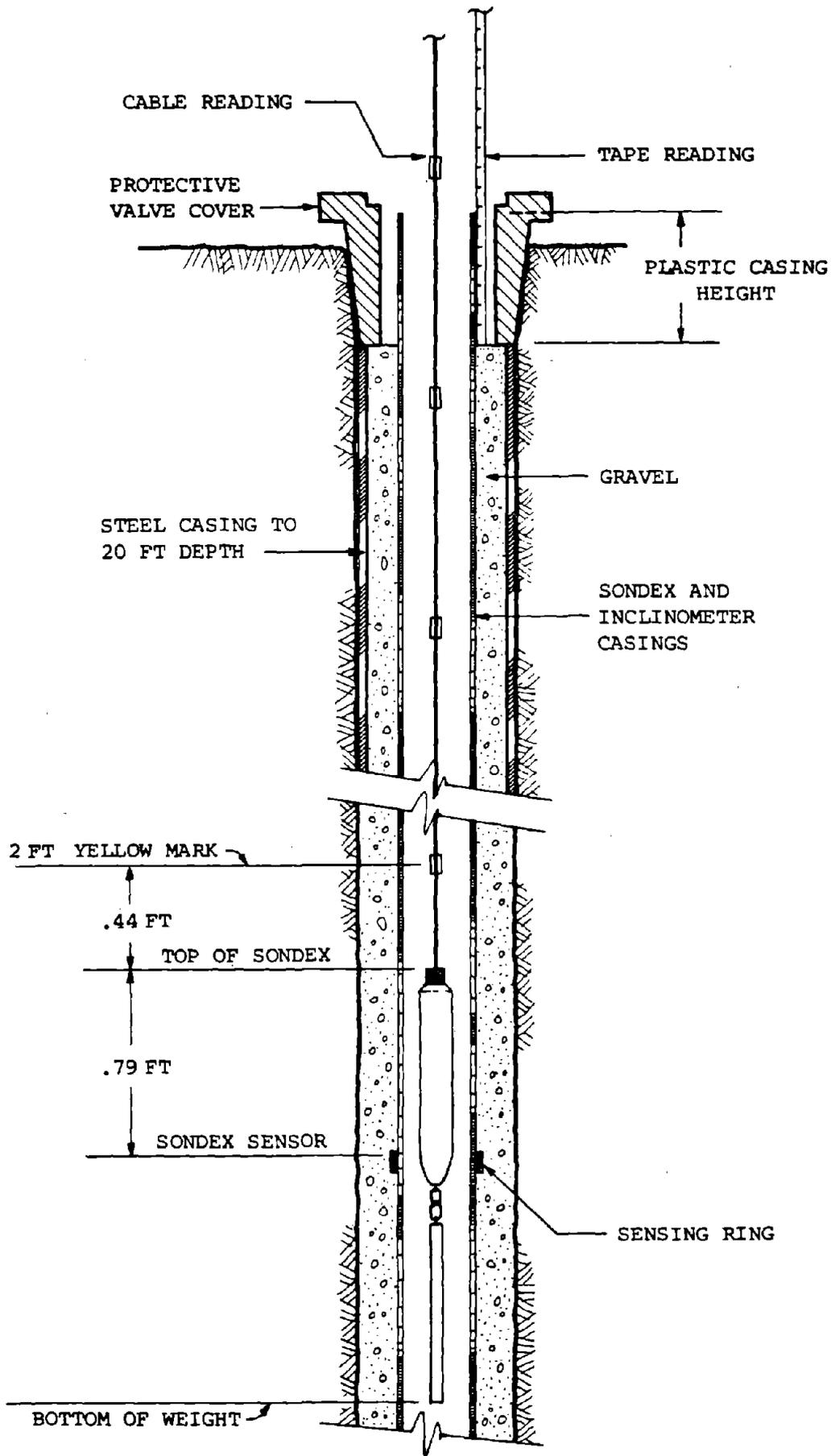


FIGURE 4.3

SONDEX OPERATION

4.2.3 Inclinometer Measurements

Progressive changes in angle of inclination of the grooved inclinometer casing were measured by a force-balance accelerometer type borehole inclinometer (Figure 4.4).

The movable inclinometer sensor provides an electrical signal proportional to the angle of inclination from its vertical axis. It contains two servo-accelerometers mounted with the sensitive axes 90 degrees apart. The sensor is supported laterally in the casing by means of guide wheels and is suspended vertically by means of the interconnecting cable. The probe wheels are guided by grooves to control directional orientation of the measurements. The Model 50325 biaxial sensor used for this study has two spring-loaded wheels at each end which travel in opposite grooves in the guide casing.

The data display of the digital indicator readout is provided by a 4-digit bipolar digital voltmeter. The digital voltmeter reading is equal to $2\sin\theta$ where θ is the angle of inclination of the guide casing. For an inclination of 20 degrees, $\sin 30^\circ = 0.5$, for which the reading is $2 \times 0.5 = 1.0000$. This value is the basic scale factor of the instrument.

The sensor was inserted into the guide casing such that both wheels of the lower set and then the upper set are traveling securely in the casing grooves. The direction of the uppermost wheel was noted on the field data sheet. The sensor was lowered to the bottom of the casing and allowed to stabilize at borehole temperature. The sensor was raised in 2 ft increments starting at the first cable marking. Both the A- and B-axis were read for each 2 ft interval. When the sensor is removed from the casing, a check was made to be sure the wheels are still traveling in the same groove.

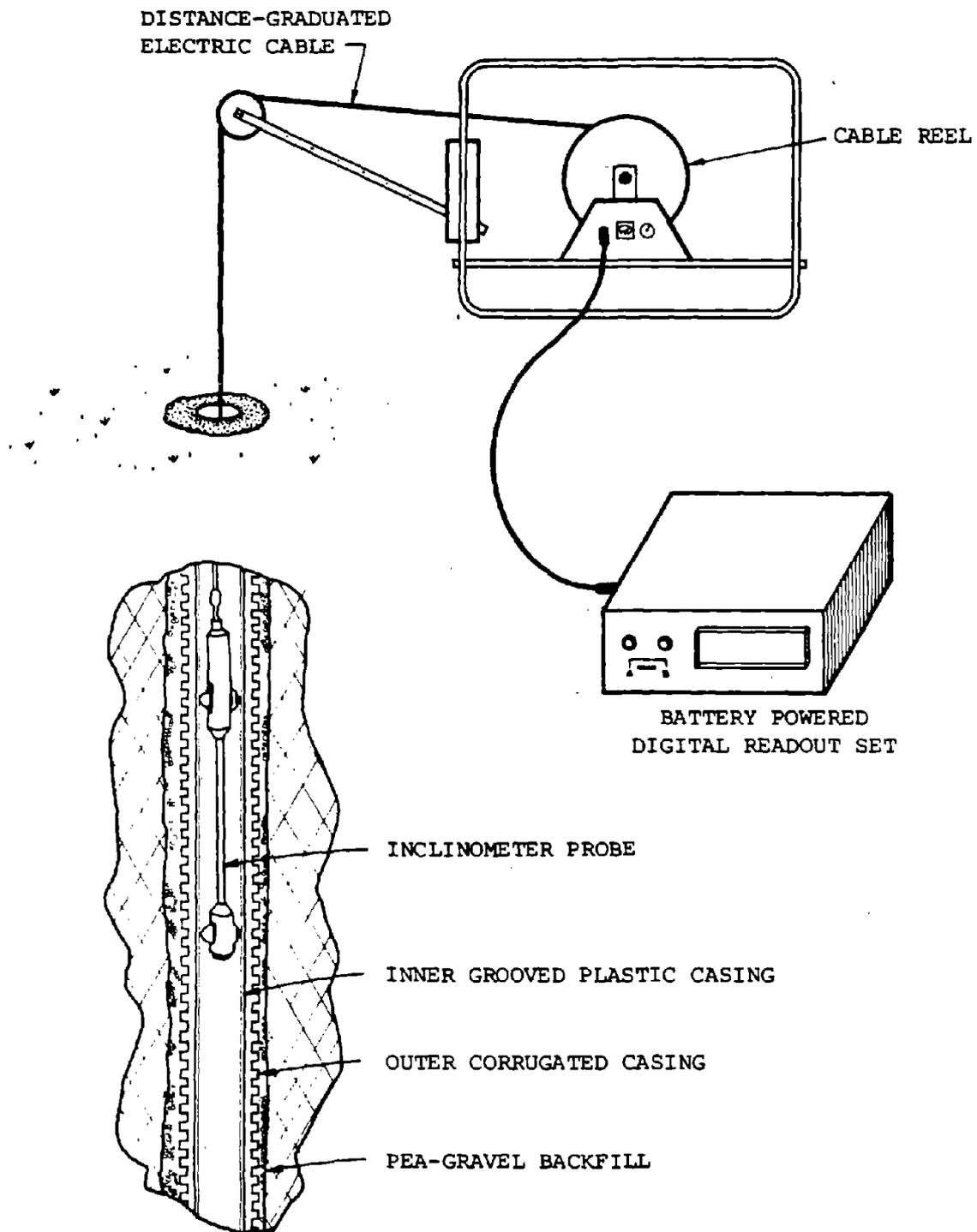


FIGURE 4.4
INCLINOMETER PROBE SET-UP

sensor was rotated 180 degrees and reinserted in the casing. The survey was completed at this orientation by lowering the sensor to the bottom of the hole and completing a second set of readings.

Initial data was acquired for SLEX-1 and SLEX-2 in September, 1981. Problems with sensor alignment in SLEX-1 indicated that not all the casing was properly aligned in this hole. When the sensor was lowered below a depth of 215 ft, it emerged from the casing in a different set of grooves from those in which it was lowered. Data was collected for the upper 215 ft of SLEX-1 only, and by reading from the surface down to that level. SLEX-2 was read to the total depth from the bottom of the hole to the surface.

The accuracy of the inclinometer measurements is dependent on extreme care being used to repeat the depth measurements at each reading in opposite grooves. Inclinometer measurements were made by WCC engineers during monitoring visits.

Two attempts were made to determine whether spiraling of the inclinometer grooves had occurred down hole. This procedure involved running a 5-ft long spiral-checking probe with guide wheels down along the grooves so that the angular rotation between the upper and lower guide wheels could be checked every 5 ft. By summing the angular rotations of the 5 ft intervals it should be possible to obtain a profile of the downhole groove rotation. Readings were taken as the probe was lowered down the hole and also as it was pulled back out of the hole along the A-axis grooves. The spiral survey tool yielded data that was inconclusive regarding the degree of spiraling.

4.2.4 TDR Cable Discontinuities

A Tektronix TDR cable tester (Figure 4.5) with a printer option was used to monitor the length of coaxial cable installed in SLEX-1, SLEX-2, REX-1 and REX-2. Use of the cable tester involved following manufacturer directions for testing the equipment, then attaching the jumper cable to the installed cable and adjusting vertical and horizontal settings to those used during initialization. The typical settings were 100 ft/division horizontally and 10 mV/division vertically, for all holes except REX-1. The TDR cable tester never recorded a cable length greater than 129 ft for REX-2, probably due to a faulty cable splice at this depth.

4.3 GROUNDWATER CONDITIONS

Groundwater level and quality were monitored in SLEX-1 and SLEX-2. A SINCO water level indicator (Figure 4.6) was used to establish the water level in both boreholes during initialization procedures and monitoring visits. This self-contained transistorized instrument consists of a reel with control panel, cable and sensor. A two conductor coaxial cable connects the control panel to the sensor. An insulating gap in the 3/8-in. diameter stainless steel sensor acts as a switch. The circuit is completed upon making contact with water which serves as an electrolyte. This low level signal is amplified and fed into an indicator light and an audible buzzer, thus signalling when water has been contacted. The circuit has a test switch to insure proper operation prior to making depth readings.

A 5-ft long, 1-1/4-in. diameter length of PVC was capped on the ends and perforated to allow sampling of water from the boreholes. The bailer was lowered into the hole on a rope with galvanized steel pipe attached to provide weight. One sample was taken to allow rinsing of the sampler. Then 1/2

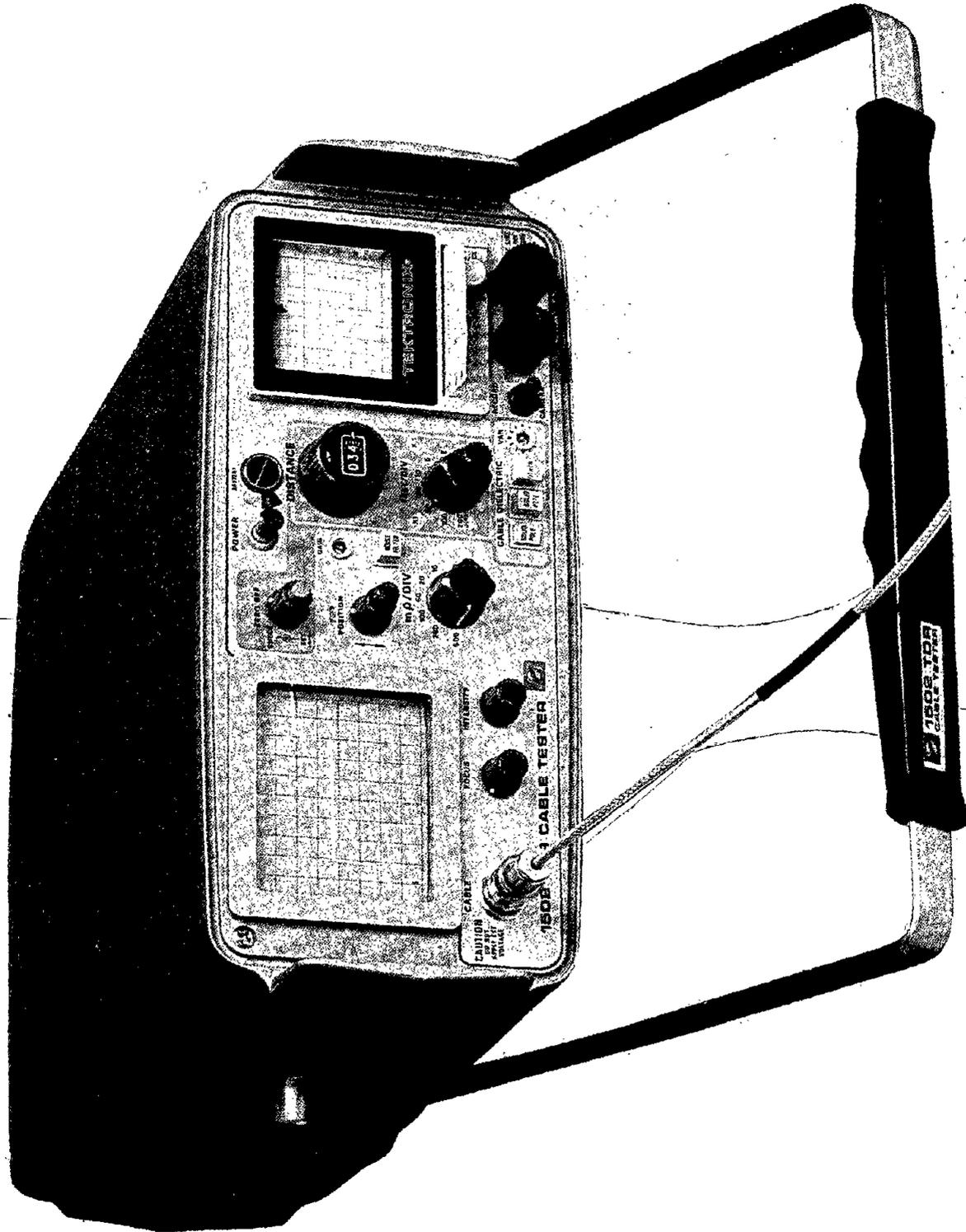


FIGURE 4.5
TDR CABLE TESTER

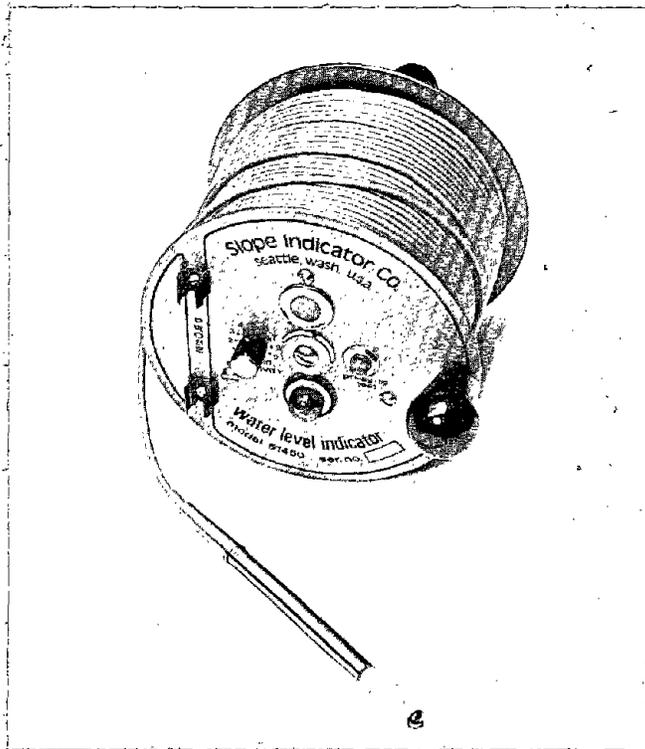


FIGURE 4.6

WATER LEVEL INDICATOR

gallon to 1 gallon samples were removed and the pH, specific conductance and temperature tested in the field. The samples were sent to Commercial Testing and Engineering Company in Golden, Colorado, for quantitative analysis of sulfate, chloride, fluoride, alkalinity (as CaCO_3), carbonate bicarbonate, total dissolved solids and the following dissolved elements: calcium, magnesium, sodium, potassium and iron. The ion balance was also determined. These parameters were selected for the study on the basis of previous hydrologic studies conducted in the vicinity of the Allen Mine (Water, Waste and Land, 1980) and recommended guidelines for the collection of baseline water quality and overburden geochemistry data (Shelton, 1981).

This sampling procedure was conducted in September, 1981, as part of the data initialization procedure and during the January monitoring visit. A review of the water monitoring scheme was done in March, 1982, and the following factors were considered:

- (1) On the basis of information regarding local water sources used for municipal and agricultural use, it was expected that no significant aquifers would be encountered. The most significant aquifer in the area is the alluvium along the Purgatoire River.
- (2) The holes were not developed as groundwater sampling holes since it was not expected that any significant aquifers would be encountered. As a result, the water-bearing zones were not defined or sealed, the holes were not washed or developed (Scalf, 1981), and the pea gravel used as backfill material was not washed.

- (3) The process of subsidence may result in loss of standing water during mining, and eventual loss of the total hole depth. In the first case, there can be no post-mining water samples to compare to the pre-mining samples. In the second case, the same aquifers cannot be sampled after mining and therefore cannot be compared to pre-mining samples.

The conclusion reached, following this review of the need for water quality sampling was that instrumentation boreholes that are likely to be disrupted by the mining process are not appropriate quality water observation wells. In this particular application, they were also of limited usefulness because the groundwater is not tapped for agricultural or municipal uses.

4.4 MINE LEVEL MOVEMENTS AND STRESSES

Displacements of the mine roof and floor were measured by means of the rod extensometers and convergence stations. The height of the mined panel was also measured. Stress changes were determined by monitoring the stressmeters. An indication of support loadings was obtained by monitoring pressure gages attached to the Hemscheidt chocks. On the basis of the underground instrumentation survey completed by Allen Mine engineers, the position of each instrument with respect to the face could be established and all data related to face advance.

4.4.1 Roof-Floor Displacements

The movement of roof and floor strata was monitored by measuring the distance between the rod studs and the cover plate of the rod extensometer installations (Figure 3.21). As with the surface rod extensometers, a metric dial gauge was used to measure this distance with the reading for the

calibration jig being made first, and a mechanic's scale was used to allow a check of the dial gauge.

The roof and floor extensometer rods could be adjusted to allow measurement of the rods whenever relative anchor-plate movements exceeded the range of the dial gage or caused the rods to protrude from the reference plate. It was not necessary to reset the rods at the first extensometer installation during the course of measurement.

The extensometer cover plates were cleaned thoroughly prior to measurement. A scale formed on the steel cover plate of 2RE, and was assumed to be calcite, possibly leached from the cement in the grout.

Roof-floor convergence was measured by using a precision-tensioned SINCO tape extensometer (Figure 4.7) between the stainless steel reference balls. The tape extensometer is a portable instrument which is hand-held while making readings. A dial gauge mounted inside a proving ring indicates the tension load applied to the tape. The tension on the tape is adjusted by a large knurled nut and screw. A second dial gauge indicates the travel of the screw required to apply the proper tension on the tape. This dial reading is the increment of distance to be subtracted from the tape reading. A thermometer is attached to the flat steel standard engineer's tape to allow adjustment of the tape readings for changes in temperature. The standard tape is punched with a small diameter hole every 1.97 in. (5 cm). The ball socket of the tape extensometer is placed on the removeable roof reference ball, and the ball socket at the tape end is placed on the permanent floor reference ball. The nearest punch hole in the tape is fixed to the extensometer with a latching pin. Tension is applied by turning the knurled ring on the extensometer until an average "0" reading is obtained on the proving ring dial, indicating that 40 pounds

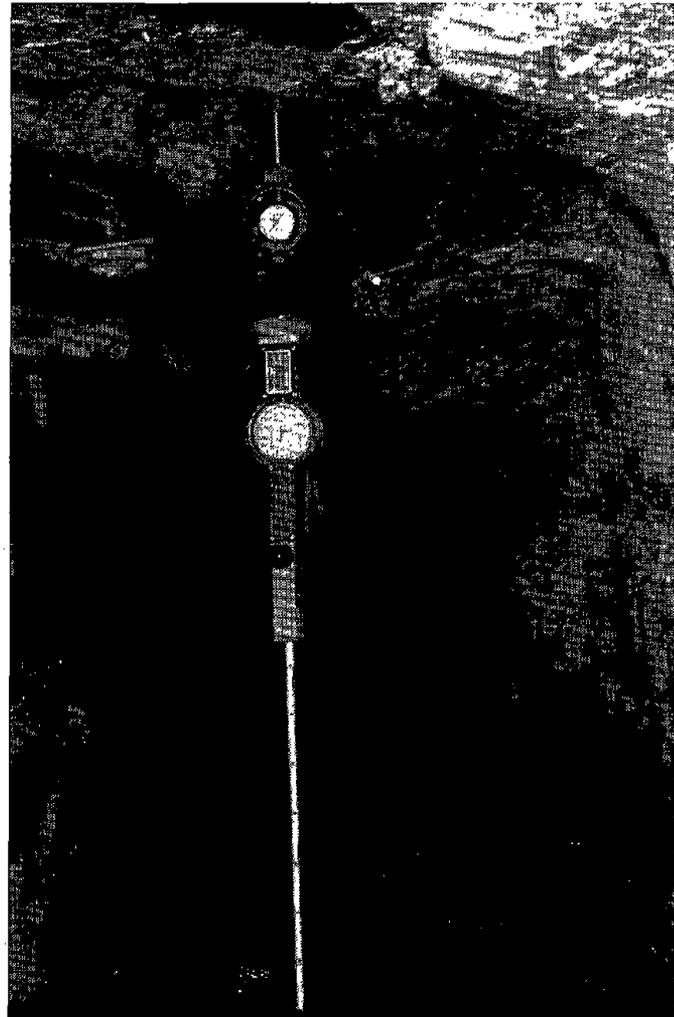


FIGURE 4.7

TAPE EXTENSOMETER FOR CONVERGENCE MEASUREMENTS

of tension has been applied. A complete convergence reading consists of the tape reading in meters, the displacement dial gauge reading in millimeters and the temperature in degrees centigrade.

The tape extensometer is susceptible to damage due to dirt and must be kept clean and periodically recalibrated. The stated manufacturer's accuracy of this instrument is ± 0.003 in., and attainment of this accuracy is largely dependent on operator skill and consistency.

The rod extensometers and convergence pairs were measured during each monitoring trip. In addition, the Allen Mine engineers read the rod extensometers and recorded the face location on a weekly basis. The rod extensometer and convergence pair 1C1 at the first instrumentation location were measured until the face was located at the instruments, after which time the instruments were dismantled and inaccessible.

4.4.2 Pillar and Floor Stress Changes

Readings of the stressmeters installed in the pillars and floor were made by clipping the stressmeter lead wires to a hand-held Irad vibrating wire readout meter or by connecting the wires to the Irad Datalogger junction box (Figure 3.20).

The vibrating wire readout operates by initially generating a voltage pulse containing a spectrum of frequencies spanning the natural frequency range of the wire in the gage being read. When the signal reaches the coil/magnet assembly mounted inside the gage adjacent to the wire, it changes the magnetic field around the wire at a frequency corresponding to that of the input signal. When one of the frequencies in the input signal coincides with the resonant frequency of the wire, the wire vibrates and continues to vibrate after

the input signal has ceased. A voltage is then generated in the coil at a frequency corresponding to that of the wire as it vibrates in the field of the coil/magnet assembly. This constant frequency signal generated by the gauge is amplified by the readout meter and conditioned to eliminate electrical noise. A number is displayed which is proportional to the square of the resonant frequency. The Datalogger incorporates this basic readout circuitry with the additional capability to automatically scan and print out the readings of up to 10 stressmeters.

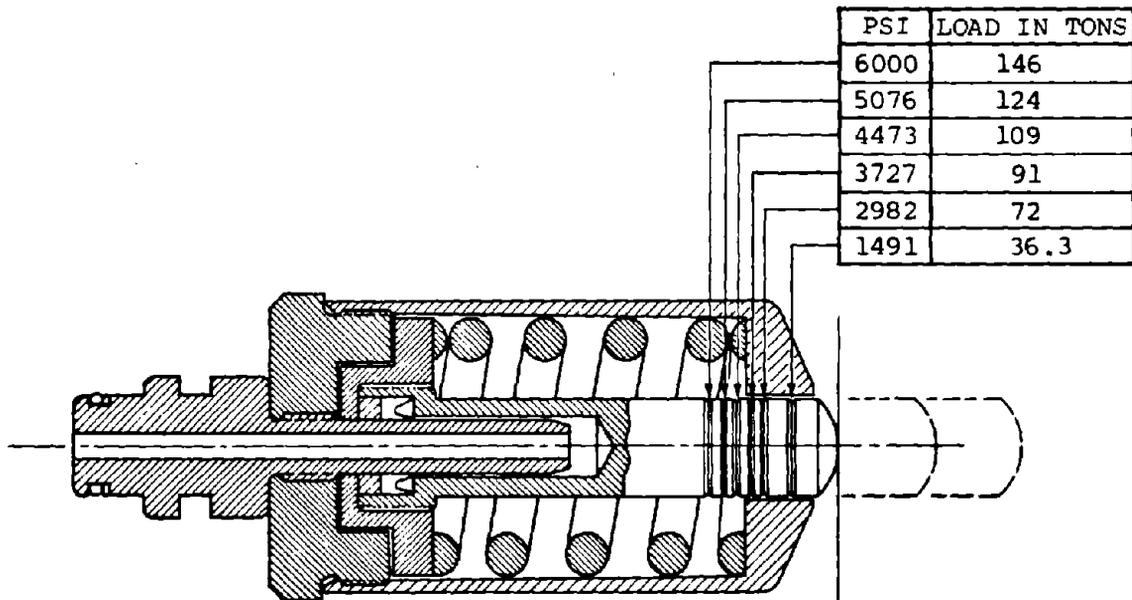
After initialization the mine stressmeters at the first installation location were connected to the Datalogger, located approximately 200 ft from the general location of the stressmeters. The Datalogger was set to a 2-day recording interval until the March, 1982 monitoring visit, when the automatic monitoring frequency was increased to twice daily to monitor stress changes as the face moved past the stressmeters. The monitoring frequency should have been increased during the January visit to allow documentation of stress changes during face approach. Concern for the ability of the two parallel-connected batteries to remain charged throughout a period of frequent power demand resulted in the decision to leave the recording interval at 2 days. The Datalogger provided 2-day readings between September 11, 1982 and November 20, 1982, when the battery voltage became too low to operate the printer. Between January 7, 1982 and March 8, 1982, during which period the batteries were placed on rubber mats and checked regularly by mine personnel, the Datalogger provided 2-day readings. Between March 9, 1982 and April 12, 1982 the Datalogger recorded twice daily. By April 12, 1982 contact with all stressmeters was lost possibly due to the lead wires being damaged and the Datalogger was moved to a location near the second instrumented area.

Stressmeters at the second location were read during monitoring trips with the manual-operated readout meter. While care was taken to prevent the readout units from getting wet or dirty or being banged or dropped, skill of the operator did not in general affect the accuracy of stressmeter readings.

4.4.3 Mined Height and Support Loads

Measurement of mined height and chock loads was made at every fourth chock where possible along the face of Panel 2. These measurements were made in order to provide an accurate average of mined height at various face locations and to determine the height of rock supported by the chocks.

The mined height was measured between the roof in front of the chock canopy and the floor in front of the pan line. A telescoping PVC pipe was fitted with a scale and expanded against the roof and floor to give this measurement. The chock load was measured by recording the length of indicator protruding from the Lee Norse Company pressure gage (Figure 4.8) on the Hemscheidt chocks with a mechanic's scale, and then transforming this reading to a load.



NOTE: LEE-NORSE COMPANY PRODUCT

FIGURE 4.8
 PRESSURE GAGE ON 4-LEG HEMSCHIEDT CHOCK

5.0 PRELIMINARY DATA ANALYSIS

Because the contract for this project was terminated 2 years prior to the original deadline, the duration of data collection was shortened and only a limited discussion of the data and its implications has been possible. Monitoring was continued until the face passed the first instrumented section and the data analysis has been oriented towards establishing baseline data, determining the magnitude of stress changes and displacements which occurred due to mining at the first location, and optimizing data acquisition techniques to be used at the second instrumented location.

5.1 FACE ADVANCE AND CONDITIONS

5.1.1 Face Advance and Conditions

A plot of Panel 2 face advance as a function of time is given on Figure 5.1 and shows the influence of a fluctuating coal demand. The average rate of advance during operating periods was 30 ft/wk and the maximum rate was 50 ft/wk. The overall rate, including idle periods, was 22 ft/wk or 90 ft/mon, for the period of study. The location of the face of Panel 2 and the room and pillar development in Panel 1, as of July 5, 1982 is shown on Figure 3.2. The rate of advance and location of the face were documented to provide accurate correlation of advance rate and face location with stress and strain development.

There are two important considerations with respect to this data. First, mining progress on Panel 2 has been intermittent and therefore may have had an effect on ground caving phenomena in a manner different from a steady, regular extraction schedule. Secondly, the state-of-the-art of subsidence engineering is such that the relevance of rate-

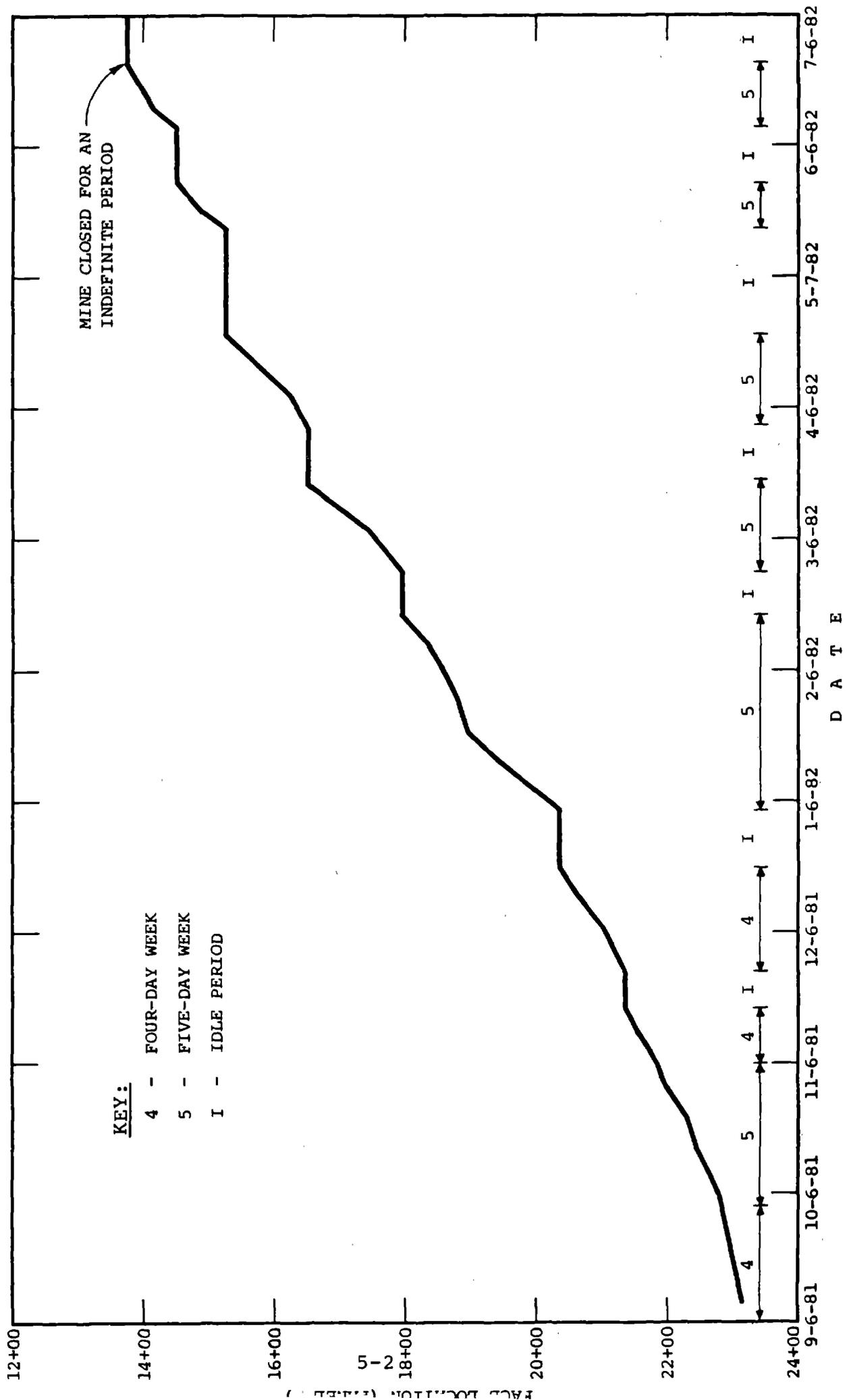


FIGURE 5.1
 PANEL 2 FACE ADVANCE VERSUS TIME

dependent effects, during and after mining, to subsidence prediction is controversial (Smith, 1981), and therefore clearly a topic for study.

The rate of face advance in Panel 2 seemed to be controlled largely by geologic conditions. Interception of a sandstone channel or roll between headings 23+80 and 22+20 resulted in a relatively slow rate of advance (15 ft/wk) between August and November, 1981. Another period of slower advance (20 ft/wk average) occurred between January 22 and February 12, 1982 when a mapped fault was encountered near the tailgate between headings 19+50 and 18+35. Both geologic features as mapped by mine engineers are shown on Figure 3.2.

5.1.2 Roof Falls

The variation in roof support types mentioned in Section 3.3.1 reflects the variation in roof stability encountered while the longwall panel was being developed. Until Station 14+00 was reached, 60 in. resin-grouted roof bolts were generally sufficient. Beyond that point development required steel H-beams and wooden spacers to maintain a stable roof. The need for this increased roof support was dictated by the occurrence of large roof falls between 14+00 and 16+00. This mine level location corresponds with a topographic high on the ground surface indicating that these roof falls were probably a result of increased stress acting on the incompetent shale roof.

Another location where roof bolts alone were insufficient to support the unstable roof occurred between 10+50 and 13+00 where up to 8 ft of roof strata (that is, all strata between the Allen seam and overlying Apache seam) fell in both the headgate entry and adjacent intake entry. Most of these falls occurred at the intersection of entries and

crosscuts which are typically areas of high stress concentrations. Another consideration is the fact that this location underlies a drainage valley on the ground surface. Peng (1978) notes that drainage valleys can be the result of surface runoff cutting through weak rock areas (that is, with a higher density of fractures). Furthermore, the removal of rock materials by erosion induces unloading in the drainage valley. This tends to increase the maximum shear stress at (mine level) entry corners, the maximum tensile stress at entry midspans and the maximum compressive stress in surrounding pillars. All these increases in stress tend to increase roof instability.

The orientation of the drainage valley is consistent with the system of joints measured on outcrops above the longwall panel (trending E-W dip 80 to 90°S and trending N-S dip 80 to 90°E). Consequently the roof falls in this area were probably the result of stress concentration in combination with the rock mass discontinuities.

In addition to increased stress, other factors which may have contributed to roof falls include the immediate roof conditions such as the presence of kettle bottoms and an incompetent carbonaceous shale which spalls almost immediately after being wetted. Consequently, moisture in the fresh air which condenses on the roof shale can lead to gradual deterioration of the roof. Deterioration of the intake entry roof progressed to a point where it was necessary to restrict personnel from using this entry until remedial roof bolting and beaming was completed. In fact, while extensometers 2FE and 2RE were being installed in the bolt entry, a major roof fall occurred near this location in the intake entry.

The progressive transfer of stresses ahead of the advancing longwall face contributed to the incidence of roof falls and

rib spalls and the need for increased support. By January, 1982, a major roof fall prevented access to crosscut 12, located at approximately 12+70.

5.1.3 Mined Height

The mined height data was reduced by basic statistical methods to obtain means and standard deviations for each day and collectively (Table 5.1). The overall average mined height was 76.4 inches. Consideration of the tabulated data shows that the 67 percentile range (that is, within two standard deviations of the mean) for the overall mined height was about 1 ft. The range and the standard deviation was greater on the dates (July 31 and September 25, 1982) when interception of the sandstone channel rendered mining conditions difficult. The variation in mined height is consistent with the generally uneven panel cross section. This variation in mined height may have an impact on the analysis of maximum surface subsidence relative to mined seam thickness.

5.1.4 Support Load

Support load data is summarized in Table 5.2 where it can be seen that the average support load measured on the Lee Norse pressure gauges mounted on the Hemscheidt Chocks was 147.2 tons for one chock leg. The bar graph of Figure 5.2 shows load for one chock leg as a function of chock position along the face. The figure also indicates whether the measurements were made during a day of no production or during a lunch break on a production day.

Preliminary analysis shows that the load on any given chock varied considerably from date to date. The highest and lowest average loads were recorded on July 31, 1981 and September 25, 1982, respectively, and may have been related

TABLE 5.1
SUMMARY OF PANEL 2 MINED HEIGHT DATA

| STATISTIC | DATE | | | | | OVERALL |
|----------------------------------|---------|---------|---------|---------|---------|---------|
| | 7/07/81 | 7/31/81 | 9/25/81 | 1/05/82 | 3/05/82 | |
| Maximum Value (in.) | 76.2 | 91.8 | 108.0 | 84.3 | 80.0 | 108.0 |
| Minimum Value (in.) | 60.5 | 62 | 74.0 | 72.0 | 69.7 | 60.5 |
| Mean (\bar{x} , in.) | 72.2 | 75.4 | 81.2 | 78.3 | 75.0 | 76.4 |
| Standard Devia- tion (S, in.) | 3.8 | 6.4 | 7.3 | 2.7 | 2.8 | 5.8 |
| Number of Values (n) | 22 | 16 | 21 | 18 | 21 | 98 |

TABLE 5.2
SUMMARY OF PANEL 2 CHOCK LOAD DATA

| STATISTIC | DATE | | | | | OVERALL |
|----------------------------------|---------|---------|---------|---------|---------|---------|
| | 7/07/81 | 7/31/81 | 9/25/81 | 1/05/82 | 3/05/82 | |
| Maximum Value (tons) | 206.1 | 206.1 | 206.1 | 218.2 | 218.2 | 218.2 |
| Minimum Value (tons) | 48.6 | 56.7 | 40.5 | 44.6 | 12.3 | 40.5 |
| Mean (x, tons) | 146.4 | 155.2 | 142.0 | 149.0 | 143.8 | 147.2 |
| Standard Devia- tion (S, in.) | 41.5 | 36.1 | 40.5 | 48.8 | 62.5 | 46.3 |
| Number of Values | 22 | 22 | 23 | 22 | 23 | 112 |

Note: load is for one chock leg only.

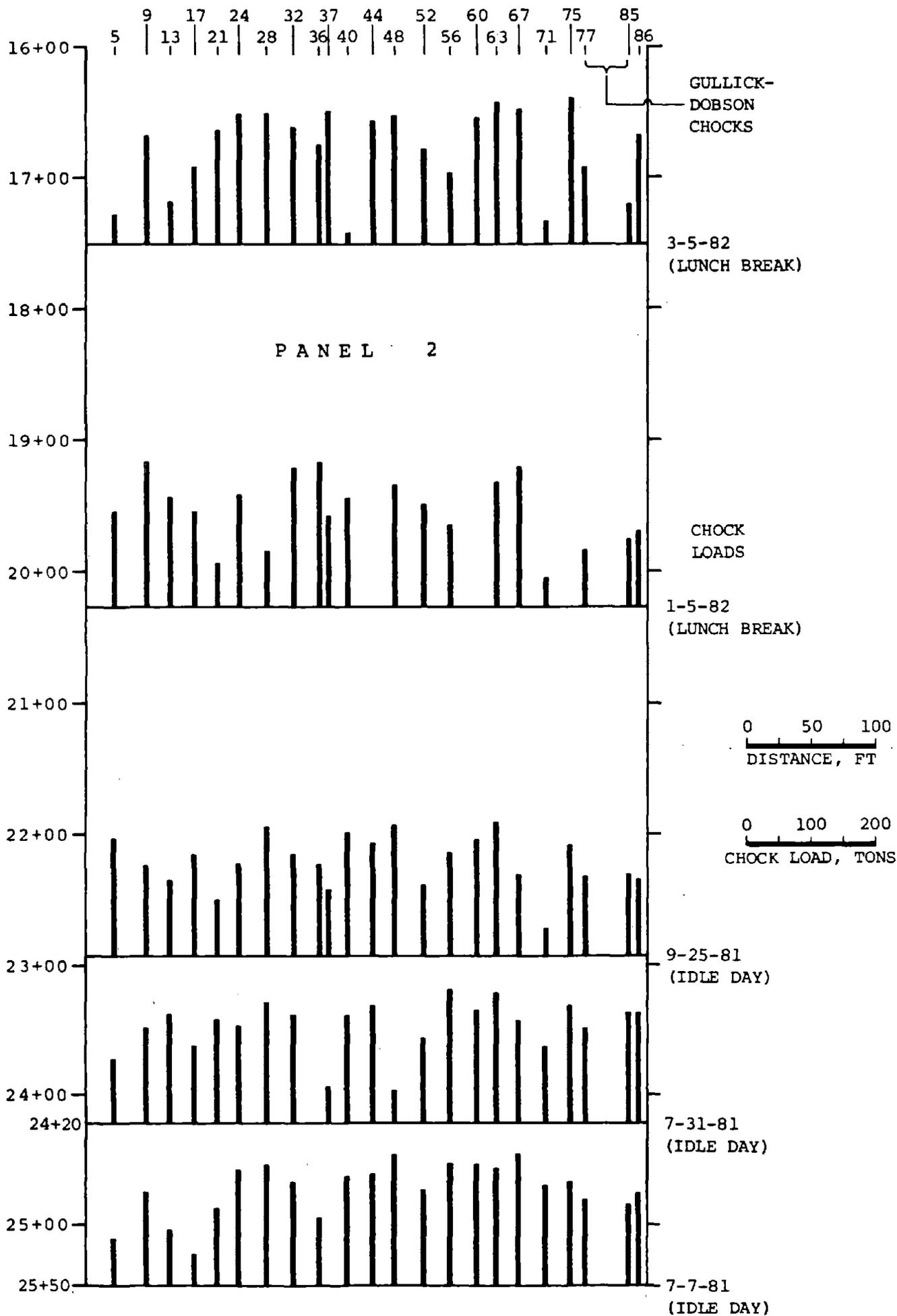


FIGURE 5.2

CHOCK LOADS ACROSS LONGWALL FACE

to the slower rate of face advance caused by interception of a sandstone channel. More data is required to explore the effects of the following factors on support load distribution:

- evenness of face,
- uniformity of mined height,
- interception of rock along part of the face,
- face advance rate,
- time history of chock loadings, and
- roof falls.

5.2 MINE LEVEL STRESSES

Analysis of absolute stress data obtained using the USBM undercoring technique (U. S. Bureau of Mines, 1981) proceeded according to the theory that displacements can be related to stresses on the basis of assumed elastic parameters. The vibrating wire stressmeter readings, obtained when monitoring pillar stress changes, were analyzed according to the procedure developed by the manufacturer which converts changes in vibrating wire readings to stress changes. The stress changes were then plotted as a function of time and face advance.

Laboratory tests were performed on 6-in. diameter cores obtained during the course of drilling holes for absolute stress measurements. The tests were performed to obtain values for the elastic modulus and Poisson's ratio which, in turn, were used for reduction of stress data.

5.2.1 Laboratory Tests

Laboratory testing of two of the 6-in. diameter cores included ultrasonic pulse velocity measurements and uniaxial compression with axial and circumferential strain gauges.

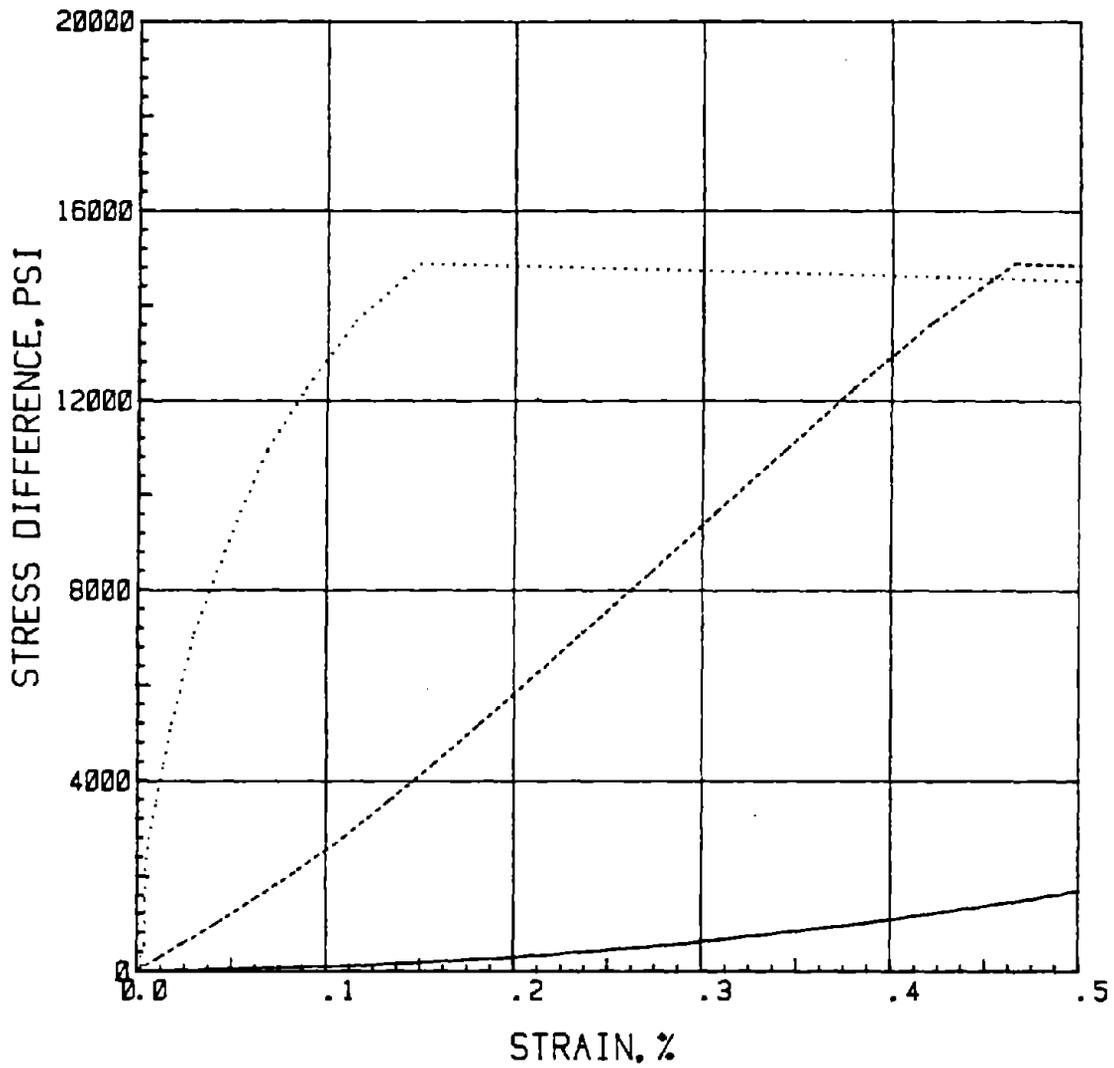
The ultrasonic pulse velocity test was conducted to examine anisotropy of the samples and the uniaxial test was performed to obtain elastic parameters.

Sample 2AS3 consisted of friable coal through which ultrasonic waves could not be transmitted, and the sample disintegrated partially when an attempt was made to smooth off the ends. The sample was too fragile to allow machining for uniaxial compression testing. The deterioration of highly fissured subcoal strata was observed in another ultrasonic testing program, in which case it was attributed to stress relief of the microfissures existing in the material (Tillman, 1982). The deterioration of the coal sample in this study may also have been the result of stress relief.

Sample 2AS5 was a competent sandstone through which ultrasonic pulse velocity measurements were made successfully. The sample was then machined into two samples for the uniaxial compression tests. The uniaxial compression plots at 2 percent strain are shown on Figures 5.3 and 5.4. The test results are summarized in Table 5.3. The ultrasonic velocity data indicate a slight anisotropy of elastic properties along the transverse versus longitudinal axis. The compressional wave velocity along the transverse axis is higher than along the longitudinal axis, implying a greater stiffness, or elastic modulus, along the transverse axis. Since this sample was obtained during the course of a test in the mine roof, the transverse axis of the sample parallels the bedding planes. A similar anisotropy was reported by Aggson (1978) from tests on a laminated shale roof rock from a coal mine in West Virginia.

5.2.2 Absolute Stress

Absolute stress analysis involved inputting the diameter changes of a 6-in. diameter undercoring holes into elastic

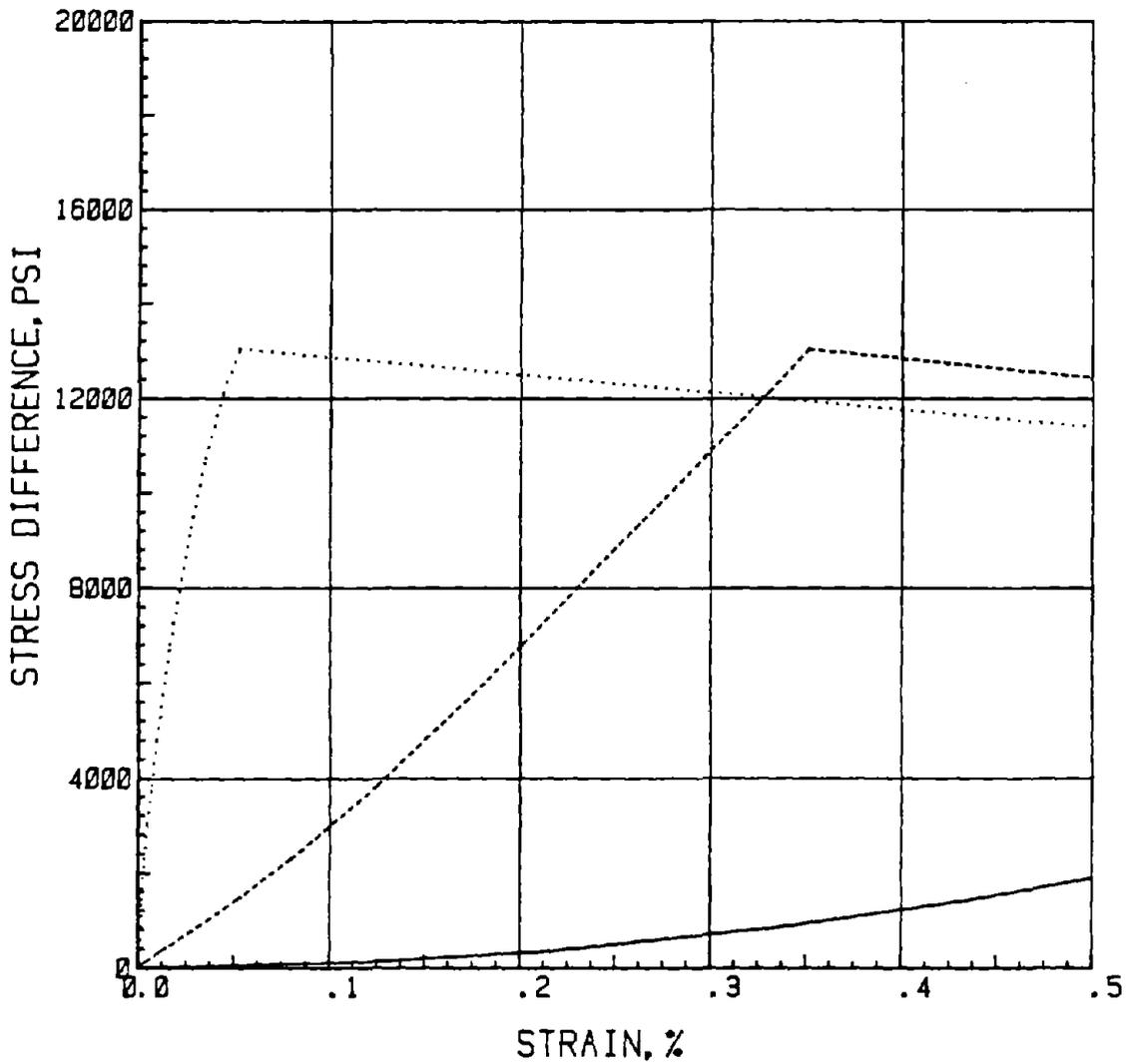


NOTES

LEGEND

- CIRCUMFERENTIAL STRAIN GAGES
- AXIAL STRAIN GAGES
- TOTAL (LVDT) STRAIN

FIGURE 5.3
 LABORATORY STRENGTH TESTS
 UNIAXIAL COMPRESSION: SAMPLE 2AS5-1



NOTES

LEGEND

- CIRCUMFERENTIAL STRAIN GAGES
- AXIAL STRAIN GAGES
- TOTAL (LVDT) STRAIN

FIGURE 5.4
 LABORATORY STRENGTH TESTS
 UNIAXIAL COMPRESSION: SAMPLE 2AS5-2

TABLE 5.3
LABORATORY TEST RESULTS FOR ROOF SANDSTONE

Sample No: 2AS5-1 and 2AS5-2
Rock Type: Sandstone

Longitudinal Wave Pulse Velocity (ft/sec)

Transversely: 13,750
Longitudinally: 12,260

Density: 160 lb/ft³

Average Uniaxial Compressive Strength: 14,280 psi

Average Young's Modulus: 3.8×10^6 psi

Average Poisson's Ratio: 0.31

equations. The equations were developed under the assumption of plane stress conditions around a hole in a continuous, isotropic, elastic medium (Hooker, et al, 1974).

Stress magnitudes and directions are summarized in Table 5.4 and test locations are shown on Figure 3.3. Tension is positive and the angle between the AA' direction and the maximum stress is measured counterclockwise from AA'. The modulus of elasticity was assumed to be 0.5×10^6 psi and Poisson's ratio was assumed to be 0.3 for calculation of stresses in coal, based on average values given by Peng (1978). Laboratory test results for sandstone were used in calculating stresses at the 2AS5 site.

The undercoring test technique was utilized with the objective of relating the absolute stress at discrete locations to the regional stress field. The tabulated results (Table 5.4) seem to indicate that the diameter changes measured after undercoring were in response to anomalous stress conditions rather than theoretical elastic concentrations of the regional stress field. Very high tensile stresses were calculated in three of the five cases, and such stresses are not likely to exist without failure in jointed coal or the sandstone. The tensile strength of the jointed coal is likely to have been zero and the tensile strength of the sandstone could be estimated to be approximately one-tenth its compressive strength or approximately 1430 psi. In either case, failure under the calculated stresses would be expected.

No consistency of stress orientation or magnitude was observed. Calculations based on diameter measurements made long after completion of the undercoring phase indicated continued changes in the magnitude, sense (for example, from tension to compression) and orientation of the absolute stresses.

TABLE 5.4
UNDERCORING TEST SUMMARY

| SITE | LOCATION | BEARING OF AA' | MODULUS (psi) | POISSON RATIO | MAXIMUM STRESS (psi) | MINIMUM STRESS (psi) | ANGLE (°) |
|------|----------|--------------------------|-------------------|------------------|----------------------------|----------------------------|--------------|
| 1AS4 | Roof | N50.2W | 0.5×10^6 | 0.3 | 13,642 | 6,859 | 42.8 |
| 1AS5 | Rib | 80.6° up from west | 0.5×10^6 | 0.3 | 10,147 | 1,103 | 7.4 |
| 2AS1 | Rib | 60.4° up from east | 0.5×10^6 | 0.3 | -1,451 | -3,327 | 23.0 |
| 2AS2 | Roof | N18.3E | 0.5×10^6 | 0.3 | -424 | -4,354 | -27.0 |
| 2AS5 | Roof | N84.8W | 3.8×10^6 | 0.31 | 15,462 | -4,650 | 32.4 |

Note: The angle between the AA' diameter and the maximum stress is measured counter clockwise from AA'.

Results for 2AS1 indicated a stress direction of almost vertical and a magnitude of -1451 psi. While this magnitude exceeds the estimated approximate overburden stress of 880 psi, use of a lower modulus of elasticity would reduce the stresses to the expected range. However, based on the fact that reasonable results were obtained for only this one test of the five successfully performed, the decision was made to forego any further data analysis for this type of measurement.

On the basis of this experience with the undercoring techniques it is considered inappropriate to perform this test in coal mines with the objective of determining the regional stress field. Not only is the test influenced by localized stresses on a disturbed surface, determination of regional in situ stresses based on local absolute stress determinations also involves use of elastic equations such as the Kirsch solution for circular openings to transform the in situ stresses to a regional coordinate system and, finally, calculation of the regional principal stresses (after Goodman, 1980). The maximum principal stress would be greater than or equal to the maximum measured local stress, and the minimum principal stress would be less than or equal to the minimum measured local stress.

Determination of in situ stresses can be more reliably accomplished by methods such as overcoring which measure stresses at some distance from exposed faces. It is apparent that the rib and roof surface stress concentrations are not a simple expression of the elastic redistribution of required stresses due to excavation. The surface stress concentrations may be affected by support loading and stress transfer mechanisms such as arching or beaming.

5.2.3 Stress Changes

The vibrating wire stressmeters provided a continuous record of stress changes in two chain pillars as well as in the floor beneath the longwall panel (Figure 3.3). As of May 1981, a complete stress change record was available for the stressmeters installed at the first instrumentation location and only this data was analyzed. The stressmeter readings were input into the following equation:

$$\sigma_r = \left[\frac{422400}{T_0} \right]^2 \left[1 - \left(\frac{T}{T_0} \right)^2 \right] + \left[11.4 - 0.66 \times 10^{-6} E_r \right]$$

where σ_r is the change in uniaxial rock stress from the initial reading T_0 and T is the current meter reading. The modulus of elasticity, E_r , was assumed to be 0.5×10^6 psi for the stressmeters in coal pillars and 1.0×10^6 psi for the floor stressmeters in shale/sandstone. To evaluate the error introduced by the need to assume values for modulus, all stressmeter data was reduced using modulus values of 0.25×10^6 psi, 0.5×10^6 psi and 1.0×10^6 psi. For the stressmeter which showed the greatest stress change (1IH20, a horizontal stressmeter in coal), the following results were obtained:

| <u>E_r</u> | <u>σ_r</u> | <u>Deviation</u> |
|-------------------------|------------------------------|------------------|
| 0.25×10^6 psi | 2570 psi | -2 percent |
| 0.5×10^6 psi | 2650 psi | |
| 1.0×10^6 psi | 2690 psi. | +3 percent |

An error of ± 3 percent was considered acceptable for purposes of preliminary analysis.

The cumulative change in stress was plotted versus distance from the stressmeter to the face for three vertical stressmeters and one floor stressmeter (Figure 5.5) and for the

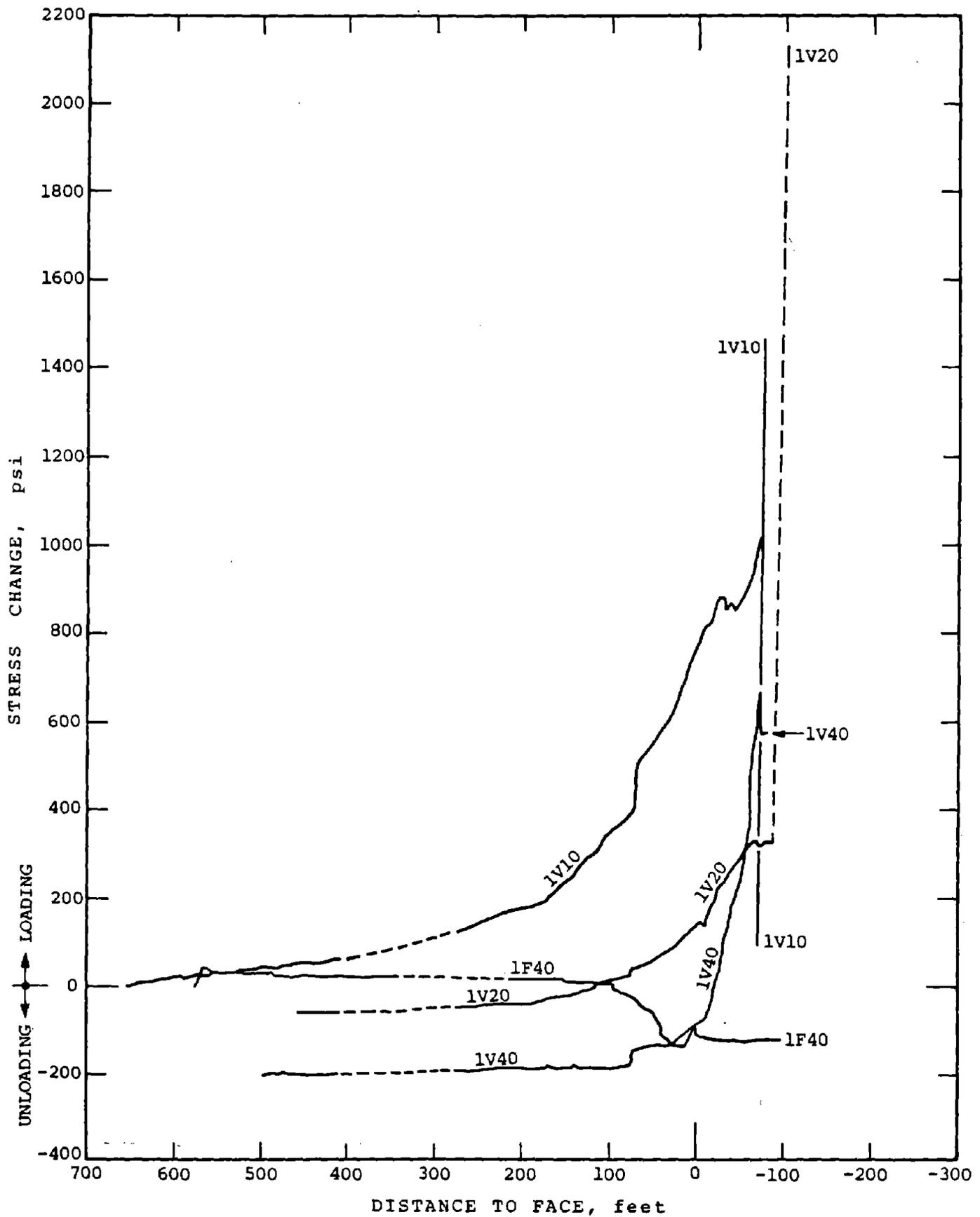


FIGURE 5.5
 VERTICAL STRESSMETERS - STRESS CHANGE VS FACE LOCATION

horizontal stressmeters (Figure 5.6). To evaluate stress changes which occurred during idle periods, cumulative changes in stress were also plotted versus time (Figures 5.7 and 5.8). Mine level instrumentation and roof support conditions at Location 1 are shown on Figure 3.19 are relevant to the following discussion. While the plots show a complex pattern of stress increases and decreases, general trends can be discerned which are similar to those reported in the literature.

The vertical stressmeters 1V10, 1V20 and 1V40 and the horizontal stressmeter 1IH10 all show rapidly increasing stress as the face advanced within 200 feet. This trend was reported by Wade and Conroy (1977), Conroy, et al, (1981) and Peng (1978) and reflects the development of a pressure arch in front of the face. Simultaneously, the floor stressmeter 1F40 shows a decreasing stress then an abrupt increase as the face passed over it. The floor stressmeter 1F120 was not effectively preloaded so that no stress changes were recorded with it. While the loss of preload pressure may be a reflection of the fact that the floor stressmeters were installed at an angle of 4 degrees from horizontal, the pressure increase is indicative of the transfer of abutment pressure in front of the face. Jackson (1981) noted that forward abutment pressure in the tailgates varies from 50 to 70 ft in advance of the longwall face.

The early loss of preload stress exhibited by stressmeters 1V20, 1V40, and 1IH20 may reflect yielding (or deterioration) of the coal around the stressmeters. The abrupt stress decrease shown on the stress change versus time plots (Figures 5.7 and 5.8) may also be indicative of pillar yielding between day 70 and 75 when the face was idle at a location 10 ft past 1C5 (see Figure 3.19). The consistent decrease of stress exhibited by stressmeters 10H10 and 10H20

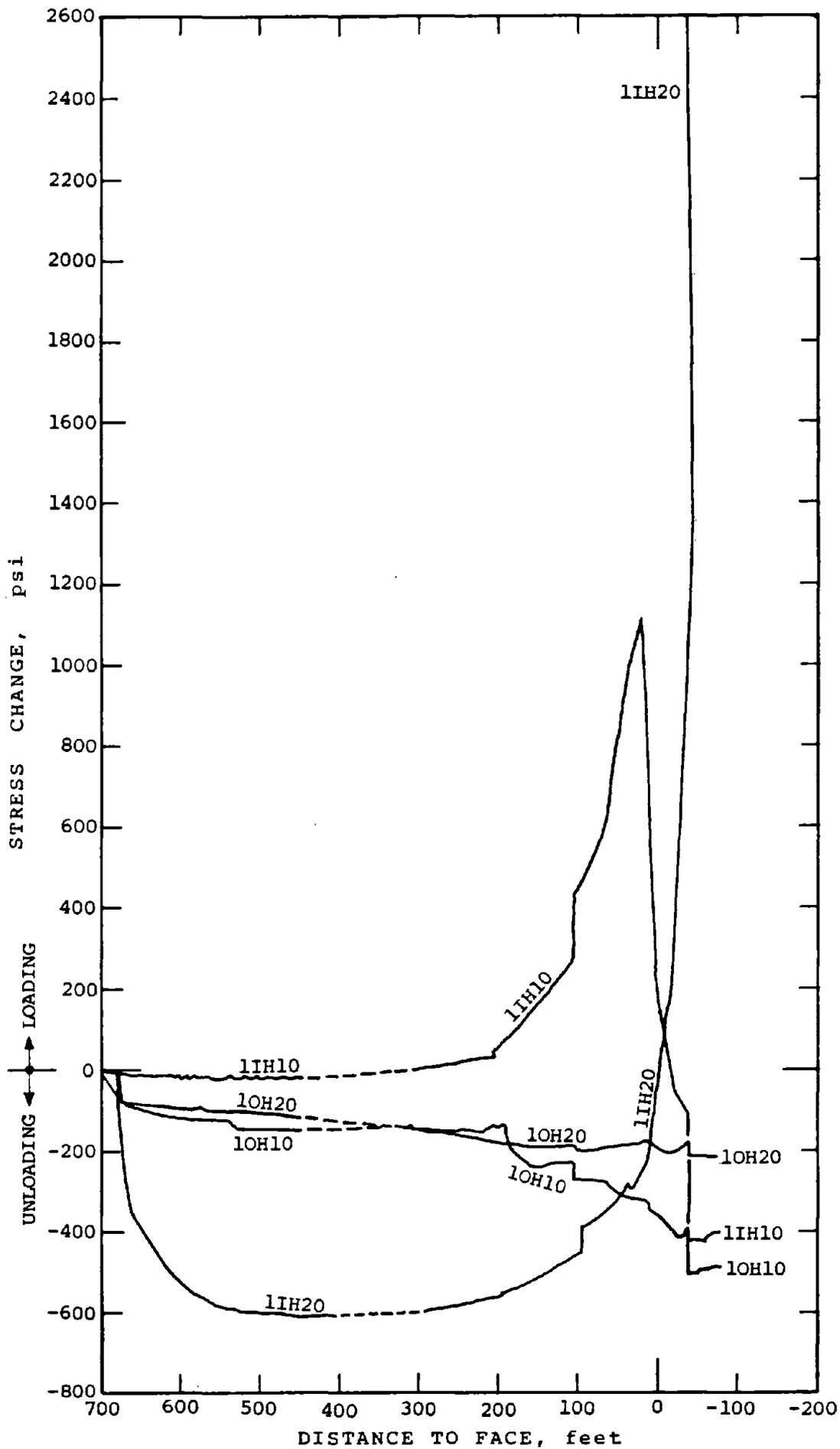


FIGURE 5.6
 HORIZONTAL STRESSMETERS - STRESS CHANGE VS FACE LOCATION

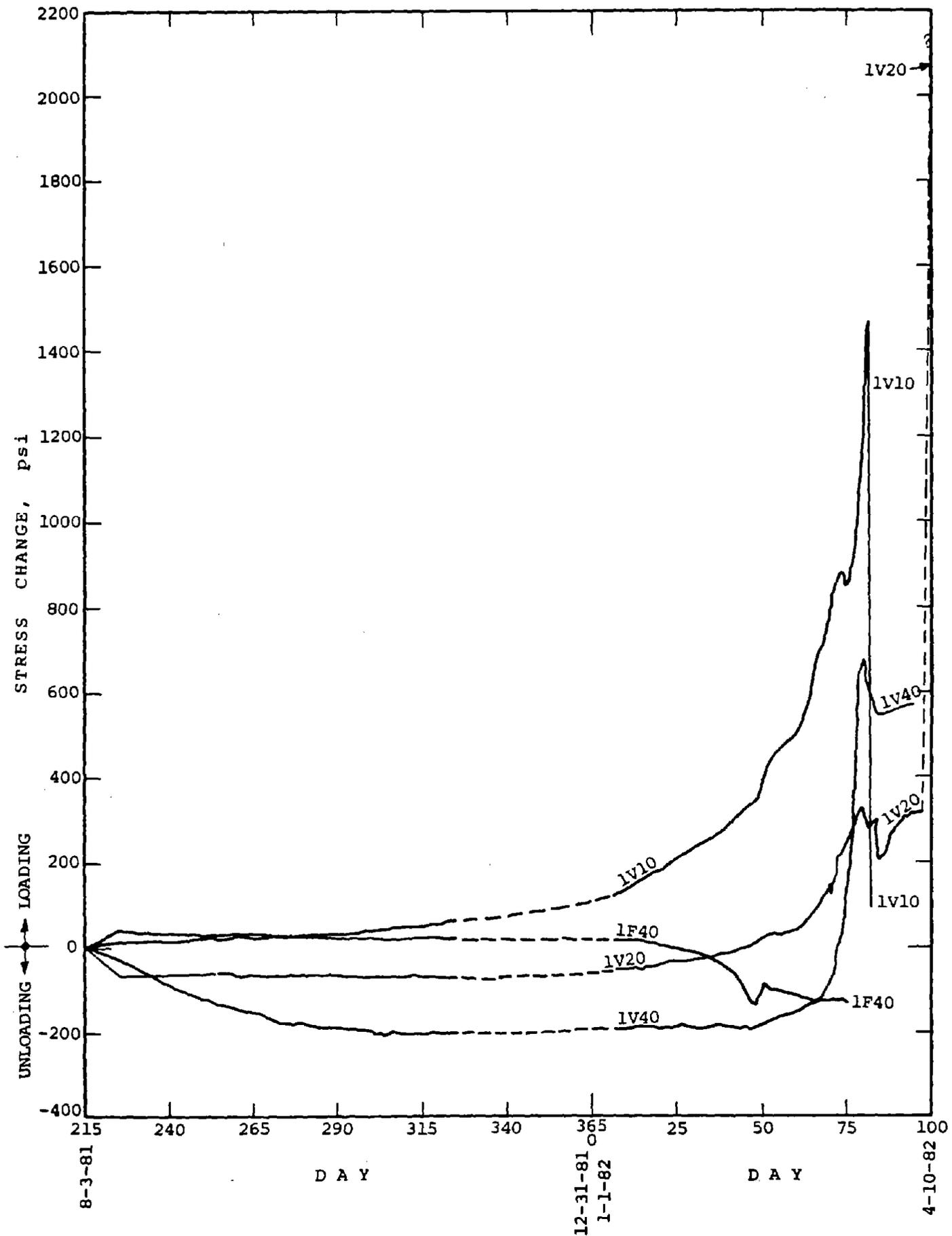


FIGURE 5.7
 VERTICAL STRESSMETERS - STRESS CHANGE VS TIME

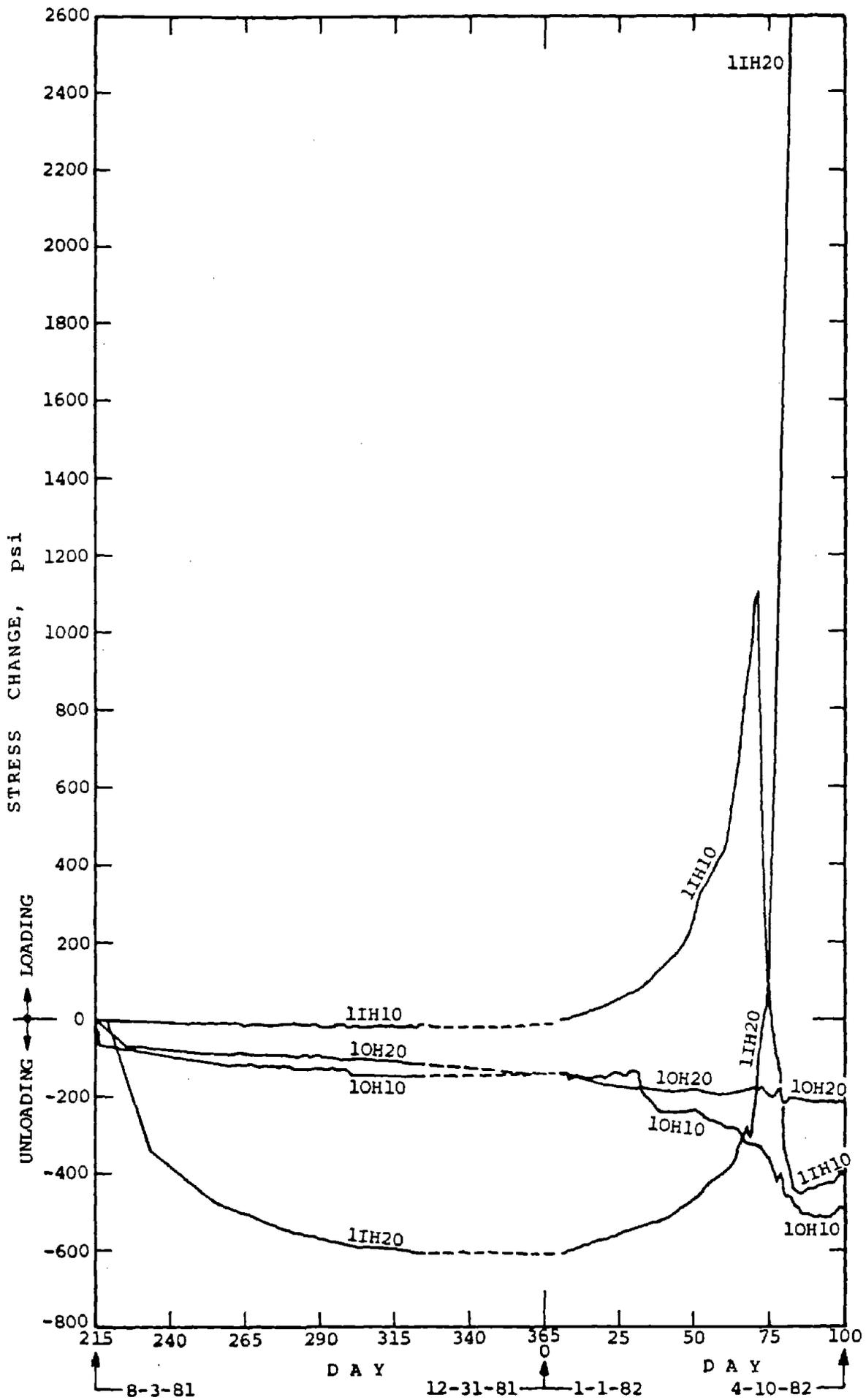


FIGURE 5.8
HORIZONTAL STRESSMETERS - STRESS CHANGE VS TIME

may be indicative of the development of a distressed (yielding) zone around the outside of the pillar.

The stress decrease recorded by 10H20, located 15 ft from the west edge of the pillar, suggests that the distressed zone was at least 15 ft wide. Data from stressmeters located near the central part of the pillar suggest transfer of load from the distressed zone to an inner confined core. As can be seen on Figures 5.7 and 5.8, stressmeters 1V20, 1V40 and 1IH20 show a stress increase which is consistent with the development of a confined core. Similar abrupt stress changes in chain pillar stressmeters were shown in data presented by Wade and Conroy (1977).

The maximum stress increases recorded, 2100 psi for 1V20 and 2600 psi for 10H20, are consistent with published results. Peng (1978) recorded a maximum vertical stress increase in the pillars of 2600 psi for an average overburden thickness of 800 ft. Wade and Conroy (1977) showed a maximum vertical stress change in the pillars of 1600 psi for an average overburden thickness of 620 ft.

5.3 MINE LEVEL DISPLACEMENTS

Displacement of the mine roof and floor were monitored by means of multipoint rod extensometers and tape extensometer convergence measurements. The relative displacement of extensometer anchors and roof-floor convergence with respect to face location is shown on Figures 5.9 and 5.10 where it can be seen that total convergence (up to 2.72 in.) was approximately 2.5 times greater than displacements indicated by the extensometer data (0.62 in. of roof sag plus 0.46 in. of floor heave equals an apparent total convergence of only 1.08 in.). Additionally, measurement of the distance between the reference plates of the roof and floor extensometers has shown convergence to be approximately four times

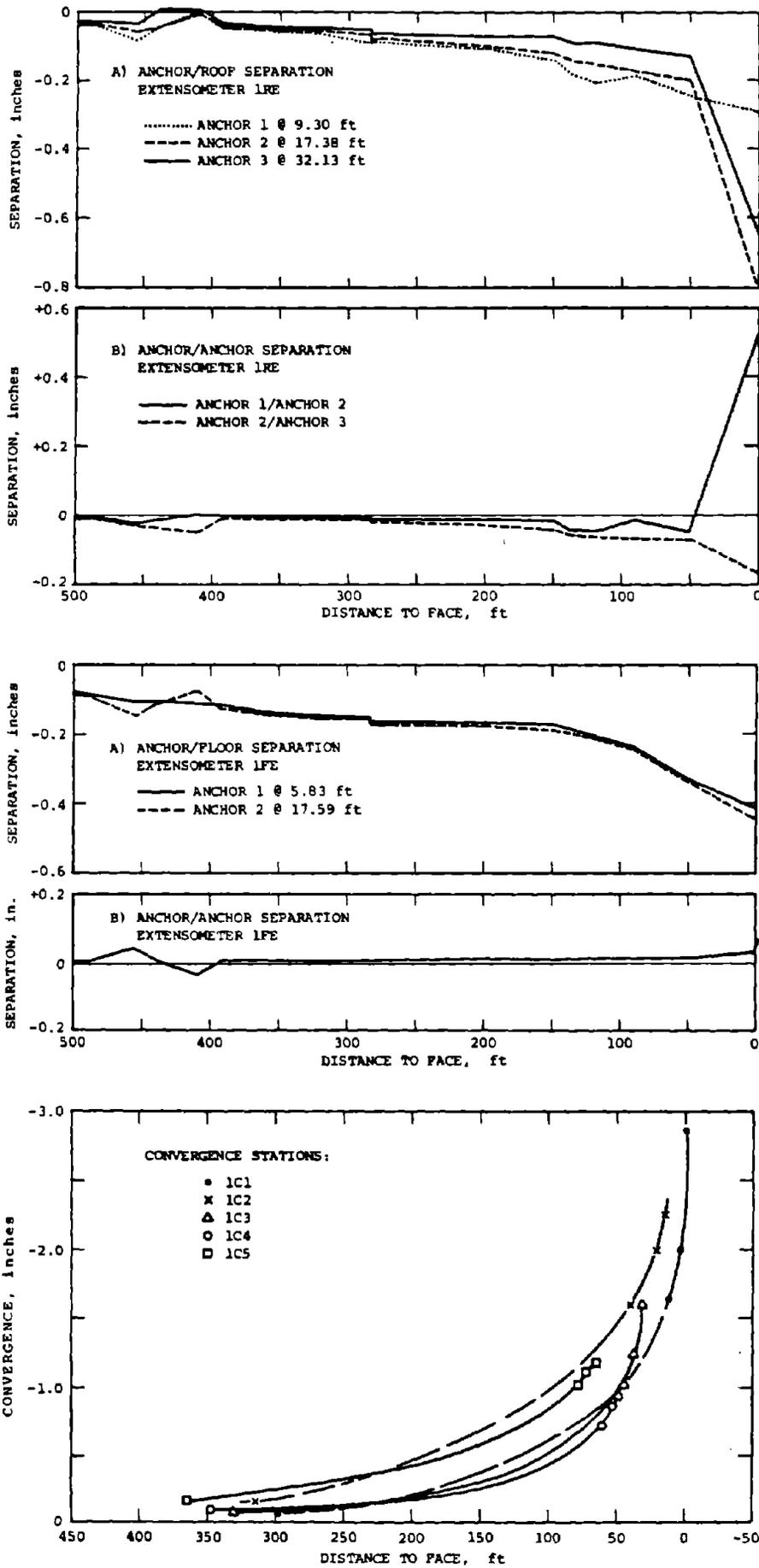


FIGURE 5.9
MINE LEVEL DISPLACEMENTS VERSUS FACE LOCATION

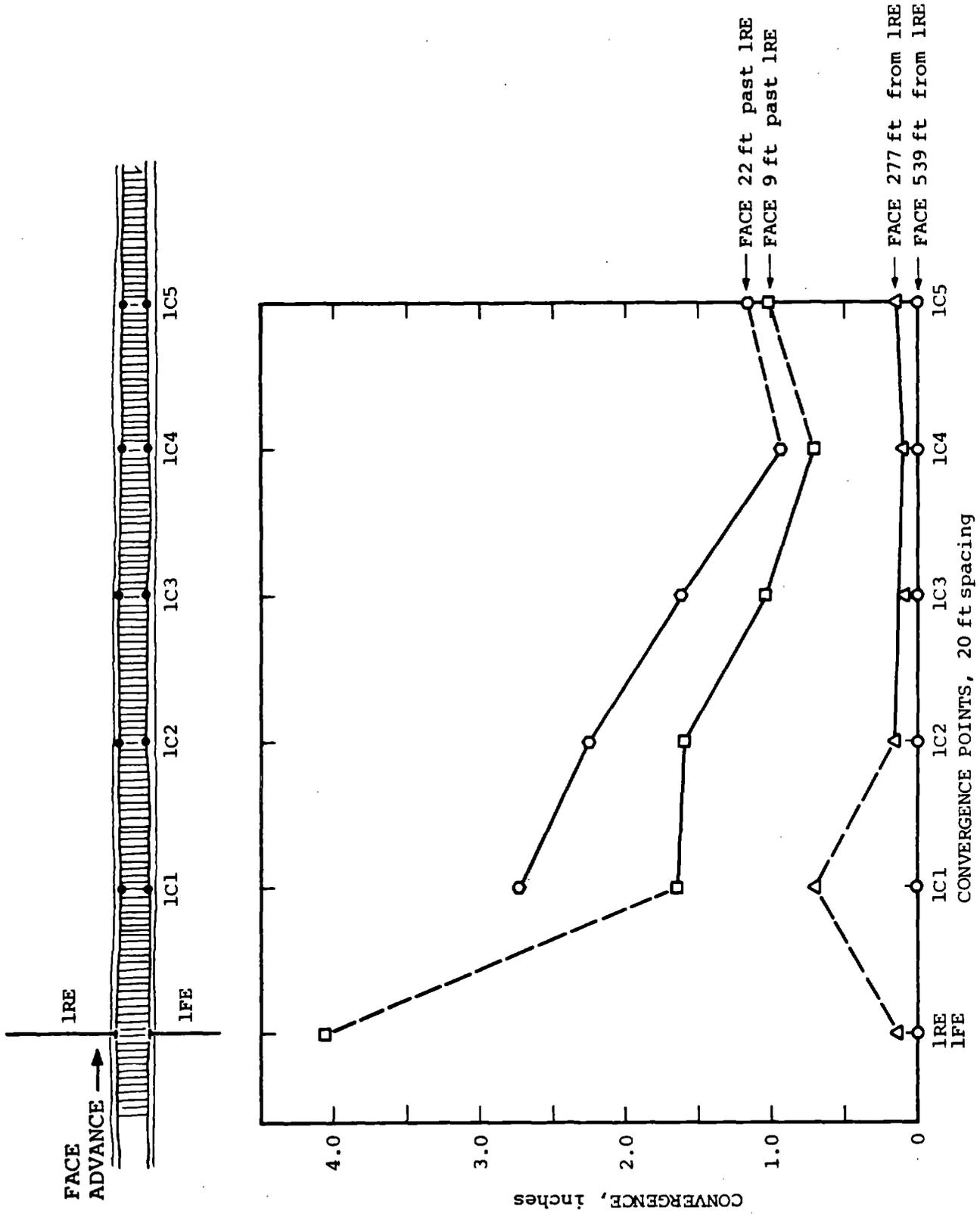


FIGURE 5.10
ROOF-FLOOR CONVERGENCE VERSUS MEASUREMENT LOCATION

greater (up to 4.0 in.) than that indicated by the extensometer data.

Strata separation, measured as the change in distance between anchors, was of the same order of magnitude as anchor/reference plate movement. Between anchors 1 and 2 in the roof 0.5 in. of extension occurred, while anchors 1 and 2 in the floor separated by 0.6 in. Roof strata separation most likely occurred at coal seams 8 and 20 ft above the Allen seam while floor strata separation probably occurred between the immediate floor stratum (shale) and a harder stratum (possibly sandstone), 8 ft below the Allen seam (Figure 3.17). The small extensometer displacements, relative to the much greater roof-floor convergence, indicate that the deepest anchors in both the roof and floor may have moved with the reference plates as a unit. While it is likely that the tendency for roof sag to occur would have been limited by the H-beams supporting the roof, the data does indicate that large rock mass movements must be causing the roof-floor convergence in spite of the roof support as evidenced by crushing of wooden cribs in the tailgate (Jackson, 1981).

The plots on Figure 5.9 show that mine level displacements begin about 400 ft ahead of the longwall face with the onset of greatest movement occurring about 150 ft outby. The plot on Figure 5.9 shows that the amount of roof-floor convergence essentially decreases linearly with distance outby the longwall face.

5.4 OVERBURDEN DISPLACEMENTS

Extensometers and inclinometers were installed to monitor vertical and horizontal displacements within the overburden. By May of 1982, the REX-1 installation had been undermined by longwall mining and the SLEX-1 installation had been affected by room-and-pillar mining. Due to the mining sche-

dule, it was possible to monitor not only the effect of face advance rate but also the time factor associated with subsidence.

5.4.1 Vertical Displacements

The only comprehensive data was obtained from the REX-1 rod extensometer. The anchor displacements versus face location are shown on Figure 5.11 while anchor displacements versus time are shown on Figure 5.12.

Anchor movements began when the face was about 500 ft from REX-1, but anchor separation indicative of strata separation did not begin until the face was about 300 ft from REX-1. At that time the shallower anchors were being displaced slightly more than the deeper anchors as might be expected with the development of a subsidence trough ahead of the face. Displacement of all anchors increased rapidly when the face was within 100 ft of REX-1 and significant strata separation began as the installation was undermined. At that time, the deepest anchors were displaced more rapidly, with strata separation of 1.57 in. occurring 170 to 240 ft above the mined seam (Figures 3.7 and 3.14). The relatively small magnitude of these strata movements is further evidenced by the TDR data in Table 5.5 which shows the coaxial cable to be essentially intact, indicating that strata separation was not sufficient to break the cable.

During the periods of March 6 to April 5, 1982, and April 23 to May 11, 1982, the longwall was idle for periods of 2 to 3 weeks. As can be seen on Figure 5.12, subsidence continued during these periods but in both cases it occurred at a rate of 0.8 in. per day for all six extensometer anchors with little or no strata separation. During the first period the face was within 100 ft of REX-1 and during the second period the face was just over 100 ft past REX-1.

TABLE 5.5
TDR DATA SUMMARY

| DATE | TOTAL CABLE LENGTH INDICATED | |
|---------|------------------------------|-------------|
| | SLEX-1 | REX-1 |
| 7-08-82 | 600 ± 12ft | |
| 7-24-82 | | 830 ± 16 ft |
| 3-09-82 | 600 ± 12ft | 835 ± 17 ft |

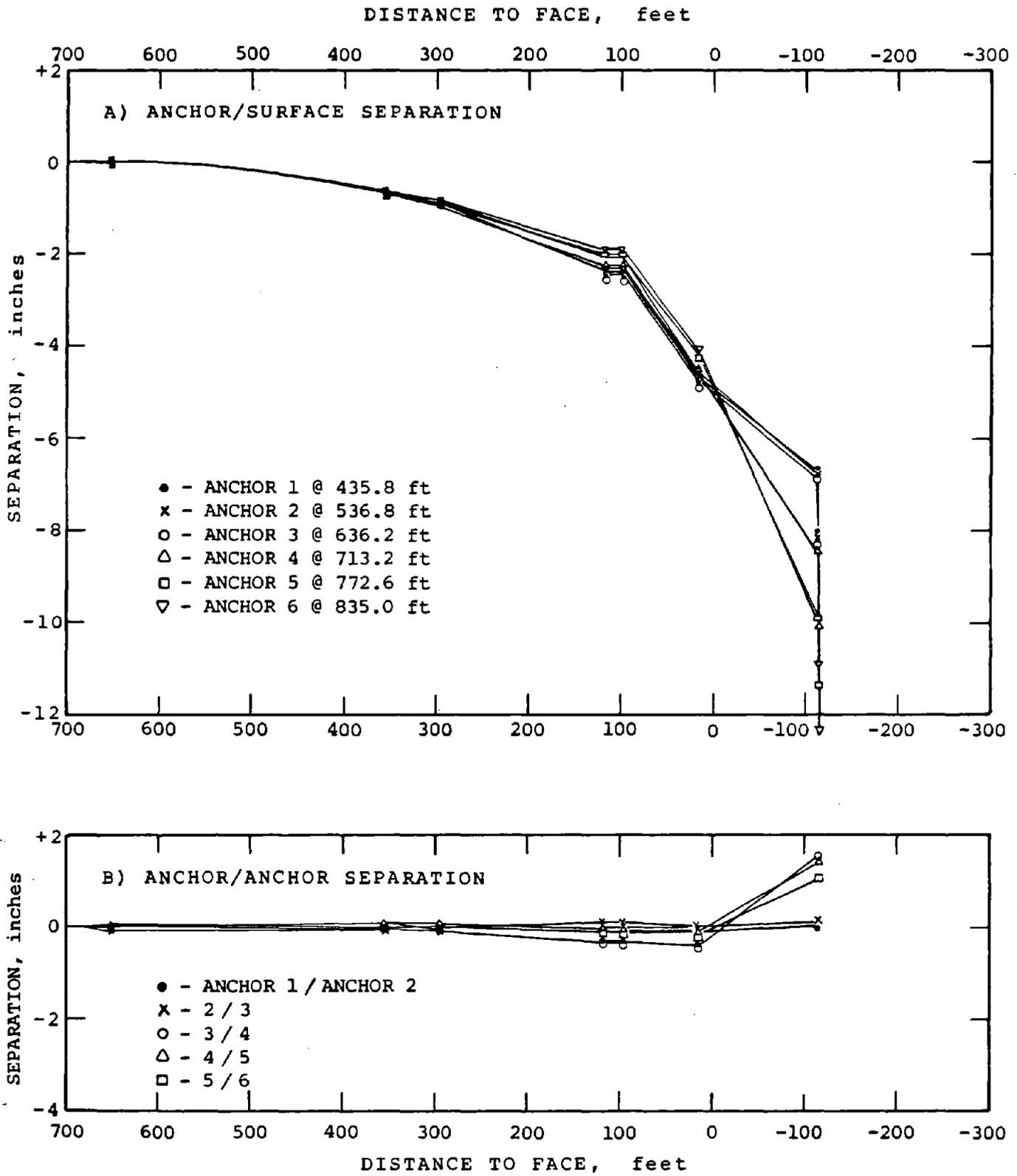


FIGURE 5.11
 REX-1 SURFACE EXTENSOMETER DISPLACEMENTS VS FACE LOCATION

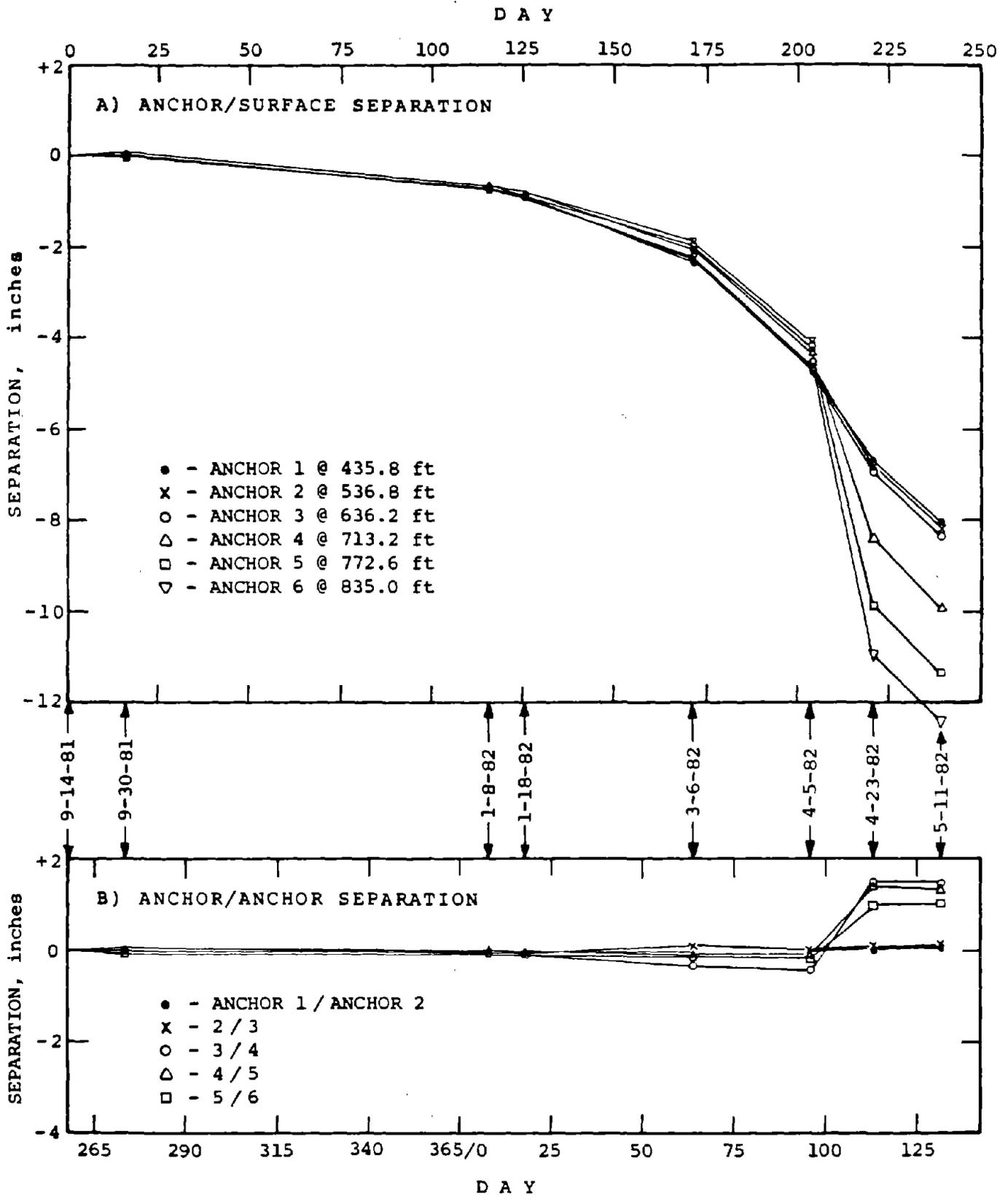


FIGURE 5.12
 REX-1 SURFACE EXTENSOMETER DISPLACEMENTS VERSUS TIME

The plots of SLEX-1 and SLEX-2 Sondex data on Figures 5.13 and 5.14 are shown primarily to illustrate how erratic the data can be and how such data must be carefully evaluated. While there was room and pillar development under SLEX-1 by March of 1982, there had not been sufficient coal extraction for subsidence to develop within the overburden in this area. There had been no mining of coal beneath SLEX-2. This lack of activity should be reflected in the Sondex data as shown for September 1981 and March 1982. The plot for January, 1982, however implies that displacement had occurred and that the displacements were very erratic. Consequently, the data for January must be considered invalid for purposes of data analysis.

The erratic data of January, 1982, can be attributed to the fact that a different cable, cable reel and pulley assembly was used to collect this data than was used in September, 1981, and March, 1982. In particular, the pulley assembly used in January made it extremely difficult to obtain accurate, reliable measurement of distance between the markers on the cable and the top of the casing.

5.4.2 Horizontal Displacements

The plots of horizontal displacements on Figures 5.15 through 5.18 indicate that movement occurred along the B-axis of SLEX-1 and along both the A-axis and B-axis of SLEX-2. Although the indicated displacements may actually reflect rockmass movements, it is more probable that these movements are due to settling of the pea gravel backfill around the SLEX casing. The nature of these displacements cannot be determined with any certainty without continued monitoring. The inclinometer data for September of 1981 indicated that the drillholes may deviate from vertical at a rate of 0.03 to 0.04 ft per ft of depth.

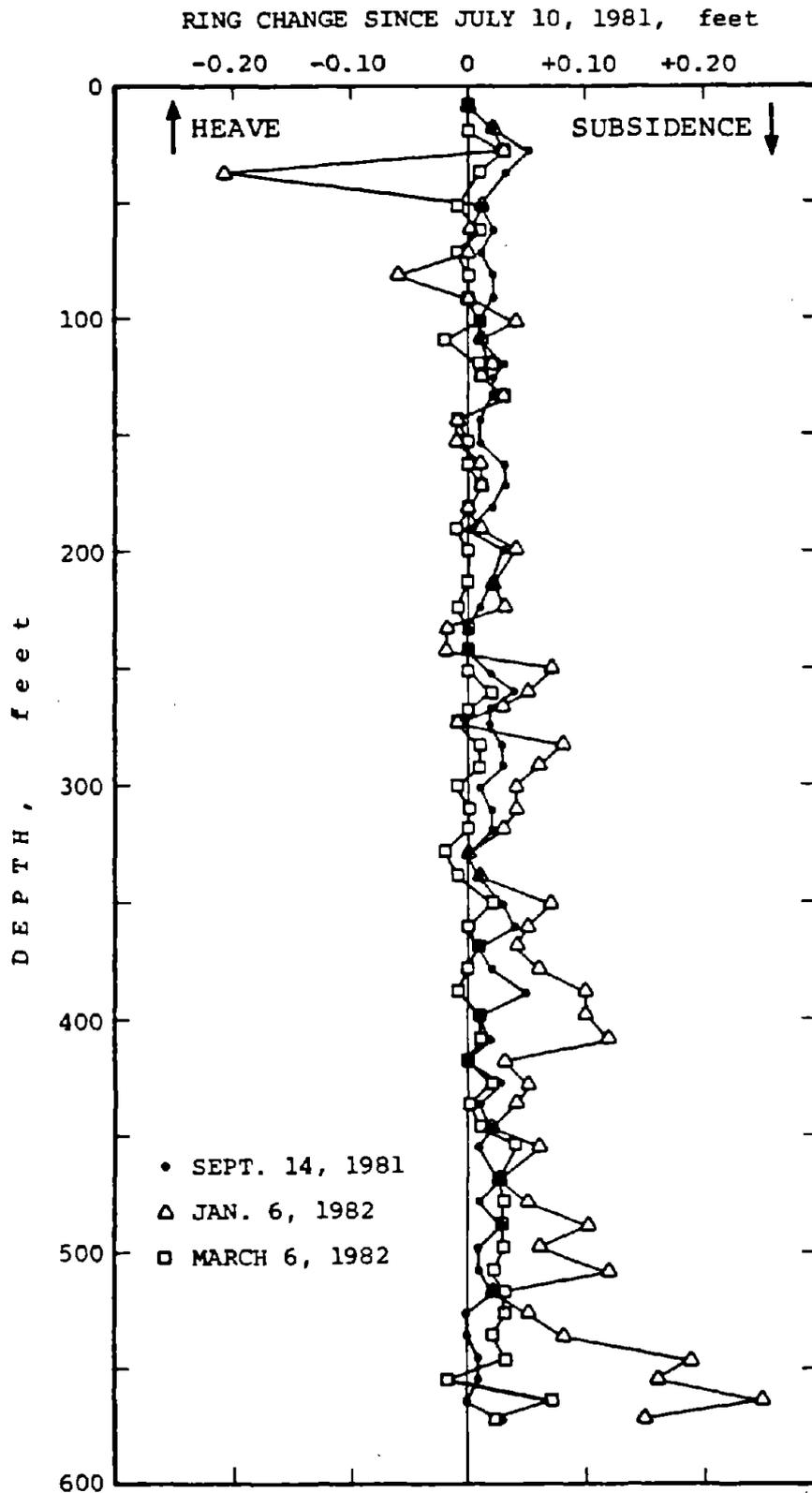


FIGURE 5.13
 RING CHANGE VERSUS DEPTH - SLEX-1

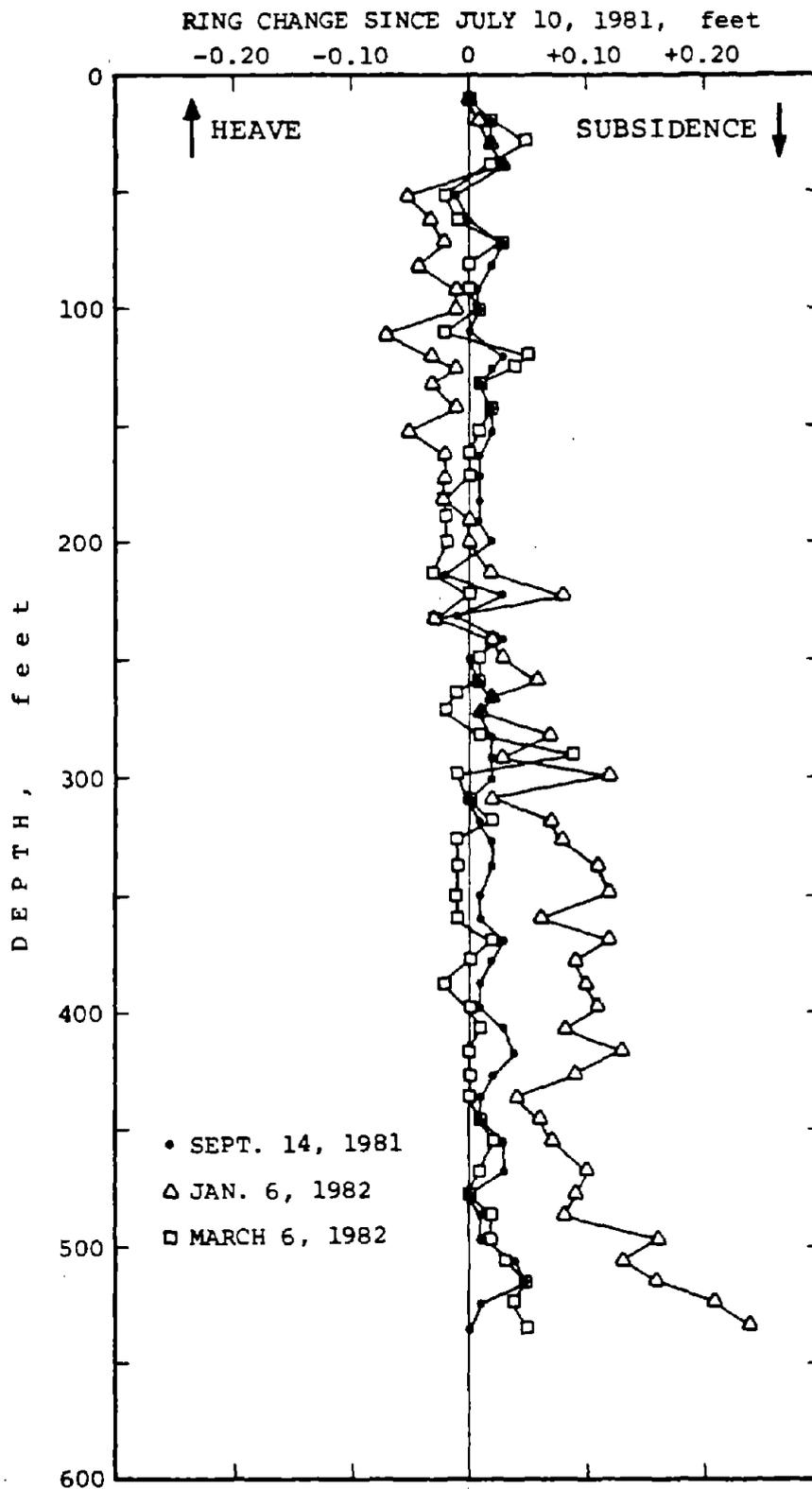


FIGURE 5.14
 RING CHANGE VERSUS DEPTH - SLEX-2

HORIZONTAL DISPLACEMENT SINCE SEPT. 14, 1981, feet

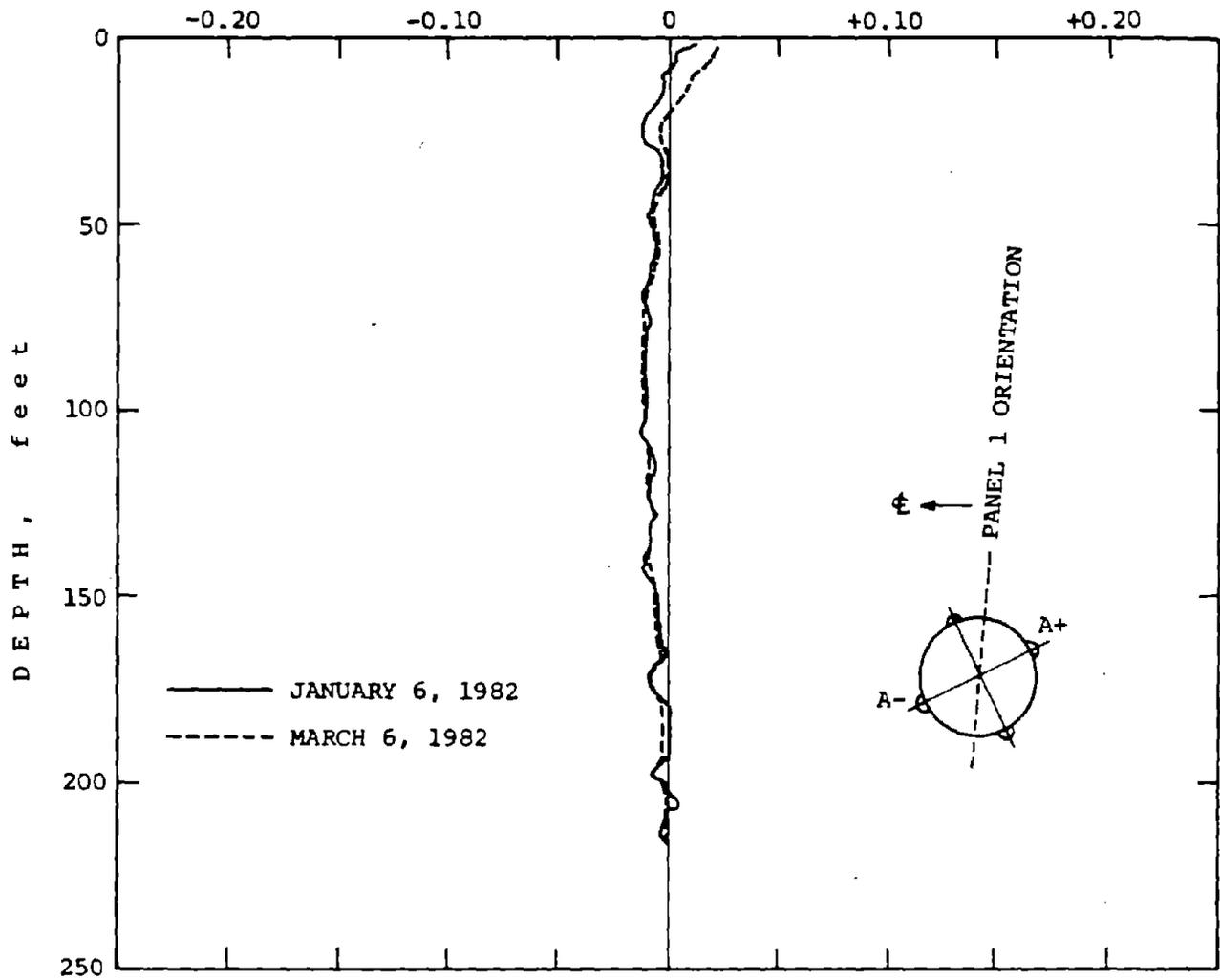


FIGURE 5.15
HORIZONTAL DISPLACEMENT VERSUS DEPTH
SLEX-1, A-AXIS

HORIZONTAL DISPLACEMENT SINCE SEPT. 14, 1981, feet

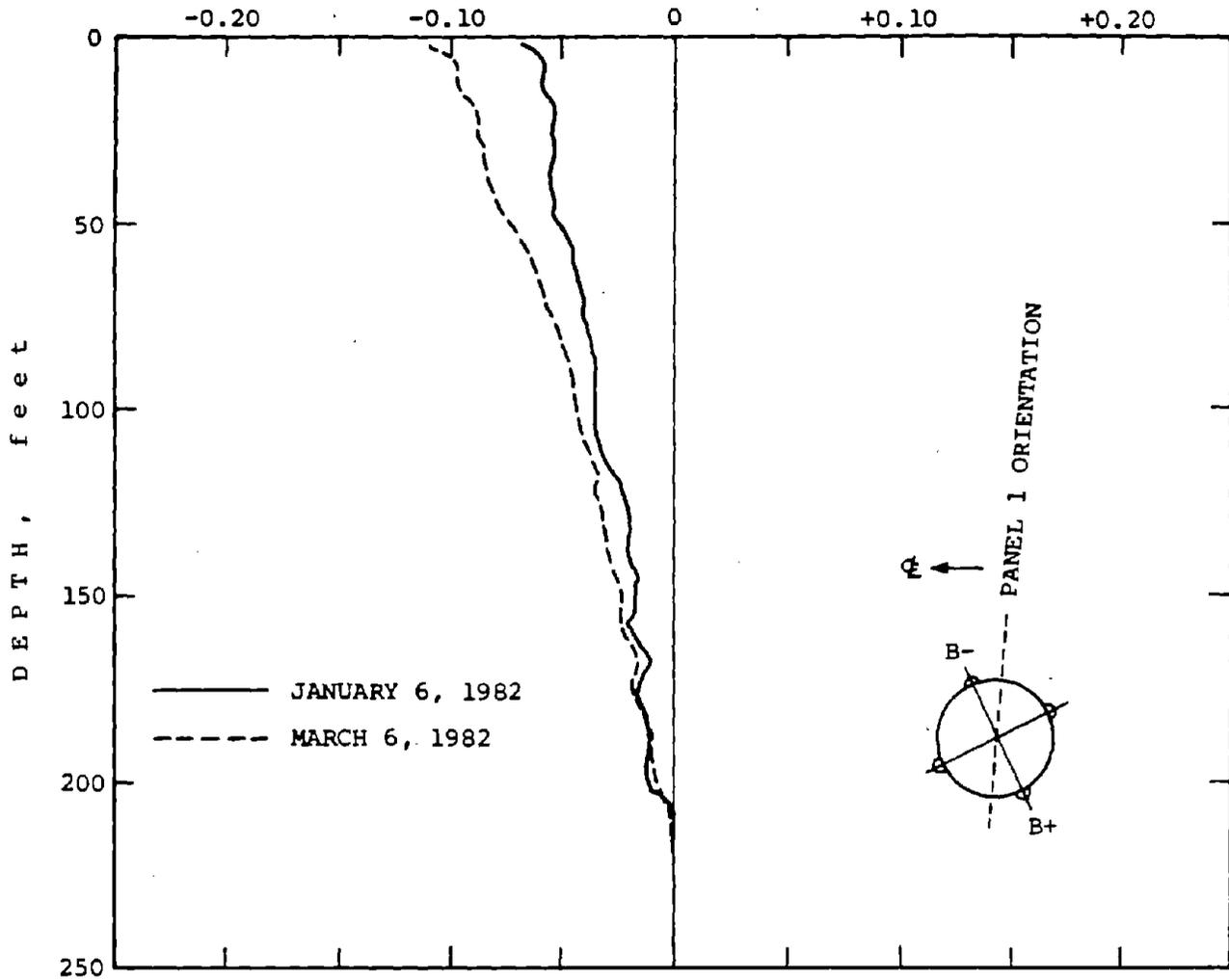


FIGURE 5.16
HORIZONTAL DISPLACEMENT VERSUS DEPTH
SLEX-1, B-AXIS

HORIZONTAL DISPLACEMENT SINCE SEPT. 14, 1981, feet

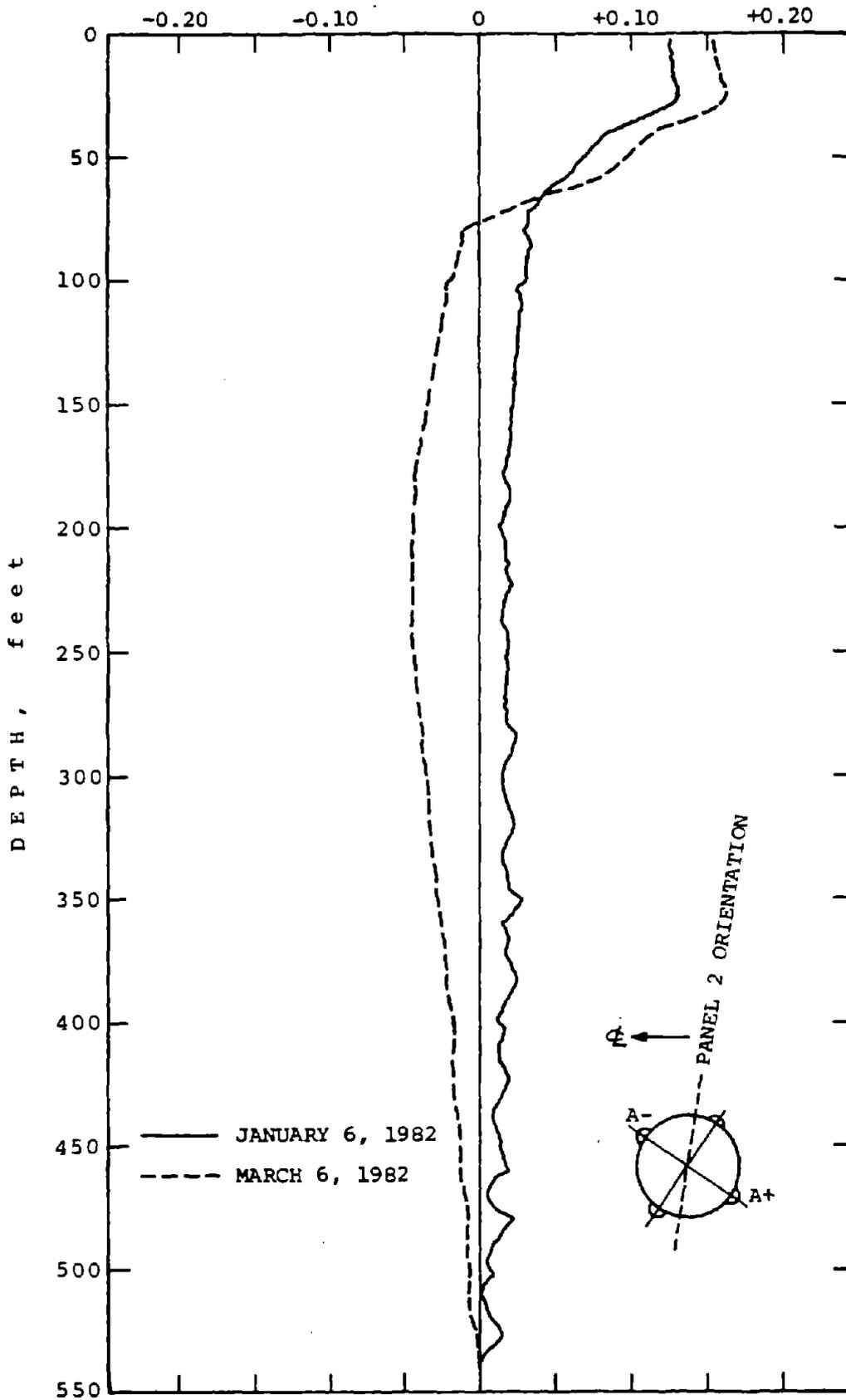


FIGURE 5.17
HORIZONTAL DISPLACEMENT VERSUS DEPTH
SLEX-2, A-AXIS

HORIZONTAL DISPLACEMENT SINCE SEPT. 14, 1981, feet

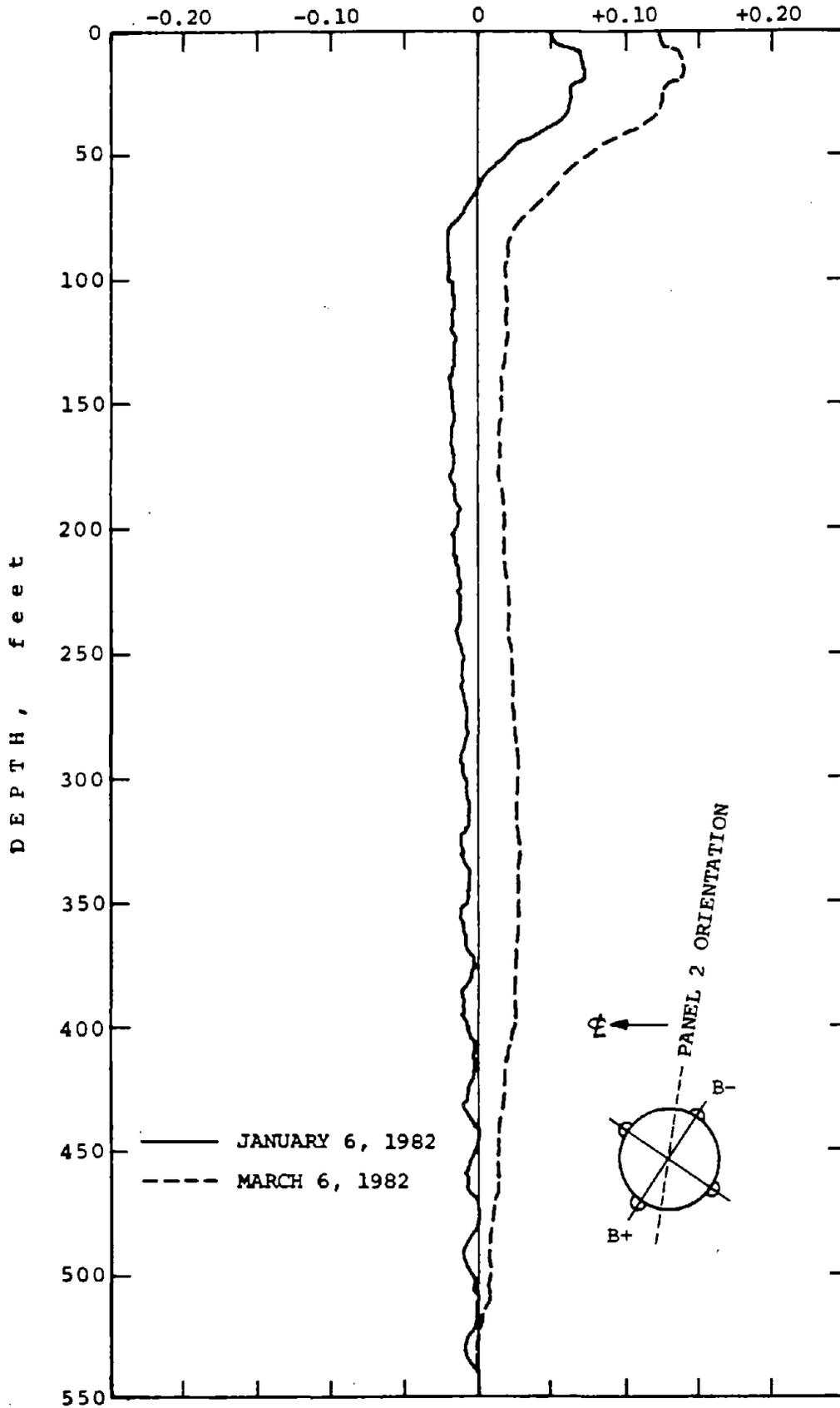


FIGURE 5.18
HORIZONTAL DISPLACEMENT VERSUS DEPTH
SLEX-2, B-AXIS

The attempts made to check spiraling of the inclinometer casing produced poor results. The data showed poor agreement between values obtained while lowering the probe and values obtained while raising the probe. In discussions with Slope Indicator Company, it was stated that readings must be taken during four runs, with the spiral-checking device rotated 90 degrees before making each subsequent run along the entire casing length

5.5 SURFACE MOVEMENTS

Ground surface movements were monitored by surveying the coordinates and elevations of 94 surface monuments. By monitoring changes in elevation it has been possible to observe the development of surface subsidence due to mining while changes in coordinates have made it possible to serve not only the effect of mining, but also topography, on horizontal movements.

As of May, 1982, the longwall operation of Panel 1 had been discontinued before survey line 3 was undermined and the face of Panel 2 was still 450 ft from survey line 3. Consequently, there is not yet data with which to determine either the angle of draw or the magnitude of maximum subsidence along any of the survey lines. Without knowing maximum subsidence, generalized subsidence curves cannot be generated.

By monitoring changes in elevations it was possible to observe subsidence trough development along survey line 2 as well as subsidence due to room and pillar mining along survey lines 1 and 3. The subsidence development curves are shown in Figures 5.19, 5.21 and 5.23 and the vertical displacements are correlated with mining activities on Figures 5.20, 5.22 and 5.24. Subsidence along line 1 is associated with room and pillar mining of Panel 1 after the

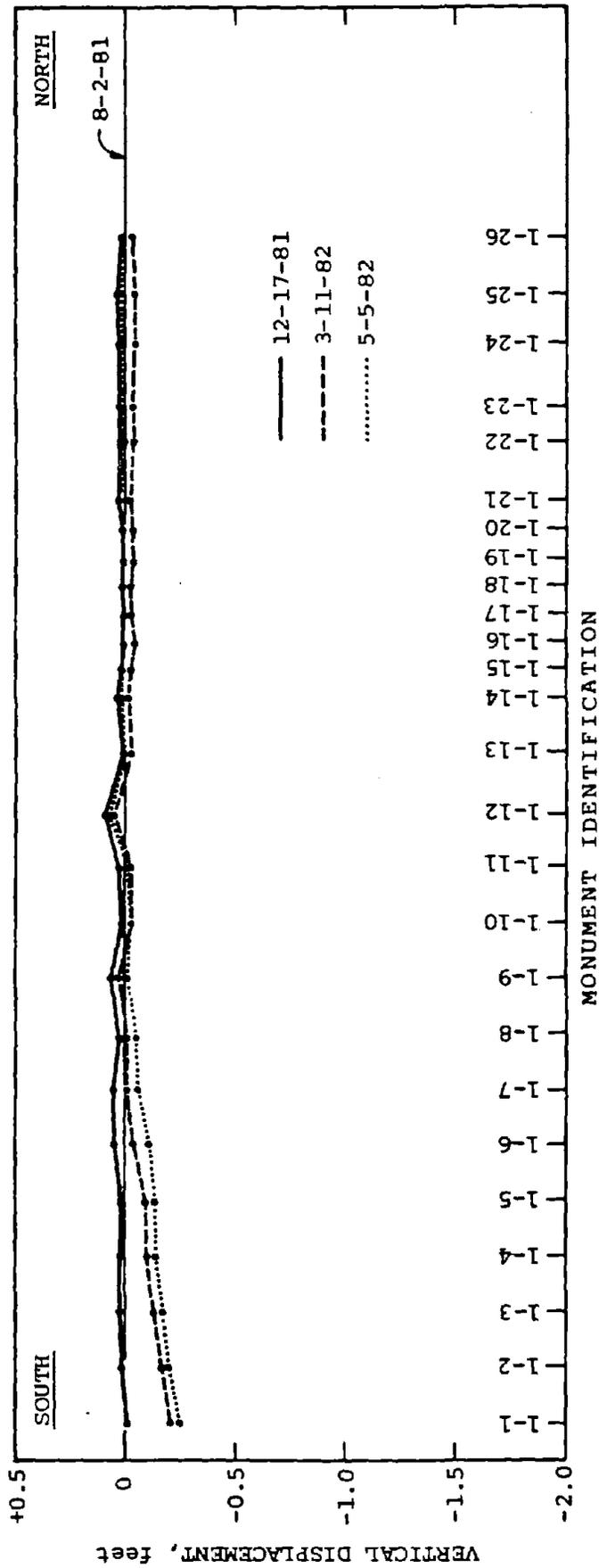


FIGURE 5.19
SUBSIDENCE DEVELOPMENT ALONG SURVEY LINE #1

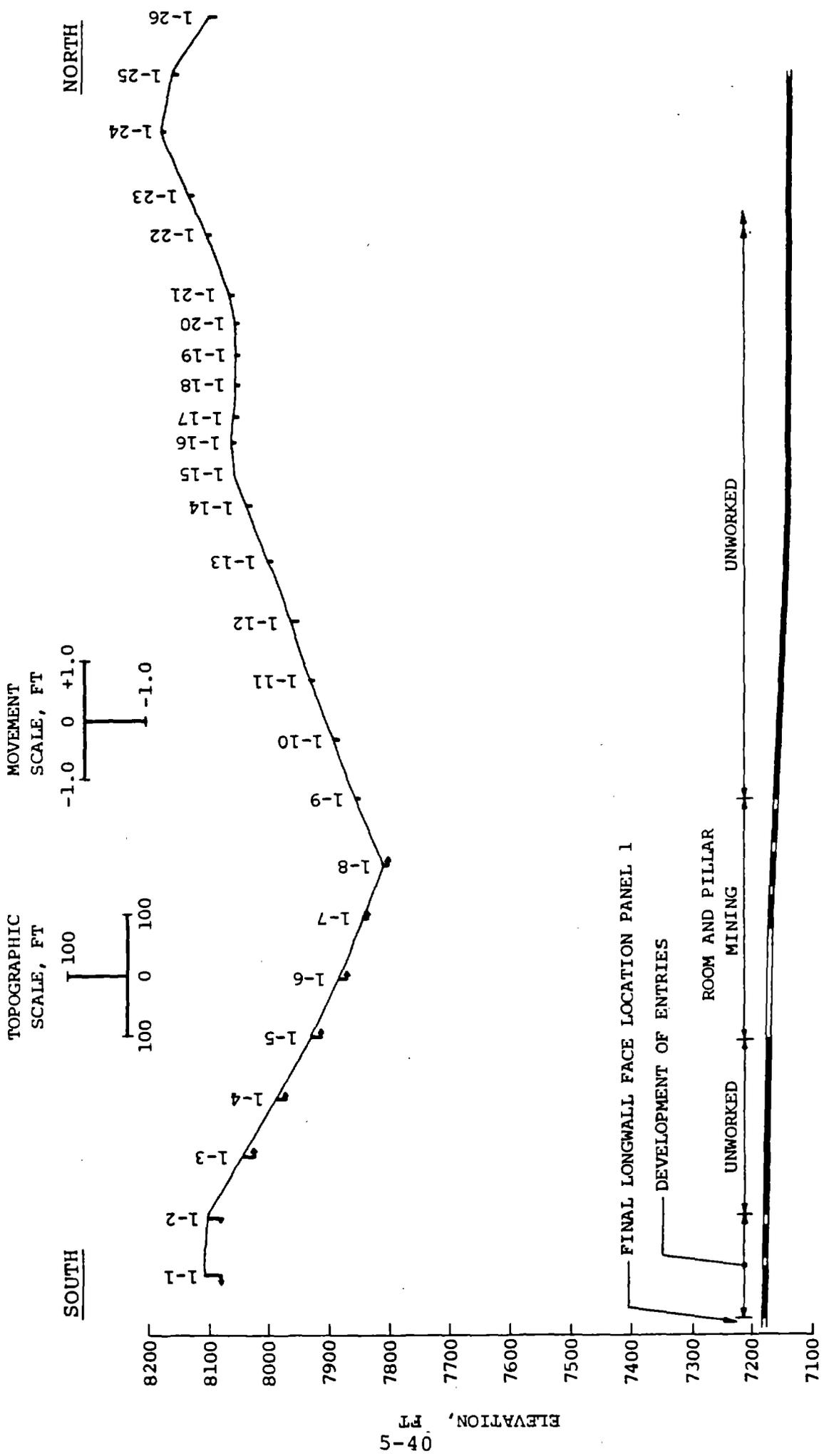


FIGURE 5.20
 SURVEY LINE 1 - VERTICAL AND HORIZONTAL SURFACE MOVEMENTS
 BETWEEN AUGUST 1981 AND MAY 1982

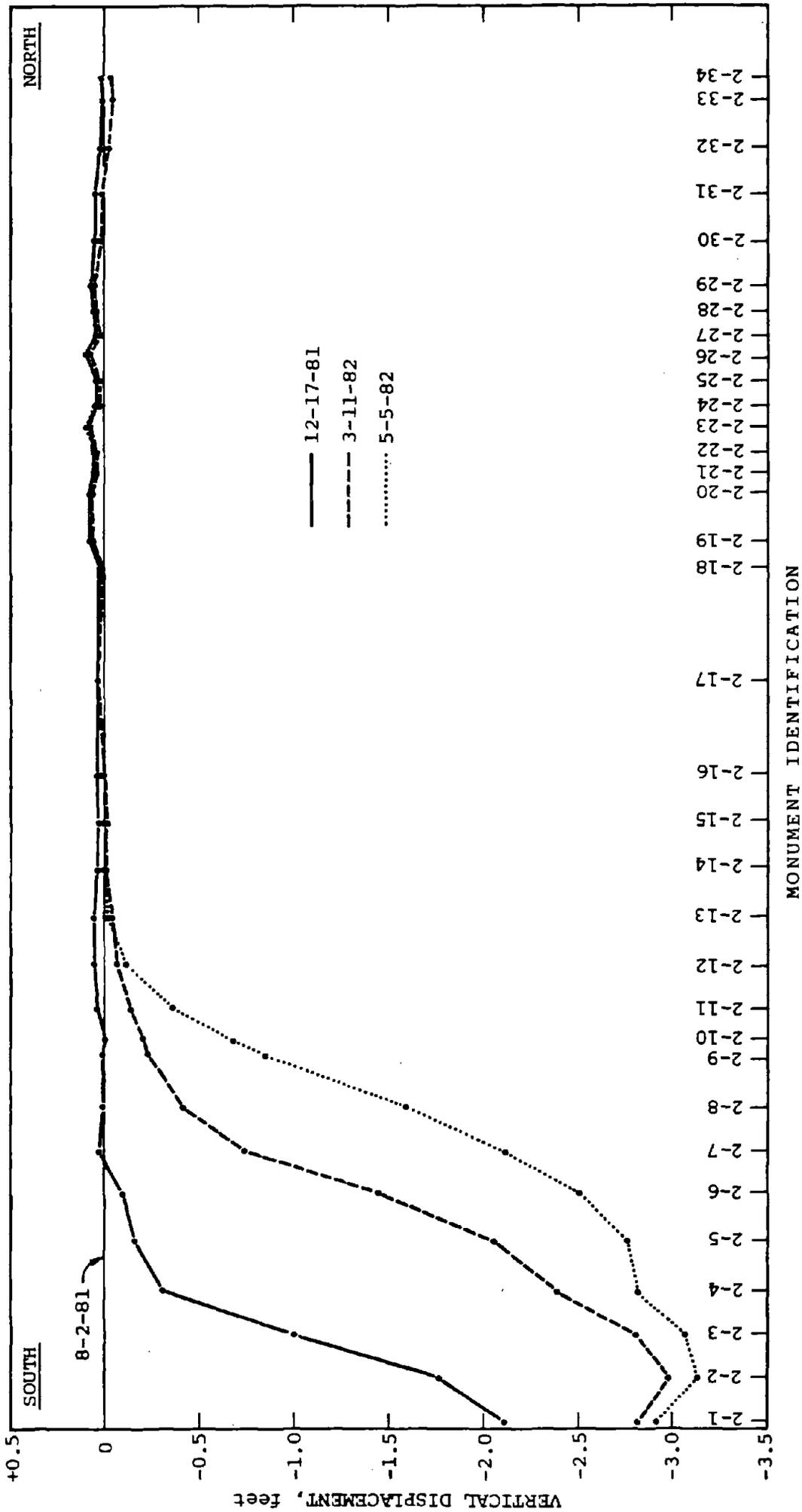


FIGURE 5.21
SUBSIDENCE DEVELOPMENT ALONG SURVEY LINE #2

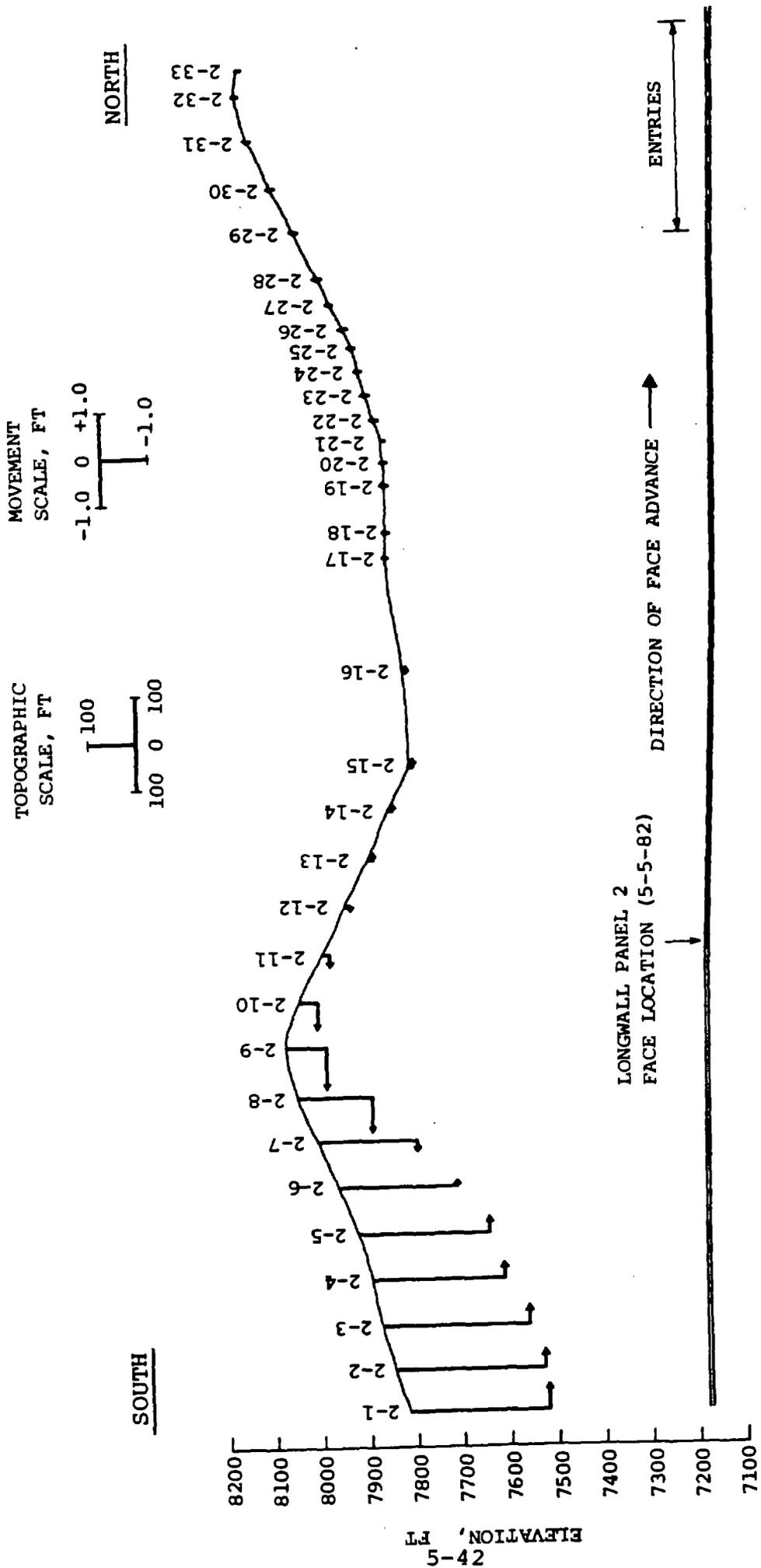


FIGURE 5.22
SURVEY LINE 2 - VERTICAL AND HORIZONTAL SURFACE MOVEMENTS
BETWEEN AUGUST 1981 AND MAY 1982

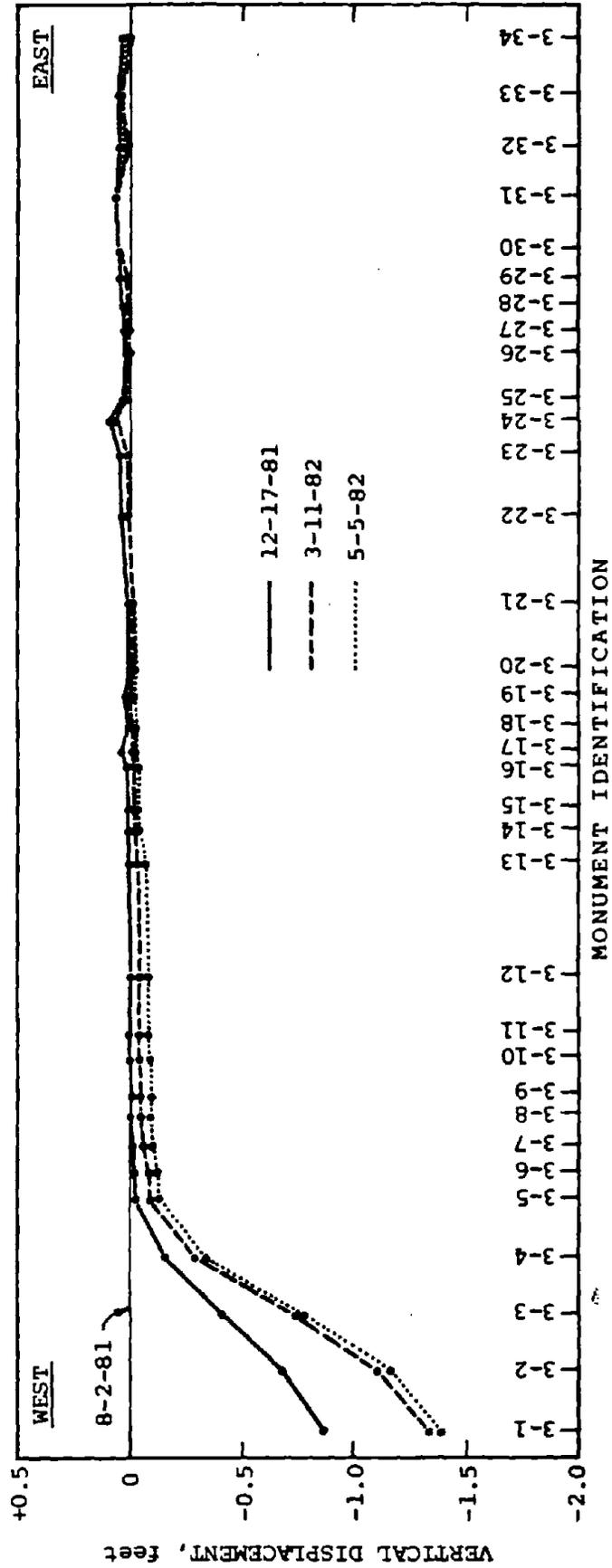


FIGURE 5.23
SUBSIDENCE DEVELOPMENT ALONG SURVEY LINE #3

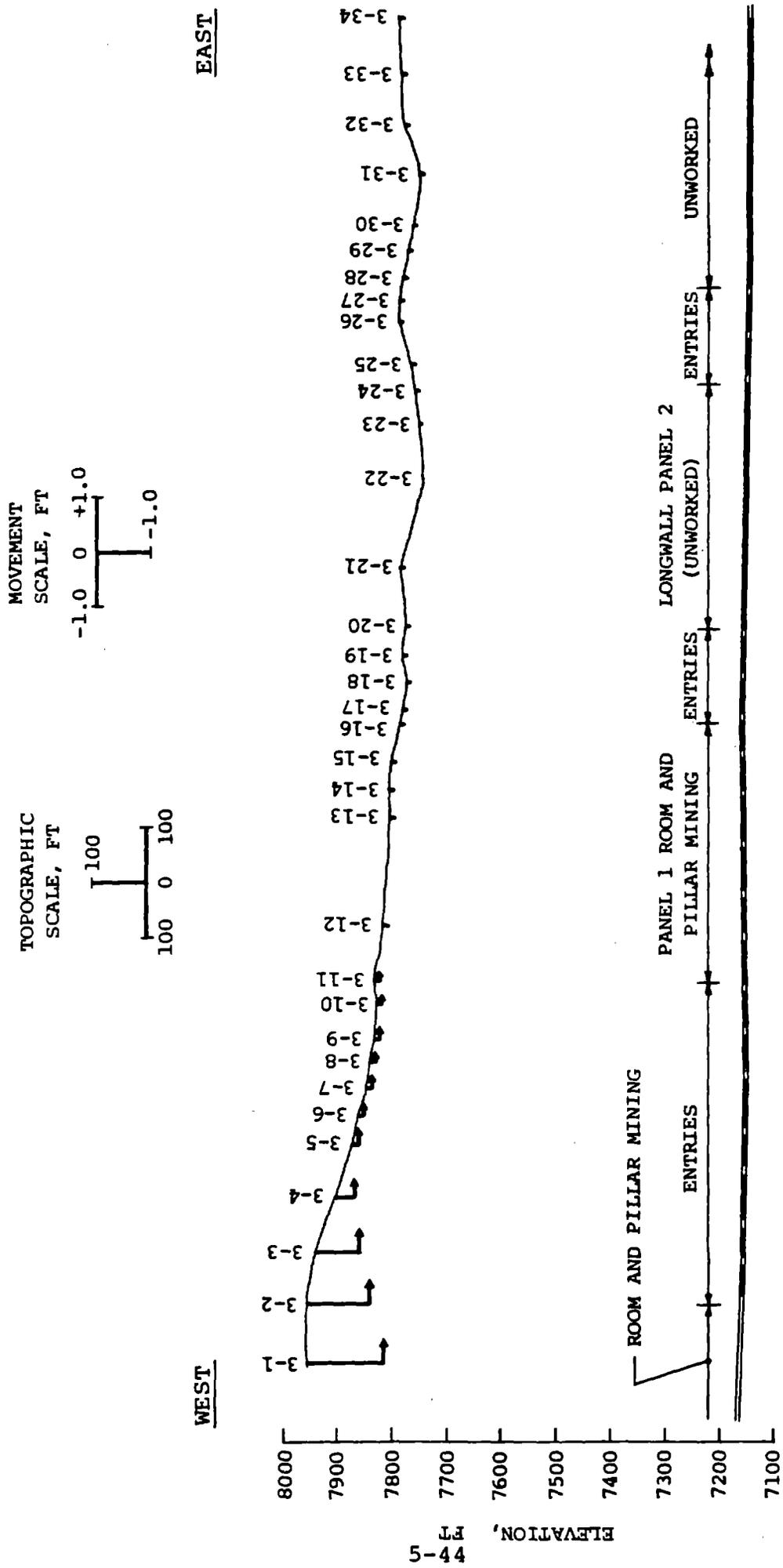


FIGURE 5.24

SURVEY LINE 3 - VERTICAL AND HORIZONTAL SURFACE MOVEMENTS BETWEEN AUGUST 1981 AND MAY 1982

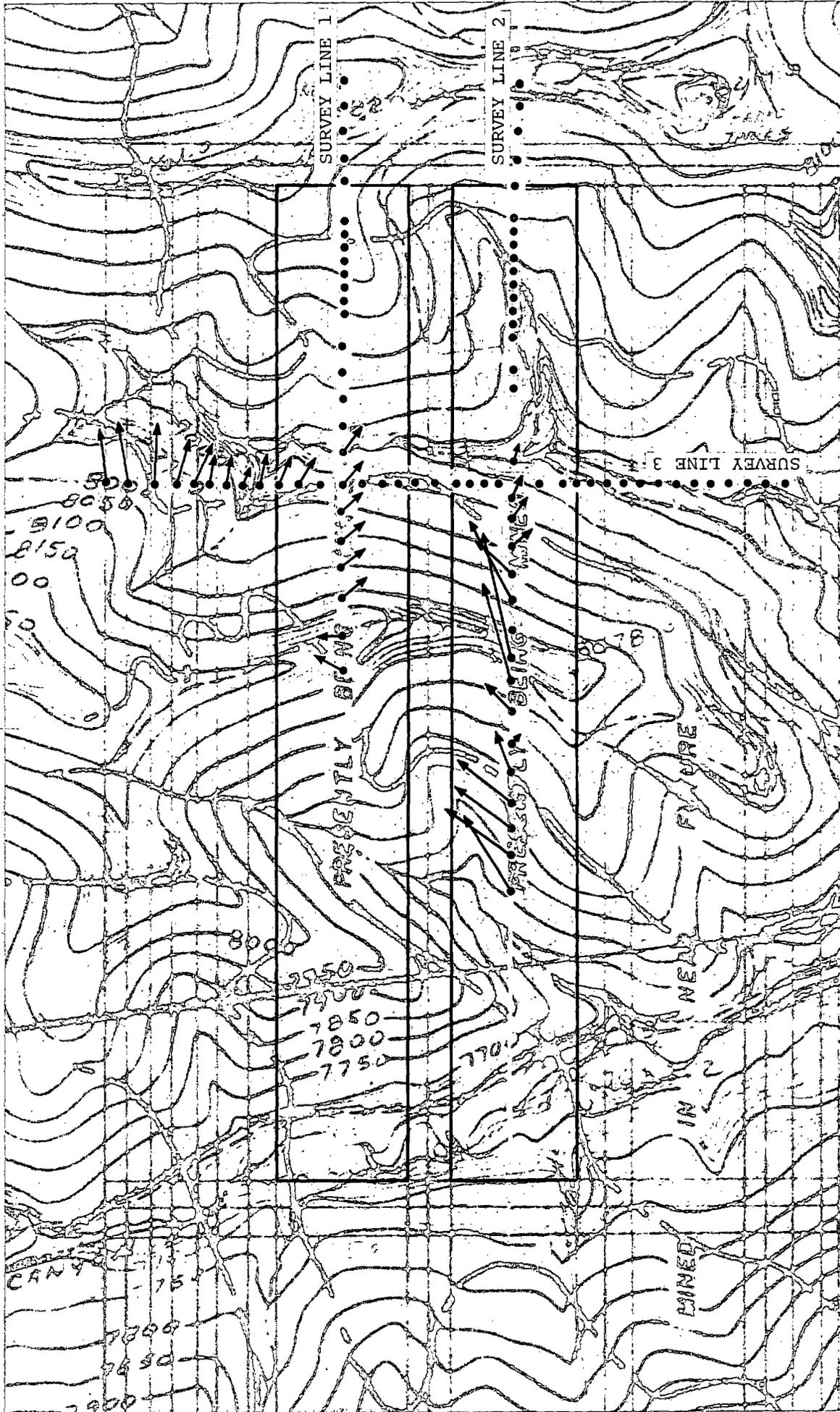
longwall operation was stopped in August of 1981. Subsidence at the west end of line 3 is associated with room and pillar mining of Section 2P (Figure 3.2) between September, 1981, and December, 1981.

The horizontal displacements plotted on Figures 5.20, 5.22 and 5.24 represent only one component of horizontal movement. The actual magnitude and direction of the horizontal movements are shown on Figure 5.25. The trend of vector orientations in this figure lends credence to the theory that topography has a significant influence on horizontal displacements and strains (Conroy and Gyarmaty, 1982, and Gentry and Abel, 1978). Due to the fact that the horizontal displacement vectors do not parallel the survey lines, and without data from the Automatic Data Acquisition System (ADAS) during undermining it was not considered appropriate to calculate surface strains.

Although it was not possible to generate a generalized subsidence curve for survey line 2, the plot of vertical displacement versus face location on Figure 5.26 resembles generalized curves, wherein vertical displacements are normalized with respect to the maximum subsidence, which have been presented in the literature (Wade and Conroy, 1977, Gentry and Abel, 1978, and Conroy and Gyarmaty, 1982).

5.6 GROUNDWATER CONDITIONS

The purpose of monitoring groundwater levels and quality in the two SLEX holes through March, 1982, was to establish baseline data. While water quality monitoring has limitations with the water sampling procedures used, the data could still be used as a basis for evaluating gross changes in groundwater quality, provided that the SLEX holes remain open to the full depths and do not become completely drained.




 VECTOR INDICATES MAGNITUDE AND DIRECTION OF HORIZONTAL MOVEMENT OF SURFACE MONUMENTS



FIGURE 5.25

HORIZONTAL MOVEMENT OF SURFACE MONUMENTS

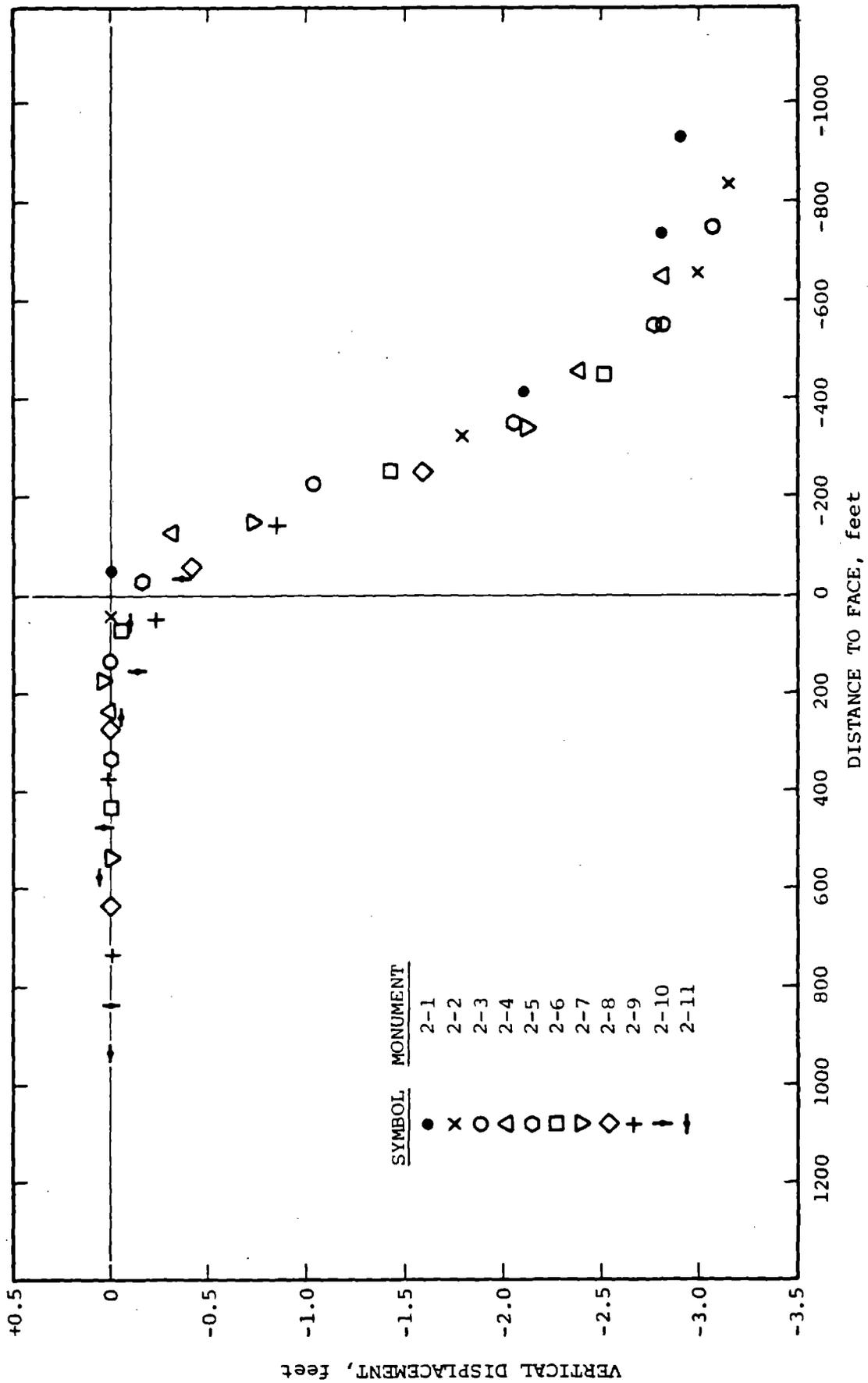


FIGURE 5.26

SURVEY LINE 2 - VERTICAL DISPLACEMENT OF SURFACE MONUMENTS VERSUS FACE LOCATION

A graphical comparison of groundwater quality in the SLEX holes with that of water sampled from the Purgatoire upstream of the Allen Mine is shown on Figure 5.27. The SLEX data are mean values for samples obtained in September, 1981, and January, 1982, while the Purgatoire River sample data are mean values for ten samples obtained during 1980 (Water, Waste and Land, 1980). The similarity of comparison is notable although differences exist between the SLEX holes with respect to magnesium and sulfate and differences exist between the river water and groundwater with respect to calcium, sodium and bicarbonate.

Water levels in the SLEX holes for September 1981, January 1982 and March 1982 are superimposed on the stratigraphic correlations of Figure 3.8 and are listed in Table 5.6. The inferred correlation on Figure 3.8 suggests that the strata is discontinuous, and the differences in water level changes also suggest that there is no direct communication between SLEX-1 and SLEX-2. Also indicative of this lack of communication was the fact that a negative gradient existed between the SLEX holes in September 1981 (the gradient of the valley in which these holes are located is from west to east).

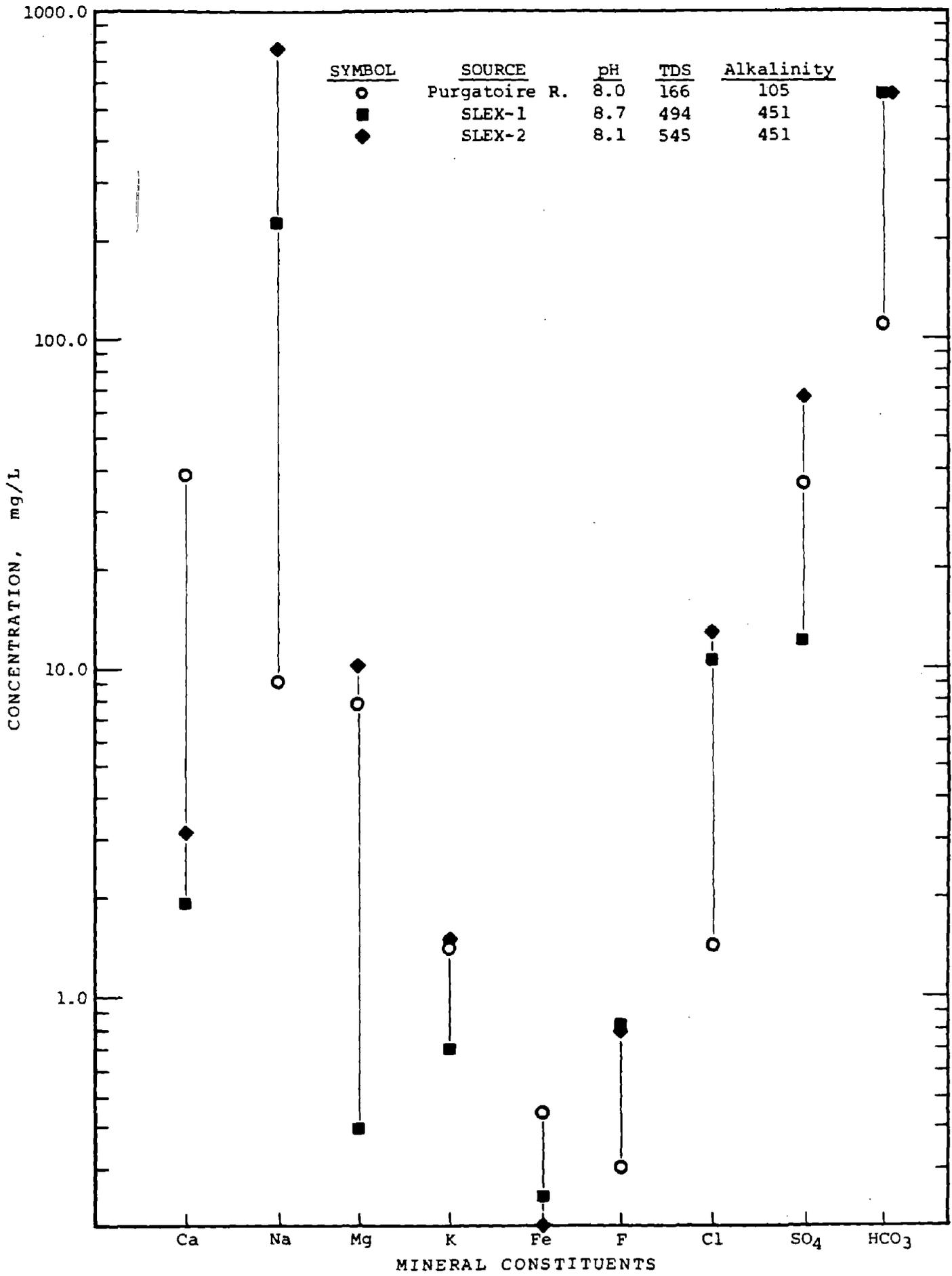


FIGURE 5.27
 COMPARISON OF WATER QUALITY IN SLEX HOLES AND
 PURGATOIRE RIVER UPSTREAM OF ALLEN MINE

TABLE 5.6
WATER LEVELS AND CHANGES IN SLEX HOLES

| DATE | SLEX-1 | | SLEX-2 | |
|--------------|-------------------|----------------|-------------------|----------------|
| | ELEVATION (ft) | CHANGE (ft) | ELEVATION (ft) | CHANGE (ft) |
| 9-22-81 | 7530.89 | | 7531.74 | |
| 1-10-82 | 7531.64 | +0.75 | 7522.82 | -8.92 |
| 3-05-82 | 7517.98 | -13.66 | 7505.13 | -17.69 |
| TOTAL CHANGE | | -12.91 | | -26.61 |

TABLE 5.7
GRADIENT FROM SLEX-1 TO SLEX-2

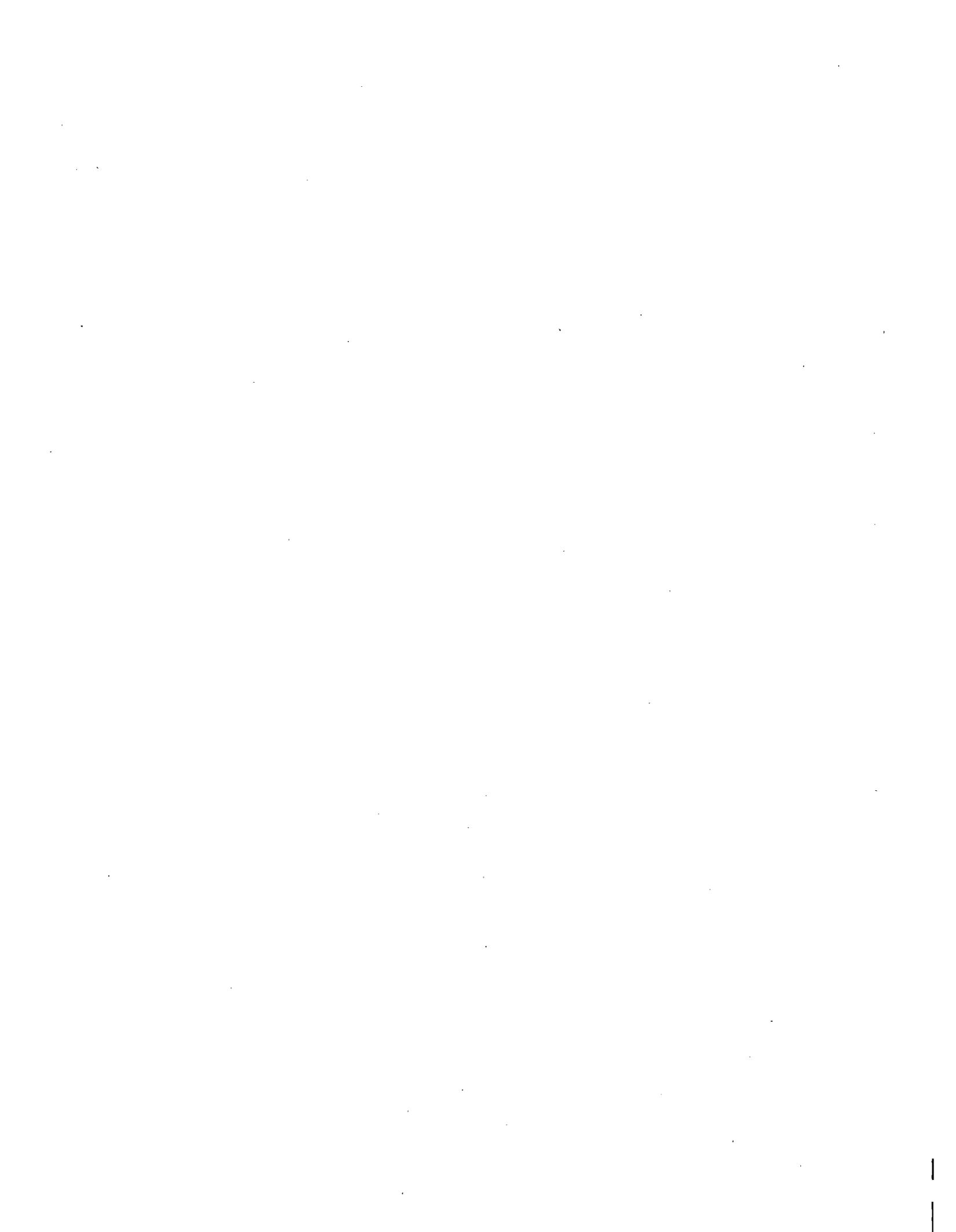
| DATE | SLEX-1 ELEVATION (ft) | SLEX-2 ELEVATION (ft) | ELEVATION DIFFERENCE (ft) | GRADIENT* (ft/ft) |
|---------|-----------------------------|-----------------------------|---------------------------------|----------------------|
| 9-22-81 | 7530.89 | 7531.74 | -0.85 | -0.0012 |
| 1-10-82 | 7531.64 | 7522.82 | 8.82 | 0.0119 |
| 3-05-82 | 7517.98 | 7505.13 | 12.85 | 0.174 |

Notes:

*Based on 8-02-81 survey, distance between SLEX holes

$$= \text{SQRT} [(174,936.77-174,717.84)^2 + (2,154,705.87-2,155,44.82)^2]$$

$$= 738.95 \text{ ft}$$



6.0 RECOMMENDATIONS FOR CONTINUED MONITORING

Preliminary analysis of the data acquired during room and pillar mining of Panel 1 and longwall mining through the first instrumented section of Panel 2 has provided baseline data for continued monitoring. Continued monitoring will be necessary not only to validate this baseline data but also to complete the major part of the study, the documentation of subsidence phenomena over Panel 2. The quantity and sophistication of instrumentation at the second instrumented section of Panel 2 will provide an expanded capability to monitor overburden strata movements and ground surface strains. The following recommendations for continued monitoring are based on experience with data acquisition and analysis through May of 1982 and the instrumentation plan submitted in April, 1981 (Woodward-Clyde, 1981).

6.1 MONITOR SCHEDULE

At least four or more monitoring trips should be made as indicated on Figure 4.1 (trips 4, 5, 6, and 7). It will be especially critical to schedule a monitoring trip (possibly extended over a period of 1 to 2 weeks) when the longwall face is between stations 11+00 and 10+00 in order to manually acquire data from the mine level instrumentation and SLEX-2.

6.2 SURFACE SURVEY

In order to develop generalized subsidence development curves and determine an angle of draw associated with longwall mining, surveys must continue to be made along lines 2 and 3. These surveys should be made simultaneously with manual acquisition of subsurface and mine level data in order to correlate movements and stress changes.

6.3 AUTOMATIC DATA ACQUISITION SYSTEM (ADAS)

Problems developed with the ADAS scanner/recorder when the 12V battery supply dropped below 10.5 volts. It was necessary to send the recorder back to the supplier to have damaged circuits repaired. The possibility exists that circuits within the expansion box were also damaged. A system check was made in July, 1982, and it appeared to be operating properly; however, a further check of the data printed out at that time indicates that there may still be problems with the system. The entire system, including strainmeter and REX potentiometers, must be assembled and a further data check made before mining of the longwall panel resumes to make sure that it is operating properly.

In view of the apparent influence of topography on horizontal surface movements (Figure 5.25), the continuous monitoring capability of the ADAS strainmeters is a powerful means for monitoring the development of total surface strains over the panel rib and the only means with which to monitor traveling strain along the panel centerline. It is suggested that the recording interval be gradually increased to a maximum of twice daily whenever significant increase in movement rates is observed.

6.4 REX/TDR AND SLEX/TDR

Although the REX-2 potentiometers are incorporated into the ADAS system, manual readings should be made periodically to check the system electronics. The continuous record of overburden displacements obtained from the REX-2 system in combination with the manual readings, will provide insight into the data obtained manually at REX-1. After the longwall has been advanced past REX-2, the continuous record will be especially valuable during periods when the face is idle.

The ease with which TDR readings can be made and the reported success with which this technique has been used to monitor subsurface fracturing (Wade and Conroy, 1980) justify continued monitoring. Problems with the REX-2 TDR cable limit the usefulness of this cable, but the REX-1, SLEX-1 and SLEX-2 cables should be monitored. Cables installed with SLEX-1 and SLEX-2 will become especially useful if subsurface displacements cause crushing or shearing of the SLEX casing such that a Sondex probe cannot be lowered down the casing.

Conroy, et al. (1981) and Woodward-Clyde (1982) presented data which show that SLEX installations can be used to reliably characterize horizontal and vertical displacements within the overburden. Consequently, the SLEX-2 installation should continue to be monitored in order to characterize fracturing, separation and bending of strata over the rib of Panel 2, and to correlate this behavior with surface horizontal strain measurements. Continued monitoring of the inclinometer casing will make it possible to evaluate the subsurface horizontal displacements recorded to date.

The Sondex probe was designed to be used with a steel surveyor's tape in order to measure depths; however using this separate tape in conjunction with the graduated, electric cable is extremely difficult in deep holes (Woodward-Clyde, 1982). To overcome this difficulty the procedure of using a carpenter's rule with the graduated cable, described in Section 4.2.2, was used. As mentioned previously, the accuracy of this procedure is dependent on the skill of the operator. To assure accuracy of ± 0.01 feet in locating the rings, two sets of measurements should be made in each SLEX hole. Whenever the two sets of measurements for each ring differ by more than 0.01 feet, the measurement should be repeated.

6.5 GROUNDWATER CONDITIONS

Continued monitoring of groundwater levels in the two SLEX casings will make it possible to further assess the discontinuous nature of the overburden. Since it should be expected that the water level in SLEX-2 will drop significantly as it is undermined it will be worth noting if a similar drop in water level occurs at SLEX-1. If groundwater is still present in the SLEX holes at the completion of mining of Panel 2, samples should be taken to evaluate any changes which have occurred in water quality; however a more sophisticated sampling procedure is not justified in view of the quality of the baseline data.

6.6 MINE LEVEL EXTENSOMETERS AND CONVERGENCE MEASUREMENTS

The relatively large roof-floor convergence, compared with the roof and floor extensometer displacements, at Location 1 indicate that the deepest anchors in the roof and perhaps the floor must be moving. While the deepest roof anchor at Location 1 was 32.13 ft above the Allen seam, the deepest roof anchor at Location 2 is 47.17 ft above the Allen seam. Consequently, continued monitoring of the mine level extensometers and convergence points must be maintained for comparison with the data obtained at Location 1 and to further assess the nature and extent of roof and floor strata separation.

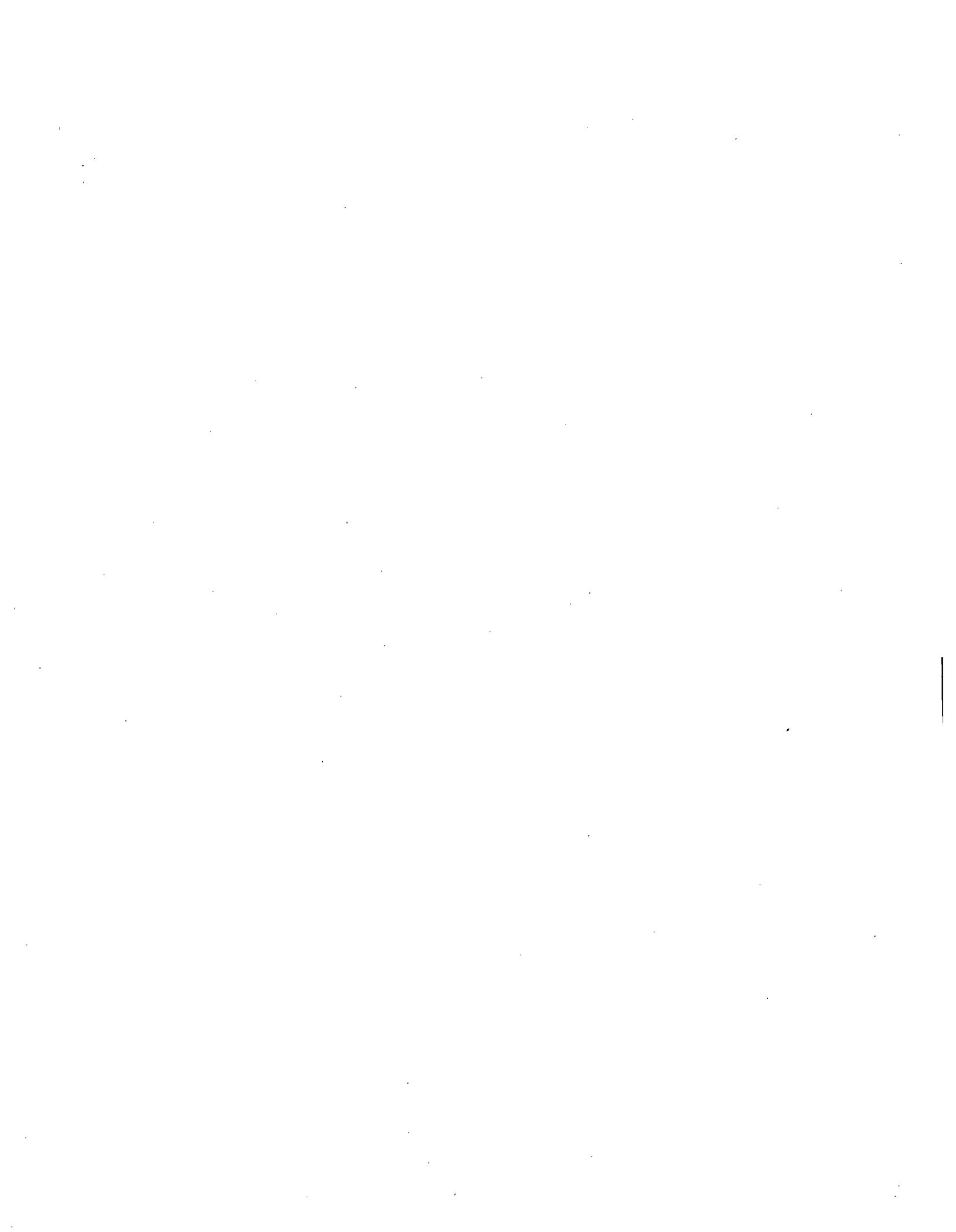
6.7 MINE LEVEL STRESS CHANGES

The preliminary assessment of confined core development, the unexpected floor stressmeter response and the relatively large horizontal stress increase at Location 1 justify the need for continued monitoring of the stressmeters at Location 2. This monitoring is facilitated by the fact that the stressmeters would be connected to an automatic data recorder

which only requires a period change of 12 volt batteries. As recommended for the surface acquisition system, the recording frequency should be gradually increased as the face approaches. A 24-hour interval is suggested when the face is located between 400 and 150 ft from the stressmeters, and a 12-hour interval is suggested when the face is closer than 150 ft.

6.8 MINED HEIGHT AND CHOCK LOADS

Continued measurement of mined height and chock loads is justified since variations in mined height and chock loads across the face can be quantified as the face is advanced. These measurements would be especially meaningful if they were made during extended idle periods as well as during periods of active face advances to assess load transfer to the shields and the magnitude of any resultant coal squeeze along the face.



7.0 SUMMARY AND CONCLUSIONS

An instrumentation program was implemented at the Allen Mine in Weston, Colorado, in order to characterize subsidence over two adjacent longwall panels. Surface instrumentation consisted of a survey monument network and automatic recording strainmeters to monitor vertical and horizontal displacements and strains. Subsurface instrumentation consisted of inclinometer-extensometer assemblies and multi-point rod extensometers with TDR coaxial cables to monitor strata displacement and separation as subsidence developed. Groundwater conditions in the inclinometer-extensometer casings were monitored as well. Mine level instrumentation consisted of multipoint rod extensometers to monitor roof and floor strata separation, tape extensometer and permanent reference points to monitor roof-floor convergence and stressmeters to monitor stress changes in the floor below the longwall panel and in chain pillars adjacent to the panel. Additionally, a series of measurements were made in an attempt to determine the existing in situ stresses. Mined height and chock loads were monitored along the longwall face as it was advanced.

At the time that this project was terminated, one of the longwall panels had been converted to room and pillar mining and the face of the second panel had only advanced past the first of two major instrumentation locations. Consequently, only a limited amount of data was collected and only a preliminary analysis of this data was possible. The following conclusions are based on the preliminary analysis.

7.1 LONGWALL FACE CONDITIONS

The thickness of mined strata has varied from 60.5 to 108 in. with a mean of 76.4 in. and a standard deviation of 5.8 in. Chock loads were found to be highly variable along the

longwall face as well as from one face location to the next. Many factors must be considered when evaluating these loads, but a preliminary analysis showed the load on one chock leg to vary from 46.5 to 218.2 tons with a mean of 147.2 tons and a standard deviation of 46.3 tons.

7.2 MINE LEVEL STRESSES

An undercoring technique was used in an attempt to determine the existing in situ stress conditions. Reasonable results were obtained for only one of the five tests performed successfully and it was concluded that this technique is inappropriate for stress determinations in coal measure strata.

The vibrating wire stressmeters installed in a chain pillar adjacent to the longwall panel not only showed the development of abutment pressure 200 ft in front of the face but also suggested the development of a 15 ft wide distressed zone around the pillar with an inner confined core. Within this confined core, the maximum vertical stress increase recorded was 2100 psi and the horizontal stress increase recorded was 2600 psi. Whereas, vertical stress increases of this magnitude have been reported in the literature, such increases in horizontal stress can only be evaluated by continued monitoring of the horizontal stressmeters at Location 2. Further analysis of this data will be possible with the results from a monitoring program which WCC has ongoing at a coal mine in West Virginia.

7.3 MINE LEVEL DISPLACEMENTS

Roof-floor convergence in the headgate entry was initiated about 400 ft in front of the face with the onset of greatest movement occurring when the face was 150 ft in front of the measurement point. The total convergence of 2.72 in. was

approximately 2.5 times greater than that indicated by the extensometer data which showed 0.62 in. of roof sag and 0.46 in. of floor heave. Consequently the thickness of strata generating the convergence must be greater than the deepest anchors located 32 ft in the roof and 21 ft in the floor. The small amount of roof sag that has occurred was most likely due to strata separation at the coal seams 8 and 20 ft above the Allen seam.

7.4 OVERBURDEN DISPLACEMENTS

The only comprehensive record of overburden displacements was obtained from the REX-1 rod extensometer which showed that displacement began about 500 ft in front of the face with the onset of greatest movement occurring 100 ft in front. When the face was 100 ft past REX-1 all six anchors had been displaced downward about 8 in. with an additional 4 in. of strata separation occurring between the deepest anchor (46 ft above the Allen Mine) and the shallowest anchor (445 ft above the Allen Mine). During periods when the longwall face was idle, subsidence of the anchors continued at a rate of about 0.08 in. per day with little or no strata separation. Consequently, the overburden appears to be subsiding as a relatively coherent rockmass.

7.5 SURFACE MOVEMENTS

Vertical and horizontal displacements at surface monuments have occurred along all three survey lines with the movements along lines 1 and 3 due to room and pillar mining and movements along line 2 due to longwall mining of Panel 2. Vertical displacements along line 2 began 150 to 200 ft in front of the longwall face with the onset of greatest movement occurring as the monuments were undermined. The largest vertical displacement recorded was 3.13 ft and the largest horizontal displacement was 0.91 ft along an azimuth of 355

degrees. Greater displacements are considered likely so that an assessment of maximum subsidence was not valid. The apparently strong influence of topography on horizontal displacements makes it necessary to obtain data from the ADAS strainmeters before using the survey data to evaluate horizontal strains.

7.6 GROUNDWATER CONDITIONS

Although the strata within the overburden are not significant aquifers, the similarity of groundwater composition and surface water composition suggests that there may be communication through the overburden to the Purgatoire River.

APPENDIX A

BIBLIOGRAPHY

- Aggson, J.R., 1978. Coal mine floor heave in the Beckley Coalbed, an analysis. United States Bureau of Mines Report of Investigations 8274, 32 p.
- Compton, Robert R., 1962. Manual of Field Geology. John Wiley and Sons, New York, 378 p.
- Conroy, P.J., Gyarmaty, J.H. and Pearson, M.L., 1981. Documentation of subsidence monitoring systems. June, Department of Energy, Carbondale Mining Technology Center, Carbondale, Illinois, Contract No. DE-AC01-78ET 10029, 435 p.
- Conroy, P.J. and Gyarmaty, J.H., 1982. Subsidence monitoring--case history. Proceedings, 23rd Symposium on Rock Mechanics, Berkeley, California pp. 1048-1056.
- Gentry, Donald W., and Abel, John F., Jr., 1978. Surface response to longwall coal mining in mountainous terrain. Bulletin of the Association of Engineering Geologists, Vol XV, No. 2, pp 191-220.
- Goodman, R.E., 1980. Introduction to Rock Mechanics. John Wiley and Sons, New York, 478 p.
- Hooker, Verne E., Aggson, James R., and Bickel, David L., 1974. Improvements in the three-component borehole deformation gage and overcoring techniques. Bureau of Mines Report of Investigations 7894, U.S. Department of the Interior, Washington, 29 p.
- Jackson, Dan, 1981. Chocks support bad top in Colorado. Coal Age, pp 100-106.
- National Coal Board (NCB), 1976. Subsidence Engineers Handbook, 2nd ed. Great Britain, 111 p.
- O'Rourke, J.E., et al. 1977. Subsidence monitoring systems for undermined areas. U.S. Department of Energy, Published by National Technical Information Service, No. FE-9123-1, 304 p.
- Peng, Syd S., 1978. Coal Mine Ground Control. John Wiley and Sons, New York, 450 p.

- Scalf, Marion R., et al. 1981. Manual of groundwater sampling procedures. National Water Well Association, Worthington, Ohio, 93 p.
- Schmechel, Frank W., Eichfeld, William F., and Santy, William P., 1979. Automated data acquisition for subsidence characterization. Society of Mining Engineers of AIME, Preprint No. 79 132, Littleton, Colorado, 13 p.
- Shelton, David C., 1981. Baseline hydrology data-gathering guidelines. State of Colorado, Department of Natural Resources, Mined Land Reclamation, Denver, Colorado, 8 p.
- Smith, Paul, 1981. A national mine subsidence program. Los Alamos Scientific Laboratory, Los Alamos, July, LA-8907-MS, 47 p.
- Tillman, Steven M., 1982. Determination of subcoal strata strength using ultrasonic testing. Bulletin of the Association of Engineering Geologists, Vol. XIX, No. 1, pp 77-86.
- United States Bureau of Mines, 1981. Economical method for determining stress in mines. Technology News, No. 96, April, 2 p.
- Wade, Lewis V., and Conroy, Peter J., 1980. Rock mechanics study of a longwall panel. Mining Engineering, December, pp 1728-1734.
- Water, Waste and Land, Ltd., 1980. Hydrology, geology, and water quality in vicinity of the Maxwell and Allen Mines. Los Animas County, Colorado, Final Report to CF&I Steel Corporation, 60 p.
- Woodward-Clyde Consultants, 1981. Instrumentation plan for characterization of subsidence over longwall panels at Allen Mine, Weston, Colorado, prepared for United States Department of Energy, Washington, D.C., 25 p.
- Woodward-Clyde Consultants, 1982. Design and demonstration of subsidence monitoring systems. January, United States Department of Energy, Carbondale Mining Technology Center, Carbondale, Illinois, Contract No. DE-AC01-78ET12220, 285 p.

APPENDIX B
INSTRUMENTATION SUMMARY

| INSTRUMENTATION | QUANTITY | ITEM | SUPPLIER | MODEL OR PART NO. |
|---|----------|---------------------------------|--------------------|-------------------|
| Survey | | Theodolite | Wild | T-2 |
| | | Precision Level | Wild | N3 and N2 |
| | | Leveling Rod | Wild | GPLE 3 |
| | | Geodimeter | AGA | 14A |
| | | Retroray Prism | -- | -- |
| Automatic Data Acquisition System (ADAS) Strainmeters | 6 | Double unit sensors | SINCO | 51711 |
| | 12 | 20 ft long extension assemblies | SINCO | 51761-I |
| | 2060 ft | Electrical cable | SINCO | 51748 |
| | 6 | Anchors & sensors | SINCO | 51717 |
| | 8 | Anchors & rods | SINCO | 51718 |
| | 14 | Anchor assemblies | SINCO | 51718-A |
| | 6 | Cable connectors | SINCO | 56450 |
| | 1 | Jumper cable | SINCO | 51822-50 |
| | 1 | Extensometer readout | SINCO | 51822 |
| | 1 | Scanner/Recorder | SINCO | 51833 |
| | 1 | Expander box | SINCO | 51834 |
| Inclinometer/Extensometers (SLEX) | 1140 ft | Grooved ABS plastic casing | SINCO | 51111 |
| | 140 | ABS plastic couplings | SINCO | 51112 |
| | 4 | ABS plastic caps | SINCO | 51115 |
| | 2 | Steel boots | SINCO | -- |
| | 1140 ft | Corrugated Sondex casing | Phillips Petroleum | Driscopipe |

APPENDIX B
INSTRUMENTATION SUMMARY (CONT)

| INSTRUMENTATION | QUANTITY | ITEM | SUPPLIER | MODEL OR PART NO. |
|--|----------|-------------------------------|-----------|-------------------|
| Inclinometer/ Extensometers (SLEX) | 57 | Sondex Casing couplings | SINCO | --- |
| | 800 ft | Distance graduated cable | SINCO | 50610 |
| | 1 | Skid-mounted cable reel | SINCO | 50501 |
| | 1 | Digitilt inclinometer probe | SINCO | 50325 |
| | 1 | Digitilt readout | SINCO | 50306 |
| | 1 | Sondex probe and sensor | SINCO | 50812 |
| Deep Hole Exten- someters (REX) | 4175 ft | 3/4 in. galvanized pipe | Interfels | WK97795 |
| | 2670 ft | 3/8 in. galvanized pipe | Interfels | WK97795 |
| | 4175 ft | 1 9/16 in. PVC casing | Interfels | WK97795 |
| | 2670 ft | 1 1/4 in. PVC casing | Interfels | WK97795 |
| | 6 | Anchors for 3/4 in. pipe | Intervels | 252 218 |
| | 6 | Anchors for 3/8 in. pipe | Interfels | 252 219 |
| | 2 | Cover plates | Interfels | 258 576 |
| | 2 | Reference heads | Interfels | 258 572 |
| | 12 | Threaded rods and fittings | -- | -- |
| | 12 | Tail rods with sensor bars | Interfels | 258 579 |
| | 1 | Dial gage and calibration jig | Interfels | -- |
| | 6 | Potentiometers | Interfels | WK97855 |
| | 1 | Junction box | Interfels | WK97856 |
| | 1 | 18-conductor cable | Interfels | 030218 |

APPENDIX B
INSTRUMENTATION SUMMARY (CONT)

| INSTRUMENTATION | QUANTITY | ITEM | SUPPLIER | MODEL OR PART NO. |
|---------------------------------|----------|-------------------------------------|----------------------------------|-------------------|
| Time Domain Reflectometry (TDR) | 2500 ft | Coaxial cable | Standard Wire and Cable | RG-8A/U |
| | 4 | Coaxial cable connectors | Radio Shack | -- |
| | 1 | TDR cable tester | Tektronix | 1502 |
| | 1 | Printer | Tektronix | Option 04 |
| Groundwater Conditions | 1 | Water level indicator | SINCO | 51453-10 |
| Mine Level Extensometers | 270 ft | 3/8 in. ϕ stainless steel rods | Interfels | WK97796 |
| | 270 ft | 5/8 in. ϕ protective tubing | Interfels | 253520 |
| | 12 | Anchors | Interfels | 252310 |
| | 2 | Two-point reference heads | Interfels | WK97796 |
| | 2 | Four-point reference heads | Interfels | WK97796 |
| | 1 | Dial gage and calibration jig | Interfels | -- |
| Convergence | 1 | Tape extensometer and accessories | SINCO | 51855 |
| | 20 | Stainless steel reference balls | SINCO | 518120 |
| | 20 | Roof bolts--cut and tapped | Allen Mine/C&M Automotive Supply | |
| Stressmeters | 18 | Vibrating wire stressmeters | Irad Gage | VBS-1 (SR) |
| | 6300 ft | Stressmeter lead wire | Irad Gage | -- |
| | 1 | Hydraulic setting tool | Irad Gage | T-2 |
| | 1 | Hand-held readout | Irad Gage | MB-6 |
| | 1 | Datalogger | Irad Gage | MA-2 |

APPENDIX B
INSTRUMENTATION SUMMARY (CONT)

| INSTRUMENTATION | QUANTITY | ITEM | SUPPLIER | MODEL OR PART NO. |
|-----------------|----------|-------------------------|-----------------------------|-------------------|
| Stressmeters | 1 | Datalogger printer | Irad Gage | MA-2PO |
| | 1 | Datalogger junction box | Irad Gage | MA-2SM-10 |
| | 1 | Datalogger 12VDC option | Irad Gage | MA-3DC |
| Absolute Stress | 1 | Steel template | C. P. Welding & Fabrication | |
| | 64 | Stainless steel pins | C. P. Welding & Fabrication | |
| | 1 | Whittemore gage | Satec Systems | W6380 |

APPENDIX C COMPUTER PROGRAMS

Eight programs were developed for purposes of data reduction. One program, developed for inclinometer data reduction, was written in FORTRAN and run on a Univac 1100/82 Computer. The other seven programs were written in BASIC and run on a Cromemco System III Microcomputer.

C.1 INCLIN

INCLIN was originally written under DOE Contract No. DE-AC01-78-ET12220 in 1981 and modified under DOE Contract No. DE-AC22-PC30117 in September 1982. The program INCLIN reduces inclinometer data, computes the statistics of the basic data, makes comparison of data sets for different dates, and line-plots horizontal deflection (offset) versus depth along the A and B axes by subroutine PLOTTER. The program has the capacity of comparing a maximum of three data sets with maximum of 300 points in each data set.

In order to account for vertical displacement of the inclinometer casing in response to subsidence, the program allows for forcing reduced data sets to agree at a specified depth. At the specified depth, the inclinometer casing can be assumed to be stationary and the horizontal deflection (offset) can be specified as having a value of 0.000, or any other value considered appropriate.

A zero-check of each basic data set must be made prior to further data reduction and comparison. If the variation between the plus and minus reading at any depth along the A and B axes exceeds the specified allowable value then the basic data must be adjusted so that the variation does not exceed the allowable value. The data is adjusted by looking at trends in the current data set as well as in previous data sets.

All computer output is written onto different output files. The output file descriptions are as follows:

File 8: basic inclinometer data with zero-checks

File 9: reduced data for one data set

File 10: comparison of two data sets with no depth adjustments

File 11: line-plots file 10

File 12: comparison of two data sets adjusted to agree at a specified depth

File 13: line-plots file 12.

In addition to the line-plots from output files 11 and 13, files 10 and 12 can also be stored and used as input data for CALCOMP plots. Attached are copies of the inclinometer data sheets and a listing of the INCLIN program.

C.2 CONVERGE

This program reduces convergence data consisting of: (a) date, (b) tape length, (c) dial gage reading, and (d) temperature. Output consists of a listing of this data as well as: (a) distance between reference points, (b) change since initial date in millimeters, and (c) change since initial date in inches. A data file is generated consisting of all the above data.

C.3 EXTENSOM

This program reduces rod extensometer data for 2, 3, 4, or 6 anchor installations. The program prompts for the name of the input data file and the number of anchor points. The

input data file consists of: (a) date, (b) dial gage calibration readings, and (c) dial gage readings for each anchor point. Output consists of a listing of: (a) date, (b) change in anchor/reference plate distance from initial date for each anchor, and (c) change in anchor/anchor distance from initial date for adjacent anchors (that is, 1/2, 2/3, 3/4, 4/5, 5/6).

C.4 RELSTRESS

This program reduces vibrating wire stressmeter data for three different values of modulus. The input for any given stressmeter consists of: (a) date, and (b) stressmeter reading. The output consists of a listing of: (a) date, (b) stressmeter reading, (c) stress change since previous reading, and (d) cumulative stress change for modulus values of 250,000 psi, 500,000 psi and 1,000,000 psi.

C.5 SCANNER

This program converts ADAS scanner/recorder readings into linear potentiometer displacements. The input for any given potentiometer consists of: (a) date, and (b) scanner/recorder reading. The output consists of a listing of: (a) date, (b) scanner reading, (c) potentiometer displacement in inches and millimeters, and (d) cumulative change in potentiometer displacement since initial date.

C.6 SLOPE

This program calculates horizontal and slope distances between surface survey monuments. The input for any given date consists of: (a) monument designation number, (b) northing coordinate, (c) easting coordinate, and (d) elevation. The output consists of: (a) designation numbers of the monuments between which the distances were

calculated, (b) horizontal distance between the monuments, and (c) slope distance between the monuments.

C.7 SONDEX

This program calculates changes in Sondex ring depths. The input for any given date consists of: (a) date and elevation of the top of the inclinometer casing, then (b) ring designation number and measured depth below top of casing for each ring. The output consists of: (a) ring designation number, (b) change in ring depth since initial data set, (c) designation numbers of rings between which the ring/ring distance was calculated, and (d) cumulative change in ring/ring distance.

C.8 SURVEY

This program calculates the horizontal and vertical displacements of surface survey monuments. Input for any given date consists of: (a) monument designation number, (b) northing coordinate, (c) easting coordinate, and (d) elevation. The output consists of: (a) monument designation number, (b) N-S component of horizontal displacement since initial data set, (c) E-W component of horizontal displacement since initial data set, (d) total horizontal displacement, (e) azimuth of horizontal displacement, (f) change in elevation since initial data set, (g) magnitude of total displacement vector, and (h) vertical angle of total displacement vector.

INCLINOMETER DATA

ENGINEERS _____ HOLE No. _____ DATE _____

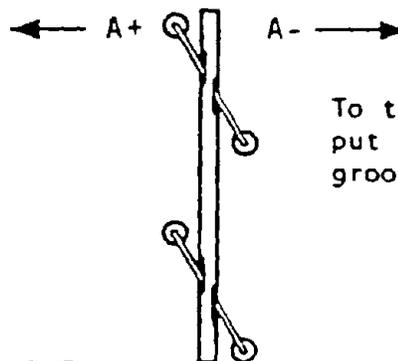
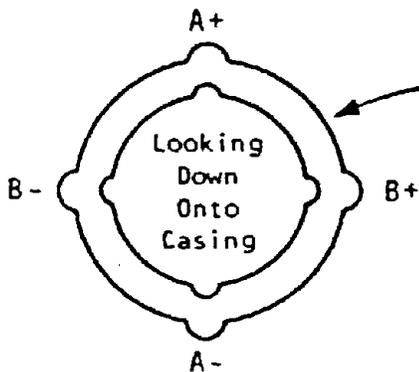
WEATHER _____ INSTRUMENT No. _____

Card No. 1

| | |
|--|---|
| 1 2 3 4 5 <input style="width: 20px; height: 20px;" type="text"/> <input style="width: 20px; height: 20px;" type="text"/> | 6 7 8 9 10 <input style="width: 20px; height: 20px;" type="text"/> <input style="width: 20px; height: 20px;" type="text"/> |
| (Number of Cards) (Hole I.D.) | |
| 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 <input style="width: 100%; height: 20px;" type="text"/> | |
| 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 <input style="width: 100%; height: 20px;" type="text"/> | |
| (Title) | |

Card No. 2

| | | |
|---|---|---|
| 1 2 3 4 5 6 7 8 9 10 <input style="width: 100%; height: 20px;" type="text"/> (Zero Reading for A-Axis if known) | 11 12 13 14 15 16 17 18 19 20 <input style="width: 100%; height: 20px;" type="text"/> (Zero Reading for B-Axis if known) | 24 25 26 27 28 29 30 <input style="width: 100%; height: 20px;" type="text"/> (Allowable Variation in Zero per Reading; e.g., +0.0100) |
| 31 32 33 34 35 36 37 38 39 40 <input style="width: 100%; height: 20px;" type="text"/> (Change in Elevation from Initial Reading; + is downward movement of casing) | 41 42 43 44 45 46 47 48 49 50 <input style="width: 100%; height: 20px;" type="text"/> (Date of Reading) | |
| 51 52 53 54 55 56 57 58 59 60 <input style="width: 100%; height: 20px;" type="text"/> North | 61 62 63 64 65 66 67 68 69 70 <input style="width: 100%; height: 20px;" type="text"/> East | |
| (Horizontal Coordinates if known) | | |



To take A+ and B+ reading,
put uppermost wheel in A+
groove

INCLINOMETER DATA

| | | | | |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |
| | | | | |

Hole No.

| | | | | | | | | | |
|---|---|---|---|----|----|----|----|----|----|
| 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
| | | | | | | | | | |

Date

NOTE TO
KEYPUNCHER:
Duplicate
on all cards

DEPTH
(Deepest
Readings 1st)

A - Axis
(A-Plus
Direction)

A - Axis
(A-Minus
Direction)

B - Axis
(B-Plus
Direction)

B - Axis
(B-Minus
Direction)

(+/-)

(+/-)

(+/-)

(+/-)

16 17 18 19 20

24 25 26 27 28 29 30

34 35 36 37 38 39 40

44 45 46 47 48 49 50

54 55 56 57 58 59 60

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PROGRAM LISTING

```

1*   C
2*   C *****
3*   C
4*   C PROGRAM INCLIN
5*   C
6*   C PROGRAM INCLIN REDUCES INCLINOMETER DATA, COMPUTES THE STATISTICS,
7*   C MAKES COMPARISON OF DATA WITH DIFFERENT DATES, AND LINE PLOTS
8*   C THE A & B OFFSETS VS. DEPTH BY SUBROUTINE PLOTTER.
9*   C
10*  C NOTE : ALL COMPUTER OUTPUT ARE WRITTEN ONTO DIFFERENT OUTPUT FILES,
11*  C WHICH SHOULD BE PRINTED WITH SUITABLE JOB CONTROL CARDS AT
12*  C THE END OF THE JOB.
13*  C
14*  C FILE 8 : WRITES THE BASIC DATA WITH ZERO CHECKS.
15*  C FILE 9 : WRITES THE REDUCED DATA.
16*  C FILE 10 : WRITES THE TWO HOLE COMPARISON WITH NO DEPTH ADJUSTMENTS.
17*  C FILE 11 : LINE PLOTS FILE 10.
18*  C FILE 12 : WRITES THE TWO HOLE COMPARISON ADJUSTED TO AGREE AT A
19*  C SPECIFIED DEPTH.
20*  C FILE 13 : LINE PLOTS FILE 12.
21*  C
22*  C USER'S GUIDE OF PROGRAM INCLIN
23*  C *****
24*  C
25*  C CARDS 1, 2, & 3 ARE THE STANDARD DATA SETS.
26*  C
27*  C CARD 1: COLS 1- 5: NO OF CARDS(NCARD,NCARD1) (I5)
28*  C NCARD FOR 1ST READING MUST BE GREATER THAN OR EQUAL TO
29*  C NCARD FOR SUBSEQUENT READINGS
30*  C 6-10: HOLE I.D. (HOLEN) (A5)
31*  C 11-55: TITLE (9A5)
32*  C
33*  C CARD 2: COLS 1-10: ZERO READING FOR A-AXIS (AZERO) (F10.4)
34*  C 11-20: ZERO READING FOR B-AXIS (BZERO) (F10.4)
35*  C 21-30: ALLOWABLE VARIATION IN ZERO WITHOUT BEING
36*  C CONSIDERED AN ERROR (ZEROLK) (F10.4)
37*  C 31-40: CHANGE IN ELEVATION FROM INITIAL READING
38*  C + MEANS TOP OF CASING MOVED DOWN (SURVEY) (F10.3)
39*  C 41-50: DATE OF READING (DATE,DATEE) (2A5)
40*  C
41*  C CARD 3: COLS 1- 5: HOLE NO (HOLEN) (A5)
42*  C 6-15: DATE OF READING (DATE,DATEE) (2A5)
43*  C 16-20: DEPTH (F5.0)
44*  C PROGRAM ASSUMES DATA AT DEEPEST POINT READ FIRST
45*  C 21-30: A-PLUS READING (F10.4)
46*  C 31-40: A-MINUS READING (F10.4)
47*  C 41-50: B-PLUS READING (F10.4)
48*  C 51-60: B-MINUS READING (F10.4)
49*  C
50*  C CARD 4: COL 1: 0 IF NO FURTHER DATA & COMPARISON OF DATA NOT
51*  C DESIRED (I1)
52*  C
53*  C 1 IF FURTHER DATA SETS (I1)
54*  C REPEAT CARDS 1, 2, & 3.
55*  C
56*  C 2 IF NO FURTHER DATA & COMPARISON OF EACH DATA SET WITH

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PROGRAM LISTING

```

57*      C          INITIAL DATA SET IS DESIRED (I1)
58*      C
59*      C          3 IF SAME AS '2' AND ALSO WANT TO FORCE DATA TO
60*      C          AGREE AT AN ARBITRARY DEPTH (I1)
61*      C
62*      C          CARD 5: COL 1-10: DEPTH AT WHICH CURVES TO BE FORCED TO AGREE
63*      C          MUST CORRESPOND TO DEPTH + SURVEY CHANGE IN
64*      C          SECOND DATA SET (F10.2)
65*      C          11-20: A-OFFSET IF SPECIFIED (F10.4)
66*      C          21-30: B-OFFSET IF SPECIFIED (F10.4)
67*      C          OFFSETS ARE SUBTRACTED
68*      C          35: OVERRIDE IF=1, USE SPECIFIED OFFSETS (I1)
69*      C          IF LEAVE BLANK, A & B OFFSETS IN COLS 11-30 CAN
70*      C          BE BLANK, AND A & B OFFSETS WOULD BE THOSE COMPUTED
71*      C          FROM THE SECOND DATA SET AT THE SPECIFIED DEPTH.
72*      C
73*      C          NOTE : CARD 5 IS ADDED ONLY IF OPTION 3, OTHERWISE SKIPPED.
74*      C
75*      C          CARD 6: COL 1-10: MIN. OFFSET VALUE FOR PLOT (F10.4)
76*      C          BETTER ASSIGNED AS -VE VALUE.
77*      C          11-20: MAX. OFFSET VALUE FOR PLOT (F10.4)
78*      C          BETTER ASSIGNED AS SYMMETRIC TO MIN. OFFSET.
79*      C          21-30: SCALE FOR OFFSET VALUES IN INCHES/INCH (F10.4)
80*      C          31-40: DEPTH ASSIGNED TO START PLOTTING (F10.4)
81*      C          41-45: NO. OF POINTS SKIPPED PER INTERVAL (I5)
82*      C          IF=0, EACH LINE PLOT WOULD BE IN 2 FT. INTERVAL.
83*      C
84*      C          NOTE : MAX. LENGTH ALLOWED FOR X-AXIS (OFFSET) IS 10 INCHES.
85*      C          BEST LENGTH FOR X-AXIS IS 8 IN. OR LESS IF USE @FANG TO
86*      C          LIST THE OUTPUT FILE.
87*      C
88*      C          *****
89*      C
90*      C          DIMENSION ACUM(300),BCUM(300),DEPTT(300),Z1(300),TITLE(9)
91*      C          DIMENSION AST(10),BST(10),WORD(20),DATE(2),DATE1(2),DATE2(2)
92*      C          COMMON NMAX, JMAX(10), XMIN, XMAX, SCALE, DEPTFL, ISKIP
93*      C
94*      C          ICOUNT=0
95*      C          KODE=0
96*      C
97*      C          *****
98*      C
99*      C          PART 1 -- ZERO CHECKS AND STATISTIC COMPUTATION
100*      C
101*      C          INITIALIZE PARAMETERS
102*      C          25 ACUML=0.0
103*      C          BCUML=0.0
104*      C          ATOTAL=0.0
105*      C          BTOTAL=0.0
106*      C          ASQUAR=0.0
107*      C          BSQUAR=0.0
108*      C          READ BASIC DATA FOR THE HEADINGS
109*      C
110*      C          READ (5,101) NCARD,HOLEN,TITLE
111*      C          READ (5,102) AZERO,BZERO,ZEROCK,SURVEY,DATE
112*      C
113*      C          IF(KODE.NE.0) GO TO 15

```

PROGRAM LISTING

```

114*      DATE1=DATE
115*      NCARD1=NCARD
116*      HOLEN1=HOLEN
117*      NPTS=NCARD
118*      C
119*      C
120*      15 WRITE TITLES ON FILE 8 WITH BASIC DATA
121*      WRITE(8,103) HOLEN
122*      WRITE(8,104)
123*      WRITE(8,120)
124*      WRITE(8,104)
125*      WRITE (8,105) TITLE,DATE
126*      WRITE (8,104)
127*      WRITE(8,106)
128*      WRITE(8,104)
129*      C
130*      C      GET NUMBER OF POINTS FOR PLOT FILE PART II
131*      IF(NCARD.LT.NPTS) NPTS=NCARD
132*      C
133*      C      WRITE TITLES ON FILE 9 FOR PROGRAM REPLOT
134*      WRITE(9,400)
135*      WRITE(9,401) HOLEN,DATE
136*      WRITE(9,402) NCARD
137*      WRITE(9,104)
138*      C
139*      C      WRITE TITLES ON FILE 9 WITH REDUCED DATA
140*      WRITE(9,110) HOLEN
141*      WRITE(9,104)
142*      WRITE(9,105) TITLE,DATE
143*      WRITE(9,104)
144*      WRITE(9,112)
145*      WRITE(9,113)
146*      WRITE(9,114)
147*      WRITE(9,115)
148*      WRITE(9,104)
149*      WRITE(9,111)
150*      WRITE(9,104)
151*      C
152*      C      READ BASIC DATA
153*      DO 10 I=1,NCARD
154*      READ (5,100) HOLEN,DATE,DEPTH,A1,A2,B1,B2
155*      C
156*      C      DEPTH ERROR CHECK
157*      IF (I .EQ. 1) DPMAX=DEPTH
158*      DEPTH1 = DPMAX - (I-1)*2.0
159*      C
160*      ADIFF=A1-A2
161*      BDIFF=B1-B2
162*      ASUM=A1+A2
163*      BSUM=B1+B2
164*      Z=0.0
165*      C
166*      C      ZERO ERROR CHECK
167*      IF(ABS(ASUM-AZERO).GT.ZEROCK) Z=1.0
168*      IF(ABS(BSUM-BZERO).GT.ZEROCK) Z=1.0
169*      C
170*      WRITE(8,107)HOLEN,DATE,DEPTH,A1,A2,B1,B2,Z

```

PROGRAM LISTING

```

171*      IF (DEPTH .EQ. DEPTH1) GO TO 30
172*      IB = I+B
173*      WRITE(6,180) DEPTH, DEPTH1, IB
174*      IF (I .EQ. NCARD) GO TO 96
175*      C
176*      30 ATHETA=(ASIN(ADIFF/4.0))
177*      BTHETA=(ASIN(BDIFF/4.0))
178*      ATHETA=ATHETA*180.0/3.14159
179*      BTHETA=BTHETA*180.0/3.14159
180*      C
181*      ADEFL= ADIFF*6.0
182*      BDEFL= BDIFF*6.0
183*      C
184*      ACUML=ADEFL+ACUML
185*      BCUML=BDEFL+BCUML
186*      C
187*      DPTH=DEPTH+SURVEY
188*      C
189*      WRITE(9,116)DPTH,ADEFL,BDEFL,ATHETA,BTHETA,ACUML,BCUML,Z
190*      C
191*      C
192*      C
193*      C
194*      C
195*      ATOTAL=ATOTAL+ASUM
196*      ASQUAR=ASQUAR+ASUM**2.0
197*      BTOTAL=BTOTAL+BSUM
198*      BSQUAR=BSQUAR+BSUM**2.0
199*      10 CONTINUE
200*      C
201*      AMEAN=ATOTAL/NCARD
202*      ASTDEV=SQRT(ABS((ASQUAR/NCARD)-AMEAN**2.0))
203*      BMEAN=BTOTAL/NCARD
204*      BSTDEV=SQRT(ABS((BSQUAR/NCARD)-BMEAN**2.0))
205*      WRITE(8,301) AMEAN,BMEAN,ASTDEV,BSTDEV
206*      ASTDEV=ASTDEV*6.0
207*      BSTDEV=BSTDEV*6.0
208*      WRITE(8,302) ASTDEV,BSTDEV
209*      C
210*      C
211*      C
212*      C
213*      C
214*      C
215*      C
216*      C
217*      C
218*      C
219*      C
220*      C
221*      C
222*      C
223*      C
224*      C
225*      C
226*      C
227*      C

```

STATISTICAL SECTION

WRITE END OF DATA SET MARKER

WRITE(9,186)

KEEP TRACK OF NUMBER OF DATA SETS

ICOUNT=ICOUNT+1

WRITE(6,187) ICOUNT, NCARD

IMAX=ICOUNT

WRITE(6,188) IMAX

DECIDE NEXT STEP

READ(5,190) KODE

IF(KODE.EQ.0) GO TO 96

IF(KODE .EQ. 1) GO TO 25

PUT END OF FILE MARK ON FILE 9 SO ISN'T AFFECTED BY REWIND

END FILE 9

PROGRAM LISTING

```

228*   C
229*   C *****
230*   C
231*   C PART 2 -- COMPARES TWO SETS OF READINGS
232*   C
233*   C REWIND 9
234*   C
235*   C IF(KODE.EQ.3) READ(5,201) AGREE,ASET,BSET,IGREE
236*   C II=1
237*   C
238*   C READ DESCRIPTIVE DATA FOR INITIAL MONITORING
239*   C DO 500 I=1,4
240*   C READ(9,104)
241*   C 500 CONTINUE
242*   C READ(9,130) HOLEN1
243*   C READ(9,104)
244*   C READ(9,140) DATE1
245*   C DO 60 I=1,8
246*   C READ(9,104)
247*   C 60 CONTINUE
248*   C
249*   C READ REDUCED DATA FOR INITIAL MONITORING
250*   C DO 70 I=1,NCARD1
251*   C READ(9,131)DEPTT(I),ACUM(I),BCUM(I),Z1(I)
252*   C 70 CONTINUE
253*   C READ(9,104)
254*   C
255*   C READ DESCRIPTIVE DATA FOR SECOND MONITORING
256*   C 75 DO 501 I=1,4
257*   C READ(9,104)
258*   C 501 CONTINUE
259*   C READ(9,130) HOLEN2
260*   C READ(9,104)
261*   C READ(9,140) DATE2
262*   C DO 80 J=1,8
263*   C READ(9,104)
264*   C 80 CONTINUE
265*   C
266*   C WRITE TITLE ON PLOT FILE FOR PROGRAM REPLOT
267*   C WRITE(10,400)
268*   C WRITE(10,403) HOLEN2,DATE1,DATE2
269*   C WRITE(10,406)
270*   C WRITE(10,402) NPTS
271*   C WRITE(10,104)
272*   C
273*   C WRITE HEADINGS ON OUTPUT
274*   C WRITE(10,184) HOLEN2
275*   C WRITE(10,104)
276*   C WRITE(10,192)
277*   C WRITE(10,193)
278*   C WRITE(10,195)
279*   C WRITE(10,104)
280*   C WRITE(10,183) DATE1,DATE2
281*   C WRITE(10,104)
282*   C WRITE(10,182)
283*   C WRITE(10,104)
284*   C

```

PROGRAM LISTING

```

285*   C   READ REDUCED DATA FOR SECOND HOLE
286*   C
287*   C   INITIALIZE DATA FOR CALCULATIONS TO FORCE CURVES TO AGREE AT SPECIFIED
288*   C   DEPTH
289*       J=0
290*       II=II+1
291*       X1=0.0
292*   C
293*       READ(9,131) DEPTH2,ACUM2,BCUM2,Z2
294*       DO 90 I=1,NCARD1
295*   C   ADJUST DEPTHS FOR CHANGE IN SURVEYED TOP OF HOLE
296*   C
297*       FACTOR=0.0
298*   C
299*   C   CHECK TO SEE IF DEPTH FROM FIRST DATA SET MORE THAN 2.0 LARGER THAN
300*   C   DEPTH FROM SECOND DATA SET
301*       IF((DEPTT(I)-DEPTH2).GT.2.0) GO TO 90
302*   C
303*   C   CHECK TO SEE IF DEPTHS FOR BOTH DATA SETS THE SAME
304*       IF(DEPTH2.EQ.DEPTT(I)) GO TO 94
305*   C
306*   C   CHECK TO SEE IF END OF DATA SET REACHED
307*   B6 ID2=0
308*       IF(DEPTH2.GE.10000.0) GO TO 97
309*   C
310*   C   CHECK TO SEE IF DEPTH FROM SECOND DATA SET GREATER THAN 1ST ENTRY
311*   C   FROM INITIAL DATA SET
312*       IF((DEPTH2-DEPTT(I)).GT.2.0) ID2=1
313*       IF(ID2.EQ.1) READ(9,131) DEPTH2,ACUM2,BCUM2,Z2
314*       IF(ID2.EQ.1) GO TO 86
315*   C
316*   C
317*   C   CHECK TO SEE THAT DEPTH FROM 1ST DATA SET GREATER OR EQUAL
318*   C   TO DEPTH FROM 2ND
319*       ID3=0
320*       IF(DEPTT(I).LT.DEPTH2.AND.I.EQ.1) ID3=1
321*       IF(ID3.EQ.1) READ(9,131) DEPTH2,ACUM2,BCUM2,Z2
322*       IF(ID3.EQ.1) GO TO 86
323*   C
324*   C   CHECK TO SEE THAT 1ST DATA CARD LESS THAN OR EQUAL TO 2ND
325*       IF(DEPTT(I).GT.DEPTH2.AND.I.EQ.1) GO TO 90
326*   C
327*       FACTOR=(DEPTH2-DEPTT(I))/(DEPTT(I-1)-DEPTT(I))
328*   C
329*   94 A=ACUM(I)-FACTOR*(ACUM(I)-ACUM(I-1))
330*       B=BCUM(I)-FACTOR*(BCUM(I)-BCUM(I-1))
331*   C
332*       AOFFST=ACUM2-A
333*       BOFFST=BCUM2-B
334*       ZZ=Z2+Z1(I)
335*   C
336*   C   INITIALIZE DATA SO BOTTOM POINT ASSUMED STATIONARY
337*       IF(X1.EQ.0.0) A1=AOFFST
338*       IF(X1.EQ.0.0) B1=BOFFST
339*       AOFFST=AOFFST-A1
340*       BOFFST=BOFFST-B1
341*       X1=1.0

```

PROGRAM LISTING

```

342*   C
343*   C   WRITE(10,191) DEPTH2,AOFFST,BOFFST,ZZ
344*   C
345*   C   CALCULATE OFFSETS AT DEPTH=AGREE, I.E., DEPTH WHERE CURVES TO BE
346*   C   FORCED TO AGREE. DO ONLY IF REQUESTED
347*   C   IF(KODE.NE.3) GO TO 210
348*   C
349*   C   DETERMINE OFFSETS AT DEPTH = AGREE
350*   C   IF(I1.GT.2) GO TO 210
351*   C   IF(DEPTH2.EQ.AGREE) AST(I1)=AOFFST
352*   C   IF(DEPTH2.EQ.AGREE) BST(I1)=BOFFST
353*   C
354*   C 210 J=J+1
355*   C   J IS A CARD COUNTER IN COMPARISON DATA SET
356*   C
357*   C   READ(9,131)DEPTH2,ACUM2,BCUM2,ZZ
358*   C
359*   C 90 CONTINUE
360*   C
361*   C 97 JMAX(I1)=J
362*   C   WRITE(10,200) J
363*   C
364*   C   CHECK TO SEE IF ANOTHER DATA SET NEEDS PROCESSING
365*   C   ICOUNT=ICOUNT-1
366*   C   IF(ICOUNT.GT.1) GO TO 75
367*   C
368*   C   PUT END OF FILE MARK ON FILE 10 SO ISN'T AFFECTED BY REWIND
369*   C   END FILE 10
370*   C
371*   C   IF (KODE .EQ. 2) GO TO 98
372*   C
373*   C *****
374*   C
375*   C PART 3 -- FORCES DATA TO AGREE AT ARBITRARY DEPTH
376*   C
377*   C   REWIND 10
378*   C
379*   C   PROCESS FOR EACH SET OF CALCULATED DATA OFFSETS
380*   C   ADJUST DATA FOR SPECIFIED NO. OF POINTS IN DATA SET
381*   C   DO 215 K=2,IMAX
382*   C
383*   C   JSET=JMAX(K)
384*   C   K1=K+1
385*   C
386*   C   IF(IGREE.EQ.1) AST(K)=ASET
387*   C   IF(IGREE.EQ.1) BST(K)=BSET
388*   C
389*   C   COPY HEADINGS ONTO FILE 11
390*   C   READ(10,104)
391*   C   WRITE(12,404)
392*   C   READ(10,202) WORD
393*   C   WRITE(12,202) WORD
394*   C   WRITE(12,203) AGREE,AST(K),BST(K)
395*   C   WRITE(12,402) JSET
396*   C   READ(10,104)
397*   C   READ(10,104)
398*   C   DO 220 I=1,11

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PROGRAM LISTING

```

399*      READ(10,202) WORD
400*      WRITE(12,202) WORD
401*      220 CONTINUE
402*      C
403*      DO 225 I=1,JSET
404*      READ(10,191,ERR=225) DEPTH2,AOFFST,BOFFST,ZZ
405*      IF(AGREE.GT.DEPTH2.AND.I.EQ.1) WRITE(6,420) K1, JSET
406*      IF(AGREE.GT.DEPTH2.AND.I.EQ.1) GO TO 96
407*      AOFFST=AOFFST-AST(K)
408*      BOFFST=BOFFST-BST(K)
409*      WRITE(12,191) DEPTH2,AOFFST,BOFFST,ZZ
410*      225 CONTINUE
411*      READ(10,104)
412*      WRITE(12,200) JSET
413*      215 CONTINUE
414*      C
415*      C      PUT END OF FILE MARK ON FILE 12 SO ISN'T AFFECTED BY REWIND
416*      C      END FILE 12
417*      C
418*      C      *****
419*      C
420*      C      PART 4 -- LINE PLOTTER
421*      C
422*      98 NMAX = IMAX-1
423*      READ(5,430) XMIN, XMAX, SCALE, DEPTPL, ISKIP
424*      REWIND 10
425*      CALL PLOTTER(10,11)
426*      IF (KODE .NE. 3) GO TO 96
427*      REWIND 12
428*      CALL PLOTTER(12,13)
429*      C
430*      96 STOP
431*      C
432*      C      *****
433*      C
434*      C      FORMAT STATEMENTS
435*      C
436*      100 FORMAT(3A5,F5.0,4F10.4)
437*      101 FORMAT(I5,10A5)
438*      102 FORMAT(4F10.0,2A5)
439*      103 FORMAT(1H1,10X,36H***BASIC INCLINOMETER DATA FOR HOLE ,A5,3H*** )
440*      104 FORMAT(1X)
441*      105 FORMAT(5X,9A5,6H DATE=,2A5)
442*      106 FORMAT(3X,8H HOLE NO.,10H      DATE,10H      DEPTH
443*      *10H  A-PLUS,10H  A-MINUS,10H  B-PLUS,10H  B-MINUS
444*      *10H ZEROCHECK)
445*      107 FORMAT(5X,3A5,5X,F5.0,4F10.4,5X,F5.0)
446*      110 FORMAT(10X,38H***REDUCED DATA FOR INCLINOMETER HOLE ,A5,3H*** )
447*      111 FORMAT(3X,14HADJUSTED DEPTH,10H  A-DEFL,10H  B-DEFL,1X,
448*      *9H  A-THETA,10H  B-THETA,10H  A-CUM,10H  B-CUM,3X,1HZ)
449*      112 FORMAT(5X,53HNOTE:A-DEFL IS THE HORIZONTAL OFFSET OF 2-FT LENGTH
450*      *9H (INCHES))
451*      113 FORMAT(10X,40HATHETA IS ANGLE OF CASING TILT (DEGREES))
452*      114 FORMAT(10X,46HACUM IS THE SUM OF HORIZONTAL OFFSETS WITH THE
453*      *33H DEEPEST POINT ASSUMED STATIONARY)
454*      115 FORMAT(10X,42HPLUS MEANS TOP OF 2-FT SECTION TILTS IN A+,
455*      *10H DIRECTION)

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PROGRAM LISTING

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456*      116 FORMAT( 7X,F10.2,6F10.4,F5.0)
457*      120 FORMAT(10X,45HIF ZERO-CHECK=1, PROBABLE ERROR IN BASIC DATA)
458*      130 FORMAT(48X,A5)
459*      131 FORMAT( 7X,F10.2,40X,2F10.4,F5.0)
460*      140 FORMAT(56X,2A5)
461*      180 FORMAT(/,2X,' DEPTH ERROR OF ',F5.1,' SHOULD = ',F5.1,' IN LINE '
462*          *,I5)
463*      182 FORMAT(7X,10H      DEPTH,10H  A-OFFSET,10H  B-OFFSET,1X,2HZZ)
464*      183 FORMAT(17X,' FROM ',2A5,' TO ',2A5)
465*      184 FORMAT(10X,'COMPARISON OF TWO INCLINOMETER READINGS - HOLE ',A5)
466*      186 FORMAT(7X,10H      10000.0)
467*      187 FORMAT(/,7X,'DATA SET ',I2,' : NO. OF POINTS = ',I5)
468*      188 FORMAT(/,7X,'TOTAL NO. OF DATA SETS = ',I5)
469*      190 FORMAT(I1)
470*      191 FDMAT(7X,F10.2,2F10.4,F3.0)
471*      192 FORMAT(10X,'NOTE: AOFFSET,BOFFSET IN INCHES')
472*      193 FORMAT(16X,'PLUS IS MOVEMENT IN A+,B+ DIRECTION SINCE INITIAL'
473*          *' READING')
474*      195 FORMAT(10X,'ZZ GREATER THAN 0 INDICATES POSSIBLE DATA ERROR')
475*      200 FORMAT(5X,'ACTUAL NO. OF POINTS IN THE ABOVE DATA SET = ',I5)
476*      201 FORMAT(3F10.0,I5)
477*      202 FORMAT(20A4)
478*      203 FORMAT(5X,'DATA FORCED TO AGREE AT DEPTH ',F7.2,
479*          *' , A-ADJUST = ',F7.4,' , B-ADJUST = ',F7.4)
480*      301 FORMAT(/,5X,'AMEAN =',F10.4,' BMEAN =',F10.4,' ASTDEV =',F10.4,
481*          *' BSTDEV =',F10.4)
482*      302 FORMAT(/,5X,'ACCURACY/SINGLE READING NO BETTER THAN',F10.4,
483*          *' IN. FOR A &',F10.4,' IN. FOR B'////)
484*      400 FORMAT(10X,'PLOT CARDS FOR REPLOT BEFORE A, B OFFSET ADJUSTMENTS')
485*      401 FORMAT(5X,'INCLINOMETER HOLE PROFILE: HOLE: ',A5,' , DATE: ',2A5)
486*      402 FORMAT(15,5X,' NO. OF DATA POINTS')
487*      403 FORMAT(5X,'OFFSET VS. DEPTH : HOLE ',A5,' , FROM ',2A5,' TO ',2A5)
488*      404 FORMAT(10X,'PLOT CARDS FOR REPLOT AFTER A, B OFFSET ADJUSTMENTS')
489*      406 FORMAT(5X,'NO DEPTH AGREEMENT IS ADJUSTED')
490*      420 FORMAT(/,7X,'!!! DEPTH FOR AGREEMENT NOT SUITABLE IN DATA SET',I2,
491*          *' : NO. OF POINTS = ',I5)
492*      430 FORMAT(4F10.0,I5)
493*          END

```

```

1*          SUBROUTINE PLOTER(IREAD,IWRITE)
2*          C
3*          C          SUBROUTINE PLOTER PLOTS LINES IN SYMBOLS BY PRINTER
4*          C
5*          INTEGER SYMBOL(11)
6*          DIMENSION TITLE(16), LINE(101), X(11), DEPTH(3,300),
7*          *          A(3,300), B(3,300)
8*          COMMON NMAX, JMAX(10), XMIN, XMAX, SCALE, DEPTFL, ISKIP
9*          C
10*         DATA (SYMBOL(I),I=1,11) /'1','2','3','4','5','6',' ','.',',I',
11*         *          'X','S'/
12*         C
13*         IF (IREAD .EQ. 10) WRITE(11,1100)
14*         IF (IREAD .EQ. 12) WRITE(13,1200)
15*         DO 1 I=1,NMAX

```

PROGRAM LISTING

```

16*      READ (IREAD,1300) DUMMY
17*      II1 = 2*I-1
18*      II2 = 2*I
19*      READ(IREAD,1400) BLANK, TITLE
20*      WRITE(IWRITE,1500) II1, II2, TITLE
21*      READ(IREAD,1400) BLANK, TITLE
22*      WRITE(IWRITE,1600) TITLE
23*      DO 2 J=1,12
24* 2 READ(IREAD,1300) DUMMY
25*      NPTS = JMAX(I+1)
26*      WRITE(IWRITE,1700) II1, II2, NPTS
27*      DO 3 K=1,NPTS
28*      KK = NPTS-K+1
29* 3 READ(IREAD,1800) DEPTH(I,KK), A(I,KK), B(I,KK)
30*      READ(IREAD,1300) DUMMY
31* 1 CONTINUE
32*      WRITE(IWRITE,1710)
33*      WRITE(IWRITE,1900) NMAX
34*      WRITE(IWRITE,1910) XMIN, XMAX, SCALE
35*      WRITE(IWRITE,1920) DEPTPL, ISKIP
36*      ISKIP1 = ISKIP+1
37*      DX = (XMAX-XMIN)/SCALE
38*      NDX = INT(DX+1.0)
39*      JX1 = INT(DX*10.0+1.0)
40*      JX2 = INT(DX*5.0+1.0)
41*      IF (JX1 .LE. 101) GO TO 100
42*      WRITE(IWRITE,1930)
43*      STOP
44* 100 DO 4 I=1,NDX
45* 4 X(I) = XMIN+(I-1)*SCALE
46*      WRITE(IWRITE,1940)
47*      WRITE(IWRITE,2000) (X(I), I=1,NDX)
48*      XSTEP = SCALE/10.0
49*      DO 5 J=1,JX1
50* 5 LINE(J) = SYMBOL(8)
51*      DO 6 J=1,JX1,10
52* 6 LINE(J) = SYMBOL(9)
53*      WRITE(IWRITE,2100) (LINE(J), J=1,JX1)
54*      NPTMAX = JMAX(2)
55*      NPT1 = INT((DEPTPL+1.0)/2.0)
56*      IF (DEPTPL .EQ. 0.0) NPT1 = 1
57*      Y = DEPTH(1,NPT1)-ISKIP1*2.0
58*      DO 7 K=NPT1,NPTMAX,ISKIP1
59*      DO 8 J=1,JX1
60* 8 LINE(J) = SYMBOL(7)
61*      LINE(1) = SYMBOL(8)
62*      LINE(JX2) = SYMBOL(8)
63*      LINE(JX1) = SYMBOL(8)
64*      DO 9 I=1,NMAX
65*      I1 = 2*I-1
66*      I2 = 2*I
67*      IF (I .GE. 2 .AND. K .GT. JMAX(I+1)) GO TO 9
68*      DISTA = (A(I,K)-XMIN)/XSTEP+1.5
69*      IDISTA = DISTA
70*      IF (IDISTA .LT. 1) LINE(1) = SYMBOL(10)
71*      IF (IDISTA .GT. JX1) LINE(JX1) = SYMBOL(10)
72*      IF (IDISTA .GE. 1 .AND. IDISTA .LE. JX1) LINE(IDISTA) = SYMBOL(I1)

```

PROGRAM LISTING

```

73*      DISTB = (R(I,K)-XMIN)/XSTEP+1.5
74*      IDISTB = DISTB
75*      IF (IDISTB .LT. 1) LINE(1) = SYMBOL(11)
76*      IF (IDISTB .GT. JX1) LINE(JX1) = SYMBOL(11)
77*      IF (IDISTB .GE. 1 .AND. IDISTB .LE. JX1) LINE(IDISTB) = SYMBOL(12)
78*      9 CONTINUE
79*      Y = Y+ISKIP1*2.0
80*      WRITE(IWRITE,2200) Y, (LINE(J), J=1,JX1)
81*      7 CONTINUE
82*      DO 10 J=1,JX1
83*      10 LINE(J) = SYMBOL(B)
84*      DO 11 J=1,JX1,10
85*      11 LINE(J) = SYMBOL(9)
86*      WRITE(IWRITE,2100) (LINE(J), J=1,JX1)
87*      WRITE(IWRITE,2000) (X(I), I=1,NDX)
88*      C
89*      C      FORMAT STATEMENTS
90*      C
91*      1100 FORMAT('1',15X,'LINE PLOT BEFORE A, B OFFSET ADJUSTMENTS')
92*      1200 FORMAT('1',15X,'LINE PLOT AFTER A, B OFFSET ADJUSTMENTS')
93*      1300 FORMAT(A1)
94*      1400 FORMAT(17A5)
95*      1500 FORMAT(/,5X,I1,' & ',I1,' = ',16A5)
96*      1600 FORMAT(13X,16A5)
97*      1700 FORMAT(13X,'NO. OF POINTS FOR ',I1,' & ',I1,' = ',I5)
98*      1710 FORMAT(/,5X,'ODD NO. = A OFFSETS , EVEN NO. = B OFFSETS')
99*      1800 FORMAT(7X,3F10.0)
100*     1900 FORMAT(/,5X,'NO. OF RECORDS IN THIS PLOT = ',I2)
101*     1910 FORMAT(5X,'XMIN = ',F7.4,' , XMAX = ',F7.4,' , SCALE = ',F7.4,
102*           *' IN./IN.')
```

CONVERGE

```

))LIST
10 INTEGER I,K,R
15 SFMODE
20 DIM M(100),N(100),T(100),U(100)
40 PRINT "THIS PROGRAM REDUCES SONDEX DATA"
50 PRINT
60 PRINT "ENTER INITIAL FILE NAME"
70 INPUT A$
80 OPEN \1,25,1\A$
90 PRINT "ENTER FILE NAME TO BE ANALYZED"
100 INPUT B$
110 OPEN \2,25,1\B$
160 INPUT \1,I,J
165 K=I : L=J
170 PRINT
180 PRINT "CHANGE IN RING DEPTH FROM DAY ";I; ", 1981, SURFACE ELEVATION ";J; " FT"
190 FOR Z=1 TO 100
200 M(Z)=0 : N(Z)=0 : T(Z)=0 : U(Z)=0
210 NEXT Z
220 INPUT \1,I,J
230 IF I=999 THEN 290
240 M(I)=J
250 IF I=1 THEN GOTO 270
260 N(I)=J-0
270 O=J
280 GOTO 220
290 INPUT \2,D,P
300 PRINT "FOR DATA OF DAY ";O; ", SURFACE ELEVATION ";P; " FT, ";C$
310 PRINT
320 PRINT "RING NUMBER      RING CHANGE(FT)      RINGS      CHANGE"
330 Q=P-L
350 INPUT \2,R,S
360 IF R=999 THEN GOTO 450
370 T(R)=S-M(R)-Q
380 IF R=1 THEN U(R)=T(R) : GOTO 400
390 U(R)=S-V-N(R)
400 V=S
425 Y=R-1
430 PRINT USING "          **      ---**.**      ** TO **      ---**.**      ,R,T(R),Y,R,U(R)"
440 GOTO 350
450 CLOSE
460 PRINT "DO YOU WISH TO REDUCE ANOTHER FILE?"
470 PRINT "      1=YES      2=NO"
480 INPUT H
490 IF H=1 THEN 60
500 END

```

EXTENSOM

```

))EVE@LIST
10 ON ESC GOTO 530
20 SFMODE
30 PRINT
40 PRINT"THIS PROGRAM REDUCES DATA FOR INTERFELS EXTENSOMETERS"
50 PRINT
60 PRINT"ENTER FILE NAME OF EXTENSOMETER DATA TO BE REDUCED"
70 INPUT A$
80 OPEN\1,25,1\A$.
90 PRINT"ENTER NEW FILE NAME"
100 INPUT B$
110 CREATE B$
120 OPEN\2,25,2\B$
130 PRINT"HOW MANY ANCHOR POINTS?"
135 INPUT N
140 INPUT\1,I,J,K,L,M,O,P,Q
150 J1=J
160 K1=K : L1=L : M1=M : O1=O : P1=P : Q1=Q
170 R=K-L : S=L-M : T=M-O : U=O-P : V=P-Q
270 PRINT
280 PRINT"REDUCED DATA (MM) FOR ";B$;", STARTING DAY ";I;", 1981"
290 INPUT\1,I,J,K,L,M,O,P,Q
300 IF I=999 THEN 530
310 J2=J1-J
320 K2=J2+K-K1 : L2=J2+L-L1 : M2=J2+M-M1 : O2=J2+O-O1 : P2=J2+P-P1 : Q2=J2+Q-Q1
330 R2=K-L-R : S2=L-M-S : T2=M-O-T : U2=O-P-U : V2=P-Q-V
340 IF N=6 THEN 430
350 P2=0 : Q2=0 : U2=0 : V2=0
360 IF N=4 THEN 430
370 Q2=0 : T2=0
380 IF N=3 THEN 430
390 M2=0 : S2=0
430 PRINT
440 PRINT\2\I;";K2;";L2;";M2;";O2;";P2;";Q2
450 PRINT\2\SPC(4);R2;";S2;";T2;";U2;";V2
460 PRINT\2\
470 PRINT USING"-----## " ,I,K2,L2,M2,O2,P2,Q2
480 PRINT USING" --##.## " ,R2,S2,T2,U2,V2
490 PRINT
500 GOTO 290
530 CLOSE
540 PRINT"DO YOU WISH TO REDUCE ANOTHER FILE?"
550 PRINT" 1=YES 2=NO"
560 INPUT H
570 IF H=1 THEN 60
580 END

```

RELSTRESS

```

))LIST
40 INTEGER M,N
70 SFMODE
90 PRINT
100 PRINT "THIS PROGRAM REDUCES DATA FROM IRAD STRESSMETERS"
110 PRINT
120 PRINT "ENTER FILENAME FOR STRESSMETER DATA TO BE REDUCED"
130 INPUT A$
230 OPEN\1,25,1\A$
320 PRINT
330 PRINT
340 PRINT SPC(7); "CHANGE IN STRESS, STRESSMETER ";A$
360 PRINT
370 PRINT
380 PRINT "E=250,000 PSI E=500,000 PSI E=1,000,000 PSI"
410 PRINT "DAY READING CHANGE TOTAL CHANGE TOTAL CHANGE TOTAL"
420 PRINT
440 G=0 : D=250000.0
450 U=0 : V=0 : W=0 : X=0 : Y=0 : Z=0
470 INPUT\1,1,J,K
480 IF I=999 THEN 610
490 IF G=0 THEN 560
500 Y=((422400.0/G)**2)*(1-(G/K)**2)/(11.4-6.6E-07*D)
510 X=Y*(11.4-6.6E-07*D)/(11.4-6.6E-07*2*D)
520 V=Y*(11.4-6.6E-07*D)/(11.4-6.6E-07*4*D)
540 Z=Y+Z : W=X+W : U=V+U
560 LET G=K
590 PRINT USING "###.## ***** --###.## --###.## --###.##",J,K,Y,Z,X,W,V,U
600 GOTO 470
610 CLOSE
620 PRINT
630 PRINT
640 PRINT "DO YOU WISH TO REDUCE ANOTHER FILE?"
650 PRINT "1=YES 2=NO"
660 INPUT H
670 IF H=1 THEN GOTO 120
680 END

```

SCANNER

```

))LOLIST
10 ON ESC GOTO 390
20 PRINT
30 PRINT"THIS PROGRAM TRANSLATES SCANNER READINGS INTO DISPLACEMENTS"
40 PRINT
50 PRINT"ENTER FILE TO BE REDUCED"
60 INPUT A$
70 OPEN\1,25,1\A$
80 PRINT
90 PRINT"DAY      READING      POTENTIOMETER DISPLACEMENT      TOTAL DISPLACEMENT"
100 PRINT"      (IN)      (MM)      (IN)      (MM)"
110 PRINT
130 INPUT\1\B,M
135 Y2=0 : Z2=0
140 INPUT\1\D,X
150 Y=M*X/100+B : Z=Y*25.4
160 Y1=Y : Z1=Z
180 GOTO 260
190 INPUT\1\D,X
210 IF D=888 THEN 320
220 IF D=999 THEN GOTO 390
240 LET Y=M*X/100+B
250 LET Z=Y*25.4
260 F=Y-Y1+Y2 : G=Z-Z1+Z2
270 PRINT USING"###.##      ##.##      ####.##      --###.##      --###.##",D,X,Y,Z,F,G
310 GOTO 190
320 PRINT
330 PRINT"THE LINEAR POTENTIOMETERS WERE RESET AT THIS TIME"
340 PRINT
370 Y2=F : Z2=G
380 GOTO 140
390 CLOSE
400 PRINT
410 PRINT"DO YOU WISH TO REDUCE ANOTHER FILE?"
420 PRINT"      1=YES      2=NO"
430 INPUT H
440 IF H=1 THEN 40
450 END

```

SLOPE

)LIST

```

10 ON ESC GOTO 440
20 PRINT"THIS PROGRAM COMPUTES HORIZONTAL AND VERTICAL CHANGES BETWEEN SURVEYS"
30 PRINT
40 PRINT"CHANGES ARE IN UNITS OF FEET"
50 PRINT"HORIZONTAL ANGLE IS MEASURED CLOCKWISE FROM NORTH"
60 PRINT"VERTICAL ANGLE IS MEASURED UP FROM HORIZONTAL"
70 PRINT
80 PRINT"ENTER INITIAL FILE NAME"
90 INPUT A$
100 OPEN\1,25,1\A$
110 PRINT"ENTER FILE TO BE COMPARED TO INITIAL FILE"
120 INPUT B$
130 OPEN\2,25,1\B$
140 PRINT
150 PRINT
160 PRINT"CHANGES IN SURVEY POINT LOCATIONS BETWEEN ";A$;" AND ";B$
170 PRINT
180 PRINT"POINT          HORIZONTAL CHANGE          VERTICAL CHANGE"
190 PRINT
200 PRINT"          N-S          E-W          NET          ELEV.          NET          ANGLE"
210 PRINT
220 INPUT\1,A,B,C,D
230 IF A=999 THEN 440
240 IF A=E+0.01 THEN 260
250 PRINT
260 INPUT\2,E,F,G,H
270 I=F-B : J=G-C : K=I**2+J**2 : L=K**0.5
280 IF I=0 THEN 300
290 GOTO 320
300 M=0
310 GOTO 330
320 M=ATN(J/I)*180/3.14159
330 N=H-D : O=(K+N**2)**0.5
340 IF L=0 THEN 360
350 GOTO 410
360 IF N=0 THEN 390
370 P=90*ABS(N)/N
380 GOTO 420
390 P=0
400 GOTO 420
410 P=ATN(N/L)*180/3.14159
420 PRINT USING" #.##          --#.##          --#.##          --#.##          --#.##          --#.##",A,I,J,L,M,N,O,P
430 GOTO 220
440 CLOSE
450 PRINT
460 PRINT"DO YOU WISH TO REDUCE ANOTHER FILE?"
470 PRINT"          1=YES          2=NO"
480 INPUT Z
490 IF Z=1 THEN 70
500 END

```


SURVEY

```

))LIST
10 ON ESC GOTO 230
20 PRINT"THIS PROGRAM GIVES HORIZONTAL AND SLOPE DISTANCES FOR SURVEY DATA"
30 PRINT
40 PRINT"ENTER FILE TO BE REDUCED"
50 INPUT A$
60 OPEN"1,25,1\A$"
110 PRINT
120 PRINT USING"FROM TO HORIZ. DIST. SLOPE DIST. FOR ****.***",A$
125 PRINT
130 INPUT"1\A,B,C,D"
140 INPUT"1\E,F,G,H"
150 IF E>A+0.01 THEN 207
160 IF E=999 THEN 230
170 LET H1=((F-B)**2+(G-C)**2)**0.5
180 LET S1=(H1**2+(H-D)**2)**0.5
200 PRINT USING"*.## *.* ** ***.## ***.##",A,E,H1,S1
205 GOTO 210
207 PRINT
210 A=E : B=F : C=G : D=H
220 GOTO 140
230 CLOSE
240 PRINT"DO YOU WISH TO REDUCE ANOTHER FILE?"
250 PRINT" 1=YES 2=NO"
260 INPUT Z
270 IF Z=1 THEN 20
280 END

```