GEOLOGIC STUDIES FOR MINE BACKFILLING PROJECTS, SOUTHWESTERN ILLINOIS

First Quarterly Report
for the Bureau of Mines, U.S. Department of the Interior

Contract Number J0177076

Paul B. DuMontelle, E. Donald McKay and Paul J. Ehret

INTRODUCTION

On May 1, 1977, the Illinois State Geological Survey, acting for the Board of Trustees of the University of Illinois in cooperation with the Bureau of Mines of the U.S. Department of the Interior, began investigating the geology, hydrogeology, and engineering geology of three areas in southwestern Illinois in which surface subsidence above abandoned coal mines has caused property damage (fig. 1). These areas were selected by the Bureau as possible sites for demonstration projects in stabilizing the land surface by pneumatic injection of material into abandoned underground coal mines. Two sites, Canterbury Manor and the 70th Street area, are in Belleville in St. Clair County (fig. 2). A third project area is in Maryville in Madison County (fig. 3). This report complies with a contract agreement to supply the Bureau with a quarterly report summarizing the progress of work and represents a major portion of the final contract obligation. Most of the field work for the study has been completed; future reports will deal primarily with the laboratory and monitoring program.

Belleville and Maryville were selected by the Bureau because of the interest of residents, the history of surface subsidence problems, and the availability of material for backfill. Residents have assisted in preliminary investigations by monitoring cracks, photographing damage, reporting water and gas leaks, and graciously allowing borings to be made and instruments to be installed on their property. Participation by residents in discussions of property damage has provided an understanding of the scope of the surface subsidence problem in the project areas.

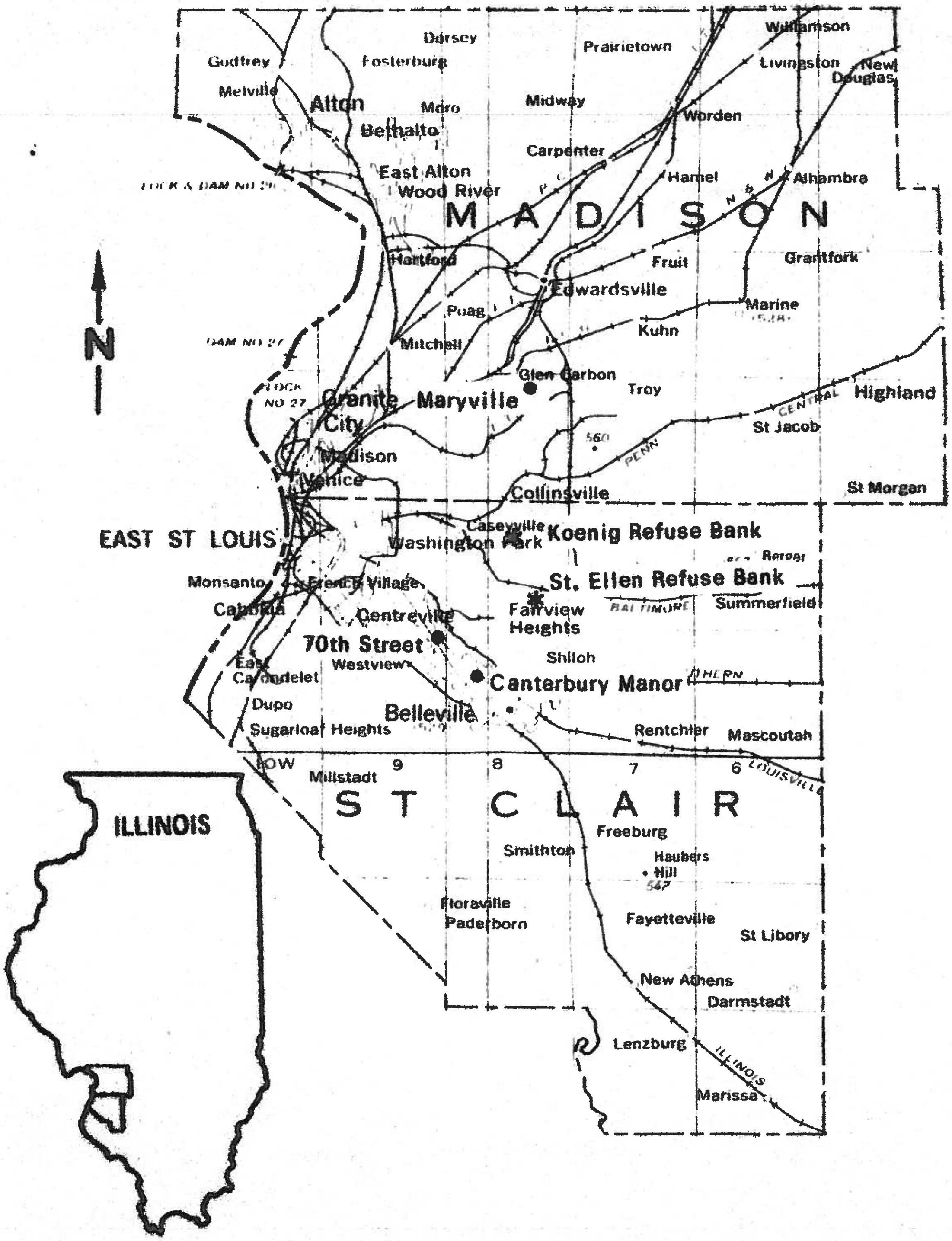


Figure 1. The Canterbury Manor, 70th Street, and Maryville project areas and the Koenig and St. Ellen Refuse Banks

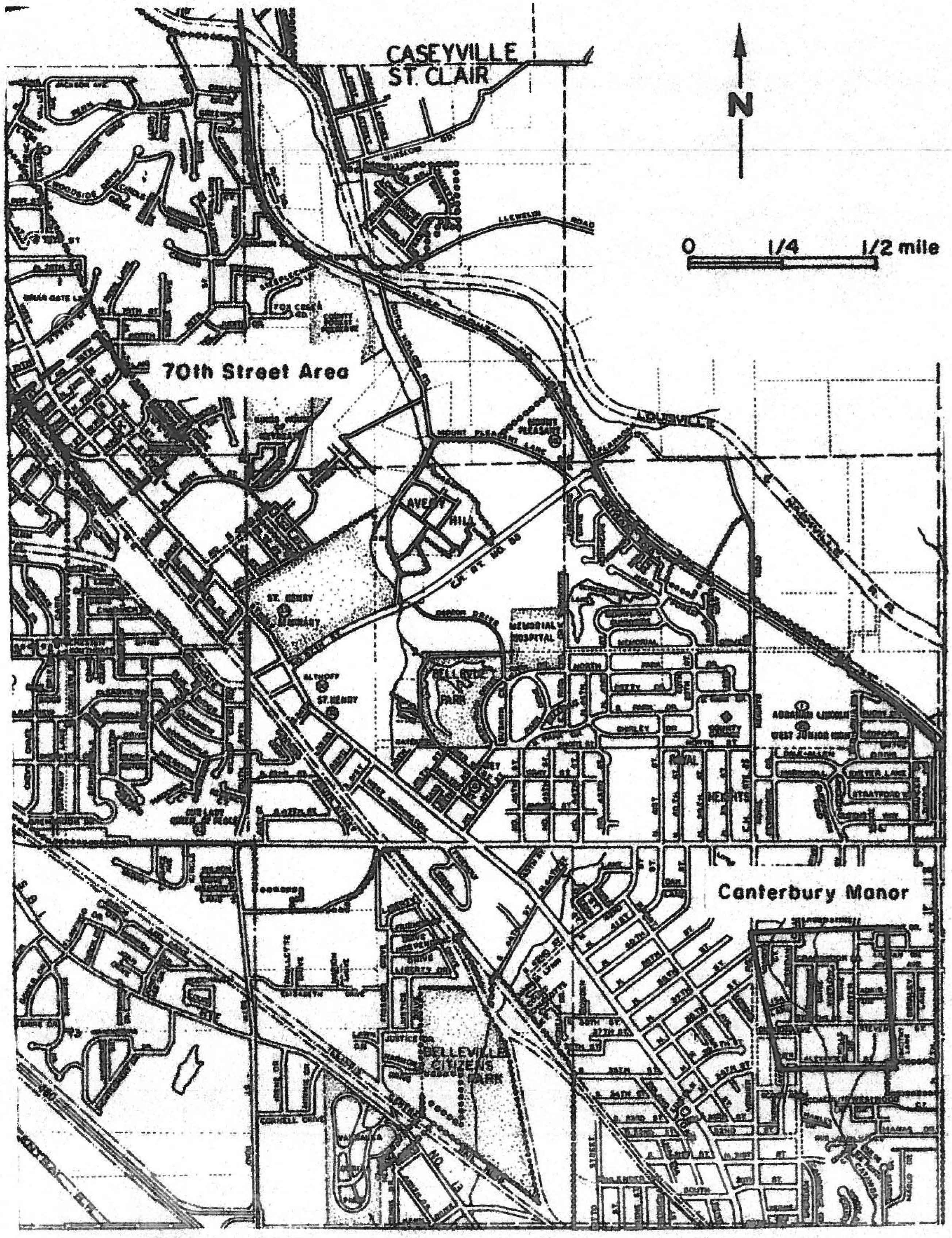


Figure 2. Proposed backfill areas in Belleville, Illinois

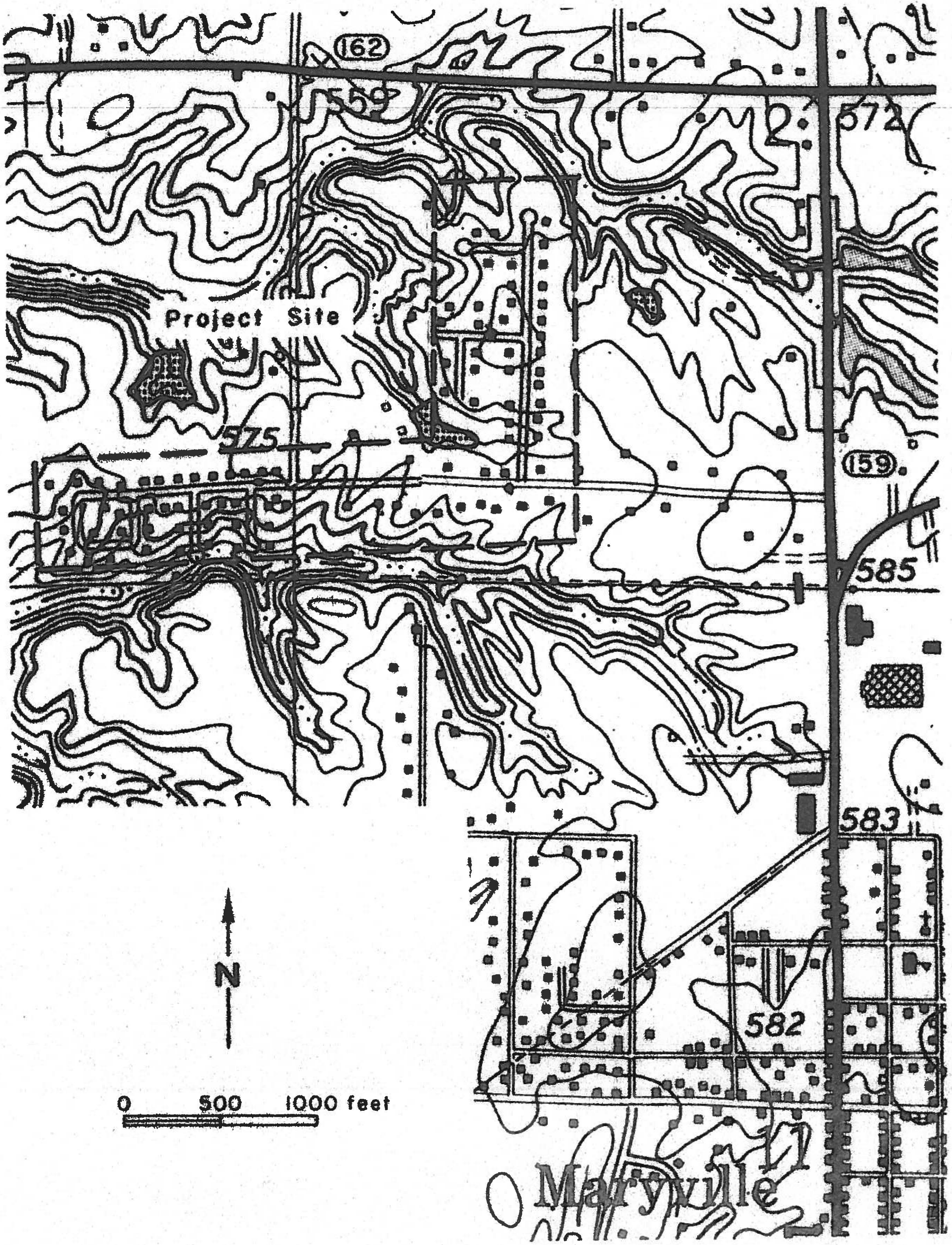


Figure 3. Proposed backfill area in Maryville, Illinois

Mine subsidence has been blamed for structural damage since coal mining began in the region. County reports by Quade for the Federal Land Bank of St. Louis in 1934 included mapping of areas of subsidence. Reports of damage to schools, park facilities, churches, commercial buildings, and residences have continued to disturb members of the community. Steven D. Babcock of Southern Illinois University, Edwardsville (1973), has described some well-documented occurrences. Additional problem areas are documented in the letter and newspaper files of Thomas O. Glover, Liaison Officer of the Bureau of Mines (1976), and in the Research Report and Recommendations for the House Executive Subcommittee on Mine Subsidence (1976). The Illinois State Geological Survey has examined the problem for some time; Cooperative Coal Mining Series Bulletin 17, Surface Subsidence in Illinois, was published in 1916. In recent years, efforts have been directed toward cooperating with Southwestern Illinois Metropolitan and Regional Planning Commission (SWIMPC) to offer residents of the region information on geological constraints for some land uses. The mined-out coal areas and areas of unstable soils, which may present significant constraints for some types of land use, are examined in the following reports: Jacobs, 1971; SWIMPC, 1975-76, and Development Policies in Background Data, 1977.

Acknowledgments

Ronald Yarbrough, Professor of Earth Science, Southern Illinois University, Edwardsville, offered continuing consultation and cooperation during the study. Thomas Glover, Liaison Officer, Bureau of Mines, provided materials and other assistance for the project. Numerous members of the USDA Soil Conservation Service staff in Edwardsville, Illinois, periodically read piezometers over a two-year period; their voluntary assistance is gratefully acknowledged.

Personnel

Paul B. DuMontelle and E. Donald McKay of the Illinois State Geological Survey are acting as co-principal investigators on the project. Paul Ehret, who was hired with contract funds as a research assistant on a full-time basis, conducted field work, monitored instruments, assisted in laboratory work, and acted as liaison with the Bureau and contractors at the sites. A temporary office has been established at Southern Illinois University at Edwardsville ([618]-692-3668). The Survey drilling rig operated by Edward G. Scoggin was used to make borings to investigate surficial materials. Mr. Scoggin also assisted in laboratory and field monitoring work. Bedrock cores were logged by Roger B. Nance and W. John Nelson. Keros Cartwright, Stephen R. Hunt, and many other Survey staff members also contributed to the project.

GEOLOGY

Geologic information for the Canterbury Manor, 70th Street, and Maryville project areas is derived principally from recent on-site investigations conducted by the Bureau of Mines and the Illinois State Geological Survey. The Bureau of Mines has completed a preliminary test drilling program in which three diamond drill cores were taken from each of the three project areas (figs. 4, 5, and 6). Each boring penetrated to below the depth of the Herrin (No. 6) Coal or to below the depth of the void where the coal had been mined. Continuous cores of bedrock materials from each boring were logged in the field by Survey personnel. Logs included description of lithologies; notation of fracture frequency and color; and, beginning with the Maryville core, Rock Quality Designation (RQD). Selected segments of core were wrapped for laboratory determination of natural moisture content. At the Survey, each core was described in detail, and measured for Shore hardness.

The Bureau's preliminary test drilling program determined that beneath Canterbury Manor and Maryville are partially closed coal mine voids; however, the voids encountered in two borings in the 70th Street area of Belleville were fully open. General depth information from the Bureau's core drilling program is summarized in table 1. The table also includes the thicknesses of bedrock lithologies measured above the coal or mine void in each boring.

To investigate the surficial geologic materials not sampled in the Bureau's initial test borings, the Illinois State Geological Survey has drilled a stratigraphic control boring to the depth of bedrock (40 to 60 feet [12 to 18 m]) both the Canterbury Manor and 70th Street areas and two such borings (approximately 90 feet [27 m] deep) in the Maryville area, which is slightly larger than the other two sites. The borings were sampled continuously with split-barrel samplers, and selected samples were saved for laboratory determination of natural moisture

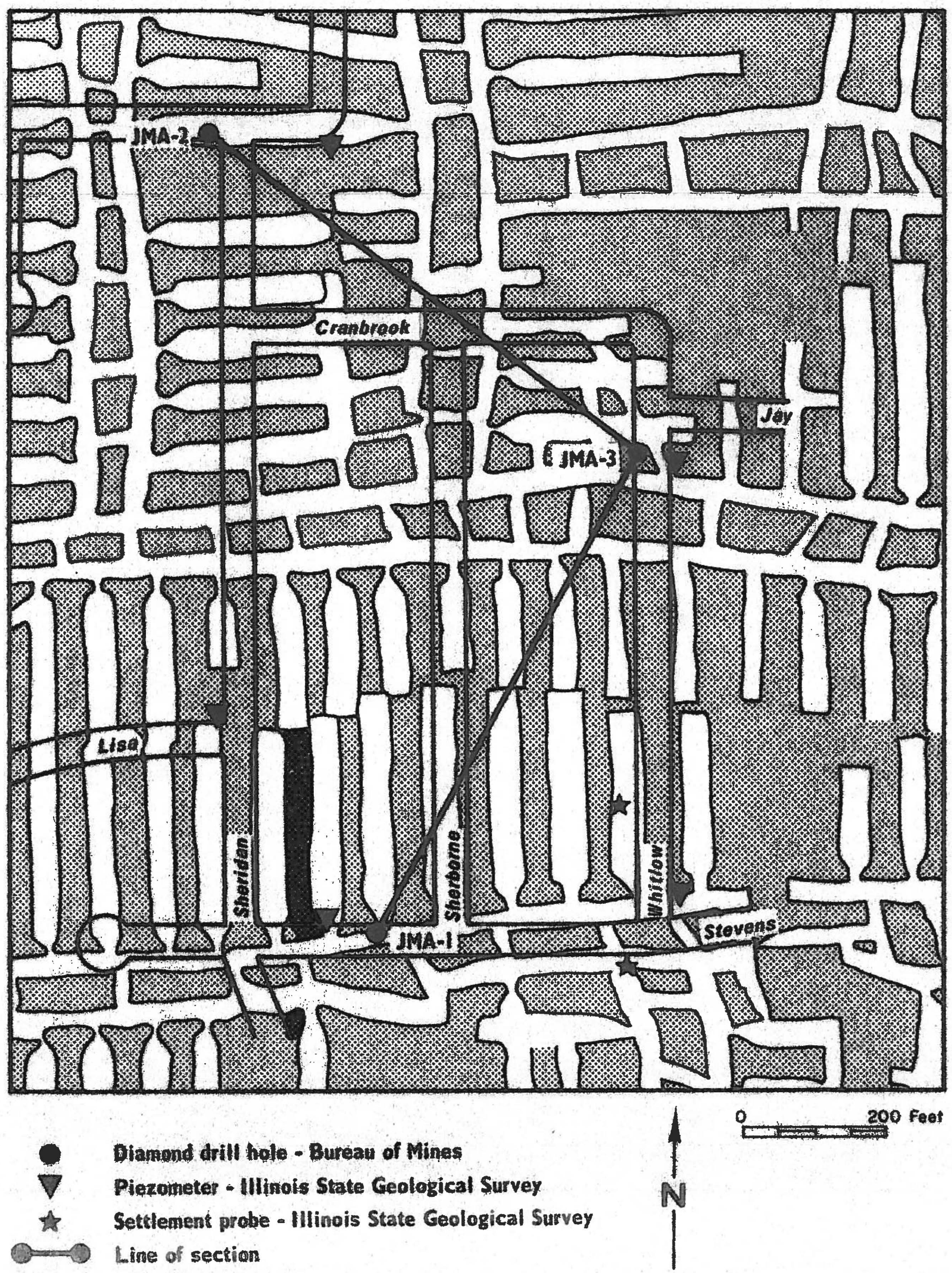


Figure 4. Canterbury Manor area. Locations of borings and instruments are indicated by symbols.. Shaded areas are mine pillars.

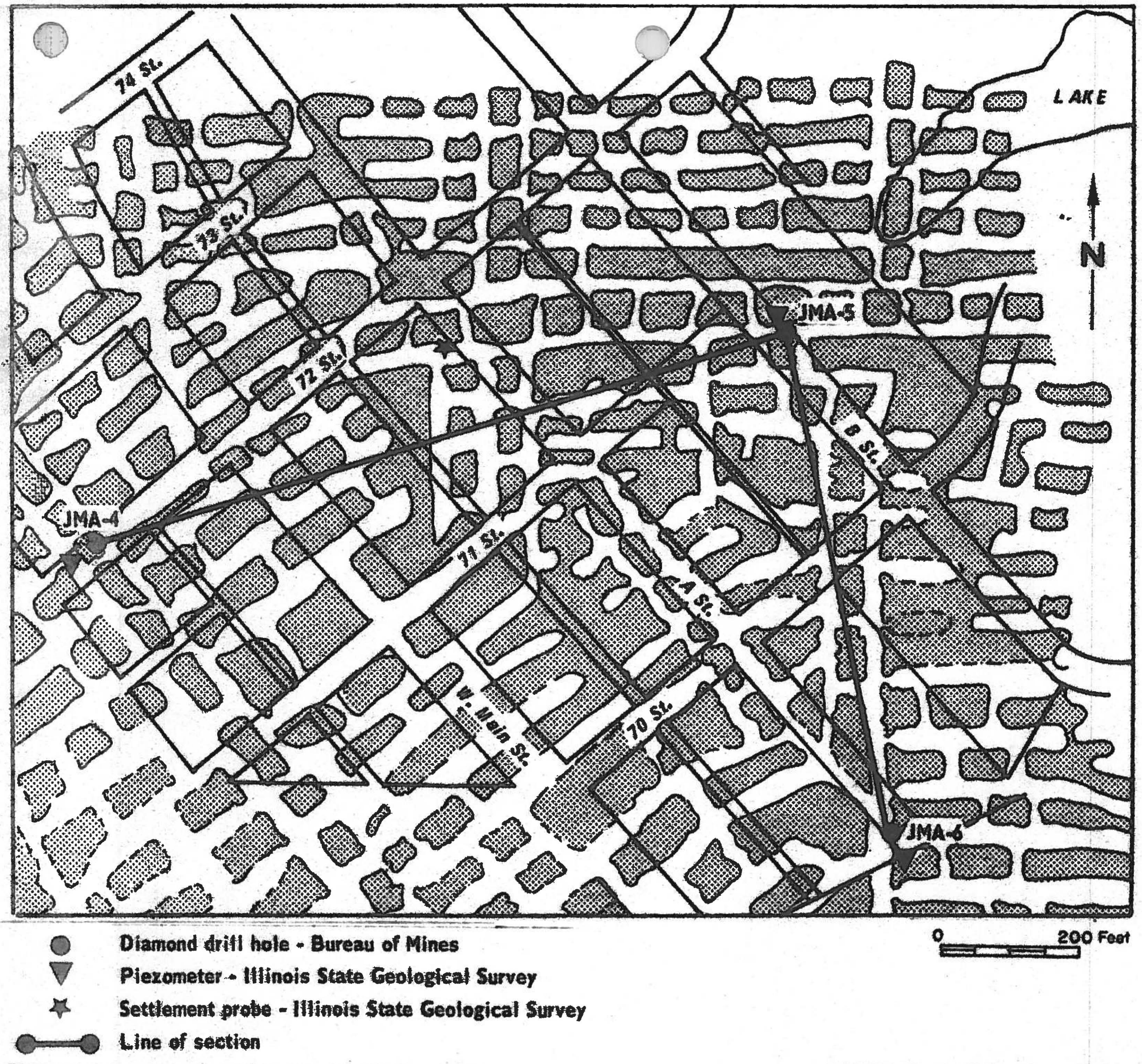


Figure 5. 70th Street area. Locations of borings and instruments are indicated by symbols. Mine pillars are shaded.

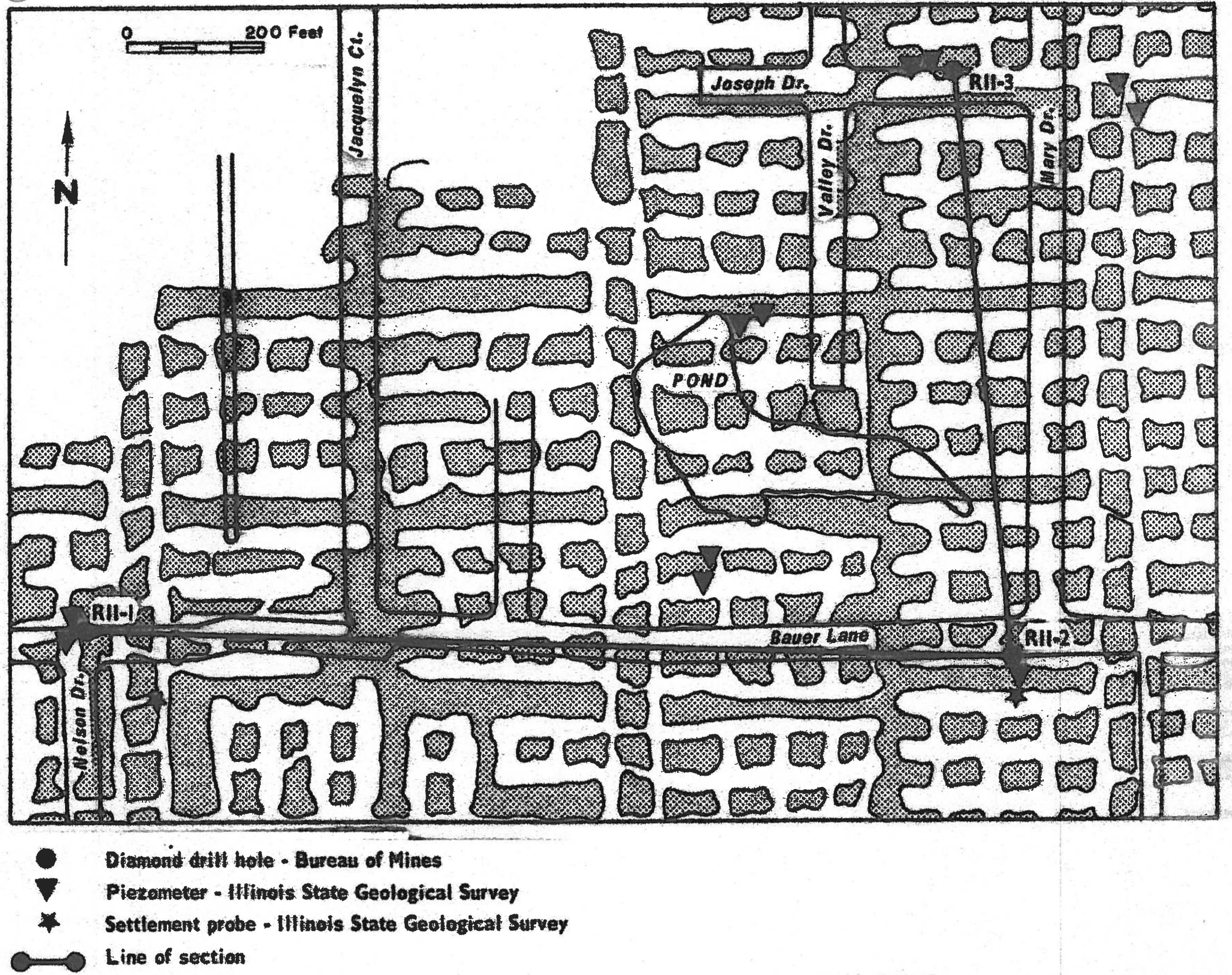


Figure 6. Maryville area. Locations of borings and instruments are indicated by symbols. Mine pillars are shaded.

Table 1. Summary of drilling information from Bureau of Mines preliminary test boring program.

	Project Area								
	Canterbury Manor Belleville, Illinois			70th Street Belleville, Illinois			Maryville, Illinois		
	JMA-1	JMA-2	JMA-3	JMA-4	JMA-5	JMA-6	RII-1	RII-2	RII-3
Boring									
Depth of surface casing (ft)	79.0	77.0	79.5	54.0	54.0	39.0	111.0	112.0	108.5
Depth to top of coal or void (ft)	151.0	146.6	149.7	176.5	177.0	160.5	210.25	218.1	221.0
Thickness/height of coal or void (ft)	6.5 void	2.0 void	7.35 coal	7.0 void	10.0 void	5.5 coal	3.5 void	1.3 void	3.0 void
Total depth (ft)	163.0	169.5	161.0	199.0	195.0	170.5	225.5	239.5	238.0
Bedrock lithologies (ft)									
Claystone	23.5	19.6	22.2	18.8	13.2	14.1	22.7	30.7	21.0
Shale	10.9	10.3	15.1	40.7	42.3	41.3	54.4	57.4	67.0
Sandstone	0.0	0.0	0.6	32.0	35.2	27.0	0.0	0.0	0.0
Siltstone	1.3	8.0	2.7	0.8	18.9	6.8	12.4	4.6	3.4
Limestone	29.7	28.3	29.5	30.3	12.4	30.8	10.0	14.3	18.8
Coal	0.2	0.2	0.2	0.1	0.2	0.2	0.0	0.0	0.0
Total thickness of rock core	65.6	66.4	70.3	122.7	122.2	120.2	99.5	107.0	110.2

content and grain-size and clay-mineral composition. In the field, samples were logged, standard penetration values were recorded, and shear strengths were measured. Where possible, deep stratigraphic control holes were closely offset from the Bureau's diamond drill borings, thus providing a nearly continuous sampling record from ground surface to below mine depth. The Survey drilled 14 additional borings 30 to 40 feet (9 to 12 m) deep to determine continuity of near-surface units in the three project areas.

THE CANTERBURY MANOR AND 70th STREET PROJECT AREAS

Stratigraphy of the Surficial Materials

The term surficial materials, as used here, refers to the loose or partially consolidated Tertiary and Quaternary deposits that overlie consolidated bedrock. In the Canterbury Manor and 70th Street areas, these surficial materials are of four types: (1) glacial till (unsorted ice-deposited sediment), (2) loess (wind-deposited silt), (3) alluvium (stream-deposited silt and silty clay), and (4) residuum (clayey material produced by weathering of bedrock). These materials were deposited intermittently during the Tertiary and Quaternary Periods of geologic time, probably during the past one and a half to two million years. When no additional materials were being deposited, materials exposed at ground surface were physically and chemically altered by weathering processes. The resulting weathered zones (paleosols) have physical properties which may differ significantly from their parent materials.

The total thickness of surficial materials in Canterbury Manor is about 60 feet (18 m). In the 70th Street area, a maximum thickness of 40 feet (12.3 m) was measured. The stratigraphy of surficial materials in the two project areas, as determined from Survey borings, is shown in figures 7 and 8. The stratigraphy of the surficial materials at the two Belleville sites is

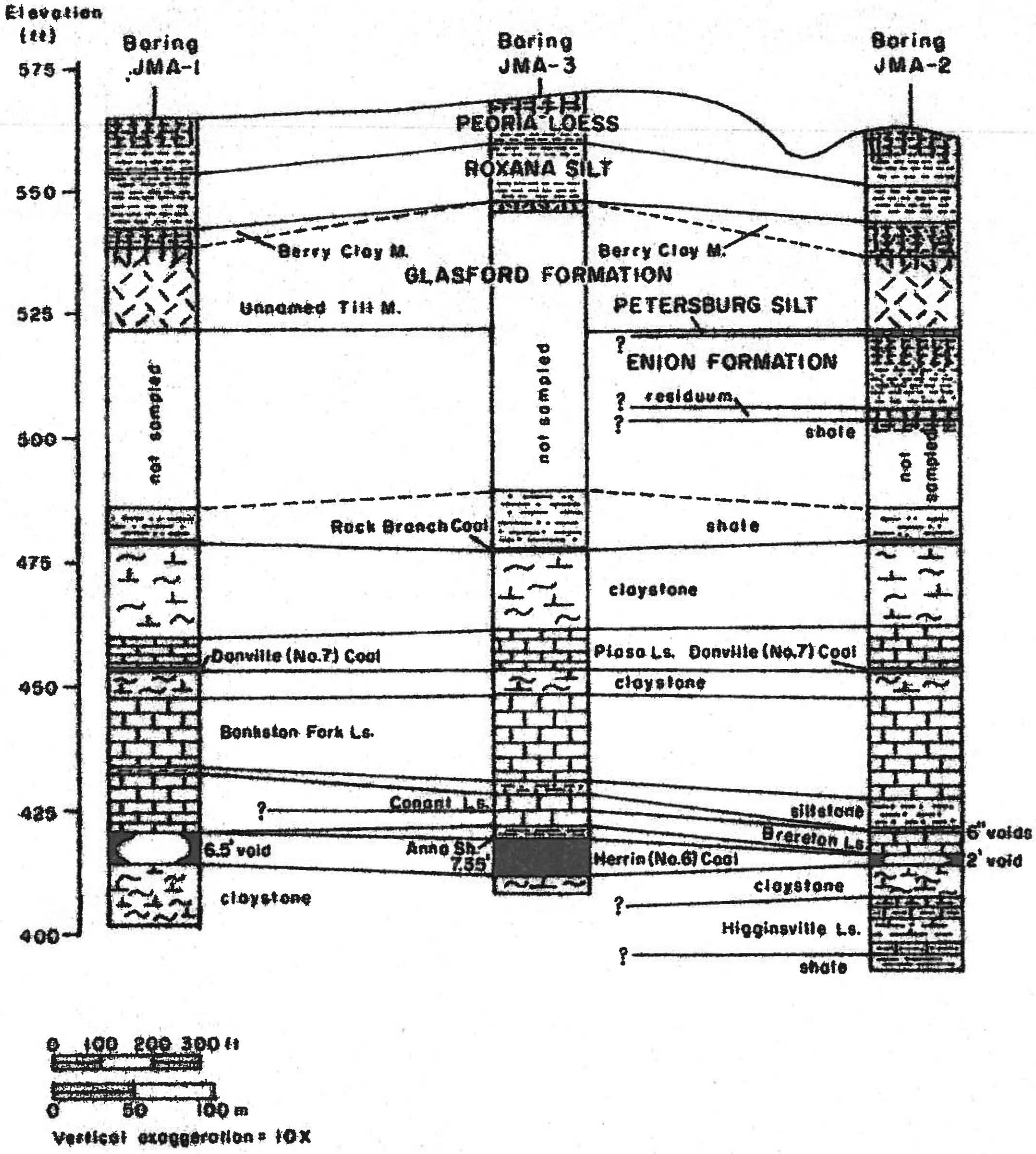


Figure 7. Stratigraphy of surficial and bedrock materials in the Canterbury Manor area of Belleville, Illinois

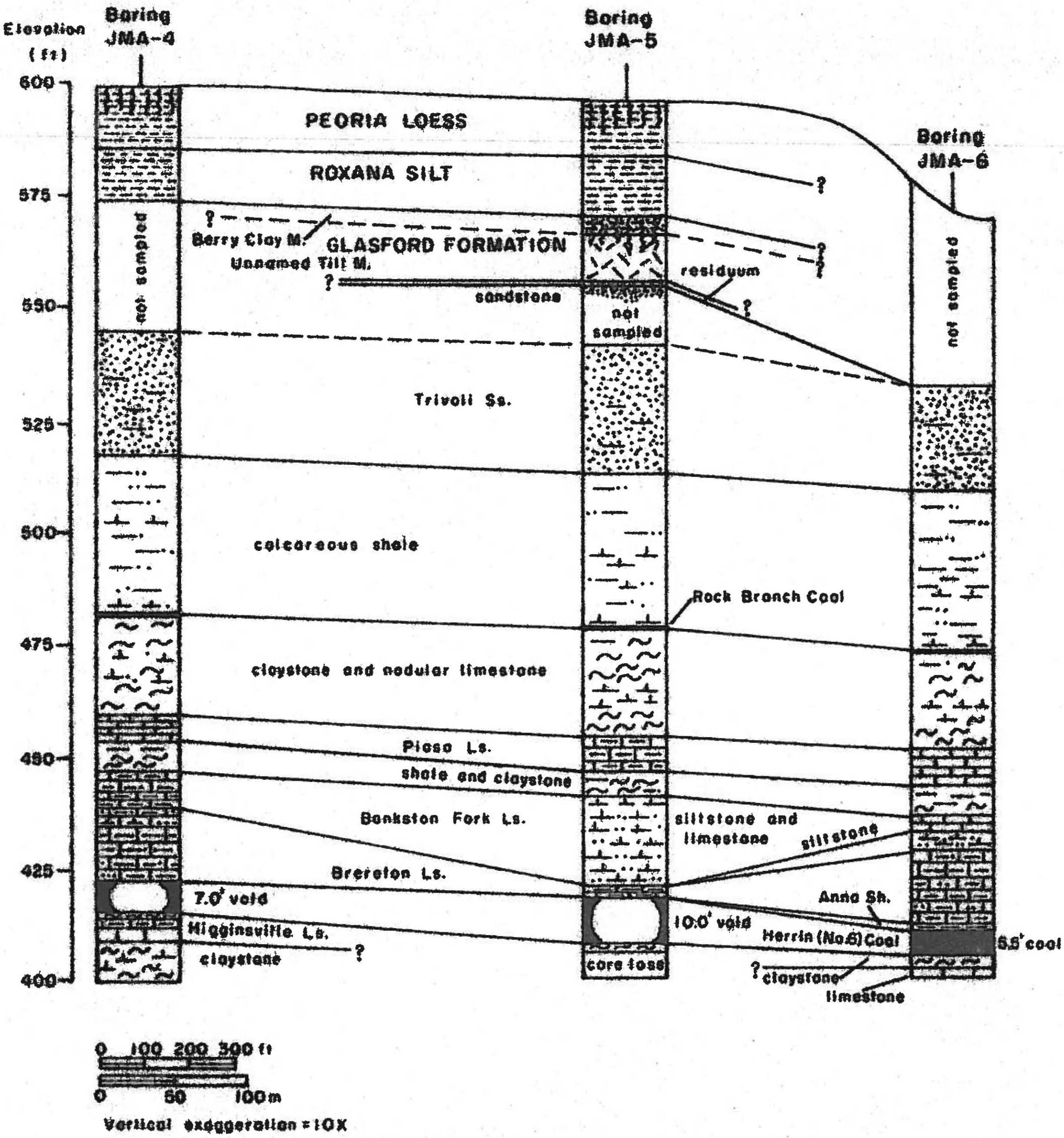


Figure 8. Stratigraphy of surficial and bedrock materials in the 70th Street area of Belleville, Illinois

similar. The uppermost unit in both areas is the Peoria Loess, a late Wisconsinan loess. The Peoria is composed predominantly of silt that was derived from the Mississippi Valley to the west and transported and deposited by the wind. It is commonly yellow brown to light gray brown and lacks any visible bedding or vertical variation in grain size. The average grain-size composition of the Peoria Loess at Canterbury Manor is 1 percent sand, 80 percent silt, and 19 percent clay. The Peoria covers the uplands east of the Mississippi Valley and is almost continuous across the two Belleville project sites. The Peoria is about 12 feet (3.6 m) thick in Canterbury and 13 feet (3.9 m) thick in the 70th Street area. It may have been partially or completely removed in areas of stream erosion.

The upper 3 to 6 feet (0.9 to 1.8 m) of the Peoria contains the Modern Soil that has been produced by weathering since cessation of loess deposition. In most places at the two project sites, the Modern Soil is partially buried by fill material or truncated by earth-moving operations performed during preparation of sites for home construction. Where undisturbed, the Modern Soil has a light-colored silty surface (A horizon) containing several percent organic matter and ranging in thickness to about 15 inches (41 cm). The A horizon is underlain by a clay-rich zone (B horizon), which may extend to 3 feet (1 m) below ground surface. Clay contents in the B horizon may approach 30 percent.

Beneath the Peoria Loess is the Roxana Silt (figs. 7 and 8). The Roxana is an early Wisconsinan loess which is similar to the Peoria, from which it is distinguished primarily by its color—reddish brown to reddish gray brown. It is commonly about the same thickness as the Peoria Loess. In the Canterbury Manor area, the Roxana has an average grain-size composition of 3 percent sand, 74 percent silt, and 23 percent clay.

The Roxana Silt overlies the Glasford Formation, which is predominantly Illinoian glacial till but includes accretionary sediments (the Berry Clay Member), which accumulated on the surface of the till during the Sangamonian Interglacial. The glacial till of the Glasford Formation in southwestern Illinois was deposited by glaciers that entered northeastern Illinois and traversed the state to a terminus west of Belleville in the St. Louis area. This glacial till contains an unsorted mixture of debris that was deposited as the glacial ice melted. The till contains an average of about 5 percent gravel (>2 mm) and has an average matrix texture of 23 percent sand, 53 percent silt, and 24 percent clay. Unweathered till is gray and oxidizes to yellow brown.

A strongly weathered paleosol, the Sangamon Soil, occurs in the upper 3 to 6 feet (0.9 to 1.8 m) of the Glasford Formation, which is 15 to 20 feet (4.6 to 6.1 m) thick. The Sangamon is formed either in accretionary deposits (Berry Clay Member), which accumulated in depressional areas on the postglacial landscape, or in the upper part of the till. The Sangamon Soil in the Berry Clay is siltier and contains less gravel and sand than the paleosol developed in till. The average grain-size composition of the Berry Clay Member is 7 percent sand, 63 percent silt, and 30 percent clay. The Berry Clay contains a high percentage of expandable clay minerals. The dominant clay mineral in the unweathered glacial till is illite.

Beneath the Glasford Formation in the Canterbury Manor area is a thin (1.4 feet [.4 m]) unweathered proglacial silt, the Petersburg Silt. The Petersburg was deposited early during the Illinoian Stage and was subsequently overridden by the advancing Illinoian glacier. It contains lacustrine (lake-deposited) silts and possibly some loess. Though not encountered in the test boring program for this study, sand and gravel outwash sediments sometimes occur in the position of the Petersburg Silt.

At Canterbury Manor, the Petersburg Silt overlies 14.5 feet (4.4 m) of silty alluvial deposits correlated with the Nebraskan-age Enion Formation.

These sediments average 3 percent sand, 64 percent silt, and 33 percent clay. Their continuity across the area cannot be determined from available information. Where encountered, these alluvial sediments are stratified but contain no beds of sand or gravel. The Enion Formation is absent in the 70th Street area.

Beneath the Enion Formation at Canterbury Manor and beneath the Glasford Formation at 70th Street is a thin (2.5 feet [0.75 m]) residual soil developed from the upper portion of the Pennsylvanian bedrock. The residuum is a clayey (average texture—20 percent sand, 41 percent silt, 39 percent clay) product of intense preglacial weathering. The residuum has a high illite content similar to the bedrock from which it was derived.

Stratigraphy of the Bedrock Material

Bedrock strata encountered in the test borings in the two Belleville area sites are of Pennsylvanian age and belong to the Modesto and Carbondale Formations in the McLeansboro and Kewanee Groups, respectively. The Pennsylvanian strata encountered in the Belleville area sites are shown in figures 7 and 8. At the Belleville sites, the Modesto Formation includes strata from the top of the Trivoli Sandstone downward to the top of the Danville (No. 7) Coal. The remaining thickness of bedrock from the top of the Danville (No. 7) Coal to the bottom of the deepest core is within the Carbondale Formation.

The Trivoli Sandstone Member, the uppermost bedrock unit in the 70th Street area, is brown to gray-brown, fine-grained, porous, micaceous, and finely laminated to massive sandstone that ranges from 23 to 29 feet (7.0 to 8.8 m) thick. The Trivoli contains zones with abundant plant debris and carbonaceous, coarsely micaceous partings. The Trivoli Sandstone is not present at Canterbury Manor, and the Modesto Formation is truncated to below the stratigraphic position of the Trivoli.

Beneath the Trivoli Sandstone in the 70th Street area is a thick (35 feet, 10.6 m) gray to dark gray, well-bedded, hard shale with numerous calcareous zones. This shale appears to be the uppermost bedrock unit in the Canterbury Manor area, where it is about 25 feet (7.6 m) thick.

The thin Rock Branch Coal immediately underlies the thick shale unit and ranges in thickness from .10 to .22 feet (3 to 7 cm). It is present in all six borings in the two Belleville area sites and serves as a stratigraphic marker.

Beneath the Rock Branch Coal is a claystone and nodular limestone unit that ranges from 15 to 25 feet (4.6 to 7.6 m) thick. It is a variegated to gray or greenish-gray, firm claystone with some light gray nodular limestone and olive-gray shale beds.

The Piasa Limestone beneath the claystone unit is the basal member of the Modesto Formation and directly overlies the thin and discontinuous Danville (No. 7) Coal. The Piasa Limestone is fine grained, light gray, and hard and commonly contains coarse fossil debris, mainly brachiopods and crinoids.

Beneath the Piasa Limestone, or beneath the Danville (No. 7) Coal where it is present, is a claystone and shale unit that maintains a relatively constant thickness of 6 to 8 feet (1.8 to 2.4 m) in the Belleville project areas. The unit consists of variegated and gray soft claystone and greenish-gray to gray, soft, poorly bedded, fossiliferous shale.

The Bankston Fork Limestone Member of the Carbondale Formation underlies the claystone and shale unit. The Bankston Fork is light gray, fine grained, argillaceous, silty, and thick bedded and is interbedded with thin shale and siltstone beds. The Bankston Fork is variable in thickness in the Belleville area sites and ranges from 3.2 feet (1 m) to 20 feet (6 m) thick.

Beneath the Bankston Fork Limestone and above the Herrin (No. 6) Coal are variable thicknesses of siltstone, Conant Limestone, Brereton Limestone, and

Anna Shale. The Conant Limestone was found in only one boring, JMA-3 in Canterbury Manor (fig. 7), where it is gray, mottled, fine grained, massive, and silty and contains scattered large brachiopod shells. The Brereton Limestone is variable in thickness and occurs in all but one boring in the Belleville area sites. The Brereton is a gray, fine-grained, silty limestone with dark shaly zones containing abundant coarse crinoid and shell debris. In borings where the Herrin (No. 6) Coal was penetrated, the Anna Shale is 1 to 2.7 feet (.3 to .8 m) thick and immediately overlies the coal. The Anna is a black, hard, fissile shale with dark phosphatic lenses and fine pyritic and calcareous shell debris. In borings that penetrated the mine void, Anna Shale debris was usually encountered on the floor of the mine.

The Herrin (No. 6) Coal was encountered in two of the six borings in the Belleville area sites. In boring JMA-6 (fig. 8), the Herrin (No. 6) Coal was 5.5 feet (1.7 m) thick, and in JMA-3 (fig. 7), 7.35 feet (2.2 m) thick.

Beneath the Herrin (No. 6) Coal or the mine void, variable thicknesses of claystone (underclay) and Higginsville Limestone were encountered, as shown in figures 7 and 8. The claystone is greenish gray, soft, mottled, and poorly bedded and is sometimes replaced in part by hard, silty, bedded shale. The Higginsville Limestone is light gray, silty, and nodular to fairly pure, massive limestone.

MARYVILLE PROJECT AREA

Stratigraphy of the Surficial Materials

The total thickness of surficial materials in the Maryville project area sometimes exceeds 90 feet (27.4 m) and is greater than the thicknesses in the Belleville project areas. Detailed knowledge of the surficial materials comes principally from two deep stratigraphic borings by the Illinois State Geological Survey that offset Bureau of Mines diamond drill holes RII-1 and RII-3 (fig. 9).

The upper part of the section at Maryville is similar to the two Belleville project areas. Both the Peoria Loess and Roxana Silt are present in the Maryville section and are somewhat thicker than in Belleville. On stable upland surfaces, the Peoria Loess approaches a thickness of 15 to 16 feet (4.6 to 4.9 m) and the Roxana reaches thicknesses of 14 to 15 feet (4.3 to 4.6 m). Both loesses in Maryville have lithologies like those in the Canterbury Manor and 70th Street areas.

The Roxana Silt overlies the Sangamon Soil developed in glacial till of the Glasford Formation. This till is tentatively correlated with the till present in the Belleville area and has properties similar to that unit. It is approximately 25 feet (7.6 m) thick, gray, and oxidizes to yellow brown. The Sangamon Soil in the top of the till is 3 to 6 feet (0.9 to 1.8 m) thick, clay-rich, and leached of carbonate minerals.

Beneath the Glasford Formation is a second glacial till, which has a strongly developed paleosol in its upper part and is placed in the Kansan-age Banner Formation. Till of the Banner Formation is texturally and mineralogically similar to the overlying Glasford, but contains numerous large inclusions of material that is not till. The Banner Formation may contain seemingly intact blocks of bedrock as much as 1 to 2 feet (0.3 to 0.6 m) thick, and the lower portion of the Banner contains large inclusions of the underlying Enion Formation. The Banner Formation is not present in the Belleville area.

The Enion Formation at Maryville is a thick (8 to 17 feet [2.5 to 5.25 m]) silt and silty clay that has a strongly developed red paleosol in its upper part.

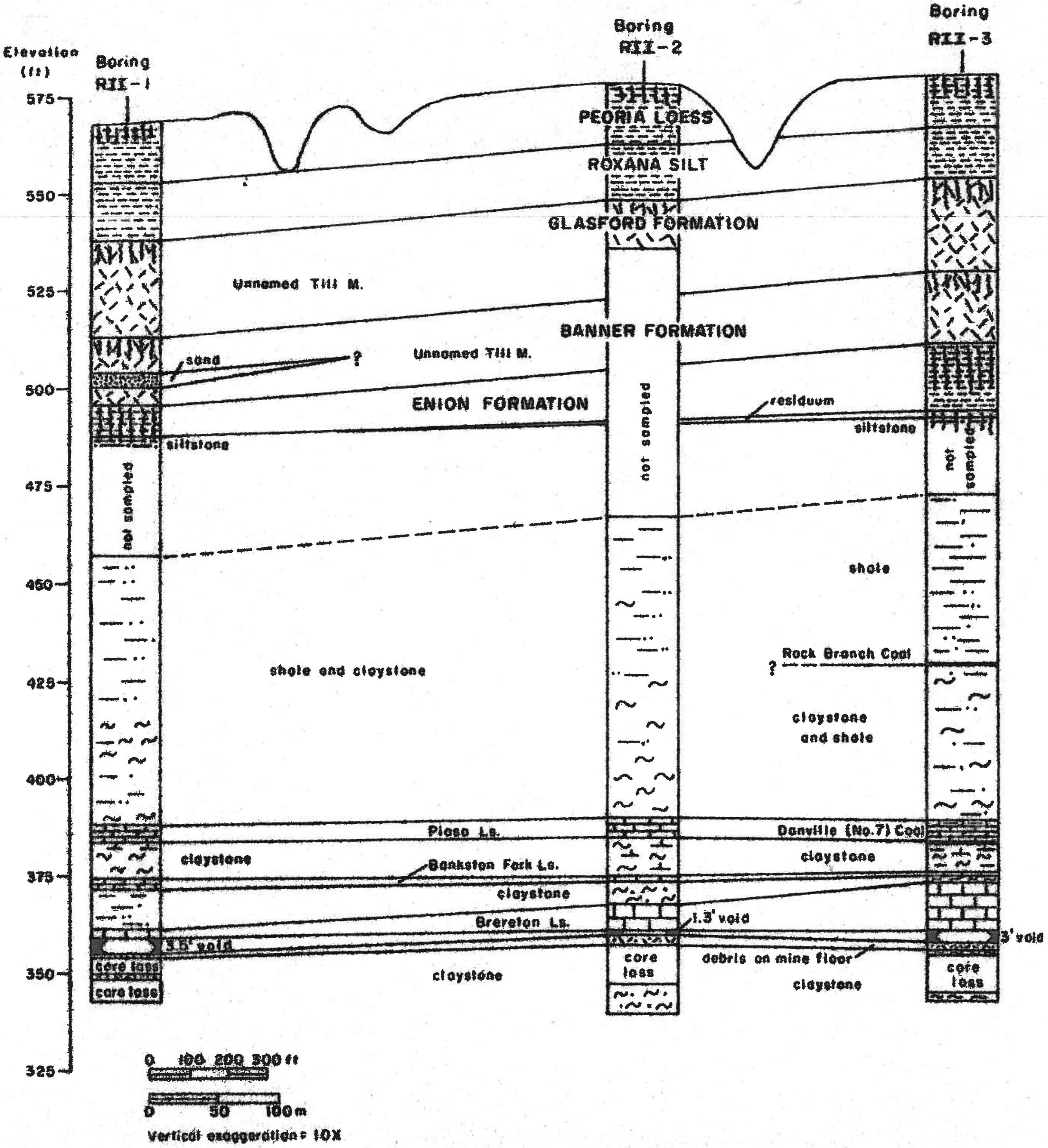


Figure 9. Stratigraphy of surficial and bedrock materials in the project area at Maryville, Illinois

The Enion may be loessial in part. It is texturally and mineralogically similar to the Peoria and Roxana and may contain evidence of a loess event during the Nebraskan Stage.

The Enion Formation overlies a strongly developed residual soil in the upper part of the Pennsylvanian bedrock. The residuum is approximately 1 to 2 feet (0.3 to 0.6 m) thick, very clayey, and contains abundant iron-manganese concretions.

Stratigraphy of the Bedrock Material

Diamond drill holes in the Maryville project area penetrated approximately 130 feet (39.6 m) of Pennsylvanian bedrock above the mine void and penetrated as much as 20 feet (6.1 m) below the void. The Pennsylvanian strata in Maryville are similar to those in the Belleville area. The upper 75 to 100 feet (23 to 30 m) of the section contains a thick sequence of shale, claystone, and siltstone units with a thin coal—probably the Rock Branch Coal—approximately 60 feet (18.3 m) below the top of rock. This thick, fine-grained section overlies the Piasa Limestone and is equivalent to similar materials below the Trivoli Sandstone and above the Piasa in the 70th Street area and to materials above the Piasa Limestone in Canterbury Manor.

The Piasa Limestone ranges from 4.2 to 4.85 feet (1.3 to 1.5 m) thick and is somewhat thinner in Maryville than in the Belleville area. Beneath the Piasa is a claystone and shale unit 8 to 10 feet (2.4 to 3 m) thick that rests on a thin but continuous Bankston Fork Limestone.

Beneath the Bankston Fork and above the mine void are a claystone and the Brereton Limestone. Together they maintain a thickness of approximately 13 feet (4 m); the thickness of each unit varies. In boring RII-1 (fig. 9), the claystone and limestone thicknesses are 10.6 feet (3.2 m) and 3.25 feet (1 m), respectively, but, in boring RII-3, the thicknesses are 0.7 feet (0.2 m) and 12.6 feet (3.8 m).

Beneath the mine voids, the diamond drill borings encountered thin debris zones on the mine floor. These zones contained coal fragments and angular pieces of Anna Shale and Brereton Limestone. Beneath the debris is a poorly recovered section of claystone (underclay) similar to that penetrated in the Belleville area. Because no limestone beneath the mine voids at Maryville was recovered, the underclays in the Maryville may be thicker than those in the Belleville area.

HYDROGEOLOGY

Procedures

Information about the hydrogeology of the three areas was obtained by observation during test borings, by examination of samples from cores, and by measurement of water level by a series of piezometers set at different depths in each area. Of the three test borings made to the depth of the coal seam, the borings that encountered voids provided information on water conditions in the mines. Selected samples of the diamond drill core were sealed in plastic bags to retain their natural moisture. The samples were returned to the laboratory, weighed, oven dried, and weighed again to determine the moisture content.

Piezometers such as the one shown in figure 10 were installed by first boring to a predetermined depth. Slots were then cut in the last foot of small-diameter plastic pipe (½- to 3/4-inch), and this end was plugged or capped. Lengths of pipe were joined together until the slotted end of the pipe rested on the bottom of the hole. A premeasured quantity of pea gravel or sand was used to backfill the hole in order to cover the slotted section of pipe. An equal quantity of dry bentonite was added to seal the pipe in the hole. Finally,

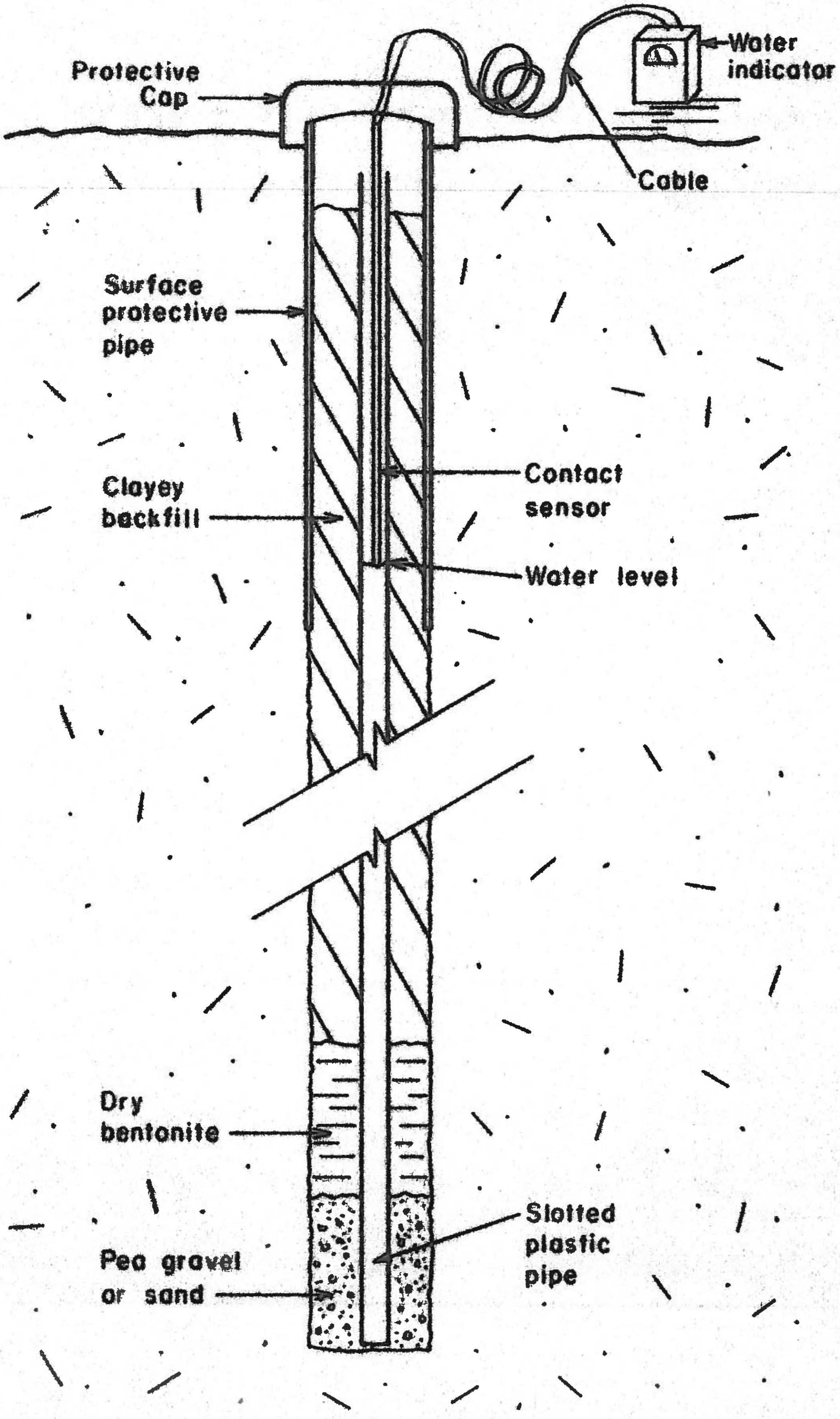


Figure 10. Piezometer

the hole was backfilled with clayey material to within a short distance of the surface. The installation was protected at the surface by enclosing the small pipe with a second plastic pipe and cap. A vent hole was drilled in the outer pipe to prevent pressure from building up as the water levels fluctuated. To measure water levels, a voltmeter, battery, and measuring cable were connected to indicate contact at the level of the water. The accuracy of the piezometer is about ±1 centimeter. The piezometers were read frequently enough to show seasonal effects on water level.

A piezometer was installed below the mine using a similar technique, except that the inner plastic pipe was grouted in position. The grout will be drilled out and the boring extended to expose a fresh bedrock sequence. If water does not rise in the pipe to measure the pressure of the water in the bedrock horizon, plans are to install a packer (plug) and use a transducer to measure pressures.

Results

Information from piezometers installed prior to the summer of 1977 will be integrated with new data. The locations of the piezometers are shown on each area map (figs. 4, 5, and 6). Results of this program are shown in figures 11, 12, and 13. These data are being compared to precipitation measurements from the nearest official weather observation station.

ENGINEERING GEOLOGY

The geology of the three areas presents natural constraints for construction. The strengths of the mine roofs and pillars in the three project areas determined the percentage of coal that could be safely mined from beneath the areas. Changes in these strength relationships may cause roof fall, floor squeeze,

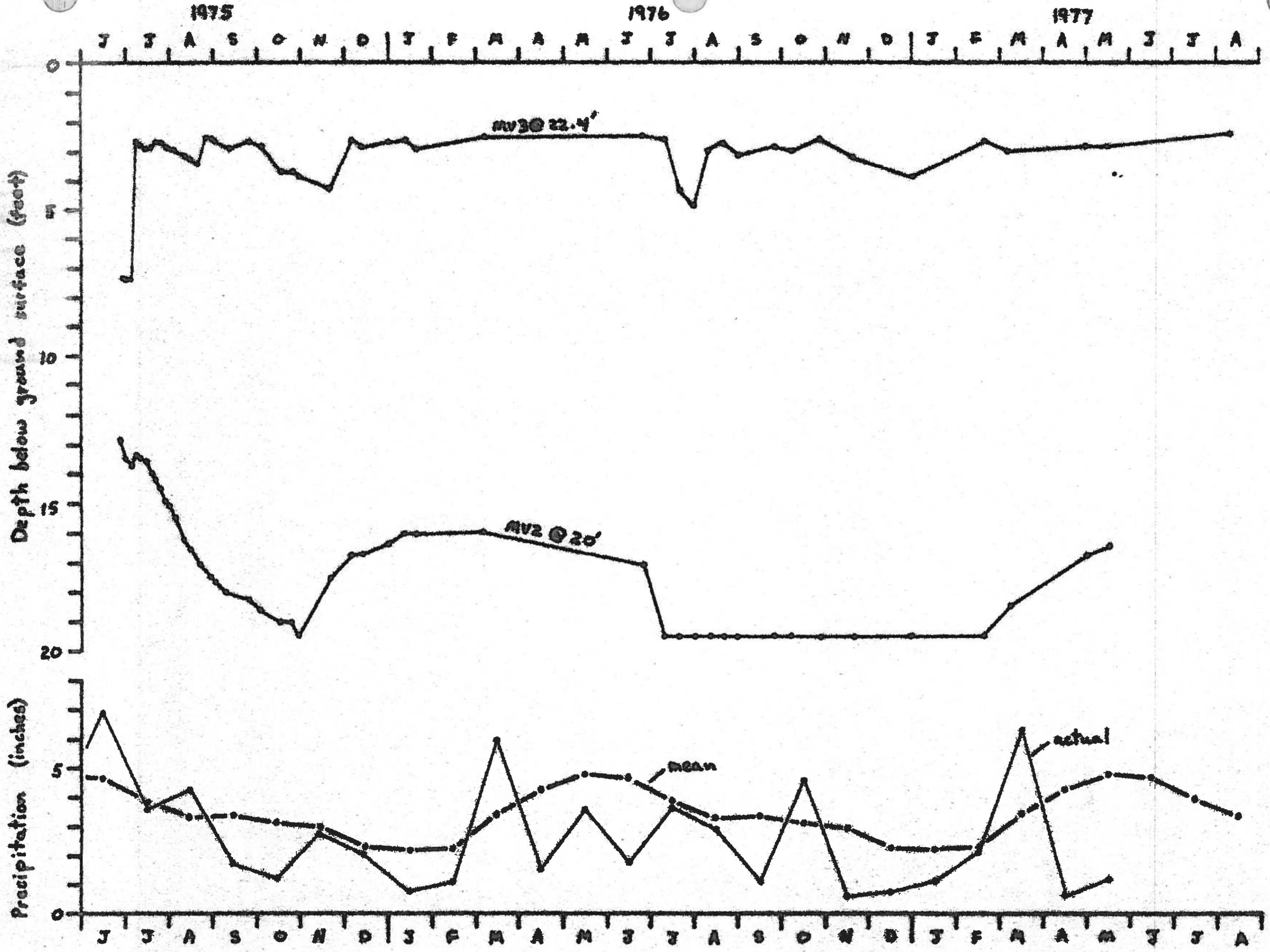
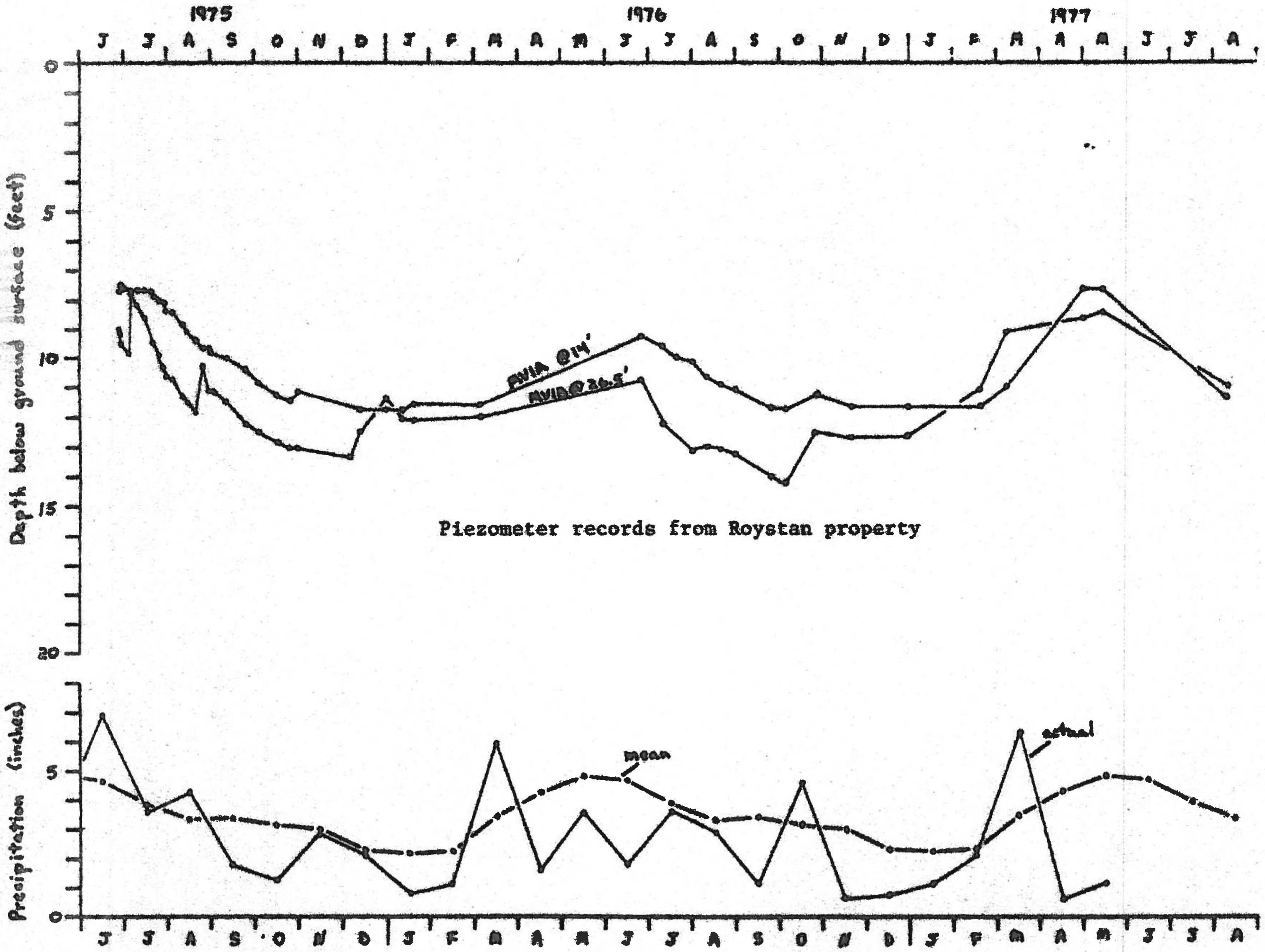


Figure 11. Piezometer and precipitation (Edwardsville station) records from Maryville, Illinois



Piezometer records from Roystan property

Figure 12. Piezometer and precipitation (Edwardsville station) records from Maryville, Illinois

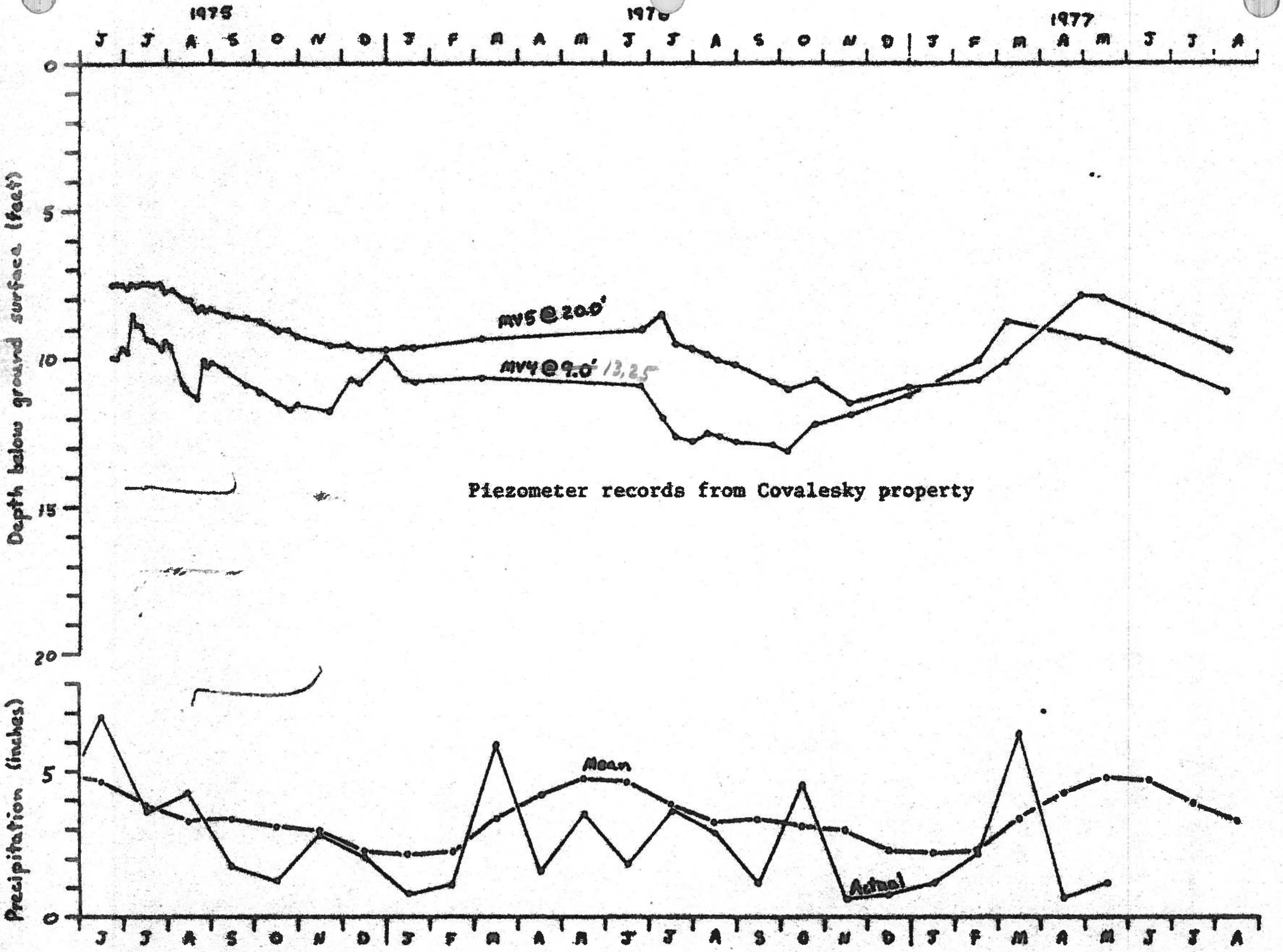


Figure 13. Piezometer and precipitation (Edwardsville station) records from Maryville, Illinois

or pillar collapse. With the mines now abandoned, several processes may affect the structure of the mines and thus change the stability of the mined-out areas. For example, an area may become stronger because of the filling of cracks by deposits, as occurs in natural caves, or an area may become less stable because of chemical changes resulting from a reaction of air or water with exposed rock. A failure in the mines may cause a sag at the surface or may bridge and stabilize in competent material over the mines. The characteristics and extent of failed rock may be directly affected by geology of the beds over a mined-out area. A rock sequence of relatively high strength, such as limestone, tends to break at a high angle toward the surface and affects small areas, whereas low-strength materials, such as claystone, tend to break at a low angle and affect a surface area that is larger than the failure area of the mine. Knowledge of the sequence of materials above the mined-out area is therefore essential to an understanding of subsidence patterns observed at the surface.

The thick layer of wind-blown silt (Peoria Loess and Roxana Silt) covers the project areas. A unique characteristic of loess is its ability to stand in near-vertical slopes, even though the silts within it have only small amounts of clay or other binding material. Loess is particularly sensitive to changes of water and weathering. An increase in moisture content results in a decrease in strength. Alteration of clays can result in a dramatic change in physical properties (W. A. White, 1968). Nearby steep valleys are prone to slump if disturbed. At a depth of a few feet, the loess units usually exhibit very low strengths.

Physical Properties of Surficial Materials

The test borings described earlier in this report were also utilized to obtain information about physical properties. The results of tests on surficial materials are shown in tables 2, 3, and 4.

Table 2. Physical properties of surficial materials from Survey test borings in Canterbury Manor, Belleville, Illinois

Rock-stratigraphic unit		Moisture content (%)[a]			Shear strength (kg/cm^2)[b]			Standard penetration (bpf)			Average grain size (%)		
		mean	n[c]	range	mean	n	range	mean	n	range	sand 2mm-62μ	silt 62-2μ	clay <2μ
Peoria Loess		25.3	20	15.2-31.7	1.1	18	0.5->4.5	10	10	5-20	0.9	80.0	19.1
Roxana Silt		23.9	25	20.8-26.9	1.1	31	0.25-2.25	10	17	4-19	2.6	74.0	23.4
Glasford Formation	Berry Clay M.	19.7	9	16.0-22.4	1.9	9	1.0-3.25	13	6	10-16	7.4	62.9	29.7
	Unnamed Till M.	16.4	19	13.6-23.4	1.7	19	0.25-2.80	24	13	9-50	22.6	53.2	24.2
Petersburg Silt		15.6	1	-	>4.5	1	-	35	1	-	0.5	84.0	15.5
Enion Formation		18.3	7	15.6-20.6	2.9	7	2.25-4.50	36	5	26-52	2.5	64.6	33.1
residuum		13.8	1	-	>4.5	1	-	63	1	-	19.7	41.6	38.7

[a] Standard moisture content (ASTM D2216-71)

[b] Standard field vane shear test (ASTM D2573-72)

[c] n is the number of test results used to compute the mean.

Table 3. Physical properties of surficial materials from Survey test borings in the 70th Street area, Belleville, Illinois

Rock-stratigraphic unit		Moisture content (%)[a]			Shear strength (kg/cm^2)[b]			Standard penetration (bpf)			Average grain size (%)		
		mean	n[c]	range	mean	n	range	mean	n	range	sand 2mm-62μ	silt 62-2μ	clay <2μ
Peoria Loess		25.6	5	23.8-27.0	1.5	5	1.1-2.75	8	4	6-9	Data not available		
Roxana Silt		26.1	8	22.5-28.3	1.2	8	0.6-2.80	6	5	5-7			
Glasford Formation	Berry Clay M.	24.4	2	24.2-24.6	2.0	2	1.55-2.40	8	1	-			
	Unnamed Till M.	17.0	7	11.8-20.9	2.1	7	0.25-4.40	9	4	5-17			
residuum		18.3	3	16.9-19.8	3.3	3	3.25-3.50	23	2	19-26			

[a] Standard moisture content (ASTM D2216-71)
[b] Standard field vane shear test (ASTM 2573-72)
[c] n is the number of test results used to compute the mean

Table 4. Physical properties of surficial materials from Survey test borings in Maryville, Illinois

Rock-stratigraphic unit	Moisture content (%)[a]			Shear strength (kg/cm^2)[b]			Standard penetration (bpf)			Average grain size (%)		
	mean	n[c]	range	mean	n	range	mean	n	range	sand 2mm-62μ	silt 62-2μ	clay <2μ
Peoria Loess	25.3	39	18.1-31.7	1.1	11	0.1-2.1	8	7	4-15	Data not available		
Roxana Silt	23.9	40	16.6-30.5	0.6	15	0.1-1.25	6	6	4-7			
Glasford Formation	16.5	28	11.8-23.6	1.7	23	0.8->4.5	13	9	5-25			
Banner Formation	17.4	22	12.9-21.8	3.6	20	1.5->4.5	24	7	13-42			
Enion Formation	20.6	14	17.7-25.3	2.7	13	1.4-3.75	24	4	11-52			
residuum	20.2	3	18.5-21.9	2.9	2	2.5-3.2	>100	1	-			

[a] Standard moisture content (ASTM D2216-71)
[b] Standard field vane shear test (ASTM D2573-72)
[c] n is the number of test results used to compute the mean.

The water content was determined by using standard techniques described by the American Society for Testing and Materials (ASTM D2216-71). In selected borings, a field vane shear test was made while the boring advanced to determine the in-place strength of the materials. This test conformed to ASTM standard test 2273-72. Comparison tests for strength were made on split-barrel samples using a calibrated field penetrometer.

Beginning with the field logging of core at Maryville, an index of strength of bedrock cores is shown by the Rock Quality Designation (RQD) method. RQD is defined as the percentage of core recovered in unbroken lengths greater than 4 inches. The classification is in part affected by the care of the operator. An estimate of the RQD of the Canterbury cores was made in the laboratory. A comparison was also made between field RQD and laboratory RQD to determine the effects of drying and stress-relief cracking of the core. An index of hardness of the core was determined by using a Shore-hardness testing instrument. Tests were performed on each lithologic unit, as shown in table 5, to determine an average index of hardness as well as the index range.

The core was examined to identify natural fractures, which are differentiated from coring-induced, handling, and stress-relief fractures by fractography techniques. The natural fractures and their angle of dip are given in table 5.

Field Instruments to Monitor Earth Movement

Movement of the ground may result from subsidence or from settlement of unstable soil materials. These movements are extremely difficult to measure; the time and place of their occurrence are unpredictable. Both deep and shallow settlement probes (fig. 14) were installed at locations shown on the maps for each area (figs. 4, 5, and 6). The deep probes were constructed by drilling a hole to the depth of firm material and casing the hole with plastic pipe. An inner galvanized steel pipe was driven or pushed 2 to 3 feet (.6 to .9 m) beyond

Table 5. Summary of strength properties of bedrock cores.

		Natural Fractures		Laboratory	Shore Hardness
Lithology	Thickness (ft)	Depth (ft)	Angle of dip (°)	RQD (%)	Index Range (mean)
Canterbury Manor JMA#1					
Shale-					5-8 (7)
Coal-	26.1	none		<10	17-27 (21)
Claystone					6-10 (8)
Limestone (Piasa)	5.2	107.0	60	>90	29-37 (34)
Claystone	6.8	111.0	70	10	6-9 (7)
		112.0	40		
		115.0	30		
Limestone (Bankston Fork)	14.5	none		>90	33-48 (41)
Siltstone	0.8	none		10	8-12 (11)
Limestone	7.6	133.0	80	>90	22-33 (27)
Limestone (Conant and Brereton)	4.5	144.0	60	60	17-24 (20)
Mine void	6.5				
Claystone	11.4	none		<10	3-6 (4)
Canterbury Manor JMA#2					
Shale-					7-9 (8)
Coal-	23.4	none		<10	
Claystone					5-28 (8)
Limestone (Piasa)	7.9	none		>90	27-38 (32)
Claystone	6.7	112.0	45	<10	3-10 (6)
Limestone (Bankston Fork)	26.8	none		>90	16-28 (21)
Siltstone-		none		<10	7-12 (7)
Limestone		none		>90	21-33 (27)
Siltstone		none		30	11-24 (16)
(2 Voids of 6" each @ 141' and 142')					

Table 5. Continued.

Lithology	Thickness (ft)	Natural Fractures Depth (ft)	Natural Fractures Angle of dip (°)	Laboratory RQD (%)	Shore Hardness Index Range (mean)
Limestone (Brereton)	4.8	none		30	6-28 (19)
Mine void	2.0				
Claystone	6.5	none		<10	4-10 (6)
Limestone (Higginsville)	11.7	none		>90	22-38 (30)
Shale	2.7	none		30	11-21 (15)
Canterbury Manor JMA#3					
Shale	11.3	none		< 5	6-8 (7)
Coal	0.2	none			10-22 (15)
Claystone	16.2	none		< 5	5-14 (8)
Limestone (Piasa)	8.2	110.5 115.0	10 40	>90	25-40 (31)
Claystone	6.0	118.2	15	< 5	4-8 (7)
Limestone (Bankstone Fork)	16.4			90	27-40 (32)
Siltstone	2.7			80	15-31 (22)
Limestone (Conant)	6.5	145.5	90	>90	20-35 (29)
Shale (Anna)	2.7	149.0(Slickensides)		50	17-24 (20)
Coal (Herrin No. 6)	7.8	153.5 156.0(Slickensides)	90	50	22-35 (27)
Claystone-limestone	3.5	158.0(Slickensides)		20	4-8 (6) 8-27 (17)

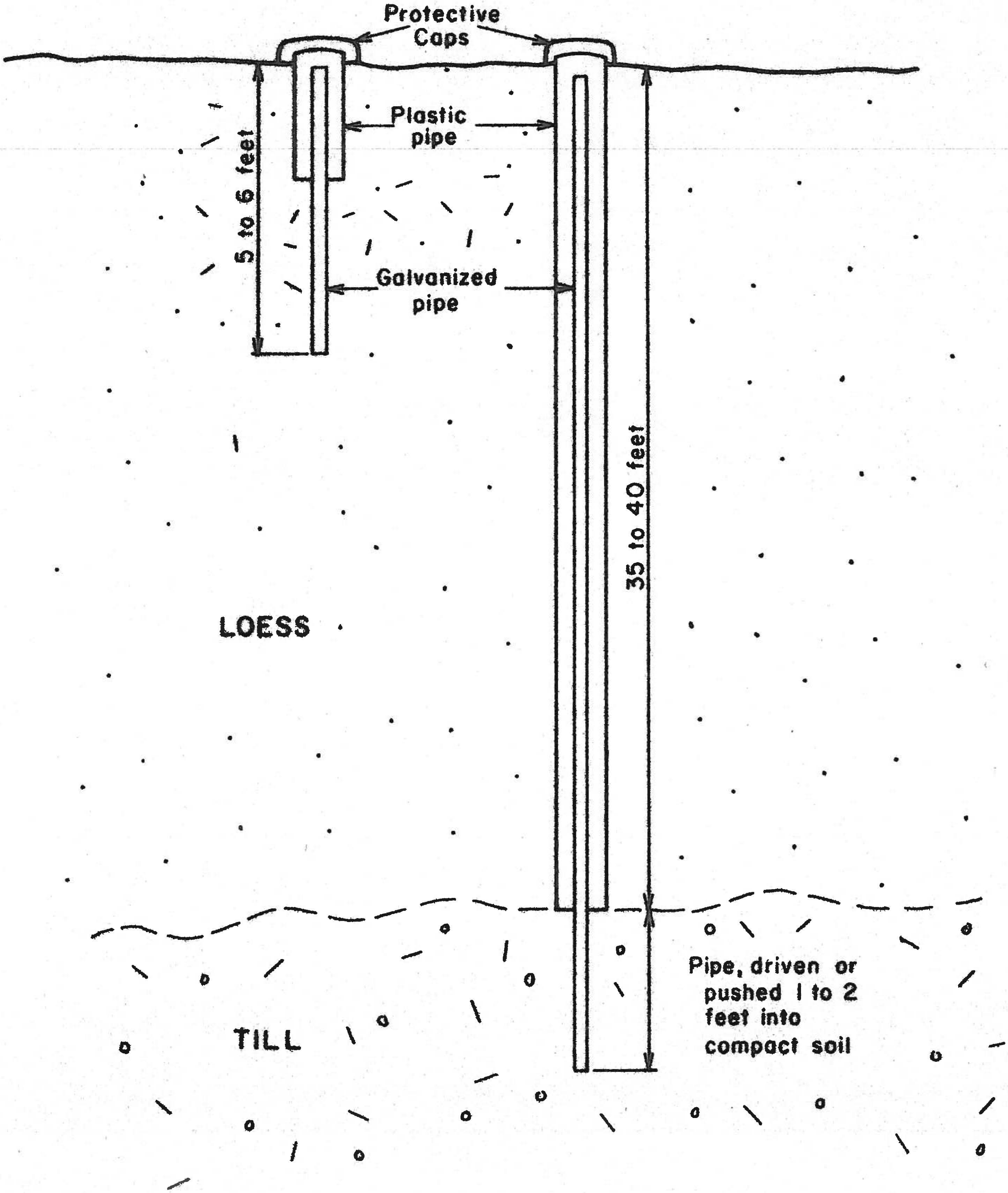


Figure 14. Deep settlement probe

the bottom of the hole. The inner pipe is designed to sit just below the ground surface and may be stabilized with soft oiled washers; the pipe rides free in the casing and reacts to any change in vertical movement of the lower soil. A shallow probe is constructed within a few feet of the deep probe to measure differences in elevations. Both borings are covered with a protective cap. These data would be much more meaningful if they could be combined with a precision survey of several monuments in each area.

The precise amount, rate, direction, and depth of earth movement can be determined from monitoring specially cased bore holes. The Survey has purchased an inclinometer to perform this kind of measurement. Borings will be made at selected sites in each area to install special casings (fig. 15). At the time of each survey, a sensor will be lowered down the casing and the deflection of the casing from earth movement will be measured. Computer programs have been written to process the raw data and graph the results.

ANALYSIS OF MATERIAL FROM THE ST. ELLEN AND KOENIG REFUSE BANKS

The U.S. Bureau of Mines selected two refuse banks as possible sources of backfill: the St. Ellen refuse bank in the N½ sec. 10, T. 2 N., R. 8 W., approximately 8 miles northeast of Canterbury Manor, and the Koenig refuse bank in the W½ sec. 10, T. 2 N., R. 8 W., approximately 10.5 miles north-northeast of Canterbury (fig. 1). The St. Ellen refuse bank is being processed for secondary coal recovery by the Minerals Management Corporation (MMC). MMC has offered to allow the Bureau to use reworked wastes for its backfill project. At the Koenig refuse bank, no such coal recovery operations are being conducted, and the refuse material is raw mine waste.

Samples of the St. Ellen refuse bank were collected from two types of reworked wastes. The first was waste removed in the initial stage of the coal recovery process. This waste was spread by earthmover in the area shown in

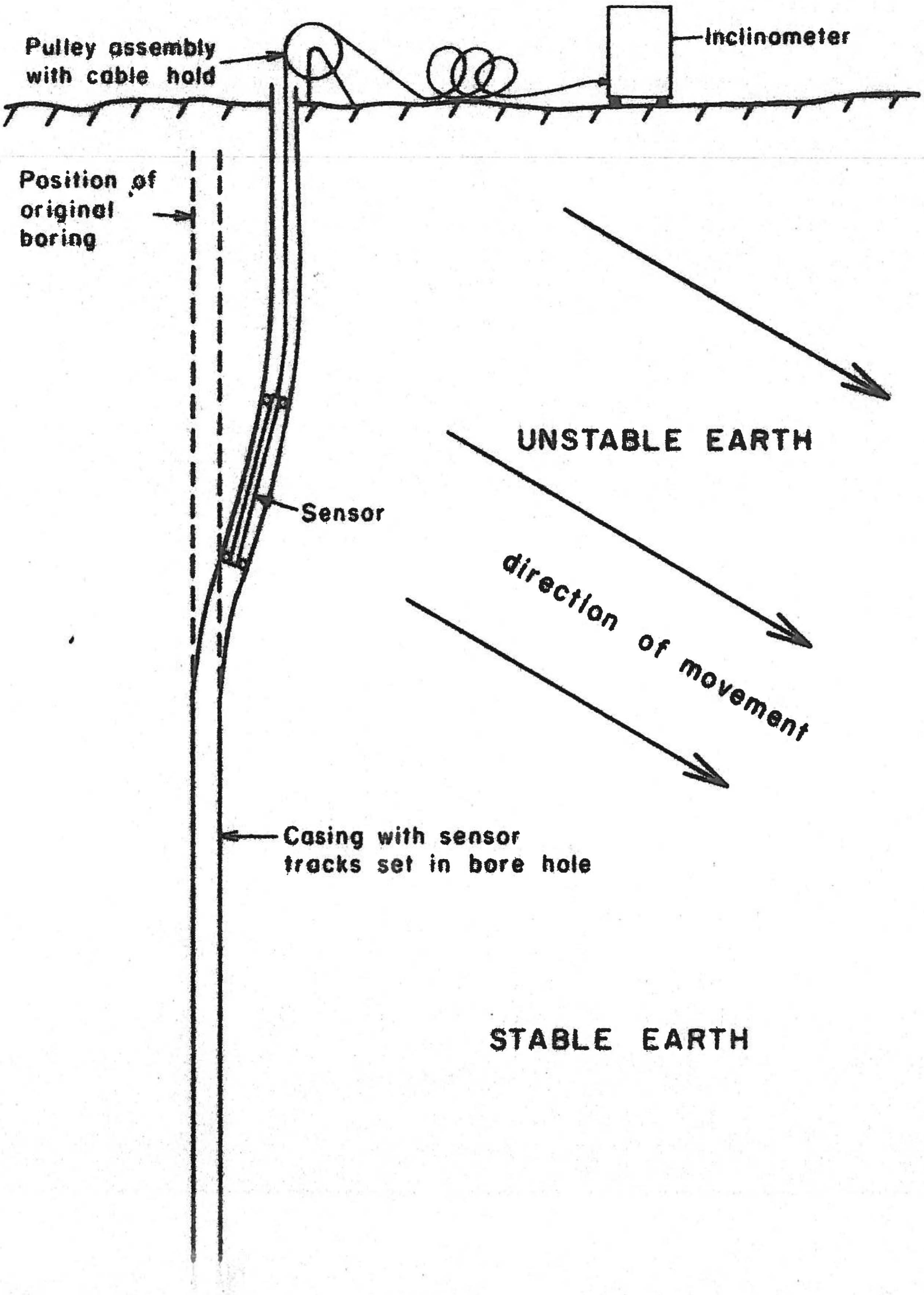


Figure 15. Inclinometer and inclinometer casing

figure 16. It is from this bank that the samples in bags 2 and 3 were taken. The second type of waste material at St. Ellen consists of a washed material from the final state of the coal recovery process. These washed wastes are deposited in slurry form in the adjacent settling canal (fig. 16). The filling of the canal with slurry requires continued dredging by backhoe. The dredge material is placed in banks beside the canal. Samples taken from these banks were combined in bag 1.

The waste material from the Koenig refuse bank was randomly sampled. The samples were taken from 1 to 2 feet (.3 to .6 m) below the surface of the banks in order to avoid the weathered and dried surface layers. The locations of subsamples of the Koenig Bank are shown in figure 17.

Laboratory analyses performed on samples from both the St. Ellen and Koenig refuse banks included determination of natural moisture content, particle-size analyses, and chemical analyses, including tests for both carbon and sulfur. Moisture contents were determined by standard methods and are expressed as percentages of dry weight in table 6.

Table 6. Moisture contents of refuse bank materials.

Refuse bank	Weight(g) Wet	Weight(g) Dry	Percentage moisture
St. Ellen (bag 1)	395.0	303	35
Koenig (bag 2)	400.0	346	18

All bag samples required drying before particle analysis, and each weighed about 30 kilograms after drying. Each sample was split to a weight of approximately 5 kilograms. After splitting, the samples were shaken and sieved for about 15 minutes. The results of the particle-size analyses are shown in table 7. Materials passing through sieve 4 required resplitting to about 200 grams. This material was then reshaken in smaller sieves on a Ro-Tap machine

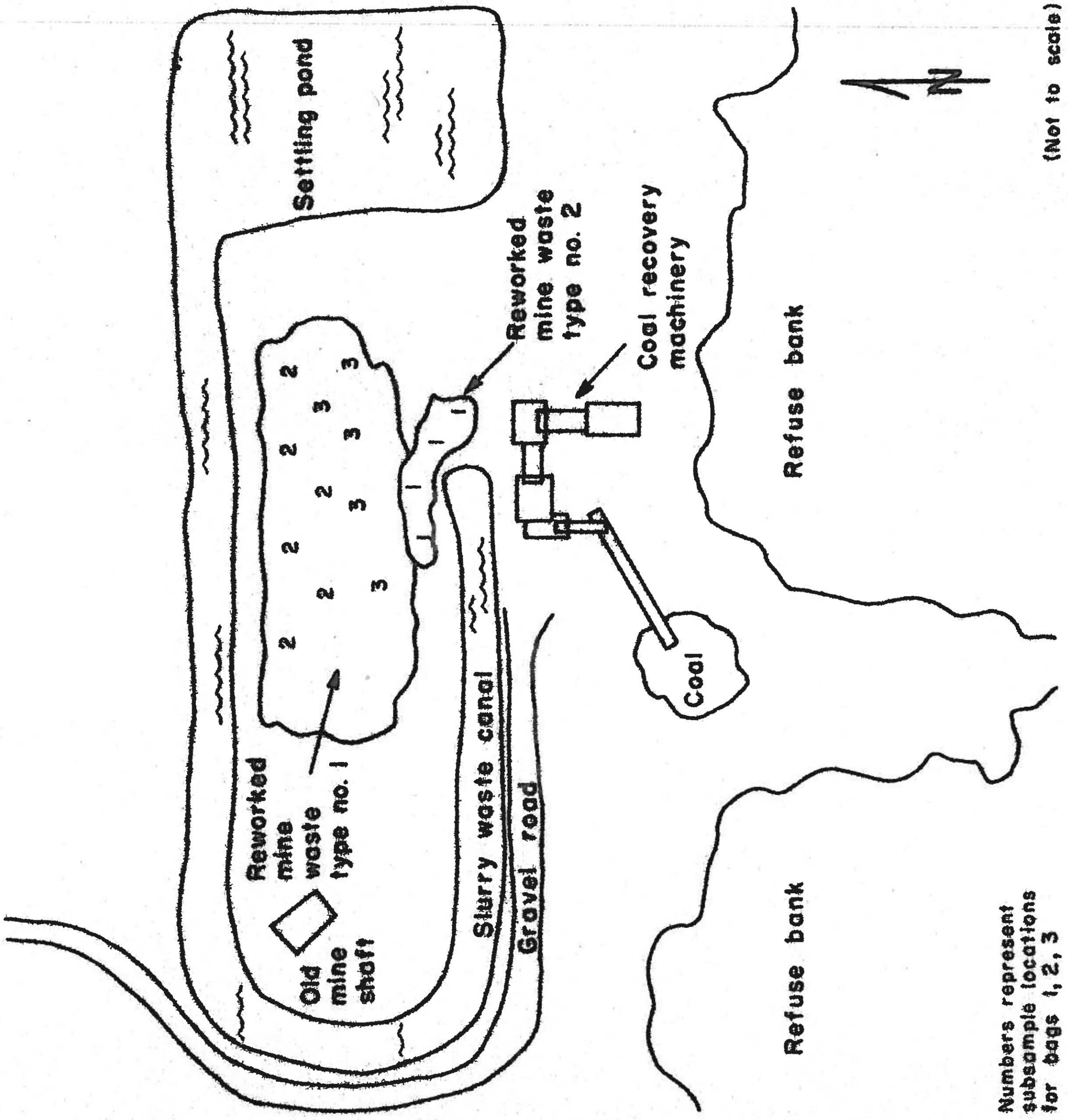


Figure 16. St. Ellen refuse bank, St. Clair County

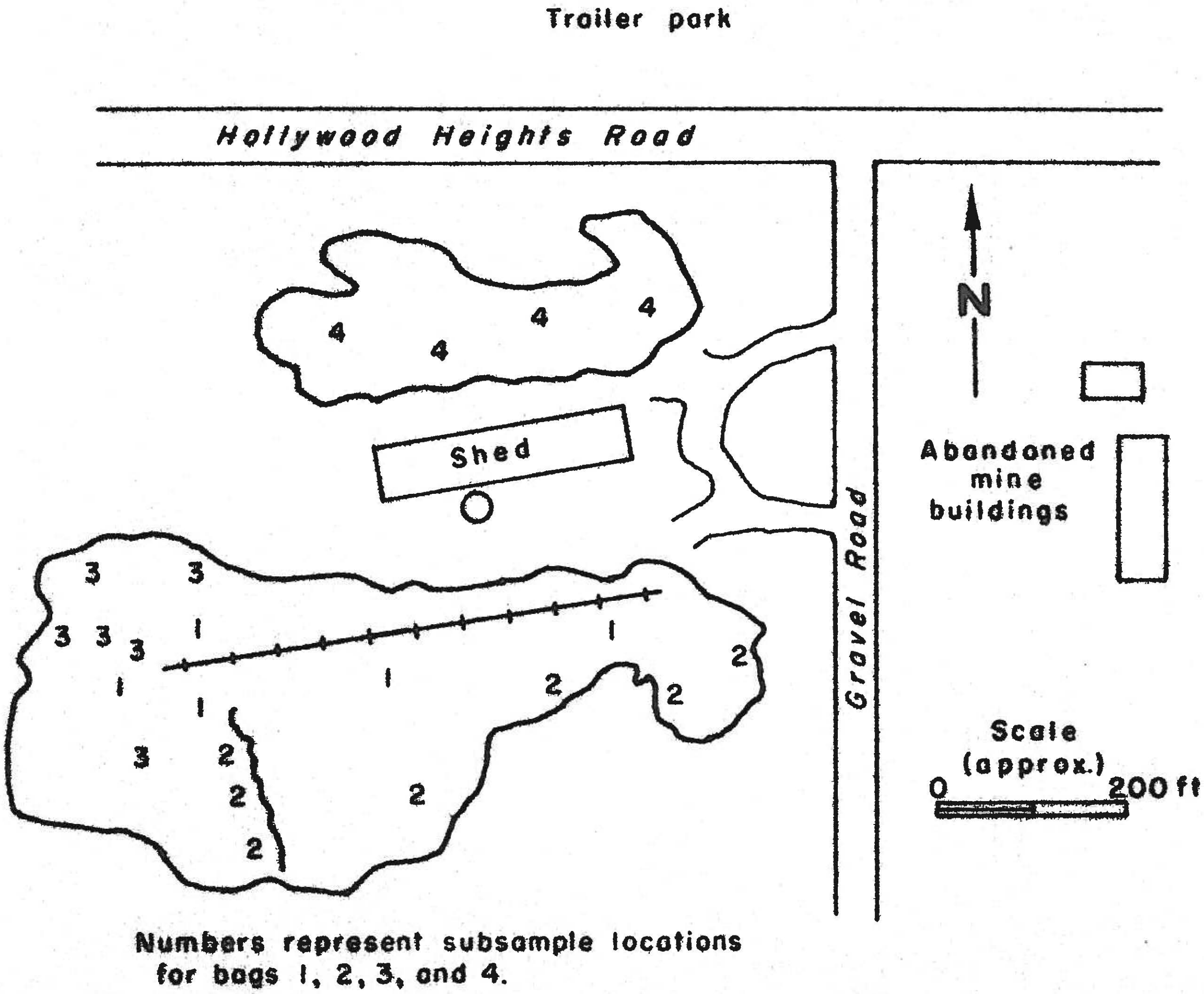


Figure 17. Koenig refuse bank, St. Clair County

Grain-size distribution of refuse[a]

Refuse Bank	Gravel 1 (2.54 mm)	 3/4 (19.1 mm)	 1/2 (12.7 mm)	 3/8 (9.52 mm)	Sand #4 (4.75 mm)	 #12 (1.68 mm)	 #18 (1.00 mm)	 #35 (0.50 mm)	 #60 (0.25 mm)	 #120 (0.125 mm)	 #230 (0.062 mm)	Silt (0.004 mm)	Clay (<0.004 mm)
St. Ellen													
Bag 1	2.1	1.2	2.4	9.4	13.8	5.0	9.7	18.7	17.5	9.8	4.1	5.7	0.6
Bag 2	18.4	9.4	12.3	8.6	16.2	12.7	5.3	5.1	3.5	2.0	1.2	5.2	0.1
Bag 3	3.1	3.8	7.4	8.8	35.0	16.6	7.8	6.5	4.3	3.0	1.3	2.2	0.2
Koenig													
Bag 1	0.7	1.6	2.9	4.3	13.2	19.5	12.7	14.6	11.9	7.9	4.3	5.7	0.7
Bag 2	0.4	0.9	4.2	7.1	15.8	29.9	15.4	13.0	6.9	3.1	1.3	1.4	0.6
Bag 3	0.0	1.4	3.3	4.6	19.1	21.2	12.3	12.5	10.0	5.7	3.1	5.7	1.1
Bag 4	1.8	3.4	5.8	7.4	20.8	21.9	11.8	10.8	7.2	4.1	2.0	2.2	0.8

[a] Percentage frequency by lower size limit or by U.S. Standard Sieve Number

for 15 minutes. Material smaller than .062 millimeters was subdivided into silt and clay fractions using the hydrometer method.

For chemical analyses, 100 grams of dry sample were split from the bulk bag sample and finely ground. The ground sample was resplit into 20-gram subsamples for total sulfur determination and into 10-gram subsamples for total organic and inorganic carbon determinations.

CONCLUSIONS

Test borings completed under contract by the Bureau encountered mine voids in each of the three project areas, and coal pillars were penetrated in the Canterbury Manor and 70th Street areas. The Herrin (No. 6) Coal seam measured 5.5 to 7.35 feet (1.7 to 2.2 m) thick in the area, and mine voids more than 5 feet (1.5 m) high were judged to be representative of the original mine opening. On this basis, two test borings in the 70th Street area of Belleville (borings JMA-4 and JMA-5) encountered full openings. The 10-foot (3.0 m) high void in boring JMA-5 probably resulted from overexcavation or roof fall during mining because rubble was not found in the mine floor. A 6.5-foot (2.0 m) void in Canterbury Manor (boring JMA-1) indicated a full opening; however, the void 2 feet (.6 m) high in boring JMA-2, which had two 6-inch (.15 m) voids immediately above it, indicates that partial collapse or squeeze of the mine has taken place. All three deep borings in the Maryville area penetrated partially collapsed or squeezed mine workings. The voids ranged in height from 1.3 to 3.5 feet (0.4 to 1.1 m).

The number of partially collapsed mine voids encountered in the project areas ranged from none in the 70th Street area to three in Maryville. This number may indicate that mine collapse is more widespread in Maryville than in the two Belleville sites; however, there is no assurance that this preliminary indication from three widely spaced borings is accurate. Only an inspection of the mines or additional test borings will determine the extent of mine collapse.

Conditions encountered by deep diamond drill holes in each of the three project areas indicate that the mine openings contain some methane and carbon dioxide. Detailed information is available from the Illinois Department of Mines and Minerals. Department personnel consider it feasible to ventilate the project area at Canterbury Manor to allow entry. Although water was not evident during drilling in any of the borings, the possibility that the mines may contain some water was not eliminated. Deep piezometers which will be installed beneath pillars in the two Belleville area sites (borings JMA-3 and JMA-6) should provide data which will allow assessment of ground-water conditions in the proximity of the mine voids. Geologic conditions, which may determine whether subsidence will occur and which affect the configuration of the settlement pattern, differ between project areas. Evaluation of available data suggests that the Maryville area may have geologic conditions more favorable for subsidence than the Belleville area. The Maryville area has an overburden of 220 feet (67 m) above the mine, which is thicker than the overburden of 146 feet (44.5 m) at 70th Street and 175 feet (53 m) at Canterbury Manor. Thickness of overburden is a significant factor in calculating the load that is carried by the mine pillars; the greater the overburden thickness, the greater the load. Of course, the percentage of coal mined and pillar size and shape are the primary determinants of the stresses to which coal pillars are subjected. These stresses and the ability of the coal pillar, mine floor or bottom, and mine roof to withstand them determine whether the potential for failure exists.

Borings show that the thickness of limestone in the mine roof at Maryville is 10 to 19 feet (3.0 to 5.8 m), which is less than the limestone thickness in Canterbury Manor or 70th Street, where limestone thicknesses are 28 to 29 feet (8.5 to 8.8 m) and 12 to 30 feet (3.7 to 9.1 m), respectively. Borings at Maryville also show a sequence of claystone in the mine bottoms that is thicker than that at the Belleville sites. At both Belleville sites, the mine bottoms contained moderately thick limestone beds, in contrast to the Maryville mine bottoms, where no limestone beds were recovered. The stability of pillars resting on these mine bottoms is affected by differences in the character and thickness of the claystones and the presence or absence of limestones. Entry into the mine areas may allow additional testing and better assessment of the importance of differences in the lithologies of the Belleville and Maryville mine bottoms.

Once failure occurs in the mine opening, the physical characteristics of the bedrock and surficial materials above the mine determine the configuration of the failure as it is propagated toward ground surface. In general low-strength materials above collapsed or squeezed areas of a mined-out area allow development of large angles that spread the settlement and thus affect large surface areas. Conversely, high strength materials in the overburden tend to decrease the size of the affected area at ground surface.

The larger proportion of limestone in Belleville may cause failure of the mines there to result in an angle of draw as the fractures propagate to the surface through the bedrock sequence that is slightly smaller than that in Maryville. Natural fractures could not definitely be credited to subsidence activity. Continued study of the strengths of the core compared with mine observations may confirm these suggestions.

The presence of weak surficial materials in a subsidence area could produce wide angles of draw enlarging the affected surface area. Shear strength measurements of surficial materials collected for this study indicate significant differences in strength of the surficial stratigraphic units. Lowest shear strength values were obtained from the Peoria Loess and Roxana Silt, the uppermost units in the three project areas. The lowest mean shear strength of any surficial unit studied was 0.6 tsf (0.6 kg/cm^2) measured in the Roxana Silt at Maryville. Low strength surficial materials, especially the Wisconsinan loesses, may be aggravating subsidence problems by increasing the angle of draw and the size of the affected area.

The Illinois State Geological Survey's study of geologic conditions affecting coal mine subsidence in southwestern Illinois is entering a phase in which the monitoring of installed instruments will be the primary field activity. Inclinometer casings and additional piezometers and settlement probes will be installed soon. Monitoring will be continued even after completion of filling operations.

Settlement probes and inclinometers installed by the Survey are designed to measure near-surface strains resulting from subsidence. The measurement of these strains is an essential step in defining the geometry of the area affected by subsidence; however, the value of these measurements is severely limited because of the lack of a surface survey network with which the measurements can be compared. We suggest a contract be let for a survey of the project areas by theodolite and electronic distance meter. Without this information, the subsidence area cannot be precisely determined and, more importantly, the effectiveness of pneumatic backfilling in controlling subsidence cannot be adequately assessed.

To insure a stable benchmark from which a surface survey can be established, the Survey is completing plans for an automatic, continuously recording device to measure elevation changes between ground surface and the mine bottom. Such a device could be installed in one of the large-diameter injection borings that encounters a pillar and cannot be used in the filling operation. The instrument will provide a continuous record of movements between the stable bottom of the mine and the potentially unstable ground surface. If movements are recorded, then deviations measured in the surface survey can be corrected to a stable datum.

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