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SITE CHARACTERISTICS OF ARGONNE NATIONAL LABORATORY IN ILLINOIS

by

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SITE CHARACTERISTICS OF ARGONNE NATIONAL LABORATORY IN ILLINOIS

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I. DESCRIPTION OF SITE

Argonne National Laboratory (ANL) is located near Lemont, in DuPage County, Ill., about 25 miles southwest of downtown Chicago. The latitude of the ANL site is 41° 42′ 03" N and longitude 87° 59′ 24" W. ANL is a direct outgrowth of the Manhattan Project and of the first self-sustaining nuclear reaction, which occurred at The University of Chicago in December 1942. ANL is operated by The University of Chicago for the U.S. Department of Energy (DOE) under Contract W-31-109-Eng-38. The laboratory and support facilities occupy about 1,200 acres of land. An additional 500 acres within the site perimeter are devoted to forest and landscaped areas. 2040 acres of land, surrounding the site in the form of a green belt, is the DuPage forest preserve, Waterfall Glen. The site in Illinois is usually denoted as Argonne-East, or ANL-E. It should be noted that ANL has another site in Idaho, which is called Argonne-West. The site characteristics of Argonne-West are not described in this report.

II. GEOLOGY

The geology of the ANL area consists of a deposit of glacial till between 90 to 120 ft of thickness on top of dolomite bedrock. The bedrock at ANL is the Niagaran and Alexandrian dolomite of Silurian age (about 400 million years old). These formations are underlain by the Maquoketa shale of Ordovician age, and older dolomites and sandstones of Ordovician and Cambrian age. The beds are nearly horizontal. The Niagaran and Alexandrian dolomites are about 200 ft thick in the ANL area.

Figure 1 shows the generalized areal geology of the bedrock surface in Illinois [1]. Figure 2 describes the stratigraphy of northeastern Illinois [2]. Note that the top of the Glenwood-St. Peter formations was chosen as a datum plane for this cross section. There are good theoretical reasons for believing that this surface at the time of deposition was as nearly a plane surface as ever existed in the area. Consequently, variations in the thickness of the formations can be shown much more clearly than if sea level datum had been used for the well logs. It should be noted that one could almost equally well have used the top of the Galena limestone as a datum plane; however, the top of the Maquoketa formation could not be used because the upper member has been completely eroded away in some cases and is replaced by Lower Silurian formations that are either absent or poorly developed where the complete formation is present.

There is one important complication in the stratigraphy of the region: all the strata older than the St. Peter sandstone underwent regional uplift and minor local folding, followed by extensive erosion before the St. Peter sandstone was deposited. Hence, the St. Peter sandstone varies greatly in thickness even within short distances; where it is thick one usually finds much or all of the Prairie du Chien group missing. In general, the strata thicken somewhat toward the south, but commonly where one layer is thicker than usual the overlying layer is thinner.

Almost nothing is known of the formations older than the upper part of the Mt. Simon sandstone; this is particularly true near the Argonne area. There is geophysical evidence that a downfaulted block of sandstone is present that may be older than Upper Cambrian.

It is known that the Pennsylvanian coal bearing strata must have extended over the area at one time; also, there is proof that Mississippian limestones were once present over the area. They have long ago been removed by erosion from the Chicago region except for some small downfaulted blocks near DesPlaines, Illinois.

Throughout most of northern Illinois and adjacent states, a moderately thick cover of glacial clay, sand and gravel masks the bedrock surface almost everywhere except along major streams or where wave action of Lake Chicago has uncovered ancient bedrock reefs. Throughout much of the area under consideration, Silurian bedrock of Niagaran age underlies the glacial drift. This is true throughout the Argonne site. The Silurian strata can be divided into several similar dolomite members that are difficult to identify without microscopic study or the use of fossils. These details are of little direct concern here. It is important to note that the top surface of the Niagaran strata has been eroded by both ancient rivers and by glacial ice and hence varies greatly in altitude within short distances. It is also important to note that the higher parts of this eroded surface are sometimes weathered sufficiently to weaken the rock considerably, especially when the rock is used as a footing for concentrated column or caisson loads.

During the Pleistocene epoch, glaciers deposited drift over most of Illinois. Arcuate-shaped moraines, roughly parallel to the shoreline of Lake Michigan, were formed in the Chicago area during the last glacial stage (the "Wisconsin" stage). Figure 3 shows the location of some of the more prominent moraines [3]. The younger moraines are generally closer to lake Michigan. ANL is on the "Keeneyville Moraine", which is part of the Valparaiso morainic system.

Figure 4 is a geologic cross section through the Chicago region near ANL [4]. It shows that the Valparaiso morainic system is composed of a younger "Cary drift" (referred to as the Wadsworth or Yorkville till member in recent publications) overlying an older "Lemont drift", a dense and very tough, sandy and silty glacial deposit. The younger drift above this layer is also tough and hard. Both till units are believed to be part of the Wedron Formation, the till deposited during the Woodfordian substage (late Wisconsin). The Woodfordian substage occurred about 22,000 to 28,000 years ago. The Wadsworth till member is a gray clayey till, whereas the Lemont drift is a silty till that intertongues with and grades upward into sand and gravel.

The Argonne deep well No. 1, drilled to a depth of 1595 ft, reveals stone formations of the bedrock. Figure 5 is the cross section of bedrock at the site [5]. From cores taken at the CP-5 reactor site, the AARR site, the Building 315 site, and the APS site [6-9], it confirmed that the top layer of bedrock at the ANL site is composed of hard, fine-grained, gray Niagarian dolomite with slightly weathered to sound conditions.

The southern boundary of ANL follows the escarpment of a broad valley, now occupied by the DesPlaines River and the Chicago Sanitary and Ship Canal. This valley was carved by waters flowing out of the Pleistocene-Holocene Lake Michigan (called "Lake Chicago"). The valley was eroded across the moraines, and was cut down about 100 ft to bedrock (see Fig. 4). The valley (the "Chicago Outlet") was carved during the period of about 14,000 to 11,000 years ago, and probably had some outflow again from about 4,000 to 2,000 years ago.

III. TOPOGRAPHY

The topography of the vicinity in general is flat to slightly hilly, with an elevation of between 700 and 750 feet above sea level for the major portion of the Argonne site. The land extending roughly 1-1/2 miles north to south and 2 miles east to west has an elevation in this same range, and drops slowly toward the southwest. An intermittent stream, Sawmill Creek, crosses Argonne and empties into the Des Plaines River, near the southern edge of the site. The normal level of the Des Plaines River adjacent to Argonne is 583 feet about sea level. Outcroppings of the Niagaran dolomite may be seen between the river and the site on the bluffs overlooking the Des Plaines valley. From these bluffs, approximately 650 feet above sea level, the land slopes gradually upward to the site.

IV. SOIL CONDITIONS

ANL performed many subsurface explorations during the construction of laboratory buildings and facilities. However, the purpose of those subsurface explorations was to determine the soil bearing capacity so that the foundations could be properly designed and safely supported by the underlying soil. Thus, most of the soil boring holes were driven down only to a depth of 40 or 60 ft from the ground surface. However, in the case of important facilities, such as Buildings 364 and 365 (the center and ring buildings of the Zero Gradient Synchrotron), the CP-5, AARR, ZPR, and APS projects, some soil boring holes of those projects did go down to bedrock. Thus, the soil properties from the ground surface to bedrock at the ANL site were studied extensively.

Reviewing the soil profiles of previous explorations, the soils at the ANL site can be considered as consisting of the following materials:

1. Topsoil - A relatively thin layer of topsoil was observed at the surface of the majority of the boring holes. The silty or clayey topsoil deposits had a thickness ranging from 0.5 ft to 2 ft. The dry density of topsoil is 119 pcf.

2. Weathered till - The weathered till deposits consisted primarily of brown to brown and gray silty clay soils with pebbles and cobbles. The weathered till deposits are distinguished from unweathered till deposits by their brownish color which is an indication of past partial desiccation and oxidation. This desiccated upper portion of the till deposit generally exhibits higher strengths than the underlying unweathered till. These cohesive soils generally exhibited water contents of 15% to 20% with unconfined compressive strengths generally in excess of 3.0 tsf. The thickness of the weathered till is about 10 ft at the ANL site. The dry density of weathered till is 125 pcf.

3. Unweathered till - The unweathered till portion of the glacial till consists primarily of gray silty clay deposits with varying amounts of gravel, sand, and shale. The depth to the unweathered till varies with the surface topography and with the long-term groundwater table, but is generally encountered at a depth of 12 to 20 ft below the existing ground surface. The moisture content within the unweathered till was generally on the order of 15% to 20%. The estimated unconfined compressive strengths and laboratory unconfined compressive strengths within this material were generally in excess of 3.0 tsf. The thickness of the unweathered till is about 50 ft. The dry density of the unweathered till is 126 pcf.

4. Outwash - Within the unweathered till soils, relatively thin layers and/or lenses of outwash ranging from about 1 ft to 5 ft in thickness were encountered. These deposits consist of terminating lenses of granular material and are not necessarily continuous between borings.

5. Lemont Drift - The Lemont drift lies below the unweathered till. The elevation of the top of this deposit ranges from about 45 to 60 ft below the existing ground surface. This deposit is characterized by dense to extremely dense fine-grained saturated granular soils, consisting of fine sand, silt and silt sand mixtures, with occasional interbedded layers of hard cohesive soils. The average thickness of the Lemont drift at the ANL site is about 60 ft.

6. Bedrock - Below the Lemont drift underlies the bedrock. The elevation of the bedrock surface varies. It ranges from 613 to 646 USGS at APS site, from 609 to 616 USGS at AARR site and from 626 to 631 USGS at Zero Gradient Synchrotron site. At other building sites, because of the shallowness of the bore holes, the elevations of the bedrock were not determined. However, at locations of the five ANL wells, the elevations of the bedrock surface were known. They ranged from 600 to 630 USGS. Figure 6 is a geologic cross section through these wells [10]. The locations of these wells, together with laboratory buildings and facilities, are shown in Fig. 7.

   The compositions of bedrock at the ANL site are mostly dolomatic limestone, dolomite, and limestone. Dolomite is generally formed from limestone when the calcite (calcium carbonate, $CaCO_3$) in the limestone is replaced by calcium magnesium carbonate volume for volume. This process, known as dolomitization, may occur either soon after limestone deposition by exchange with sea water or after lithification by exchange with magnesium-bearing solutions. It should be noted that dolomitization is very selective. It often produced interbedded limestone and dolomite during the process. The geologists and engineers in the ANL subsurface explorations identified the bedrock material at the APS site as dolomite limestone, at the AARR, CP-5 and ZPR sites as dolomite, and at the Zero Gradient Synchrotron site as limestone. If their identifications for bedrock material are correct, then the bedrock at the ANL site is indeed interbedded with limestone and dolomite. However, for the purpose of this study, we assume that the bedrock at ANL consists of only dolomite.

In summary, it can be reasonably assured that the profiles of soils and bedrocks at the ANL site consist of the following materials:

Type of Material	Thickness
Topsoil	2′
Weathered till	10′
Unweathered till	50′
Lemont drift	60′
Dolomite-Niagran	100′
Dolomite-Alexandrian	100′
Shale-Maquoketa	165′
Dolomite-Galena and Plattville, and Limestone-Formations	340′
Sandstone-Glenwood and St. Peter Series	500′
Sandstone-Franconia and Galesville Formations	250′

V. SEISMIC WAVE VELOCITIES

The values of seismic wave velocities of the glacial till are important in the seismic hazard analysis because they determine the amplification factor of the seismic excitations when seismic waves propagate through the soil to free surface. During the subsurface explorations, the shear wave velocities of the glacial till at the ANL site were determined. However, they were obtained from the soil samples under laboratory conditions. Thus, they are not the crosshole seismic wave velocities which are used for analyzing the amplification factor of the seismic excitations.

Only recently, during the subsurface exploration of the APS project, were crosshole seismic tests performed. These tests were performed at boreholes APS-1, -2, -3, APS-4, -5, -6, APS-7, -8, -9, and APS-10, -11, -12. The locations of these crossholes are shown in Fig. 8, together with the other 16 boreholes.

The crosshole tests are in-situ tests for measuring, at different depths, the shear and compression wave velocities of soil between two or more closely spaced boreholes. This method consists of a source hole or shot hole and two receiving or detecting holes, all colinear. Body waves are generated in the source boring and their arrivals are recorded at the adjacent detector borings. The wave velocities are computed knowing the distance between the source and detector boreholes and detector boreholes and the times of arrival. The distance between the crossholes is shown in Fig. 9. The test results of P- and S-waves are given in Tables I-IV.

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10. ANL-E Environmental Impact Statement dated March 9, 1979.

Table I. Summary of Crosshole Seismic Test Results, Argonne National Laboratory - Advanced Photon Source, Location: APS 1, 2, 3

Depth(ft)	VELOCITY(FT/SEC) P	S	SOIL DENSITY (LBS/FT3)	G (PSF)	E (PSF)	V	Depth(ft)
5	3590	1026	139.4	4.56e+06	1.33e+07	0.456	5
10	5140	1028	138.2	4.53e+06	1.34e+07	0.479	10
15	4827	1159	142.3	5.93e+06	1.74e+07	0.469	15
20	4176	1218	155.9	7.18e+06	2.09e+07	0.454	20
25	4923	1343	152.7	8.55e+06	2.50e+07	0.460	25
30	5756	1386	149.5	8.92e+06	2.62e+07	0.469	30
35	5015	1368	146.3	8.50e+06	2.48e+07	0.460	35
40	5832	1404	133.5	8.17e+06	2.40e+07	0.469	40
45	5458	1428	138.3	8.76e+06	2.56e+07	0.463	45
50	6168	1285	146.9	7.53e+06	2.23e+07	0.477	50
55	5560	1441	134.4	8.67e+06	2.54e+07	0.464	55
60	6272	1668	164.4	1.42e+07	4.15e+07	0.462	60

BOREHOLE DISTANCE, SOIL DENSITY AND VELOCITY CALCULATIONS

RECEIVER HOLE SEPARATION DIST(FT): 14.42

DEPTH (FT)	REC'VER HOLE DIST CORRECTION(IN) HOLE # 2 X1	Y1	HOLE # 3 X2	Y2	NET DIST (FT)	DRY DENSTY	H20 CONT %	WET SOIL DENSTY (PCF)	PRESSURE/SHEAR WAVE ARRIVAL TIMES (MSEC) P0	P1	S0	S1
5	0.30	-0.35	-0.39	-0.96	14.36	120.5	15.7	139.4	4.0	8.0	14.0	28.0
10	0.46	-0.74	0.15	-2.30	14.39	119.0	16.1	138.2	3.2	6.0	11.5	25.5
15	0.50	-1.46	1.27	-3.60	14.48	121.5	17.1	142.3	3.0	6.0	12.0	24.5
20	0.62	-2.20	2.89	4.83	14.62	136.0	14.6	155.9	4.0	7.5	9.0	21.0
25	0.29	-2.80	4.48	-6.39	14.77	132.7	15.0	152.7	4.0	7.0	6.5	17.5
30	-0.40	-3.59	6.12	-8.68	14.97	129.5	15.5	149.5	3.9	6.5	11.0	21.8
35	-0.84	-3.89	6.62	-9.62	15.05	126.2	15.9	146.3	4.0	7.0	12.0	23.0
40	-1.47	-4.22	7.37	-11.13	15.16	115.1	16.0	133.5	4.6	7.2	10.7	21.5
45	-1.71	-4.14	8.46	-12.66	15.28	117.2	18.0	138.3	5.0	7.8	10.3	21.0
50	-1.94	-3.66	9.78	-14.31	15.42	128.4	14.4	146.9	5.0	7.5	9.0	21.0
55	-2.09	-2.74	11.24	-16.09	15.57	113.8	18.1	134.4	5.0	7.8	11.0	21.8
60	-2.01	-1.72	12.48	-17.68	15.68	142.3	15.5	164.4	5.5	8.0	11.1	20.5

G = DYNAMIC SHEAR MODULUS
E = YOUNG'S MODULUS
V = POISSON'S RATIO

Table II. Summary of Crosshole Seismic Test Results, Argonne National Laboratory - Advanced Photon Source, Location: APS 4, 5, 6

Depth(ft)	VELOCITY(FT/SEC) P	S	SOIL DENSITY (LBS/FT3)	G (PSF)	E (PSF)	V	Depth(ft)
5	4838	932	141.8	3.82e+06	1.13e+07	0.481	5
10	5370	1253	143.1	6.98e+06	2.05e+07	0.471	10
15	5485	1242	143.8	6.88e+06	2.03e+07	0.473	15
20	6051	1116	143.4	5.55e+06	1.65e+07	0.482	20
25	7598	1504	143.5	1.01e+07	2.98e+07	0.480	25
30	5557	1679	144.3	1.26e+07	3.67e+07	0.450	30
35	5213	1768	143.6	1.39e+07	4.00e+07	0.435	35
40	5946	1569	141.4	1.08e+07	3.16e+07	0.463	40
45	5554	1709	137.6	1.25e+07	3.61e+07	0.448	45
50	6816	1752	141.3	1.35e+07	3.94e+07	0.465	50
55	5445	1680	146.8	1.29e+07	3.72e+07	0.447	55
60	6321	1756	146.8	1.41e+07	4.10e+07	0.458	60

BOREHOLE DISTANCE, SOIL DENSITY AND VELOCITY CALCULATIONS

RECEIVER HOLE SEPARATION DIST(FT): 14.96

DEPTH (FT)	REC'VER HOLE DIST CORRECTION(IN) HOLE # 5 X1	Y1	HOLE # 6 X2	Y2	NET DIST (FT)	DRY DENSTY	H2O CONT %	WET SOIL DENSTY (PCF)	PRESSURE/SHEAR WAVE ARRIVAL TIMES (MSEC) P0	P1	S0	S1
5	0.02	-0.49	0.47	-1.05	15.00	123.1	15.2	141.8	5.4	8.5	14.9	31.0
10	0.02	-1.68	0.93	-2.21	15.04	122.7	16.6	143.1	3.0	5.8	10.3	22.3
15	0.05	-3.59	1.55	-3.57	15.09	131.7	9.2	143.8	3.1	5.9	10.6	22.7
20	0.09	-5.35	2.10	-5.04	15.13	125.6	14.2	143.4	2.9	5.4	11.0	24.5
25	-0.20	-6.87	2.62	-6.44	15.20	125.3	14.5	143.5	3.9	5.9	10.8	20.9
30	-0.46	-7.93	3.41	-7.69	15.28	128.3	12.5	144.3	4.0	6.8	9.2	18.3
35	-0.56	-9.04	4.45	-8.65	15.38	125.1	14.8	143.6	4.3	7.2	10.8	19.5
40	-0.56	-10.33	5.42	-9.37	15.46	123.4	14.6	141.4	4.3	6.9	9.9	19.7
45	-0.70	-11.65	6.40	-10.09	15.55	123.0	11.9	137.6	4.6	7.4	10.1	19.2
50	-1.07	-13.08	7.53	-11.08	15.68	124.6	13.4	141.3	5.6	7.9	10.4	19.4
55	-1.18	-14.70	8.78	-12.33	15.79	131.2	11.9	146.8	5.5	8.4	11.4	20.8
60	-0.80	-16.54	9.28	-13.65	15.80	131.2	11.9	146.8	5.5	8.0	10.5	19.5

G = DYNAMIC SHEAR MODULUS
E = YOUNG'S MODULUS
V = POISSON'S RATIO

Table III. Summary of Crosshole Seismic Test Results, Argonne National Laboratory - Advanced Photon Source, Location: APS 7, 8, 9

Depth(ft)	VELOCITY(FT/SEC) P	S	SOIL DENSITY (LBS/FT3)	G (PSF)	E (PSF)	V	Depth(ft)
5	3402	855	140.3	3.19e+06	9.34e+06	0.466	5
10	5891	988	140.5	4.26e+06	1.27e+07	0.486	10
15	5872	1037	143.8	4.80e+06	1.43e+07	0.484	15
20	5732	1228	140.6	6.59e+06	1.95e+07	0.476	20
25	4874	1490	139.4	9.61e+06	2.79e+07	0.448	25
30	5080	2059	138.1	1.82e+07	5.10e+07	0.402	30
35	6594	1517	141.4	1.01e+07	2.97e+07	0.472	35
40	7020	1410	141.6	8.75e+06	2.59e+07	0.479	40
45	6271	1490	131.9	9.10e+06	2.67e+07	0.470	45
50	4563	1394	122.0	7.36e+06	2.13e+07	0.449	50
55	6706	1605	147.1	1.18e+07	3.46e+07	0.470	55
60	6160	1935	138.6	1.61e+07	4.66e+07	0.445	60

BOREHOLE DISTANCE, SOIL DENSITY AND VELOCITY CALCULATIONS

RECEIVER HOLE SEPARATION DIST(FT): 15.73

DEPTH (FT)	REC'VER HOLE DIST CORRECTION(IN) HOLE # 8 X1	Y1	HOLE # 9 X2	Y2	NET DIST (FT)	DRY DENSTY	H2O CONT %	WET SOIL DENSTY (PCF)	PRESSURE/SHEAR WAVE ARRIVAL TIMES (MSEC) P0	P1	S0	S1
5	0.02	0.85	-0.96	-0.33	15.65	120.0	16.9	140.3	5.8	10.4	17.2	35.5
10	-0.20	1.56	-1.62	-0.47	15.61	123.7	13.6	140.5	3.9	6.5	12.3	28.1
15	-0.43	1.86	-2.47	-0.92	15.56	126.0	14.1	143.8	3.0	5.6	8.5	23.5
20	-0.39	2.09	-3.44	-1.22	15.48	120.1	17.1	140.6	2.9	5.6	11.9	24.5
25	-0.13	2.84	-4.72	-1.88	15.35	121.5	14.7	139.4	3.8	6.9	13.2	23.5
30	-0.10	3.84	-6.10	-2.62	15.24	123.1	12.2	138.1	4.0	7.0	9.1	16.5
35	-0.45	4.82	-7.38	-3.36	15.17	123.6	14.4	141.4	4.3	6.6	10.5	20.5
40	-0.86	5.65	-8.77	-4.19	15.09	123.9	14.3	141.6	4.4	6.5	10.5	21.2
45	-1.47	6.17	-9.96	-4.99	15.05	114.9	14.8	131.9	4.7	7.1	10.6	20.7
50	-2.22	6.49	-10.70	-5.68	15.06	105.6	15.5	122.0	5.4	8.7	11.3	22.1
55	-2.99	7.59	-11.20	-6.30	15.09	126.6	16.2	147.1	5.9	8.2	11.9	21.3
60	-3.34	9.35	-11.67	-6.43	15.09	121.6	14.0	138.6	5.8	8.2	12.2	20.0

G = DYNAMIC SHEAR MODULUS
E = YOUNG'S MODULUS
V = POISSON'S RATIO

Table IV. Summary of Crosshole Seismic Test Results, Argonne National Laboratory - Advanced Photon Source, Location: APS 10, 11, 12

Depth(ft)	VELOCITY(FT/SEC) P	S	SOIL DENSITY (LBS/FT3)	G (PSF)	E (PSF)	V	Depth(ft)
5	2461	718	137.7	2.21e+06	6.41e+06	0.453	5
10	4675	907	141.3	3.61e+06	1.07e+07	0.480	10
15	3648	1092	143.4	5.31e+06	1.54e+07	0.451	15
20	4671	1068	148.6	5.26e+06	1.55e+07	0.472	20
25	6178	1246	146.9	7.08e+06	2.09e+07	0.479	25
30	5649	1596	139.8	1.11e+07	3.22e+07	0.457	30
35	6362	1393	133.9	8.07e+06	2.38e+07	0.475	35
40	6236	1559	128.7	9.72e+06	2.85e+07	0.467	40
45	5557	1169	143.0	6.06e+06	1.79e+07	0.477	45
50	6139	1551	130.5	9.75e+06	2.86e+07	0.466	50
55	6372	1647	146.8	1.24e+07	3.62e+07	0.464	55
60	6573	1404	158.2	9.68e+06	2.86e+07	0.476	60

BOREHOLE DISTANCE, SOIL DENSITY AND VELOCITY CALCULATIONS

RECEIVER HOLE SEPARATION DIST(FT): 15.00

DEPTH (FT)	REC'VER HOLE DIST CORRECTION(IN) HOLE # 11 X1	Y1	HOLE # 12 X2	Y2	NET DIST (FT)	DRY DENSTY	H20 CONT %	WET SOIL DENSTY (PCF)	PRESSURE/SHEAR WAVE ARRIVAL TIMES (MSEC) P0	P1	S0	S1
5	-1.54	-0.72	-1.42	0.58	15.01	119.0	15.7	137.7	6.6	12.7	16.2	37.1
10	-2.12	-0.69	-2.59	1.12	14.96	121.8	16.0	141.3	5.4	8.6	11.3	27.8
15	-2.91	-0.42	-3.44	2.02	14.96	127.0	12.9	143.4	3.5	7.6	11.3	25.0
20	-3.57	-0.41	-4.23	3.01	14.95	130.0	14.3	148.6	3.8	7.0	11.0	25.0
25	-3.34	-0.89	-5.49	4.07	14.83	130.2	12.8	146.9	4.0	6.4	10.5	22.4
30	-3.25	-1.03	-7.11	5.29	14.69	119.5	17.0	139.8	3.9	6.5	11.0	20.2
35	-4.32	-0.93	-8.90	6.43	14.63	116.5	14.9	133.9	4.1	6.4	9.2	19.7
40	-6.23	-1.17	-10.58	7.45	14.66	114.0	12.9	128.7	4.2	6.5	9.4	18.8
45	-8.47	-1.62	-12.04	8.23	14.72	128.9	10.9	143.0	4.5	7.2	7.2	19.8
50	-9.83	-1.80	-13.35	8.74	14.73	110.6	18.0	130.5	4.9	7.3	10.0	19.5
55	-10.54	-1.37	-14.94	8.50	14.66	130.3	12.7	146.8	5.0	7.3	9.7	18.6
60	-10.39	-1.11	-17.09	7.61	14.46	134.8	17.4	158.2	5.8	8.0	10.0	20.3

G = DYNAMIC SHEAR MODULUS
E = YOUNG'S MODULUS
V = POISSON'S RATIO

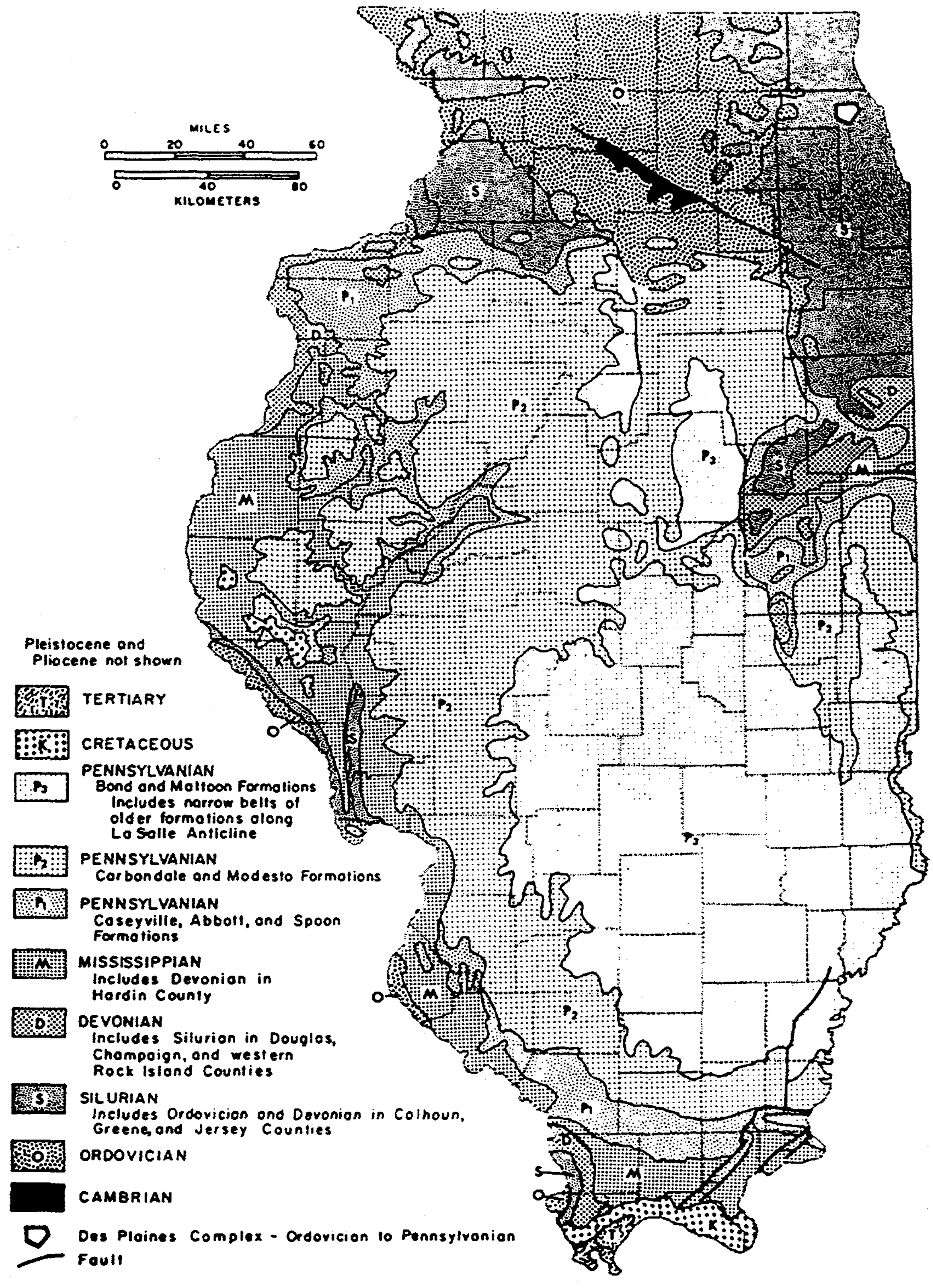


Fig. 1. Generalized Bedrock Geologic Map of Illinois

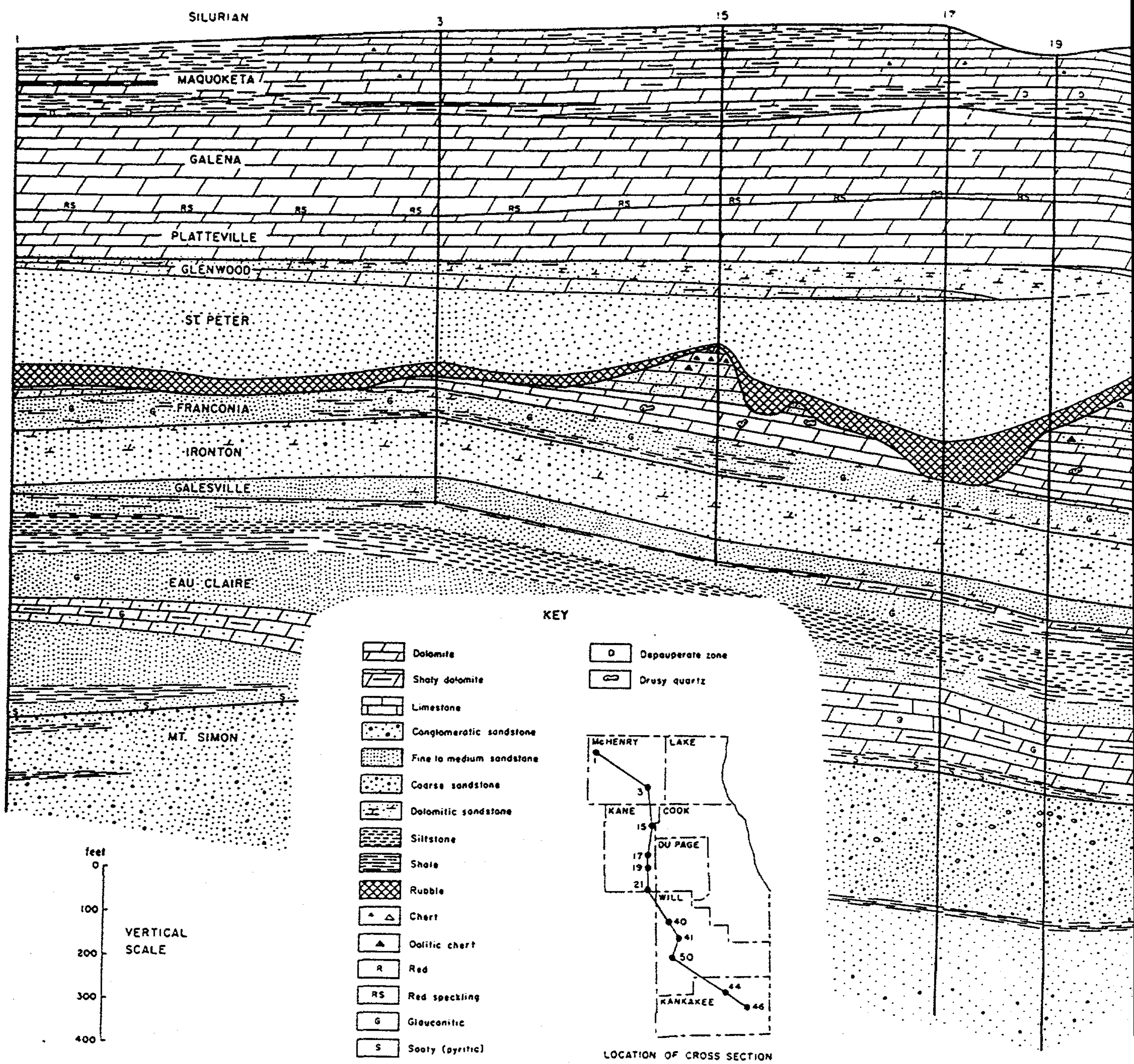
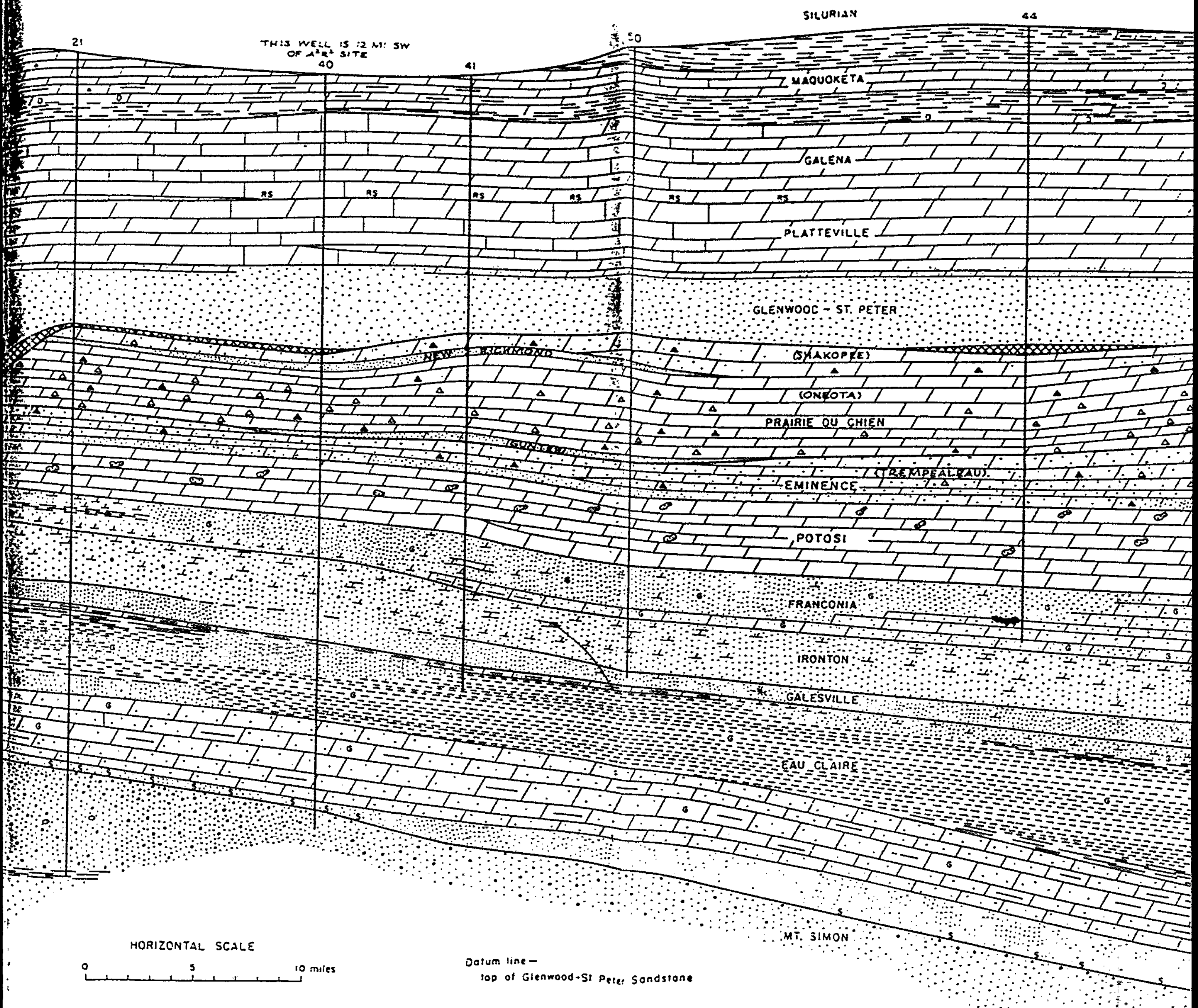


Fig. 2. CROSS SECTION OF CAMBRIAN AND ORDOVIC



AN FORMATIONS THROUGH NORTHEASTERN ILLINOIS

C. Buschbach

1959

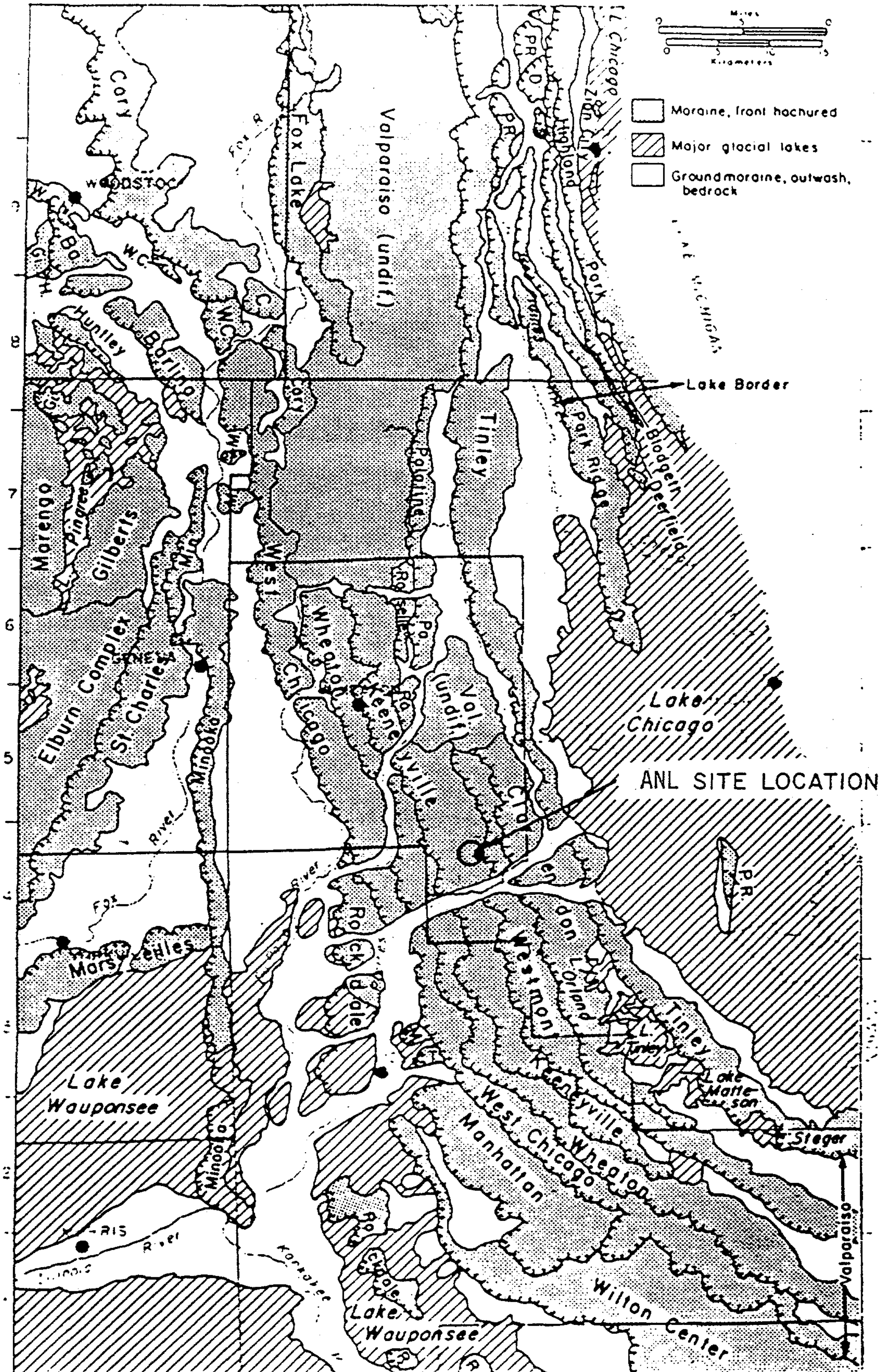


Fig. 3. Glacial Geology of Northeastern Illinois

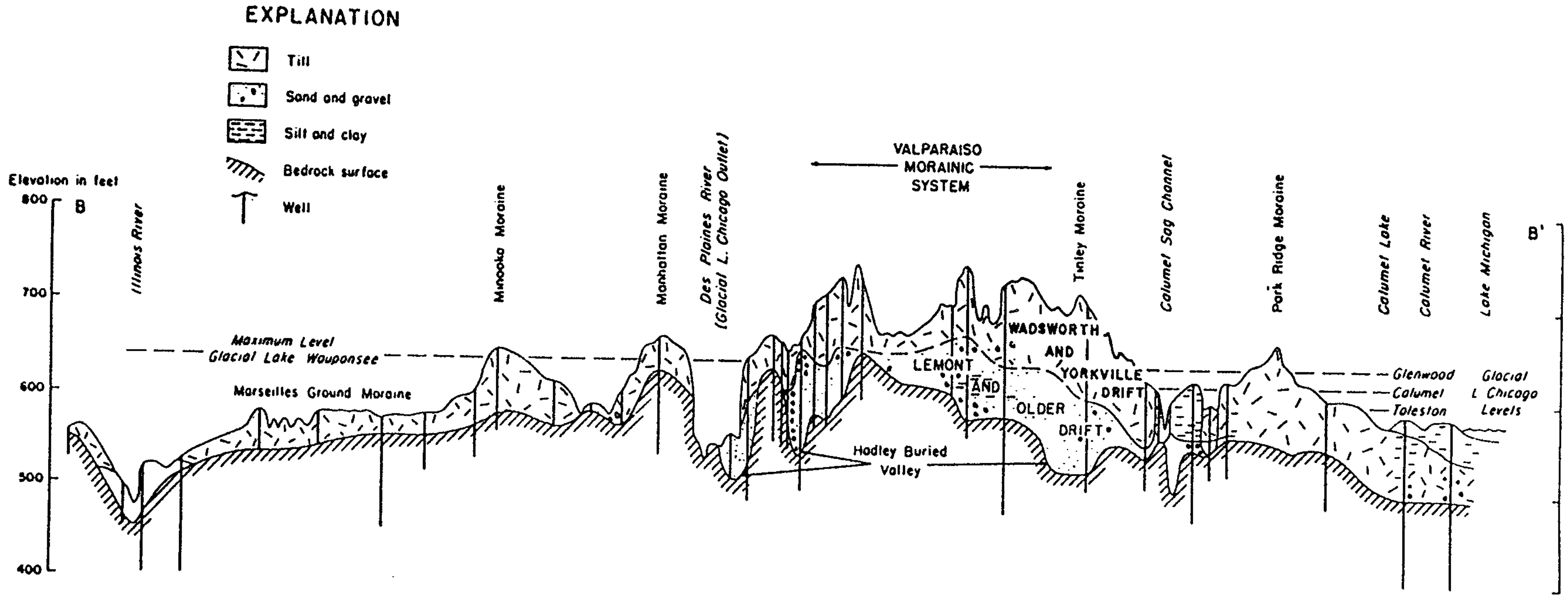
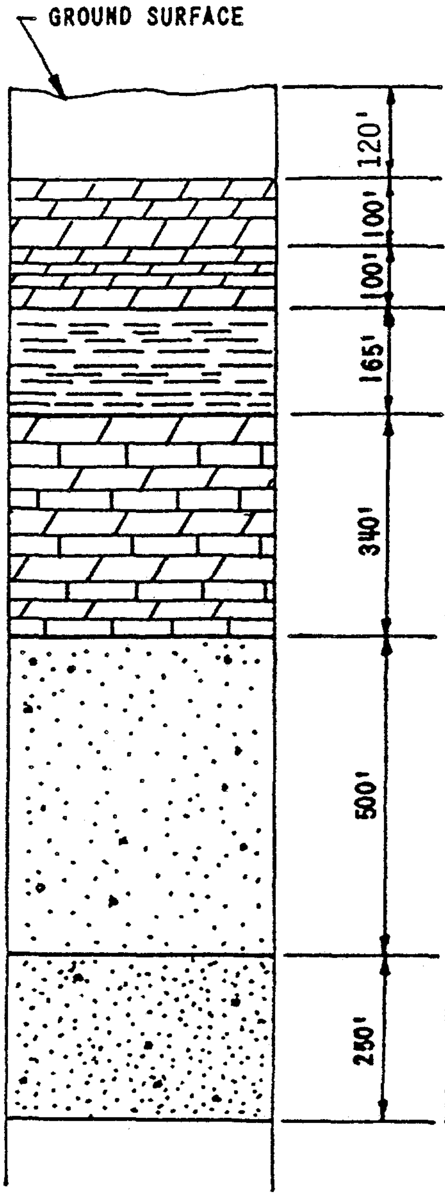


Fig. 4. Cross Section Showing Glacial Deposits in the Chicago Area



LITHOLOGY - SERIES & FORMATION	SYSTEM
GLACIAL TILL	QUARTERNARY
DOLOMITE-NIAGARAN	MIDDLE SILURIAN
DOLOMITE - ALEXANDRIAN EDWARD & KANKAKEE FORM.	EARLY SILURIAN
SHALE - MAQUOKETA	LATE ORDOVICIAN
DOLOMITE & LIMESTONE - GALENA & PLATTVILLE FORMATIONS	MIDDLE ORDOVICIAN
SANDSTONE - GLENWOOD & ST. PETER SERIES	MIDDLE ORDIVICIAN
SANDSTONE - FRANCONIA & GALESVILLE FORMATIONS	LATE CAMBRIAN

Fig. 5. Bedrock at ANL Site

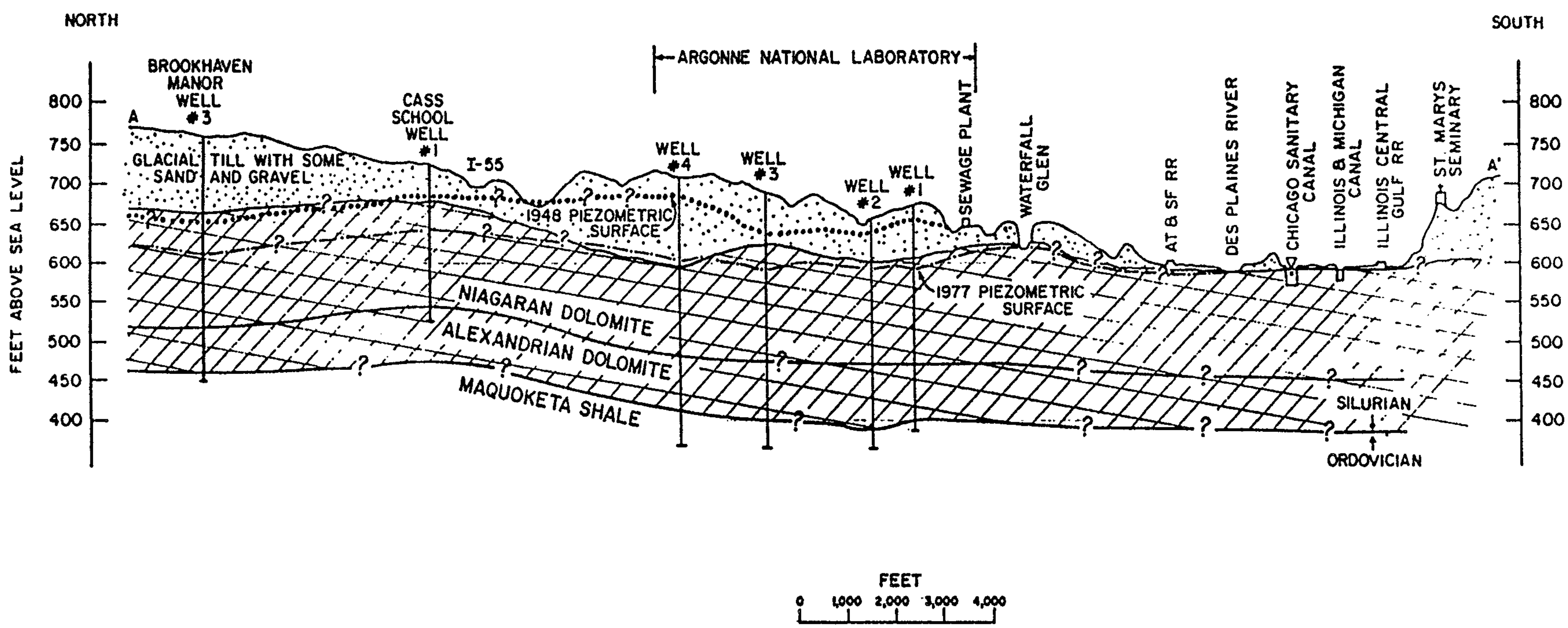


Fig. 6. Cross Section Showing Geology of Argonne National Laboratory

Note: ANL deep well No. 1 is not shown here because the depth of the well has exceeded the limit of the paper size.

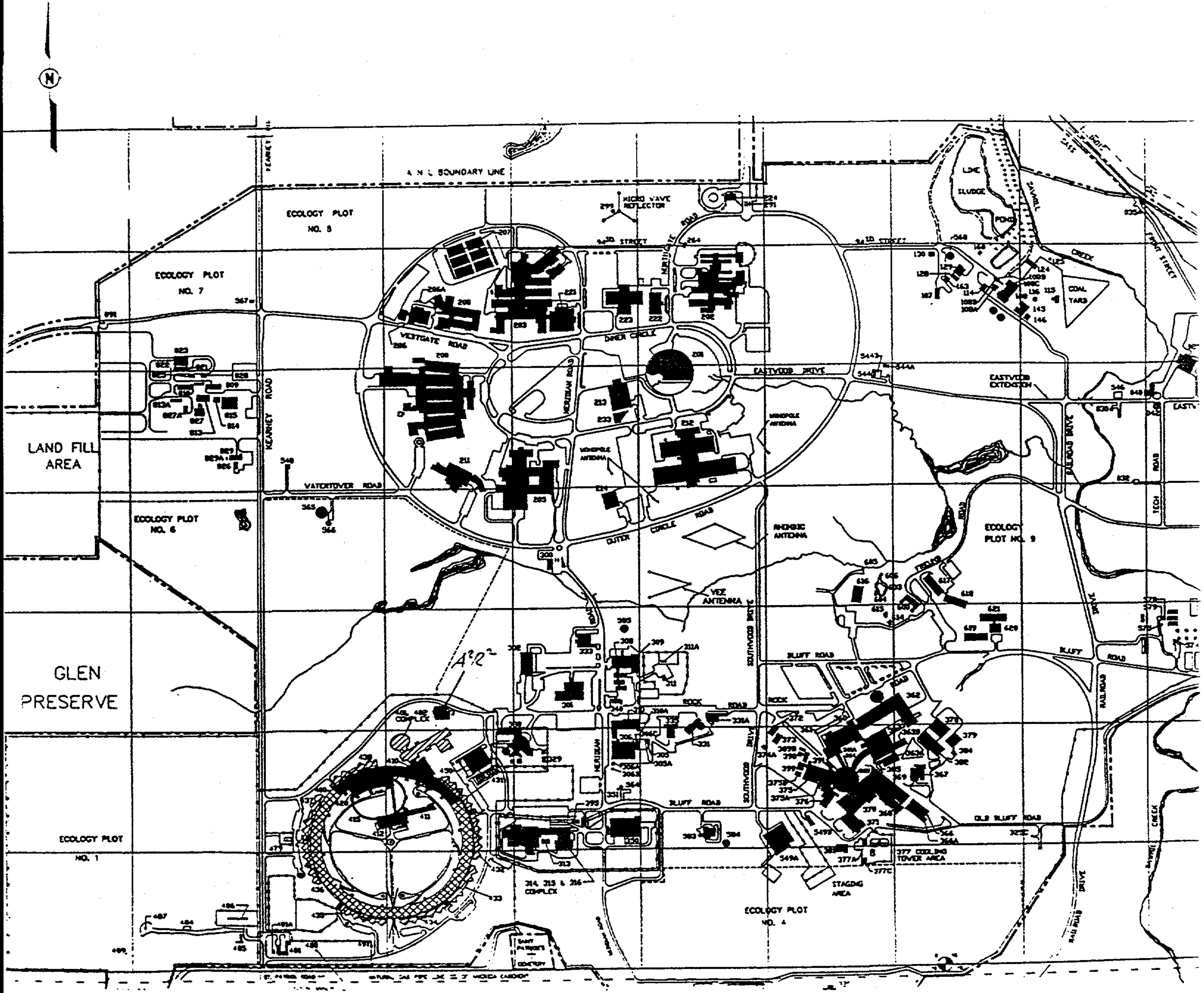


Fig. 7. ANL-E Site

	ID #
Shallow Well #1	031
Shallow Well #2	032
Shallow Well #3	163
Shallow Well #4	264
Deep Well #1	160

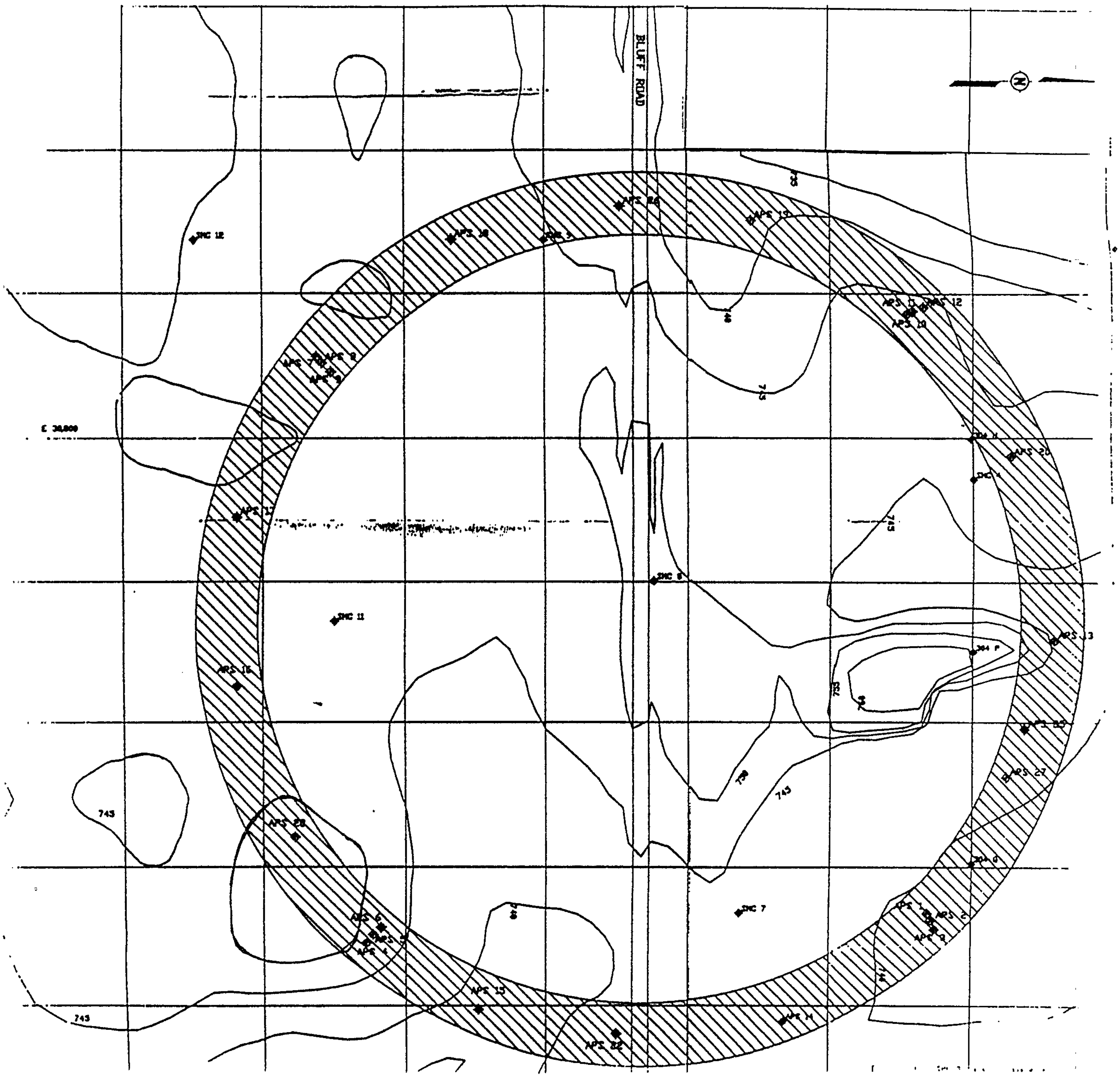


Fig. 8. Locations of Crossholes and Boreholes

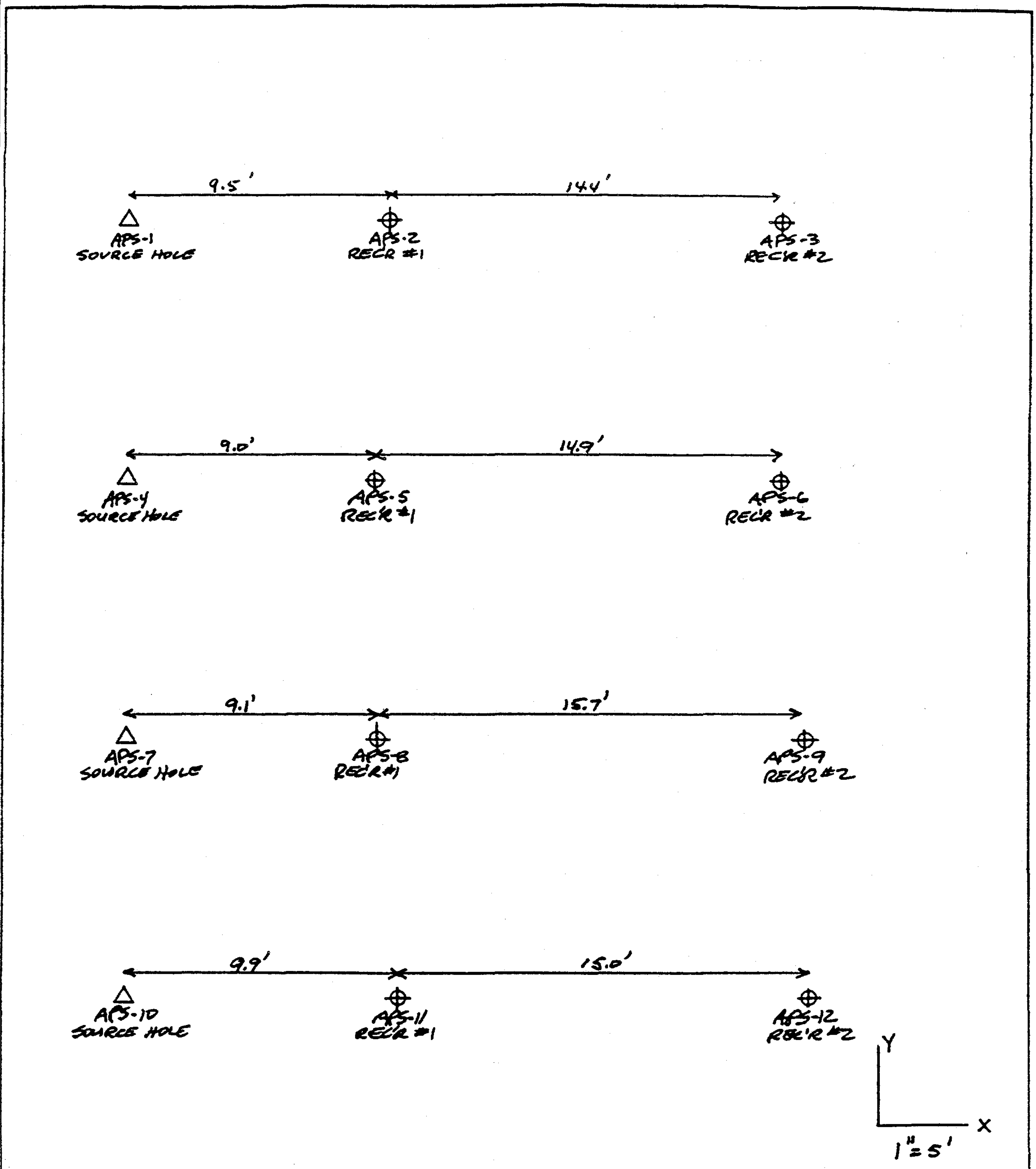


Fig. 9. Distances Between Crossholes