A SEISMIC REFLECTION SURVEY OF THE SURFACE OF THE BASEMENT COMPLEX IN INDIANA

by

ALBERT J. RUDMAN

Indiana Department of Conservation

GEOLOGICAL SURVEY

Report of Progress No. 18

1960

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GEOLOGICAL SURVEY
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A SEISMIC REFLECTION SURVEY OF THE SURFACE OF THE BASEMENT COMPLEX IN INDIANA

By Albert J. Rudman

ABSTRACT

The surface of the basement complex that underlies five counties in southwestern Indiana has been mapped by the reflection seismograph method. Seismic shot points were spaced 1 to 3 miles apart along six traverses in Gibson, Pike, Posey, Vanderburgh, and Warrick Counties. A structure map on the surface of the basement complex shows an elongate northwestward-trending depression that is as much as 22 miles in width and that has a maximum depth of 3,500 feet below the regional slope of the basement surface. Structure maps drawn on the surface of Devonian limestone, the Trenton Limestone, and the St. Peter Sandstone show a monocline over the northeast flank of this basement depression. The depression in the surface of the basement complex and the monocline shown on Paleozoic maps may be related structurally to the LaSalle Anticline.

INTRODUCTION

Information concerning the configuration of the surface of the basement complex in Indiana is scarce. A recent map of the basement complex (Gutstadt, 1958, fig. 5) is based on only six test wells in the north-central land eastern parts of the State (Kottlowski and Patton, 1953) and on extrapolations of known thicknesses of the overlying sedimentary rocks. Aeromagnetic maps of 92 Indiana counties were used by Henderson and Zietz (1958) for the construction of a contour map of the surface of the basement complex. They analyzed 79 magnetic anomalies in these counties and determined the depth of the basement complex at the locations of these anomalies. Although Henderson and Zietz's map of the surface of the basement complex shows the broad structural high of the Cincinnati Arch and the structural low of the Illinois Basin (fig. 1), their control is based on an average of less than one datum point per county.

Knowledge of the configuration of early Paleozoic strata in Indiana also is scarce. Only 24 wells have been drilled to the top of Devonian limestone in southwestern Indiana (pl. 1 and table 1), and of these, only five have been drilled to the Trenton Limestone.

A detailed structure contour map of the surface of the basement complex, which is presumably Precambrian in age, would contribute information needed for regional geologic studies in Indiana. In 1957 the Indiana Geological Survey initiated a seismic reflection program

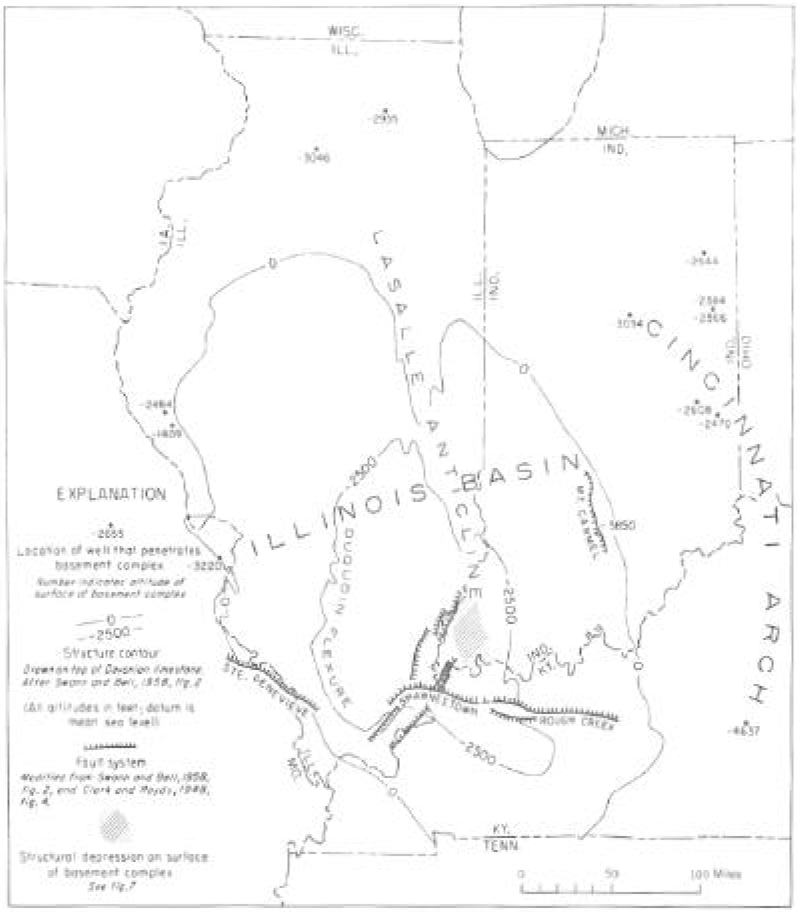
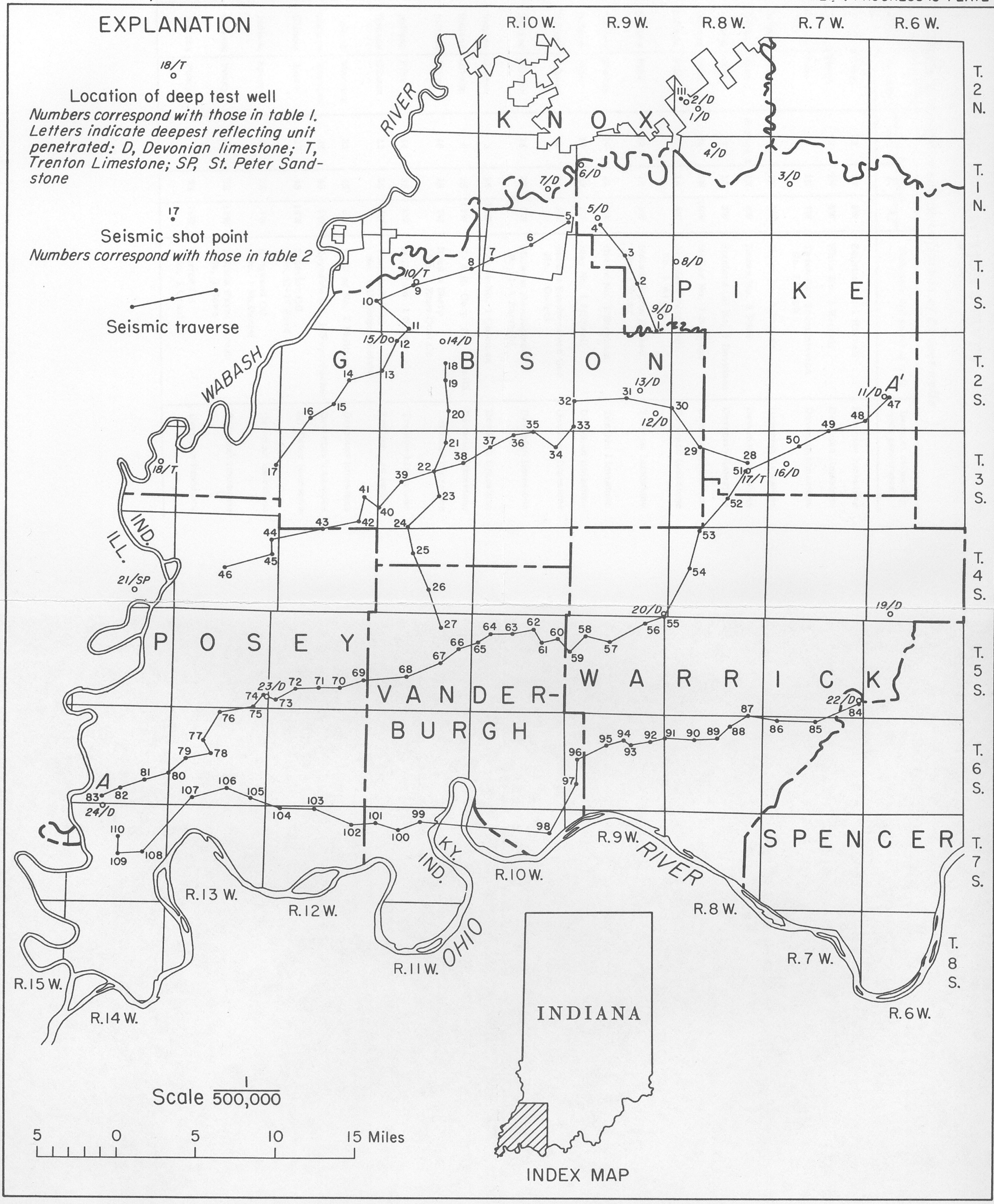


Figure 1. --Structural features of the Illinois Basin.

to provide data for such a map. Two field seasons were spent in the area studied for this report (pl. 1), and this fieldwork represents the first part of a comprehensive program to map the surface of the basement complex and the surfaces of early Paleozoic strata throughout the State. As this preliminary report is concerned primarily with the presentation of data, sections dealing with geologic setting, field operations, and conclusions are treated only briefly. It should be understood that the structural trends suggested in this paper are based on widely spaced control points and that details need to be substantiated by additional investigation. All data collected during this investigation are on open file in the offices of the Indiana Geological Survey.



INDEX MAP OF PART OF SOUTHWESTERN INDIANA SHOWING LOCATION OF TEST WELLS, SEISMIC SHOT POINTS, SEISMIC TRAVERSES AND LOCATION OF TRAVERSE A-A' ILLUSTRATED ON PLATE 2

Table 1.--*Location and identification of 24 test wells*

Well location no.	State	County	Location Sec.	T.	R,	Operator and name of well	Deepest reflecting unit penetrated
1	Indiana	Knox	29	2N	8W	Zanetis No. 1 Harrell	Devonian limestone
2	Indiana	Knox	19	2N	8W	White No. 1 Harrell	Devonian limestone
3	Indiana	Pike	17	1N	7W	Texas Gas Transmission No. 5 Smith	Devonian limestone
4	Indiana	Knox	4	IN	8W	Skiles No. 1 Parker	Devonian limestone
5	Indiana	Pike	Survey 5	1N	9W	Brown No. 9 Peed	Devonian limestone
6	Indiana	Pike	7	IN	9W	Stanford Oil No. l Davidson	Devonian limestone
7	Indiana	Knox	23	1N	10W	Muller No. 1 Simpson	Devonian limestone
8	Indiana	Pike	7	1S	8W	Aberdeen Petroleum No. 1 Willis	Devonian limestone
9	Indiana	Pike	25	1S	9W	Indiana Farm Bureau No. 1 Subar	Trenton Limestone
10	Indiana	Gibson	16	1S	11W	Brown No. 1 Bingham	Trenton Limestone
11	Indiana	Pike	20	2S	6W	May No. 1 Stillwell	Devonian limestone
12	Indiana	Gibson	25	2S	9W	Indiana Southwestern Gas No. 1 Gudgel	Devonian limestone
13	Indiana	Gibson	23	2S	9W	Midwest Development No. l-A Barthold	Devonian limestone
14	Indiana	Gibson	3	2S	11W	Choate No. 1 Coleman	Devonian limestone
15	Indiana	Gibson	6	2S	11W	T. & H. Corp. No. 1 Smith	Devonian limestone
16	Indiana	Pike	18	3S	7W	Ryan & Sharp No. 1 Enos Coal Co.	Devonian limestone
17	Indiana	Pike	14	3S	8W	Miller No. 1 Nixon	Trenton Limestone
18	Indiana	Gibson	13	3S	14W	Continental Oil No. l-D Cooper Estate	Trenton Limestone
19	Indiana	Warrick	32	4S	6W	Phillip. No. 2 Phillips	Devonian limestone
20	Indiana	Warrick	36	4S	9W	Reynolds No. 1 Weyerbacher	Devonian limestone
21	Illinois	White	27	45	14W	Superior Oil No. C-17 Ford	St. Peter Sandstone
22	Indiana	Spencer	25	5S	7W	Kingwood Oil No. 1 McDaniel	Devonian limestone
23	Indiana	Posey	36	55	13W	Indiana Farm Bureau No. 1 Rowe	Devonian limestone
24	Indiana	Posey	4	7S	14W	Carter Oil No. 1 Graulich	Devonian limestone

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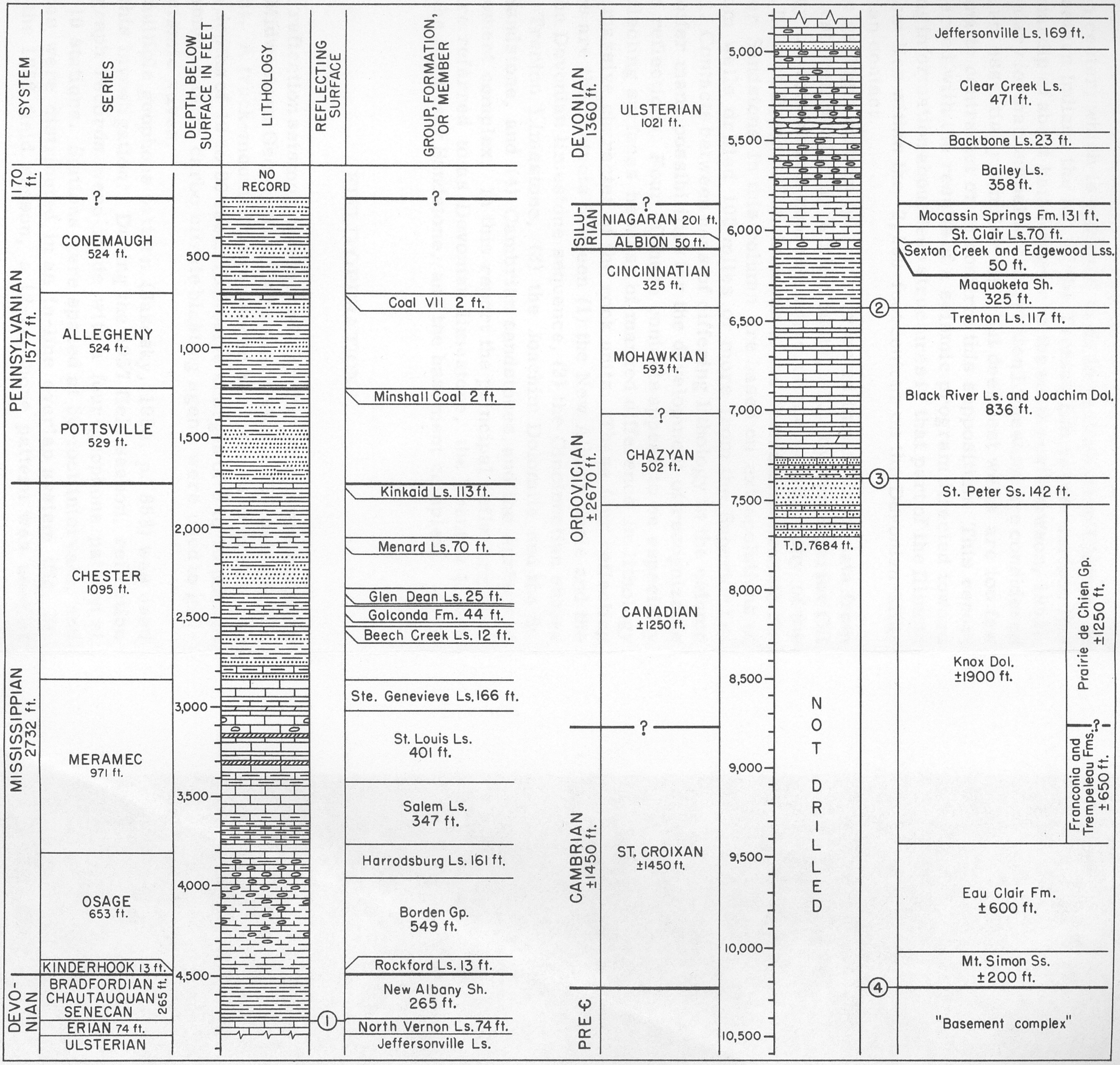
PRINCIPLE OF THE SEISMIC REFLECTION METHOD

The seismic reflection method is one of the most applicable for investigating geologic structures at great depths. Seismic reflection methods involve use of elastic waves generated by explosions in shallow bore holes. Elastic waves travel downward and, after being refracted and reflected from beds at depth, return to the earth’s surface. Principal reflections occur at the contact between layers of contrasting lithology. A reflection seismograph records the characteristic motion of these principal reflections and their time of arrival at the earth's surface. If the contact between two formations generates a characteristic reflection, this reflection can be identified on successive records obtained at various seismic shot points. Arrival times of these reflections are then plotted as a cross section (pl. 2). From a knowledge of the velocity of the elastic waves in the geologic section, depths to each geologic contact can be computed at every seismic shot point. These depths then may be plotted in the form of a geologic structure cross section (pl. 2) or structure map.

GEOLOGIC SETTING

Major structural features in Indiana include parts of the Michigan and Illinois Basins and the broad structural high that corresponds to the Cincinnati Arch and its extensions. The Illinois Basin, a major oil-producing province occupying most of Illinois and parts of Indiana and Kentucky, is here defined to include the 58,000-squaremile area bounded by the sea level structure contour on the Devonian -Mississippian contact (fig. 1). Three major structural features exist within the Illinois Basin: the Duquoin Flexure in central Illinois, the southeastward-trending LaSalle Anticline in the central part of the basin, and the eastward-westward-trending Rough Creek-Shawneetown fault zone across southern Illinois and western Kentucky (fig. 1). All the rocks of the Illinois Basin dip toward a



GEOLOGIC COLUMN OF SUPERIOR OIL COMPANY'S DEEP TEST WELL IN WHITE COUNTY, ILLINOIS common center, which is believed to be in southeastern Illinois. In southwestern Indiana the top of the Trenton Limestone surface has a regional dip of about half a degree to the southwest (Dawson, 1952). Sedimentary formations below the Trenton Limestone are considered to have an essentially similar dip, but deep test wells are too few in Indiana to contradict or to confirm this supposition. This report is concerned with the results of a seismic program directed toward obtaining information about deep structures in that part of the Illinois Basin that lies within the -2,500-foot contour on the Devonian-Mississippian contact.

The geologic column (pl. 3) interpreted in part from data from a deep test well drilled in White County, Ill. , by the Superior Oil Co. may be considered representative of the stratigraphy of the central Illinois Basin. Thicknesses of the formations beneath the St. Peter Sandstone in this column are based on extrapolations of data from wells drilled 100 miles or more from the Superior Oil Co. well. Contacts between beds of differing lithology in the column should offer many possibilities for the development of recognizable seismic reflections. Four of these contacts appear to be especially good reflecting surfaces because of marked difference in lithology and the massive character of the rock units. These four reflecting surfaces are the contacts between (1) the New Albany Shale and the top of the Devonian limestone sequence, (2) the Cincinnatian shales and the Trenton Limestone, (3) the Joachim Dolomite and the St. Peter Sandstone, and (4) Cambrian sandstones and the surface of the basement complex. In this report the principal reflecting surfaces are referred to as Devonian limestone, the Trenton Limestone, the St. Peter Sandstone, and the basement complex.

FIELD OPERATIONS

All reflection seismograph records for this study were obtained with a Midwestern Geophysical Laboratory Model 416 seismic instrument. A truck-mounted power auger was used to drill the shot holes to depths of 10 to 80 feet. Explosive charges of 5 to 10 pounds of Nitramon, a nitro carbo nitrate blasting agent, were used to generate seismic waves.

A multiple geophone pattern (Jakosky, 1950, p. 853) was used during this investigation. During the 1957 field season, reflection seismograph records were made with a four-geophone pattern at each of 10 stations. Stations were spaced at 50-foot intervals, and geophones were distributed in an in-line overlap system (fig. 2). During the 1958 field season, a 12-geophone pattern was used at

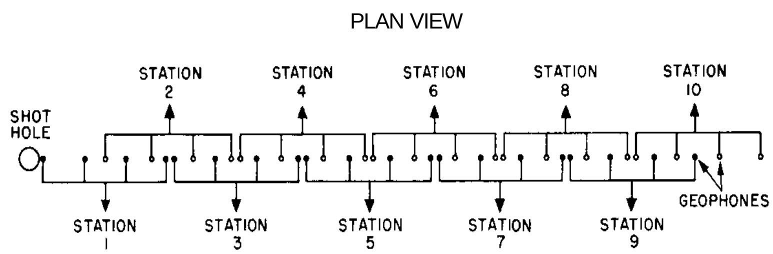


Figure 2. --Diagram of a multiple geophone pattern with four geophones per station in an in-line overlap system.

each of 12 stations. The stations were spaced at 125-foot intervals, and the geophones again were placed in an in-line overlap system.

Seismic shot points were located 1 to 3 miles apart along principal traverses that are approximately normal to the regional strike (pl. 1). A few traverses were run in a north-south direction to provide data for correlation between the principal traverses. Preliminary studies of the reflection seismograph records in the area of investigation indicated that the character of the reflections from the individual reflecting surfaces persists overlarge areas and that correlation between widely separated shot points is possible. Correlations using continuous profiling methods (Jakosky, 1950, p. 704) would, of course, be more reliable, but in view of the large area covered in this investigation, the time-consuming method of continuous profiling was not considered practical for a regional study.

INTERPRETATION AND PRESENTATION OF DATA

CORRELATION OF REFLECTION DATA

Four characteristic reflections have been recorded throughout the area of investigation, and they are believed to mark the tops of Devonian limestone, the Trenton Limestone, the St. Peter Sandstone, and the basement complex. These reflections correspond with the major contrasts in lithology identified as reflecting surfaces on the geologic column (pl. 3). Analysis of a synthetic seismogram constructed from a sonic log of a basement test in Lawrence County, Ind. , indicates that the Devonian, Trenton, and basement complex can act as reflecting surfaces (Biggs, Blakely, and Rudman, in preparation). A study of the time-distance cross sections (pl. 2), step-out times of reflections, and of $X^2 - T^2$ velocity surveys also substantiates the seismic events as true reflections and not multiple reflections (Symposium on the subject of multiple reflections, 1948).

Locations of seismic shot points are identified by number on plate 1. Several reflection records were made at each seismic site, and the data presented in this report are from the best records obtained at a given site.

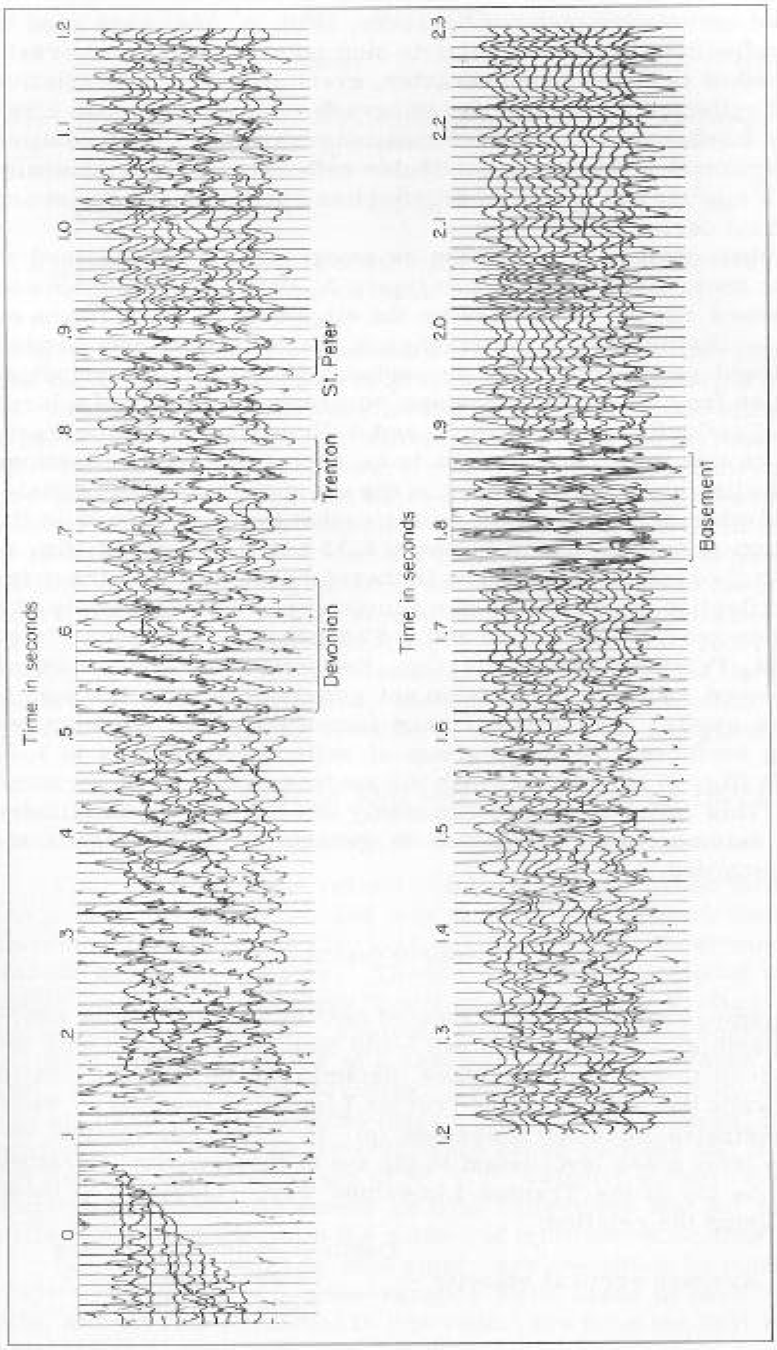
Spot correlation methods (Jakosky, 1950, p. 704) were used to trace reflections from shot point to shot point along the traverses. This method is based upon character, event sequence, and relative time of reflected events on a seismograph record. Although a reflection furnishes no definite information regarding the composition of the subsurface layers, a particular reflecting surface generally yields a similar and sometimes distinctive characteristic reflection throughout certain areas.

A photograph of a reflection seismograph record obtained at seismic shot point 26 is shown in figure 3. Principal reflections on this record can be recognized by the alignment of wave forms or cycles. Distinctive characteristics of the reflections indicated on this record generally persist throughout the area. The principal reflection from Devonian limestone occurs in the center of a large group of reflections between 0. 52 and 0. 65 second (fig. 3). Early cycles in this group are thought to be associated with reflections from the limestone-shale contact at the top of the New Albany Shale. Study of other seismic records indicates that the second cycle in the reflection group occurring between 0. 73 and 0. 79 second (fig. 3) persists throughout the area and is therefore identified as the principal reflection from the Trenton Limestone. The first cycle of a reflection group between 0. 86 and 0. 89 second (fig. 3) is correlated with a St. Peter Sandstone reflection. Reflections occurring between 0. 89 second and 1. 77 seconds do not generally persist throughout the area studied and have not been identified with particular reflecting surfaces. A large group of reflections starting at 1.77 seconds (fig. 3) is identified with the surface of the basement complex. This reflection group commonly has the largest amplitudes on the seismograph records and is generally the last significant event recorded.

VELOCITY AND DEPTH CALCULATIONS

Seismic shot points were located next to deep test wells wherever possible. Reflection times could then be associated with the known depth to a reflecting surface. Seismic shot points were located near 3 wells that penetrated the Trenton Limestone and near 17 wells that penetrated Devonian limestone (pl. 1). Average vertical velocities from a sea level datum to the top of the Devonian limestone and to the top of the Trenton Limestone were calculated at these points using the relation:

$$(1)\ \text{Average vertical velocity} = \frac{\text{Depth of reflecting surface below sea level}}{\text{Reflection time}}$$


Time in seconds
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
1.1
1.2
Devonian
Trenton
St. Peter
Time in seconds
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2.0
2.1
2.2
2.3
Basement

Average vertical velocities from a sea level datum to the tops of reflecting surfaces will be more simply termed “velocities” in this report. Devonian limestone velocities range between 12,400 and 13,600 feet per second, and Trenton Limestone velocities range between 13,900 and 15,100 feet per second. These velocities were substantiated and supplemented by $X^2 - T^2$ velocity studies (Symposium on the subject of multiple reflections, 1948) and then were used in the calculations of the altitudes of Devonian limestone and the Trenton Limestone surfaces listed in table 2.

The method used to calculate Devonian and Trenton velocities was not applicable for the calculation of St. Peter velocities because seismograph records were not obtained in the vicinity of St. Peter test wells. Only one well has been drilled to the St. Peter Sandstone within the area of this investigation (pl. 1, well location no. 21), and a satisfactory seismograph record was not obtained in the vicinity of this test well. Velocities to the top of the St. Peter Sandstone were therefore calculated indirectly using the following equation:

$$(2)\ \text{Average vertical velocity to the St. Peter Sandstone} = \frac{\text{Depth of Trenton Limestone below sea level} + 920\ \text{feet}}{\text{St. Peter reflection time}}$$

In this equation 920 feet is assumed as a constant Trenton-St. Peter interval. St. Peter Sandstone velocities as determined from equation 2 ranged between 14, 400 and 15, 600 feet per second. Although the interval from the Trenton Limestone to the St. Peter Sandstone may be more or less than 920 feet within the area of this study, a change of 100 feet in this constant introduces an error of only ± 300 feet per second in the calculated velocities. The St. Peter Sandstone velocity is thus considered reliable to within 2 percent.

Subsea-level altitudes of the surface of the basement complex were calculated indirectly because the interval between the St. Peter Sandstone and the basement complex could not be considered constant. The velocity in this interval is considered to be a constant 16, 000 feet per second in the following equation:

$$(3)\ D_{bc} = (T_{bc} - T_{sp}) \times 16,000 + D_{sp}$$

in which D_{bc} is the depth to the surface of the basement complex,
D_{sp} is the depth previously calculated to the surface of the St. Peter Sandstone, and
T_{bc} and T_{sp} are the reflection times to the basement complex and the St. Peter Sandstone.

Depths to the surface of the basement complex were converted to subsea-level altitudes and are listed in table 2. These altitudes, when used in equation 1, yielded basement complex velocities be

Table 2.--*Altitudes of principal reflecting surfaces at 111 seismic shot points*

Seismic shot point no.	County	Location			Altitude of principal reflecting surfaces, sea level datum			
		Sec.	T.	R.	Devonian limestone	Trenton Limestone	St. Peter Sandstone	Basement complex
1	Pike	36	1S	9W	-2,580	-4,040	-5,000	- 9,600
2	Pike	15	1S	9W	-2,580	-4,140	-4,900	- 9,400
3	Pike	10	1S	9W	-2,540	-4,020	-4,900	- 9,300
4	Pike	32	1N	9W	-2,590	-4,130	-5,000	-10,100
5	Gibson	36	1N	10W	-2,650	------	------	-10,900
6	Gibson	3	1S	10W	-2,770	-4,330	-5,100	- 9,800
7	Gibson	7	1S	10W	------	------	------	------
8	Gibson	12	1S	11W	------	------	------	------
9	Gibson	21	1S	11W	-3,320	------	-5,800	------
10	Gibson	24	1S	12W	-3,420	-5,080	-5,900	-10,400
11	Gibson	32	1S	11W	------	------	------	------
12	Gibson	6	2S	11W	-3,520	-5,120	-6,000	------
13	Gibson	18	2S	11W	-3,520	-5,220	-6,000	-14,400
14	Gibson	14	2S	12W	-3,710	-5,380	-6,200	------
15	Gibson	27	2S	12W	-3,790	-5,470	-6,400	-14,900
16	Gibson	32	2S	12W	-3,850	-5,590	-6,500	-14,100
17	Gibson	13	3S	13W	-3,980	-5,670	-6,600	------
18	Gibson	10	2S	11W	-3,380	-4,930	-5,800	------
19	Gibson	15	2S	11W	------	------	------	------
20	Gibson	26	2S	11W	------	------	------	------
21	Gibson	2	3S	11W	-3,520	-5,070	-6,000	-12,000

22	Gibson	15	3S	11W	-----	-----	-----	-----
23	Gibson	22	3S	11W	-3,610	-5,230	-6,100	-14,700
24	Gibson	32	3S	11W	-3,800	-5,400	-6,400	-13,400
25	Gibson	16	4S	11W	-3,810	-5,470	-6,400	-13,300
26	Vanderburgh	27	4S	11W	-3,720	-5,380	-6,400	-13,600
27	Vanderburgh	2	5S	11W	-----	-----	-----	-----
28	Pike	14	3S	8W	-2,600	-3,920	-4,800	-9,200
29	Gibson	5	3S	8W	-2,570	-4,120	-4,900	-9,400
30	Gibson	30	2S	8W	-2,720	-4,110	-5,000	-9,600
31	Gibson	22	2S	9W	-2,750	-4,200	-5,200	-9,700
32	Gibson	30	2S	9W	-----	-4,310	-----	-9,600
33	Gibson	31	2S	9W	-2,990	-4,440	-5,400	-10,000
34	Gibson	1	3S	10W	-3,060	-4,610	-----	-10,500
35	Gibson	3	3S	10W	-----	-----	-5,500	-----
36	Gibson	4	3S	10W	-----	-4,700	-5,600	-11,300
37	Gibson	6	3S	10W	-3,390	-4,870	-5,800	-----
38	Gibson	13	3S	11W	-3,550	-5,080	-6,000	-13,500
39	Gibson	20	3S	11W	-3,600	-5,230	-6,100	-13,600
40	Gibson	30	3S	11W	-3,720	-----	-6,200	-13,300
41	Gibson	25	3S	12W	------	-----	-----	-----
42	Gibson	35	3S	12W	-3,790	-5,470	-6,300	-----
43	Gibson	33	3S	12W	-4,010	-5,660	-6,600	-13,000
44	Posey	12	4S	13W	-4,150	-----	-----	-12,000
45	Posey	13	4S	13W	-4,150	-5,800	-6,800	-11,400

Table 2.--*Altitudes of principal reflecting surfaces of 111 seismic shot points-Continued*

Seismic shot point no.	County	Location			Altitude of principal reflecting surfaces, sea level datum			
		Sec	T.	R.	Devonian limestone	Trenton Limestone	St. Peter Sandstone	Basement complex
46	Posey	21	4S	13W	------	-----	-----	-----
47	Pike	29	2S	6W	-2,080	-----	-----	-----
48	Pike	36	2S	7W	-2,140	-3,490	-4,300	-8,900
49	Pike	3	3S	7W	-2,190	-3,590	-4,500	-8,900
50	Pike	5	3S	7W	-2,350	-3,790	-4,700	-9,100
51	Pike	14	3S	8W	-2,550	-3,980	-4,900	-9,400
52	Warrick	27	3S	8W	-2,670	-4,060	-5,000	-9,400
53	Warrick	5	4S	8W	-2,800	-4,120	-5,200	-9,400
59	Warrick	17	4S	8W	-2,890	-4,310	-5,200	-9,900
55	Warrick	1	5S	9W	-2,960	-4,410	-----	-10,200
56	Warrick	2	5S	9W	-----	-4,470	-5,500	-----
57	Warrick	9	5S	9W	-3,160	-4,650	-5,600	-10,700
68	Warrick	8	5S	9W	-----	-----	-----	-----
59	Warrick	18	5S	9W	-3,280	-4,860	-5,800	-14,400
60	Vanderburgh	12	5S	10W	-3,330	-----	-5,800	-14,700
61	Vanderburgh	11	5S	10W	-3,510	-5,030	-6,000	-14,500
62	Vanderburgh	10	5S	10W	-3,500	-5,060	-6,000	-14,100
63	Vanderburgh	9	5S	10W	-----	-----	-----	-----
64	Vanderburgh	8	55	10W	-3,620	-5,160	-6,200	-13,600
65	Vanderburgh	7	5S	10W	-----	-5,220	-----	-----
66	Vanderburgh	13	5S	11W	-3,710	-----	-----	-----

67	Vanderburgh	23	5S	11W	-3,820	-5,480	-6,500	-----
68	Vanderburgh	29	5S	11W	-3,910	-5,640	-6,600	-13,800
69	Posey	25	5S	12W	-3,980	-5,730	-6,700	-13,800
70	Posey	26	5S	12W	-4,050	-5,780	-----	-----
71	Posey	28	5S	12W	-4,120	-5,780	-6,800	-----
72	Posey	29	5S	12W	-4,210	-5,870	-----	12,600
73	Posey	31	5S	12W	-4,270	-5,990	-----	-----
74	Posey	36	5S	13W	-4,300	-5,980	-6,900	-11,300
75	Posey	36	5S	13W	-----	-----	-----	-10,900
76	Posey	3	6S	13W	-4,290	-6,050	-7,100	-10,600
77	Posey	9	6S	13W	-----	-----	-----	-10,500
78	Posey	16	6S	13W	-4,280	-6,060	-7,100	-----
79	Posey	19	6S	13W	-4,270	-6,040	-7,100	-10,700
80	Posey	25	6S	14W	-4,310	-5,990	-7,000	-10,600
81	Posey	26	6S	14W	-4,330	-5,990	-7,000	-10,600
82	Posey	27	6S	14W	-----	-----	-----	-----
83	Posey	33	6S	14W	-----	-----	-----	-----
84	Spencer	36	5S	7W	-2,550	-3,990	-4,800	-8,500
85	Warrick	4	6S	7W	-2,680	-4,170	-5,000	-8,500
86	Warrick	6	6S	7W	-2,750	-----	-5,100	-8,600
87	Warrick	2	6S	8W	-----	-----	-----	-----
88	Warrick	3	6S	8W	-----	-4,310	-5,200	-8,800
89	Warrick	10	6S	8W	-----	-4,320	-5,300	-8,800
90	Warrick	8	6S	8W	-2,950	-4,500	-5,400	-8,700

Table 2-.-*Altitudes of principal reflecting surfaces at 111 seismic shot points* -Continued

Seismic shot point no.	County	Location			Altitude of principal reflecting surfaces, sea level datum			
		Sec.	T.	R.	Devonian limestone	Trenton Limestone	St. Peter Sandstone	easement complex
91	Warrick	12	6S	9W	-3,090	-4,590	-5,500	- 8,900
92	Warrick	12	6S	9W	-----	-----	-----	-----
93	Warrick	10	6S	9W	-3,260	-4,880	-5,800	-8,900
94	Warrick	10	6S	9W	-----	-----	-----	-----
95	Warrick	9	6S	9W	-3,380	-4,940	-6,000	-9,100
96	Vanderburgh	19	6S	9W	-3,530	-5,180	-6,100	- 9,500
97	Venderburgh	30	6S	9W	-3,670	-5,300	-6,200	-9,990
98	Vanderburgh	12	7S	10W	-----	-----	-----	-----
99	Vanderburgh	3	7S	11W	-----	-----	-----	-----
100	Vanderburgh	8	7S	11W	-4,050	-5,650	-6,700	-10,300
101	Vanderburgh	7	7S	11W	-4,150	-5,790	-6,700	-10,100
102	Posey	12	7S	12W	-----	-----	-----	-l0,000
103	Posey	4	7S	12W	-4,270	-5,890	-6,900	-10,200
109	Posey	6	7S	12W	-4,310	-6,000	-7,000	-10,300
105	Posey	35	6S	13W	-4,360	-6,120	-7,100	-10,500
106	Posey	27	6S	13W	-4,350	-6,110	-7,100	-10,500
107	Posey	32	6S	13W	-4,420	-6,150	-7,000	-10,700
108	Posey	14	7S	19W	-----	-----	-----	-----
109	Posey	22	7S	14W	-----	-----	-----	-----
110	Posey	15	7S	19W	-----	-----	-----	-----
111	Knox	19	2N	8W	-2,320	-----	-----	-----

tween 14,900 and 15,900 feet per second. An error of 500 feet per second in the interval velocity of 16,000 feet per second, together with a 2-percent error in the St. Peter depth values, contributes only a 3-percent error in the overall calculation of depth and velocity to the basement complex. Although $X^2 - T^2$ studies indicate that the St. Peter Sandstone and basement complex velocities are reasonable, these velocities are not as reliable as the Devonian and Trenton velocities. Additional velocity studies are presently being made by the Indiana Geological Survey, and a detailed report on this subject is planned.

LIMITATIONS OF DATA

Evaluation of the reliability of this seismic survey is dependent upon a clear understanding of the limitations of seismic data. These limitations may be better understood after a brief examination of the possible sources of errors. Inaccuracies of calculated altitudes of the reflecting surfaces result from incorrect ground altitudes, errors in the application of weathered layer corrections (Jakosky, 1950, p. 717), incorrect vertical velocities, and miscorrelations of reflections.

Altitudes of the ground surface were obtained from topographic maps and are believed to be accurate to within ± 20 feet. Depths to the base of the weathered layer, as determined by the seismic refraction method (Nettleton, 1940, p. 305), are considered accurate to within 10 percent (Joseph F. Whaley, Indiana Geological Survey, oral communication). In the reduction of the data to datum elevation (Nettleton, 1940, p. 308) a 10-percent error in the determination of the thickness of a 100-foot weathered layer introduces an error of ± 0.002 second. This amounts to an error of approximately ± 30 feet in subsea-level altitude calculations.

Average vertical velocities to Devonian limestone and the Trenton Limestone (see p. 13) are considered reliable because of good correlation with data from nearby wells. The general lack of well data below the Trenton Limestone makes velocities to the St. Peter Sandstone and the basement complex less reliable. An error of 2 percent in the St. Peter Sandstone velocity introduces a maximum error of approximately ± 140 feet in the calculations of subsea-level altitudes. A 3-percent error in a basement complex velocity introduces an error of approximately ± 450 feet.

Although miscorrelations of reflections between seismic shot points are to be expected in a spot correlation shooting program, the strong, persistent character of the Devonian, Trenton, and St. Peter reflections and the gentle regional dip of these formations in

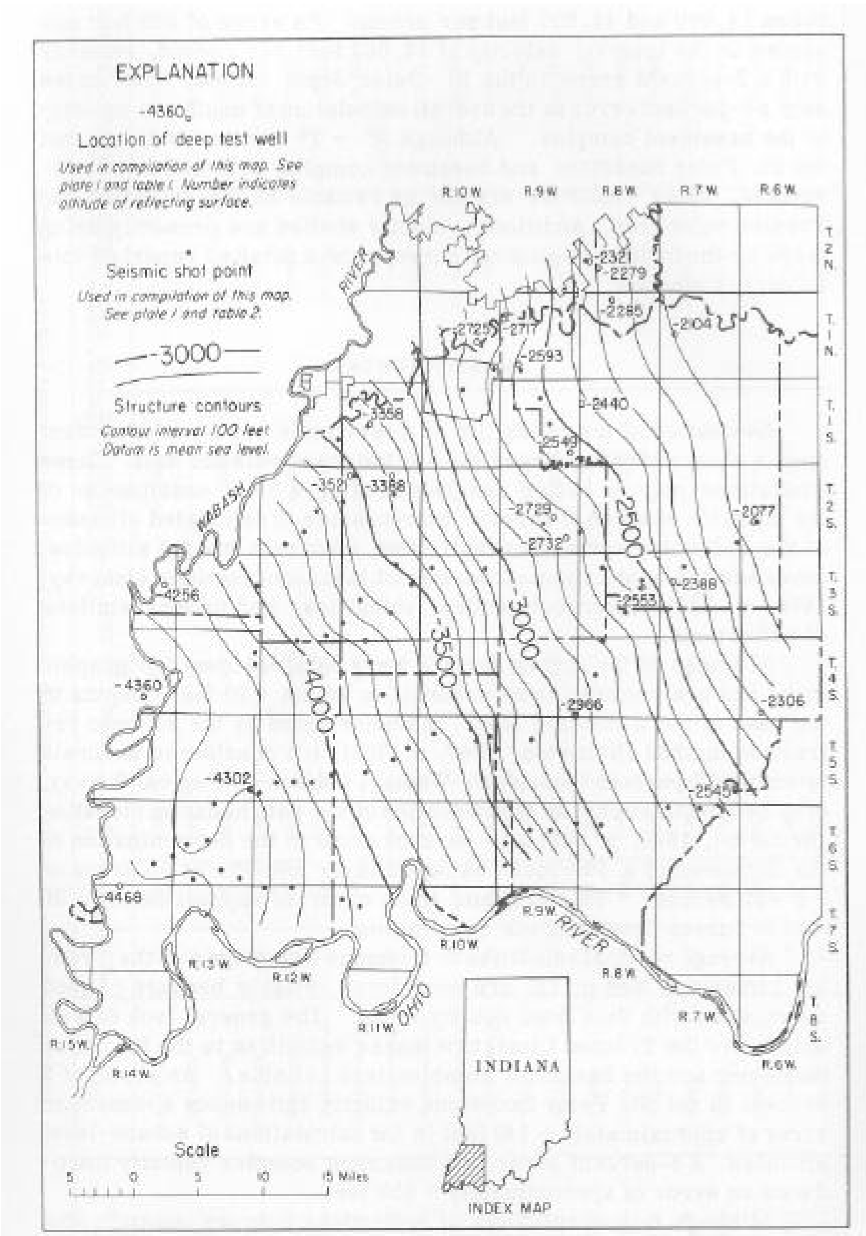


Figure 4. --Map of part of southwestern Indiana showing structure on top of Devonian limestone.

the area of investigation (figs. 4, 5, 6) combine to strengthen the reliability of the correlations of these reflections. The steeper dip of the surface of the basement complex (fig. 7), however, makes the correlation of this reflection less reliable. A miscorrelation of one cycle (± 0.02 second) introduces an error of approximately ± 150 feet in the calculated altitude of the surface of the basement complex.

This discussion of errors is intended to give the reader an approximate measure of the reliability of the data presented in this report. A compilation and summary of possible errors indicate that altitudes of the surface of Devonian limestone and the Trenton Limestone should be accurate to within ± 50 feet, altitudes of the top of the St. Peter Sandstone to within ± 200 feet, and altitudes of the basement complex to within ± 650 feet. Contours on the maps presented in this report are generalized. The error analysis mentioned above gives quantitative limits to the degree of generalization used in contouring.

CONCLUSIONS

The first part of a seismic investigation to map structure on the surface of the basement complex and early Paleozoic strata in Indiana has revealed several structures of regional significance. Structure maps on the surface of Devonian limestone (fig. 4), the Trenton Limestone (fig. 5), and the St. Peter Sandstone (fig. 6) show a tightening of the contours into a northwestward-southeastward-trending monoclinal structure. This structure is in a direct line with a southeasterly extension of the axis of the LaSalle Anticline and may be interpreted as a subdued expression of the anticline in Indiana.

All the Paleozoic maps (figs. 4, 5, 6) show a pronounced structural low in T. 6 S., R. 13 W. Although the trend of the contours generally conforms with a central deep that Swann and Bell thought (1958, fig. 2) is located in southeastern Illinois, the maps also indicate that the central deep may extend into southwestern Indiana. It also is possible to interpret and contour the structural low as a graben.

One of the most interesting geologic features revealed by this investigation is the northwestward-trending elongate depression shown on the structure map of the surface of the basement complex (fig. 7). This depression is as much as 22 miles across and has a maximum depth of 3,500 feet below the regional slope of the basement complex. The time and structure cross sections (pl. 2) along seismic traverse A-A' (pl. 1) show the asymmetry of this structure and its relationship to the overlying Paleozoic sedimentary rocks.

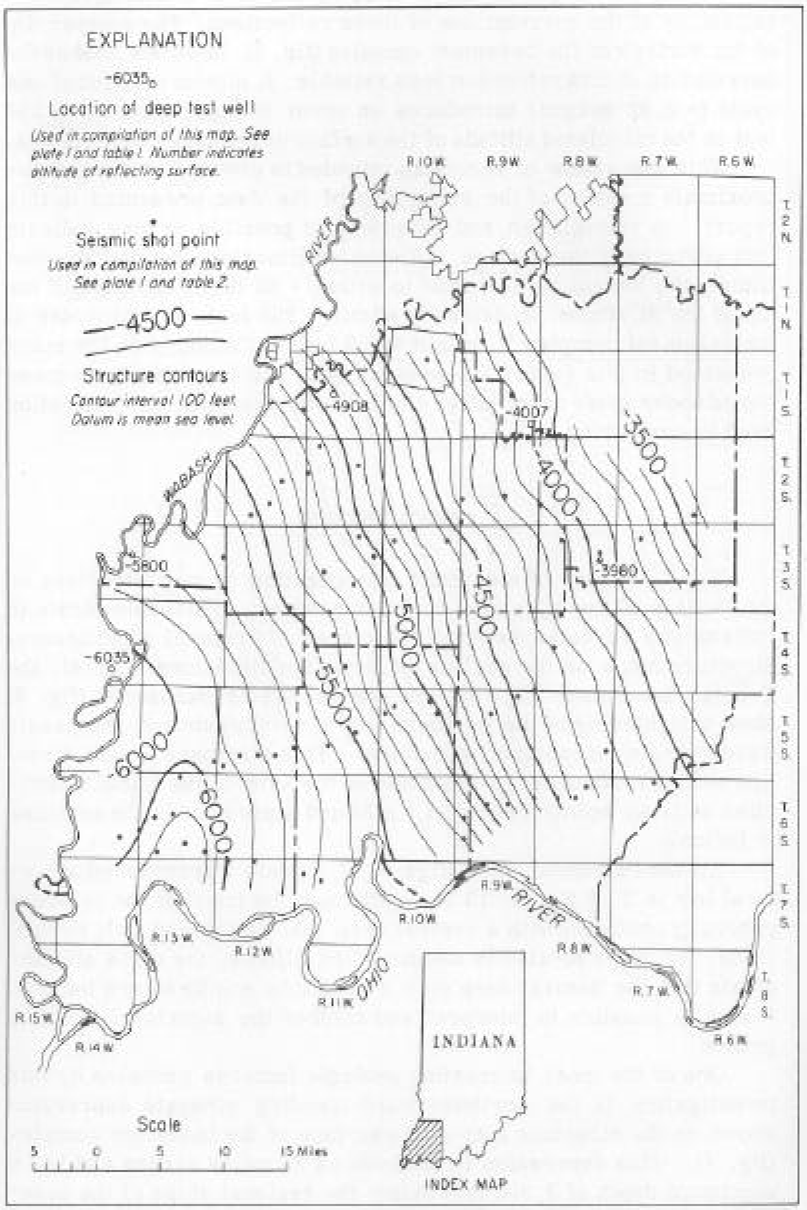


Figure 5. --Map of part of southwestern Indiana showing structure on top of Trenton Limestone.

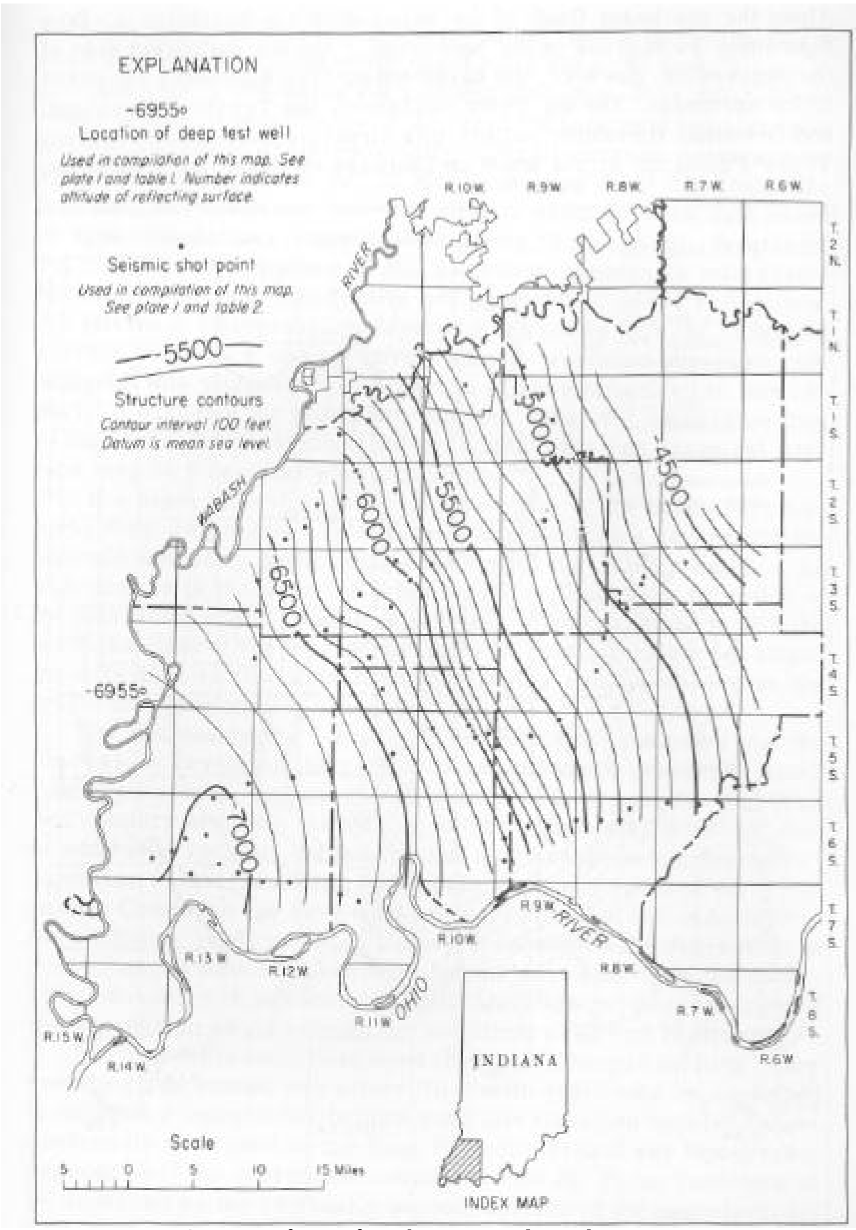


Figure 6. --Map of part of southwestern Indiana showing structure on top of St. Peter Sandstone.

Along the northeast flank of the depression the basement surface dips about 14 degrees to the southwest. On the southwest side of the depression, however, the basement surface dips about 4 degrees to the northeast. The St. Peter Sandstone, the Trenton Limestone, and Devonian limestone reflect this structure to a lesser degree. These Paleozoic strata show an increase of dip to the southwest,

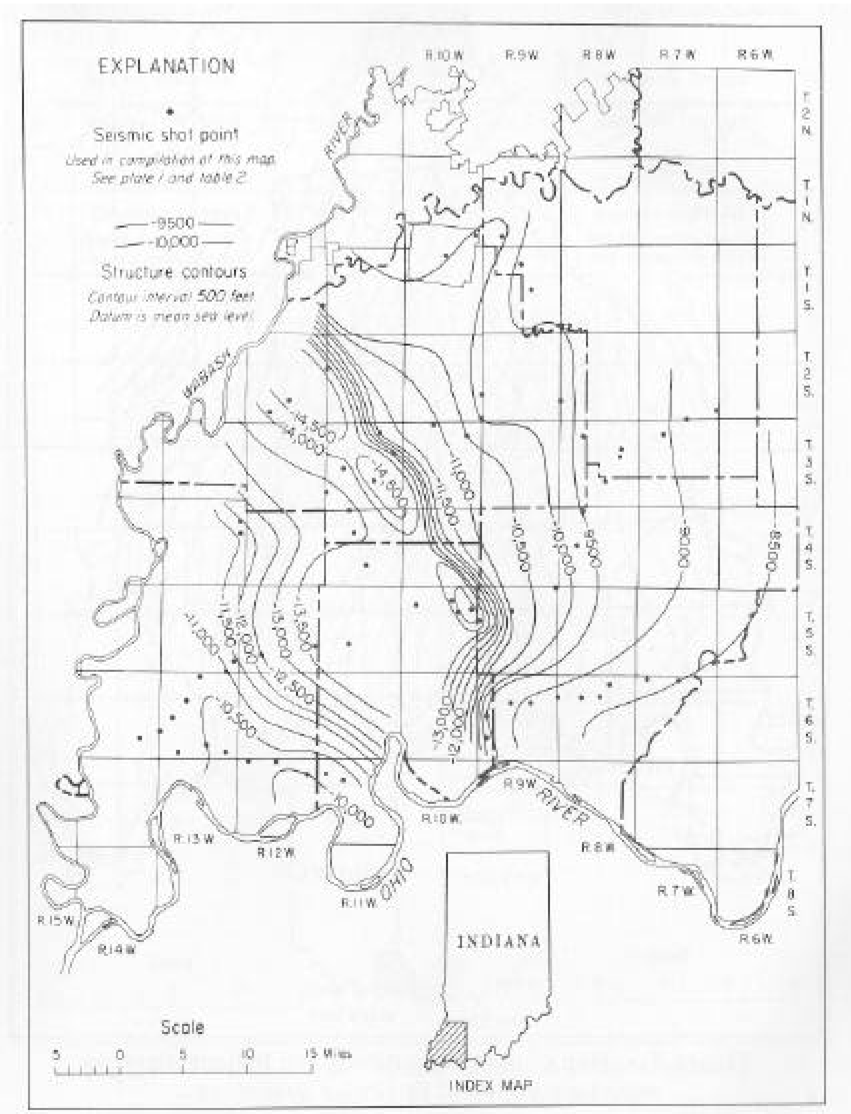


Figure 7. --Map of part of southwestern Indiana showing structure on top of the basement complex.

over the northeast flank of the depression, and a flattening of dip over the southwest flank of the depression (figs. 4, 5, 6, 7).

Analysis of the basement complex map (fig. 7) is difficult because subsea-level altitudes of the top of the basement complex have been extrapolated from especially difficult seismic correlations. The time cross section (pl. 2) along traverse A-A' illustrates the fact that more than one interpretation is possible from data based on spot correlation. Between shot points 55 and 76 (pl. 2) a major depression in the surface of the basement complex is interpreted because of the superior quality and persistence of the reflections. An alternate interpretation (dashed line) shows that the basement surface might be a comparatively smooth westward-dipping slope. Although this alternate interpretation is not emphasized in this report, it suggests the possibility that the basement depression (fig. 7) may be an intrabasement feature and that the true basement surface may be a regionally smooth plane.

If a depression does exist on the surface of the basement complex, then its presence introduces some problems concerning the tectonic and early sedimentary history of the Illinois Basin. An examination of the area indicates that a southeasterly extension of the west flank of the LaSalle Anticline is in good alignment with the northeast flank of the depression (fig. 1). This coincidence of alignment is used as the basis for the following two hypotheses on the origin and development of the depression:

(1) The nearly flat-lying St. Peter Sandstone indicates that the depression developed largely as a pre-Chazyan trough in which contemporaneous deposition and subsidence account for the thick sedimentary section. According to this hypothesis, the 3, 500 feet of additional rocks in the depression could range in age from Precambrian to late Canadian, although sedimentary rocks of early and middle Cambrian age have not been recognized in the midcontinent area (Moore, 1958, p. 113). Minor subsidence of the depression in post-Chazyan time would account for the development of the monoclinal structure in Indiana, and uplift along the northeast margin of the depression would account for anticlinal structure in Illinois.

(2) The depression developed from pre-Chazyan faulting. The resulting depression was either filled with sediments or continued to exist as a topographic feature until late Canadian time. An unconformity developed on the Knox Dolomite erased any topographic expression of the depression and allowed the St. Peter Sandstone to be deposited on the regionally smooth surface of the unconformity. Differential vertical movement along the fault line in late Paleozoic time explains the present anticlinal and monoclinal structures of the LaSalle Anticline.

Both of the hypotheses suggested above indicate that the depression is part of a linear basement control for the LaSalle Anticline. This association is based on seismic studies in Indiana and needs to be verified by additional data in Indiana and along the LaSalle Anticline in Illinois.

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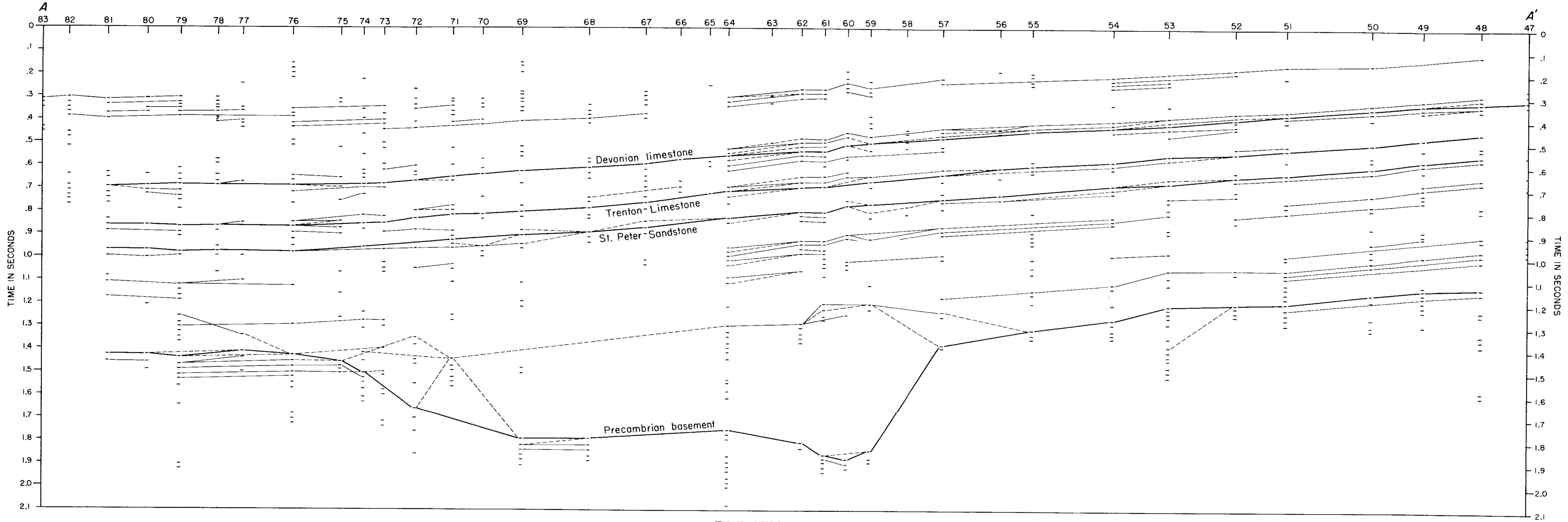
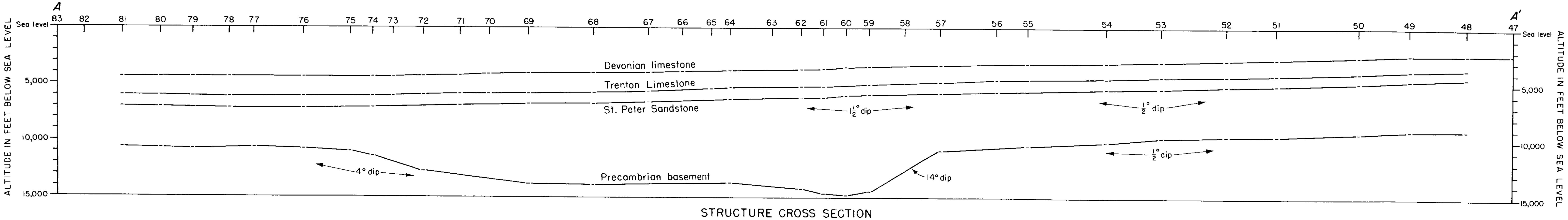


TIME CROSS SECTION



STRUCTURE CROSS SECTION
Vertical exaggeration approximately 2½ times

EXPLANATION

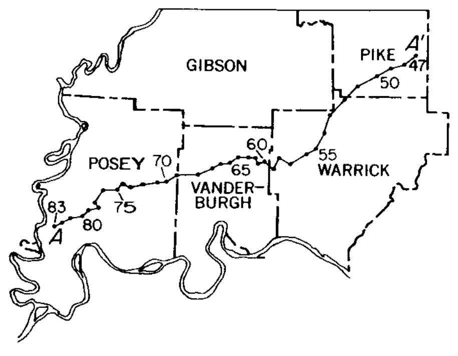
47
Number indicating seismic shot point location
See pl. 1 and table 2

Tick indicating reflection time from sea level to reflecting horizon and back

Correlation lines
Heavy line correlates principal identified reflection; light line correlates unidentified reflection; dashed line indicates alternate correlation

(Average altitude of seismic shot points along traverse *A-A'* is 440 feet above mean sea level)

Scale
1 0 1 2 3 4 5 Miles



Index map showing location of seismic shot points along traverse *A-A'*

TIME AND STRUCTURE CROSS SECTIONS ALONG TRAVERSE A-A'

By Albert J. Rudman

1960