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A Seismic Refraction Survey of the Meredosia Channel Area of Northwestern Illinois

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ABSTRACT

The depth and configuration of the bedrock surface in the Meredosia Channel area of northwestern Illinois were determined by seismic refraction surveying and by interpreting borehole information. The Meredosia Channel, the upper segment of the Princeton Bedrock Valley system, is a drift-filled segment of the pre-Late Wisconsinan Mississippi River Valley.

The mean elevation of the bedrock surface in the Meredosia Channel is approximately 450 feet above sea level. However, a glacially scoured groove more than 100 feet deep, 3.75 miles long, and 3,000 feet wide has been delineated in the channel. The elongate groove, oriented east-west along the south wall of the channel, is cut to an elevation of 340 feet above sea level and tapers upward to mean bedrock surface elevations of 450 feet on the east end. The groove was cut by a Kansan or pre-Kansan ice cap moving eastward. Scattered data in the vicinity suggest that there may be additional grooves in the region.

Although grooves of nearly this magnitude have been noted elsewhere in glaciated terrane, in the Mackenzie Valley, Canada, for example, they have not been described in the drift-covered bedrock valley systems of the mid-continent. The presence of a glacial scour feature of this size in a bedrock valley suggests that what has been called the "deep valley stage" of valley development in the mid-continent is, at least in part, a product of glacial action.

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INTRODUCTION

The Meredosia Channel, the upper segment of the Princeton Bedrock Valley system in northwestern Illinois, is a drift-filled lowland connecting the present-day Mississippi River Valley and the Green River Lowland (fig. 1). The channel narrows to 3.75 miles in width and has surface elevations ranging from slightly less than 580 feet to 600 feet above sea level. Bedrock uplands flanking the channel are mantled with glacial drift and loess and rise to elevations of more than 700 feet.

This report presents the results of a study of the bedrock topography in and around the Meredosia Channel. The study was made in order to determine whether the bedrock drainage system west of the present Mississippi River was connected to that on the east by a deep, preglacial channel as suggested by Horberg (1950). The study also provided a basis for evaluation of ground-water resources in northwestern Illinois.

Acknowledgments

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Previous Studies

Horberg (1950) describes the Meredosia Channel as outlining the course of the preglacial Mississippi River. His arguments are based on physiographic evidence and well data. His interpretation, following that of Leverett (1899), is that "the ancient Mississippi River occupied the upper Mississippi bedrock valley south to the present upper rapids in northern Rock Island County where it turned southeastward through buried Princeton Valley to the 'Big Bend' of present Illinois River near Hennepin" (Horberg, 1950, p. 44-45) (see fig. 1). Horberg (1950) states further (p. 45), "The unusually low elevation of bedrock at Dubuque, Iowa, less than 300 feet above sea-level, is of special interest because it suggests the presence of a deep and narrow bedrock channel along the valley which elsewhere is not indicated by the subsurface data now available." He shows the thalweg of the valley extending through the Meredosia Channel at elevations of less than 300 feet; however, from subsurface evidence within the study area, Horberg (1950) lists bedrock elevations as 418 feet at Erie, 434 feet at Prophetstown (Erie and Prophetstown shown in fig. 1), and 425 feet in sec. 31, T. 19 N., R. 4 E. Horberg concludes (p. 49) that "the preglacial Mississippi Valley lies buried either to the west in Iowa or to the east in Illinois, and that only the eastward course is supported by purely physiographic evidence."

Frye (1938) and Trowbridge (1954) proposed that the main preglacial valley was in central Iowa and that the present Mississippi Valley in southeastern Minnesota and northeastern Iowa resulted from diversion by Nebraskan ice and erosion to the deep valley stage during later interglacials. Horberg (1950) favors a preglacial age for the deep valley stage.

Frye, Willman, and Black (1965, p. 48 and 49) state, "It seems probable that the Nebraskan glacier largely determined the position of the Ancient Mississippi River throughout its course above the mouth of the Missouri River, and less directly, the position of the river southward to the head of the Embayment region."

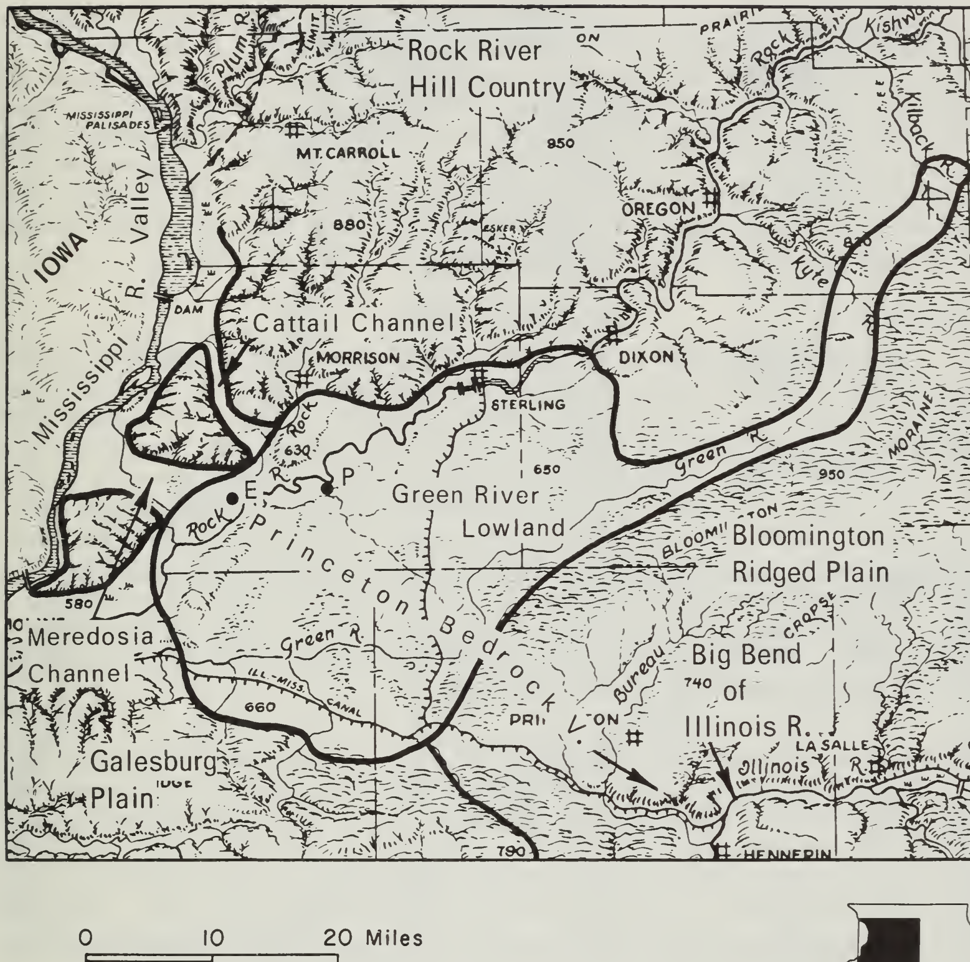


Fig. 1 - Physiography of the Meredosia Channel area, northwestern Illinois. The approximate axis of the buried Princeton Bedrock Valley is also shown. E, Erie; P, Prophetstown. (Adapted from Bier, 1956.)

Anderson (1968) reconstructs the entire glacial history of the area; of the early history of the Mississippi, he states, "The fact that the course of the Mississippi River appears to coincide with the eastern limit of the Nebraskan drift north of the Rock Island area suggests that this course may have been determined by Nebraskan ice" (p. 13).

After the preliminary exploration phase of the present study, Sowayan (1969) concluded, on the basis of finding bedrock elevations in the channel greater than 400 feet above sea level, that the preglacial Mississippi route did not traverse the Princeton Valley system. He suggested that the Cleona Channel in Iowa was the preglacial route and that diversion took place during Nebraskan glacial advance. McGinnis, Sowayan, and Jensen (1970) concurred with this interpretation; however, a deep cut (elevation less than 360 feet above sea level) found in the Meredosia Channel by drilling (data discovered after completion of the study by Sowayan) somewhat weakened their argument.

Areal Geology

The bedrock geology of the Meredosia Channel area is shown in figure 2. The Meredosia Channel area is underlain by nearly flat-lying Silurian dolomite. Unmapped outliers of Pennsylvanian strata have been reported by Anderson (1967) along the Rock River near the southern limits of the study area. Scattered outcrops of Pennsylvanian strata have also been mapped as far as 10 miles north of Erie. The Galena Dolomite and Maquoketa Shale Groups of Champlainian and Cincinnatian (middle and upper Ordovician) age, along with scattered outliers of Silurian dolomite, form the bedrock surface in the northwest part of the study area. Inferences regarding variations in bedrock lithology can be made from observations of seismic velocities as discussed in the section on geophysical measurements. These observations suggest that the edge of the Pennsylvanian shales is farther north than mapped previously.

Structure

Meredosia Channel occupies an east-west trending structural sag. Foster (1956) gives a structural map of the top of the Galena Dolomite Group, showing that the Galena is dipping due south, about 30 feet per mile at a point about 6 miles north of Erie. The top of the Galena is at approximately sea level at that point; therefore, it would be at -180 feet at the town of Erie. Buschbach (1965) shows the Galena also rising to nearly sea level about 25 miles southwest of Erie and dipping approximately 20 to 25 feet per mile to the north on the north side of an anticlinal structure on the Galena.

SEISMIC REFRACTION MEASUREMENTS

The present study utilizes available borehole logs (fig. 3) and 71 seismic refraction profiles (fig. 4) to better define the bedrock surface and also to aid in the identification of bedrock lithologies and valley-fill materials. A gravity study was also made with the present study; however, since the gravity field proved to be unrelated to bedrock topography in the Princeton Valley area, it was not included in this report.

Because of the widespread distribution of shallow aquifers in the lowlands of the Meredosia Channel region, wells to bedrock from which bedrock elevations can be determined are rare. A seismic refraction study, along with an incorporation of all available outcrop and well-control data, was deemed the most useful way to develop a detailed knowledge of the shape of the bedrock lowlands. A thin drift and loess cover in the incised uplands does not lend itself to geophysical surveying; therefore, this study was conducted only in the lowlands.

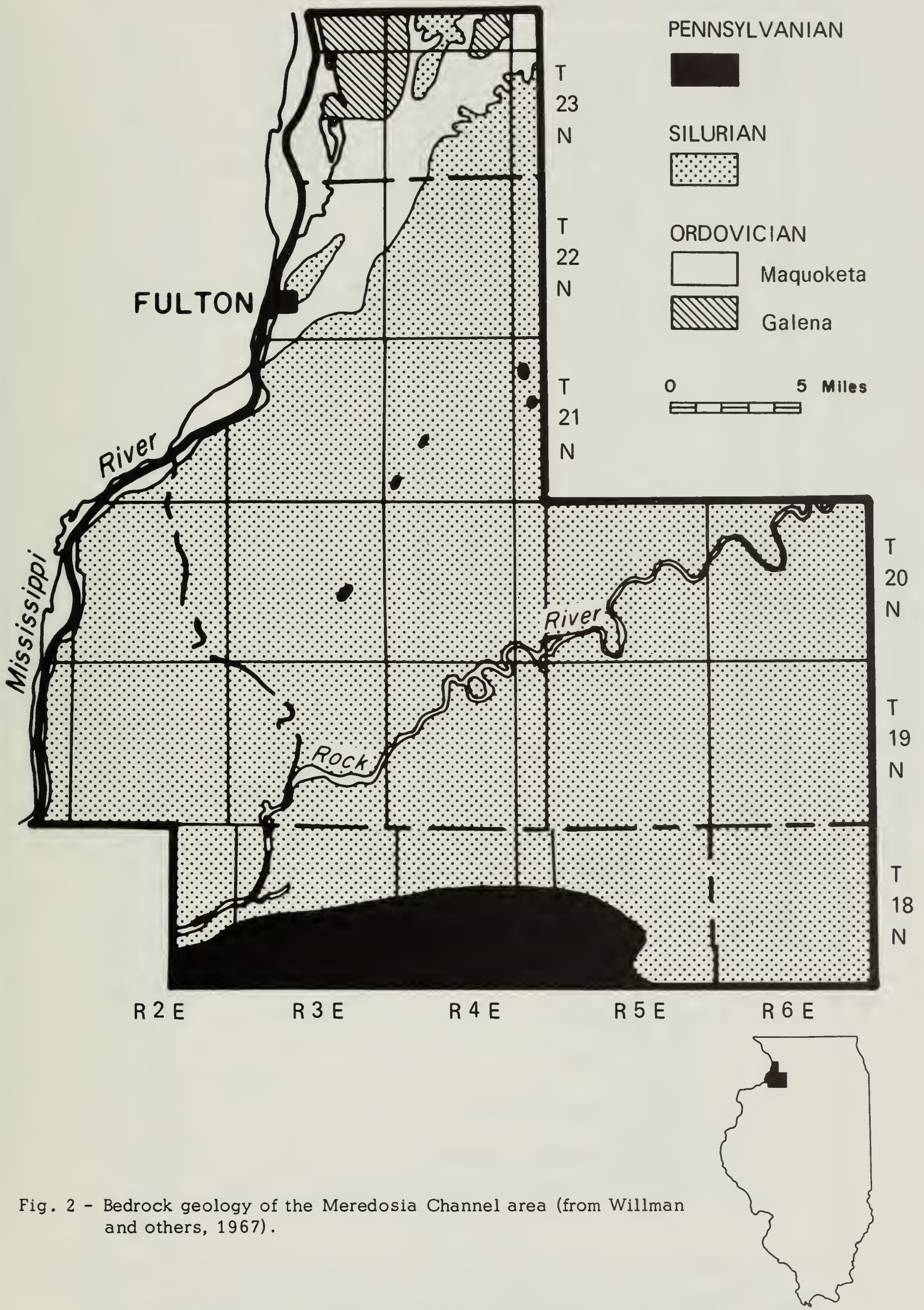


Fig. 2 - Bedrock geology of the Meredosia Channel area (from Willman and others, 1967).

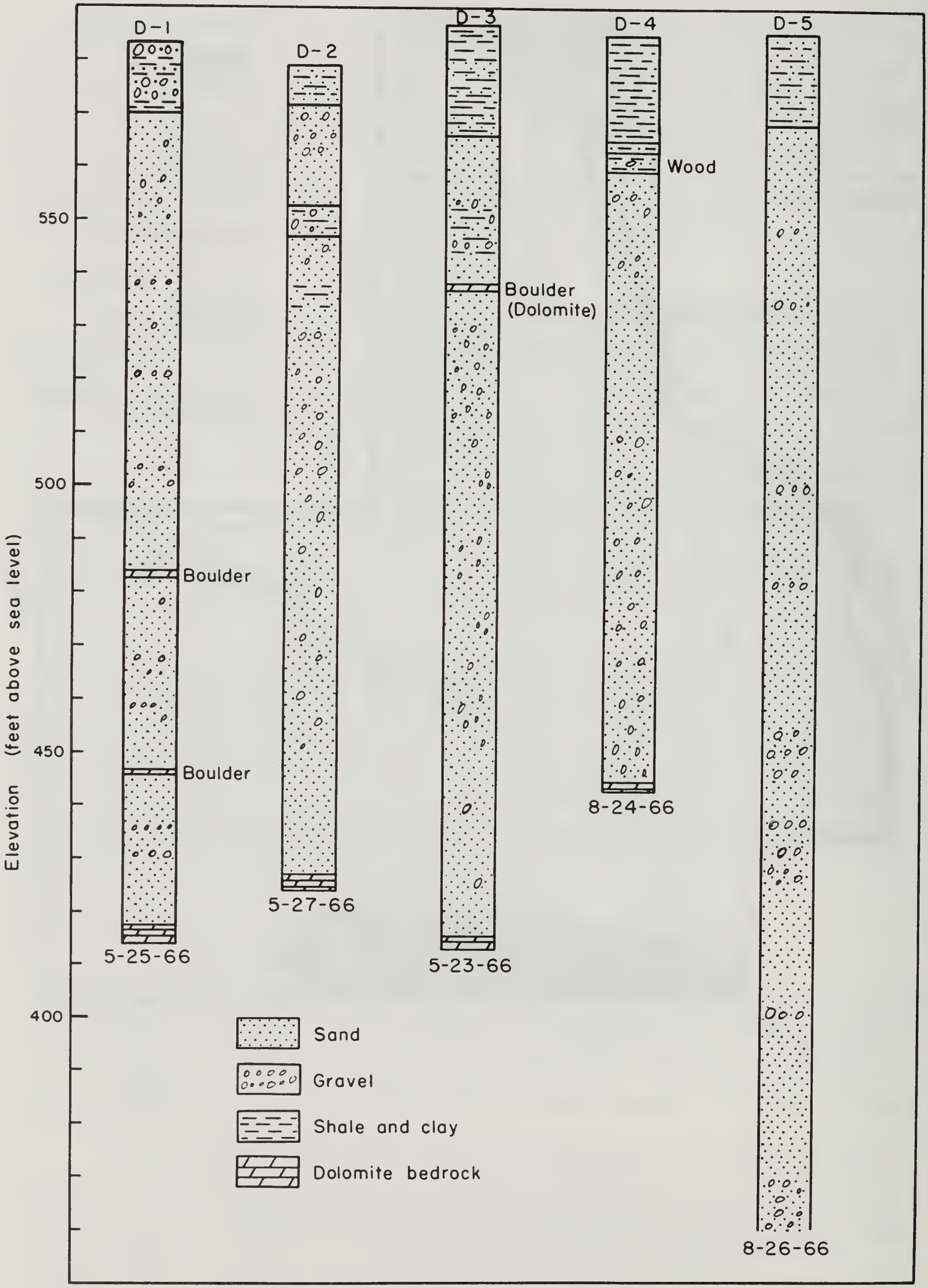
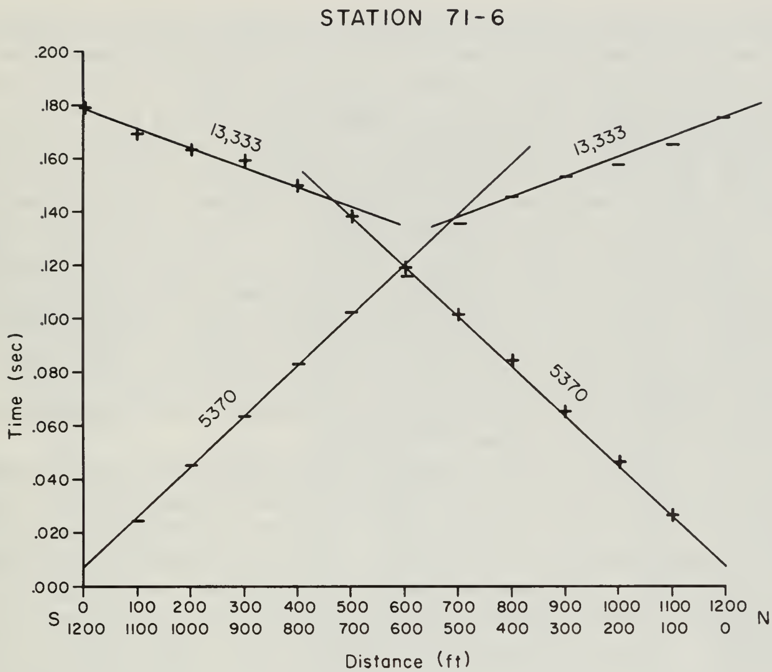


Fig. 3 - Graphic logs of deep drillholes provided by the U.S. Army Corps of Engineers. Locations of the holes are shown on figure 6.



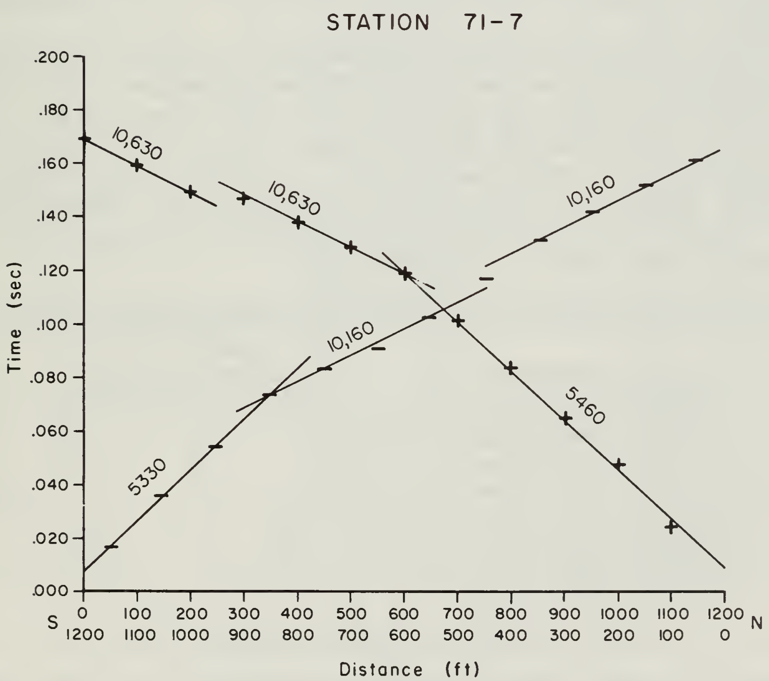


Fig. 4 - Time-distance curves from seismic stations over the deepest portion of the Meredosia Channel. Locations of the stations are shown in figure 5.

Of the 71 seismic refraction stations occupied during the course of the study, 60 were reversed (shot at each end of the geophone spread); the remainder were shot in one direction only. Three continuous profiles were shot across portions of the Meredosia Channel, as illustrated in figure 5.

A 24-channel Seismograph Service Corporation reflection-refraction seismograph owned by Northern Illinois University was used during the summer of 1968. In later studies we used a GEOSPACE 12-channel refraction seismograph belonging to the Illinois State Geological Survey. During the initial stages of the project, when depths of the order of 300 feet to bedrock were expected, a 2400-foot geophone spread was utilized. After several shots in the deeper parts of the Meredosia Channel, as mapped by Horberg (1950), we found that 1200-foot spreads were sufficient to measure depths to bedrock. Shot holes were drilled to 6-foot depths and loaded with 2 pounds of Nitramon S primer. The shot was generally placed 100 feet from the first geophone, and geophones were placed at 100-foot intervals along the spread.

Seismic velocities within 15 feet of the surface were not measured. Other studies in Illinois have shown that velocities in the weathered surficial layers average 1200 feet per second. This velocity was used to represent the first seismic layer throughout the survey. Velocities below the weathered layer to bedrock ranged from 4570 feet per second to 6125 feet per second; however, at only one station was a velocity greater than 6000 feet per second recorded (see appendix). The mean velocity of sediment below water table in the lowlands is 5130 feet per second, which is representative of velocities for saturated sands and gravels. The prevalence of velocities in the 5000 feet per second range reflects the absence of higher velocity glacial till in the subsurface of the lowland areas.

Bedrock velocities range from 9000 feet per second to 16,650 feet per second. In general, only one bedrock velocity was detected at each site; however, at five stations both a low bedrock velocity at the bedrock surface and a higher velocity somewhat deeper were measured. Lower velocities may correspond to old glacial tills, weathered dolomite, or possibly Pennsylvanian shales or sandstones, whereas the higher velocities indicate the presence of Silurian dolomites. Taking into account all reversed refraction stations, table 1 indicates the velocity distribution in the bedrock.

TABLE 1 - VELOCITY DISTRIBUTION IN BEDROCK IN THE MEREDOSIA CHANNEL AREA

Velocity interval	Number of stations recording
9,000-10,000 ft/sec	2
10,000-11,000 ft/sec	11
11,000-12,000 ft/sec	6
12,000-13,000 ft/sec	15
13,000-14,000 ft/sec	11
14,000-15,000 ft/sec	7
15,000-16,000 ft/sec	7
16,000-17,000 ft/sec	2

Some of the lower bedrock velocities were found in the lower Rock River drainage basin in the area southeast of the Meredosia Channel where Anderson (1967) noted sporadic outcrops of Pennsylvanian shale. Velocities in the 9000

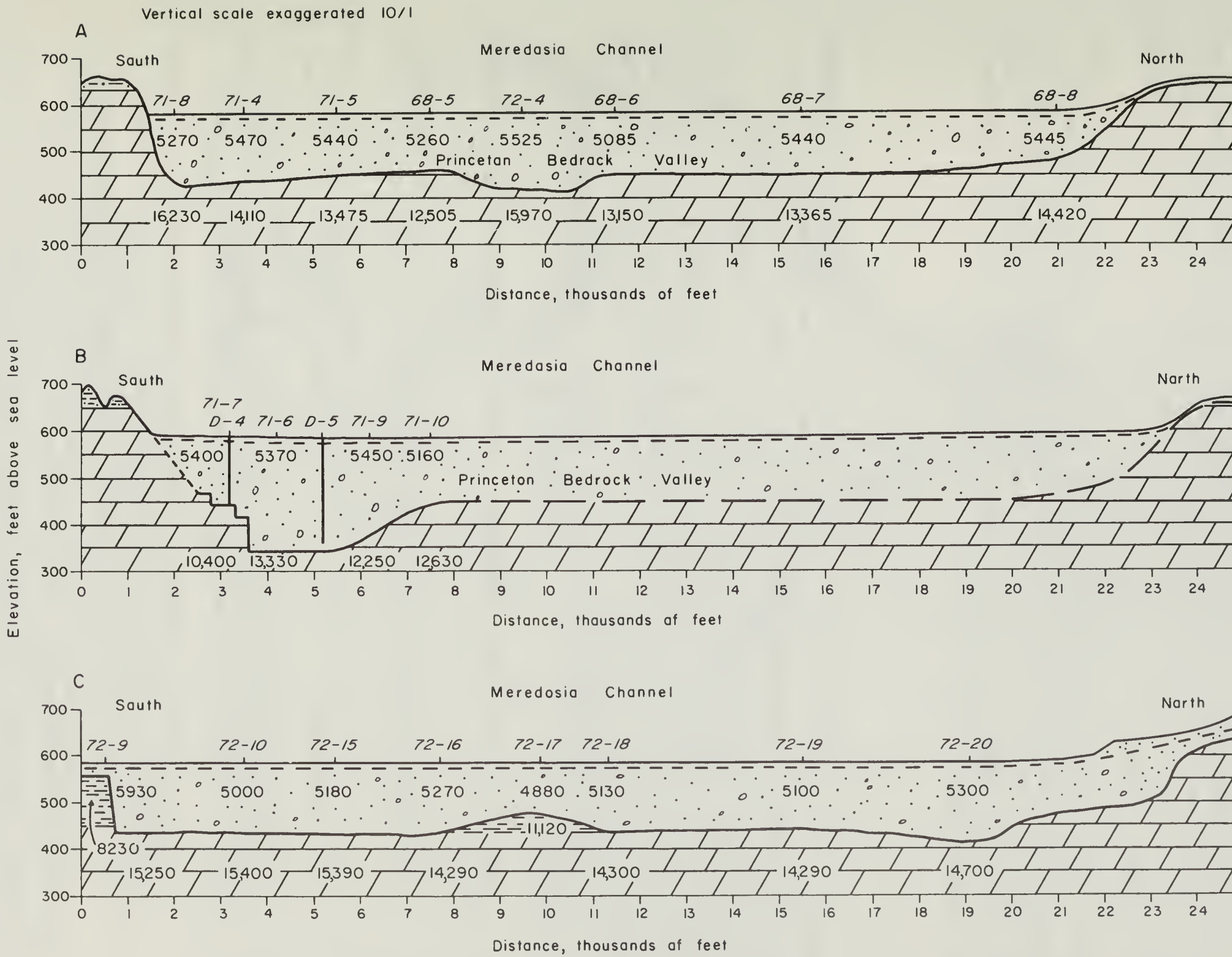


Fig. 5 - Geologic cross-sections across the Meredosia Channel based on seismic refraction profiles and borehole information. Numbers below seismic station numbers (e.g., 5270 and 16,230 below 71-8) are travel velocities in feet per second. Locations of cross-sections are shown in figure 6.

to 12,000 feet per second range probably represent shale bedrock, and therefore Pennsylvanian strata are suspected to lie beneath the lower Rock River lowland area. Boreholes drilled into bedrock in several locations in this area encountered scattered shale and sandstone of Pennsylvanian age. Since bedrock in the uplands surrounding the lower Rock River basin has been mapped as Silurian dolomite, the presence of Pennsylvanian sediment in the valley bottoms was unexpected and may represent deposition in a pre-Pennsylvanian erosional unconformity on the Silurian surface.

Three north-south continuous profiles across, or partially crossing, the Meredosia Channel were completed (fig. 5). All of the stations on these profiles exhibit bedrock velocities in excess of 12,000 feet per second except for the southernmost station of Profile B-B' and a station on the south end of Profile C-C'. These stations of low-velocity bedrock no doubt indicate the presence of something other than Silurian dolomite.

DISCUSSION

In the initial stages of this study, that is, when the 2400-foot geophone spreads were used and the gravity survey was made, it was assumed that Horberg's (1950) bedrock topography map of Illinois was essentially correct in detail. The map of Horberg, although proven over and over again to be correct in its portrayal of regional bedrock topography, does lack the precision needed for studies of a local nature. With large amounts of new bedrock data concentrated in small areas to resolve specific problems, an occasional new interpretation having regional significance does result. The authors believe the present work introduces data of this nature.

The bedrock topographic map shown in figure 6 contains several noteworthy features:

1. Bedrock elevations in the "deep" channels average 450 feet above sea level;
2. A closed depression in the Meredosia Channel is cut more than 100 feet below average depths in the channel;
3. The flat-bottomed, steep-walled Cattail Channel is cut to about 500-foot elevation;
4. The present Mississippi Channel, north and west of Meredosia, is cut to depths similar to those of the Meredosia Channel and also contains a deeply cut groove that may be another closed depression;
5. The broad lowland southeast of Meredosia Channel does not fit physiographically with the Meredosia Channel;
6. Low-velocity bedrock rests on a high-velocity bedrock surface at elevations of about 500 feet in the lower Rock River Valley south of Meredosia Channel;
7. The east-west trend of the Meredosia Channel is continued in the subsurface north of the lower Rock River Valley.

The bedrock topography map of Horberg is also shown for comparison (fig. 7).

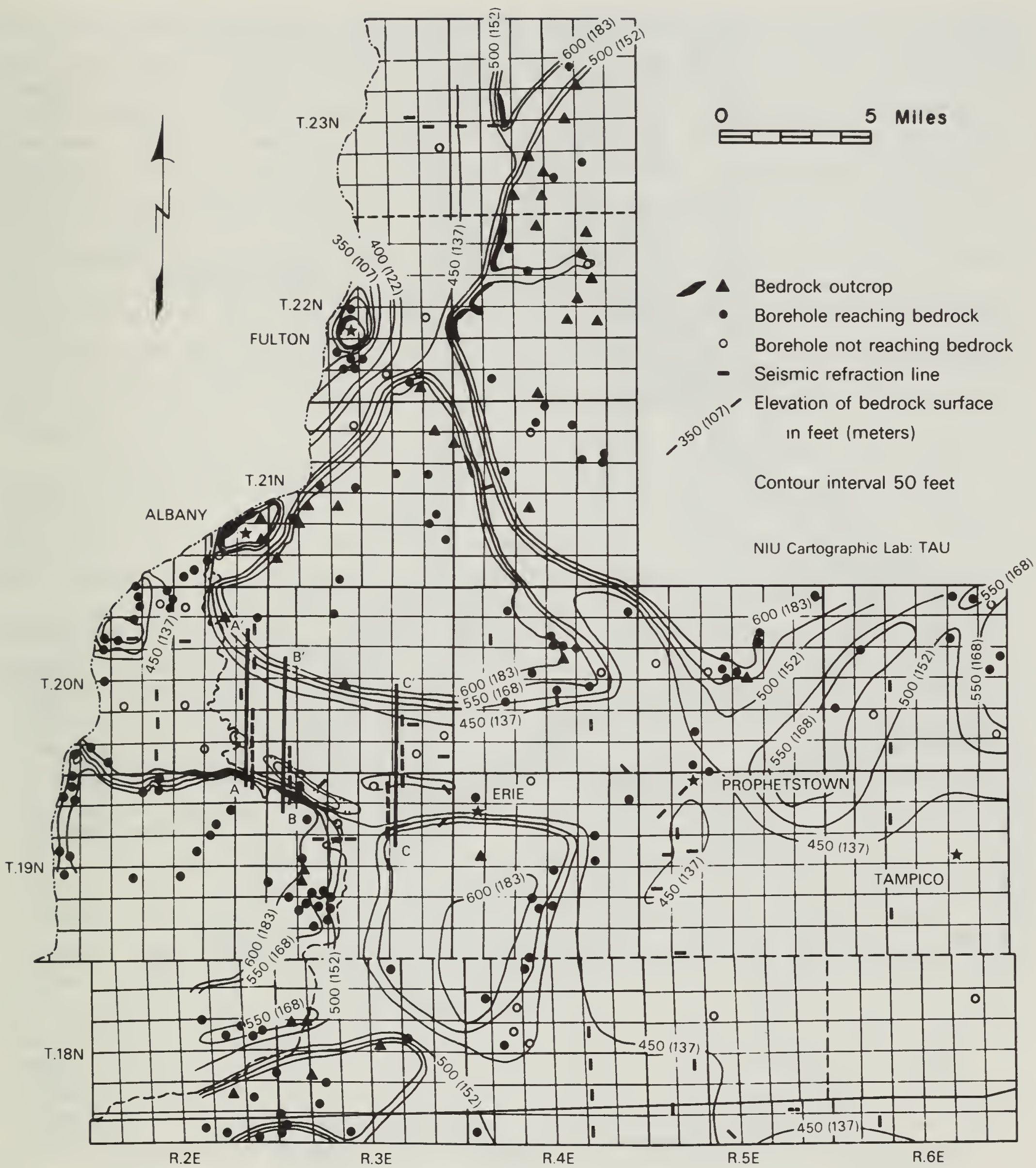


Fig. 6 - Bedrock topography and seismic refraction lines in the Meredosia Channel area. Lines of geologic cross-sections (A-A', B-B', and C-C', fig. 5) are shown.

On the basis of the observations listed, it can be stated that a deep channel cut below 300 feet does not trend through the Meredosia Channel and that there is no evidence anywhere in the area studied of any bedrock surface elevations less than about 340 feet above sea level. Consideration of crustal flexure due to glaciation set aside for the moment, bedrock grade elevation in the Meredosia Channel (thalweg) is not less than about 420 feet. The Rock

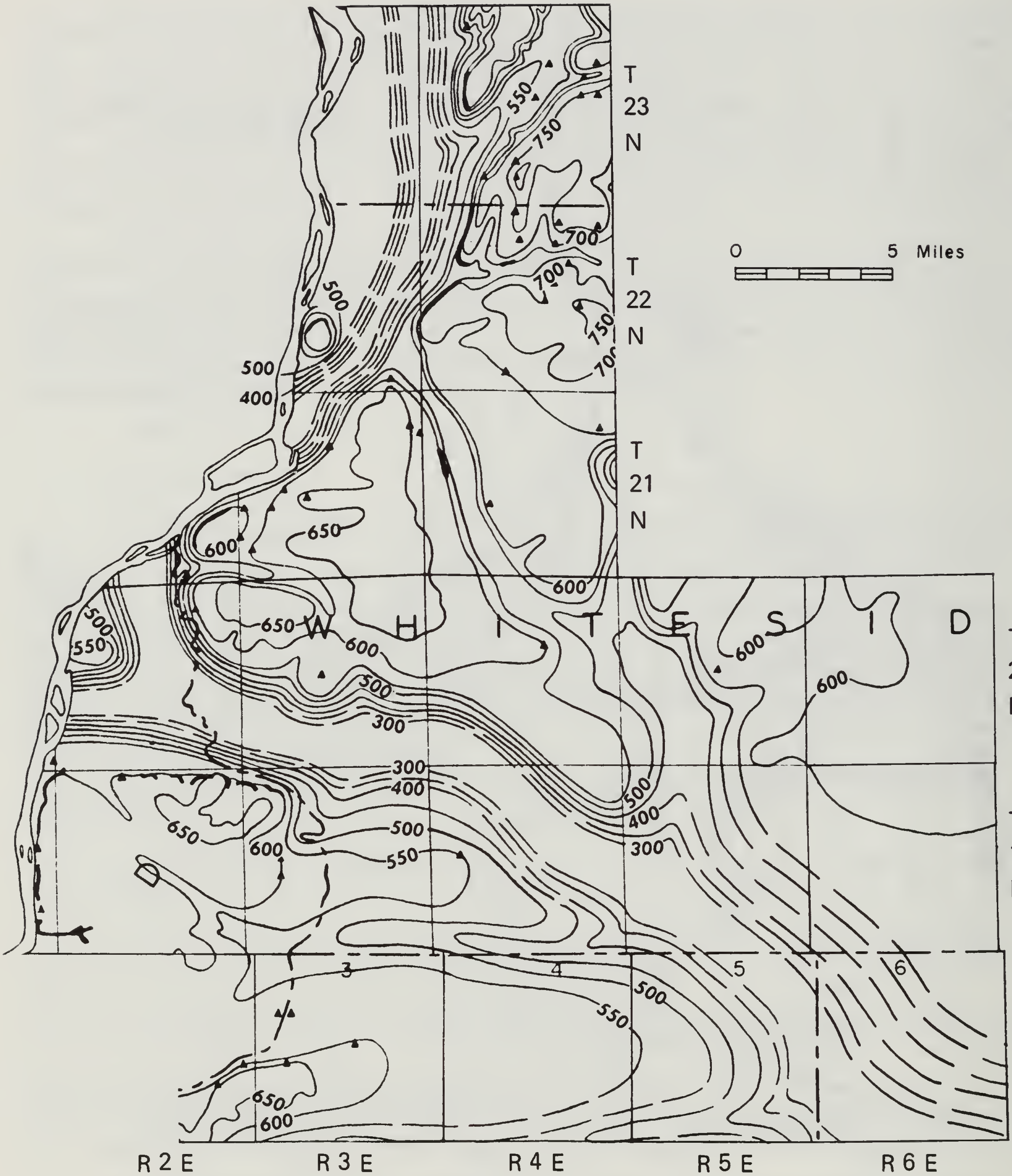


Fig. 7 - Bedrock topography of the Meredosia Channel area, from Horberg (1950 [1957]).

River Bedrock Valley is eroded to an elevation of about 500 feet, as is the Cattail Channel. These channels, therefore, never occupied a position as prominent as Meredosia Channel in the history of Mississippi River drainage.

The closed, 100-foot-deep depression in the Meredosia Channel is about 3000 feet wide and extends in an east-west direction nearly 4 miles along the south wall of the channel. The depression was noted after preliminary studies were concluded during the first summer of seismic exploration in 1968. The geophysical study had been completed when the records from U.S. Army Corp of Engineers boreholes drilled in 1966 in the Meredosia Channel were made available to the authors. A deep hole (D-5 in fig. 3) appeared to contradict information gathered during the seismic study. The borehole was drilled more than 226 feet (bedrock elevation less than 360 feet above sea level) into sands and gravels and did not penetrate bedrock. Subsequent seismic studies made over the drill holes confirmed the presence of abnormally low bedrock (elevation 340 feet), and therefore the seismic study was expanded to explore in more detail the configuration of the low bedrock surface. Continuous seismic profiles were run both east and west of the borehole, and it was found that the borehole was inadvertently but fortuitously placed over a closed depression. Closed depressions or very narrow deep channels have long been suspected by staff members of the Illinois State Geological Survey; however, this report is the first documentation of such a feature.

Glacial scour of the dolomite bedrock floor of the channel is the most likely cause of the depression. Frye (1963), McGinnis (1968), and Willman and Frye (1969) infer that crustal bending also gives rise to anomalous bedrock elevations; however, the depression noted in the present paper is probably not the product of crustal bending inasmuch as it extends over too short a distance.

Glacial scour of the Meredosia Channel is consistent with the glacial history of the region. It is suspected that the Meredosia Channel area was entered at least once by glaciers during each of the four major glaciations. During Nebraskan and Kansan time the valley may have been entered from the west, whereas during Illinoian and Wisconsinan time it was entered from the east (Anderson, 1968; Willman and Frye, 1969). Reports of gravels of Kansan age resting on the floor of the Meredosia Channel seem to indicate that the elongate depression could not have been cut as late as Illinoian or Wisconsinan time (Willman and Frye, 1969).

Glaciated grooves on bedrock have been described by Smith (1948) and Wold and Ostenso (1966). Smith describes grooves up to 300 feet wide, more than 100 feet deep, and up to 8 miles long in the Mackenzie Valley of northwest Canada. They occur over a 50 square mile area and, although they occur within the walls of the major valley, they are not controlled by local topography but by the direction of ice movement. Smith believes the entire valley was at one time covered by an ice sheet moving essentially parallel with the axis of the major valley. Wold and Ostenso (1966) illustrate bedrock valleys in western Lake Superior that may or may not be closed depressions. The travel time of reflections observed in the valleys indicates that the relief may be as much as 150 to 200 feet and that the valleys are several miles across. The origin of these depressions remains unclear although the Lake Superior basin was certainly scoured through glacial processes. Flint (1957, p. 83) suggests that where a main valley is covered by an extensive ice sheet the ice is thicker over the valley and less impeded by topographic barriers than is ice over tributaries. Tributaries are left hanging as the main valley is deepened.

The possibility of deepening a bedrock valley floor below grade through water action has been discussed by Matthes (1947). He describes a macroturbulence phenomenon in natural streams undergoing rising river stages; in this phenomenon a vortex in the stream produces upward displacement of the river bed. Lifting, according to Matthes, occurs not only in bed-load materials but in resistant beds as well. The vortex is associated with a "boil" on the water surface and occurs along the axis of the main current or at other points where sufficient energy is developed. Matthes claims this phenomenon is active in the present Mississippi River and is an important agency in bed scour and in pothole formation. He refers to the process as a "kolk," which is a term used by Dutch engineers to explain this vortex type of bed deepening.

In the abnormal deepening produced by the "kolk" process, one might expect a relatively rough bedrock floor according to illustrations shown by Matthes. If the deepening is a result of glaciation, one would expect the depression to be rounded and smooth. From the type of data available, that is, seismic refraction profiles, it is not possible to describe with certainty the microtexture of the bedrock surface; however, at station 71-6 (figs. 4 and 5B), located directly over the depression, the seismic data suggest that the bottom is smooth and therefore probably was produced by glacial scour.

Station 71-7 (figs. 4 and 5B), shot immediately south of 71-6, displays evidence of bedrock ledges having relief of about 25 feet. Thus, although the valley bottom is horizontal and planar, the south walls of the valley rise to the surface in steps as they do in many alluviated valleys in carbonate terrane. The north wall of the depression rises gradually in a manner one might expect to be produced by glacial scour. Thus both glacial and water erosion may be represented in the walls of the depression. The Meredosia Channel and its depression may have been initially scoured by glaciers moving into a valley from the west in Nebraskan and Kansan time and later modified by the plucking action described by Matthes (1947).

Seismic stations and wells to bedrock in the present Mississippi channel northwest of the Meredosia Channel indicate bedrock elevations similar to those found in the Meredosia Channel, with the exception of several wells in and just to the southeast of Fulton. Here also low elevations (~350 feet) are observed and another depression may be present. Seismic studies were not conducted in the vicinity of Fulton to verify the nature of this depression; therefore, an open-ended low was constructed on the bedrock topography map. This low also is located in a narrow constriction similar to, but smaller than, the Meredosia Channel and therefore is probably similar to the Meredosia depression.

Southeast of the Meredosia Channel, the Princeton Bedrock Valley flattens out into a broad lowland. This lowland, in general characteristics, predates Pleistocene glaciation (Horberg, 1950). It may have been a physiographic low developed on a northward extension of Pennsylvanian shales of the Illinois Basin. It probably owes its development to a combination of factors, including structure, stratigraphy, and stream erosion.

By means of exploration seismic profiles, which were located in the lower Rock River Valley to further establish bedrock configuration, unusually low bedrock velocities were detected. These velocities ranged from about 9000 feet per second to 12,000 feet per second, considerably less than the velocities observed elsewhere. An examination of the bedrock record from cores in boreholes and a review of Anderson's paper (1967) indicate the presence of Pennsylvanian shale outcrops in the lower Rock River. Since the elevation of the bedrock surface in the valley bottom is of the order of 500 feet and uplands flanking the valley contain Silurian outcrops, an explanation must be found for the implied structure.

Shale bedrock is inferred from seismic data in the lower Rock River Valley northward to seismic station 72-9 (fig. 5). At this station a ledge on the bedrock surface is apparent. The floor of the eastward extension of Meredosia Channel is associated with higher velocities of Silurian type. It would appear that prior to Pleistocene deepening of the Meredosia Channel, the channel was filled with a tongue of Pennsylvanian sediments.

From the observations discussed, one can attempt a reconstruction of the early development of the bedrock valley in Meredosia Channel and its environs. Beginning with the most recent glacial events, Anderson (1968) has shown that glaciers extended into the Meredosia Channel from the east in both Wisconsinan and Illinoian time. If Kansan gravels are contained in the channel, these glaciers could not have modified the bedrock surface in the valleys. On the basis of data presented in this paper, we conclude that either Kansan or Nebraskan glacial lobes must have extended into Meredosia Channel.

A history of the valley, based partly on conjecture and partly upon arguments supported by observations of structure, drainage systems, and glaciers, is as follows. Glaciers from the west moved in lobes down lowland areas (Horberg and Anderson, 1956). Drainage normally flowing into the lowlands must either have been diverted to routes along glacial margins or have backed up as ice marginal lakes and spilled over divides into tributaries of adjacent systems. Channels, such as the Meredosia Channel, were developed across divides by stream erosion. Further ice build-up caused glacial advance into tributary systems deepened by torrential flooding and high stages. Glaciers advanced into the deepened tributaries and produced glacially scoured features like those observed on the floor of Meredosia Channel.

The early Pleistocene history of the Meredosia Channel proposed here is in essential agreement with the history proposed by Frye in 1938. Studies made in the last decade on all drainage routes of the ancient upper Mississippi River system indicate a youthfulness of the system and the presence of steep-sided valleys cutting through the uplands with sharp-angle turns and hanging tributary valleys. These characteristics are not representative of a well-developed preglacial drainage system unaltered by glacial diversion.

Frye, Willman, and Black (1965) suggest that the preglacial drainage of the Mississippi system has been so altered that it is no longer detectable. On the basis of presumed preglacial geomorphology, structure, and stratigraphy and with some conjecture, it is possible to infer a preglacial drainage network as has been done by Horberg and Anderson (1956).

The constraint requiring an explanation for abnormal elevations in bedrock valleys and often expressed in previous studies is no longer a valid consideration if it can be presumed that deepening by glacial scour was a factor in the modification of bedrock valleys.

SUMMARY

Elevations in major bedrock valleys of northwestern Illinois average 450 feet above sea level, more than 150 feet above those postulated by Horberg (1950). Although Horberg and Anderson (1956) state that master valleys and principal tributaries have gradients descending toward the Gulf of Mexico, the present study, based on detailed measurements in the Meredosia Channel, illustrates that this condition does not exist here. A closed and elongate east-west depression located along the south wall of the channel descends more than 100 feet below average Meredosia Channel elevations.

Frye (1938) suggests that the "deep valley stage" occurred during interglacials; however, it appears that the "deep valley stage" occurred about the same time as glacial maxima since the bedrock valley bottom, at least in the Meredosia Channel, is marked by the effects of glacial deepening. Glacial scour noted in this study probably occurred during Kansan glacial maxima.

The bedrock valley of the Mississippi River west and northwest of the Meredosia Channel has elevations similar to those in the Meredosia Channel. A closed depression is also suggested near Fulton although data are insufficient to document closure.

Documentation of large-scale glacial grooves on bedrock valley floors in the mid-continent introduces a new type of glacial feature by which the glacial history of the region can be interpreted. Grooves as wide as that in the Meredosia Channel have not been reported elsewhere in the literature. Large-scale grooves not only require a reinterpretation of bedrock topography in the mid-continent but also change quantitatively the presumed dimensions of glacial drift aquifers.

Evidence of large-scale glacial scour on the bedrock valley floor in the Meredosia Channel suggests that thick Nebraskan or Kansan glaciers moved eastward across the present Mississippi Valley in the study area.

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APPENDIX: SUMMARY OF RESULTS OF SEISMIC REFRACTION SURVEY

Station no.	Location			Velocities			Thicknesses		Surface elevation (ft above msl)	Bedrock elevation (ft above msl)
	Sec.	T. (N.)	R. (E.)	V_0 (ft/sec)	$\overline{V}_1$ (ft/sec)	$\overline{V}_2$ (ft/sec)	Z_0 (ft)	Z_1 (ft)		
68- 3	1	19	3	1,200*	5,195	12,830	—	140	590	450
4	12	19	3	1,200*	5,000	10,550/14,500	—	41	580	539
5	36	20	2	1,200*	5,300	12,635	3	117	579	459
6	25	20	2	1,200*	5,090	13,150	5	132	584	447
7	24	20	2	1,200*	5,440	13,365	5	130	584	449
8	13	20	2	1,200*	5,445	14,420	6	106	585	473
9	12	20	2	1,200*	4,170	10,520	9	69	680	602
10	7	20	2	1,200*	—	11,390	34	—	595	561
11	8	20	2	1,200*	—	11,015	26	—	610	584
12	10	20	2	1,200*	5,635	14,495	8	142	585	435
13	29	19	5	1,200*	5,200	10,260	5	157	615	453
14	32	19	5	1,200*	5,245	12,010	5	170	610	430
15	8	19	5	1,200*	5,030	13,370	3	153	620	464
16	18	19	5	1,200*	5,225	13,010	4	167	615	444
17	17	19	5	1,200*	5,155	9,555	5	141	610	464
18	7	19	5	1,200*	5,225	15,645	10	161	610	439
19	5	19	5	1,200*	5,085	14,225	5	168	610	437
20	36	20	4	1,200*	5,205	12,730	6	158	590	426
21	26	20	4	1,200*	5,000	13,375	5	144	590	441
22	22	20	4	1,200*	5,000	12,090	7	126/35	590	457/548
23	8	20	4	1,200*	—	10,650	45	—	720	675
24	14	18	4	1,200*	5,580	12,320	5	125	610	480
25	23	18	4	1,200*	5,210	12,225	3	121	610	486
26	26	18	4	1,200*	5,690	12,310	5	119	610	486
27	35	18	4	1,200*	6,125	12,500	3	113	610	494
28	26	20	3	1,200*	5,210	14,020	6	133	585	446
29	36	20	3	1,200*	5,340	16,650	9	136	589	444
30	17	21	4	1,200*	4,570	15,275	10	103	605	492
31	14	23	3	1,200*	4,690	14,700	38	141	620	441
32	24	23	3	1,200*	5,435	16,435	20	141	605	444
33	19	23	4	1,200*	5,000	15,100	12	135	600	453
34	20	23	4	1,200*	4,750	14,650	11	100	605	494
35	33	20	2	1,200*	5,205	13,505	25	138	605	442
36	28	20	2	1,200*	5,165	13,335	23	145	600	432

37	21	20	2	1,200*	4,940	12,300	26	139	603	438
38	20	18	5	1,200*	5,050	12,560	10	153	625	462
39	30	18	5	1,200*	5,000	12,350	5	161	630	464
40	33	18	5	1,200*	5,035	13,240	5	169	610	436
41	26	18	5	1,200*	5,360	13,810	5	174	620	441
42	32	18	6	1,200*	5,070	11,735	6	178	620	436
71- 1	21	20	6	1,200*	5,000*	10,260	5	59	604	540
2	33	20	6	1,200*	5,400	11,430	9	142	625	474
3	9	19	6	1,200*	5,070	10,970	4	152	618	462
4	36	20	2	1,200*	5,470	14,110	5	143	579	431
5	36	20	2	1,200*	5,440	13,975	7	124	579	448
6	6	19	3	1,200*	5,370	13,330	4	238	580	338
7	6	19	3	1,200*	5,400	10,400	5	136	580	439
8	1	19	2	1,200*	5,270	16,230	5	139	580	436
9	31	20	3	1,200*	5,450	12,250	6	192	580	382
10	31	20	3	1,200*	5,160	12,630	5	134	580	441
11	28	19	6	1,200*	5,290	12,000	8	201	631	422
72- 1	13	18	2	1,200*	5,000	11,360	10	60	570	500
2	13	18	2	1,200*	5,000	10,635	5	30	580	545
3	12	18	2	1,200*	5,000	11,260	5	40	580	535
4	12	18	2	1,200*	5,000	10,715	5	32	580	543
5	2	18	2	1,200*	5,000	11,820*	5	31	582	546
6	5	19	3	1,200*	5,340	10,875	9	169	580	402
7	14	19	3	1,200*	5,000*	8,140/11,480*	5	25	585	555
8	15	19	3	1,200*	5,000*	10,960*	5	33	587	549
9	10	19	3	1,200*	5,930	8,230/15,250	5	22/146	585	558/432
10	10	19	3	1,200*	5,000	15,400*	6	143	586	435
11	16	19	3	1,200*	5,760	15,210*	7	96	580	477
12	16	19	3	1,200*	5,000	10,745/15,210	5	61	580	514
13	17	19	3	1,200*	5,000	9,000/15,210	5	21	590	564
14	25	20	2	1,200*	5,525	15,970	7	151	580	422
15	10	19	3	1,200*	5,180	15,390*	4	155	586	427
16	3	19	3	1,200*	5,270	14,290*	4	146	585	435
17	2	19	3	1,200*	4,880	11,120*	11	100	585	474
18	35	20	3	1,200*	5,130	14,300	8	142	585	435
19	35	20	3	1,200*	5,100	14,290*	10	133	585	442
20	26	20	3	1,200*	5,300	14,700*	4	170	585	411

* Indicates an assumed velocity or that geophone spread was not reversed.

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