U.S. DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Common-depth-point seismic-reflection survey on the Mississippi River in the vicinity of Alton, Illinois

by George B. Tirey[1], Richard A. Wise[2], and Elizabeth A. Winget[3]

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1. Present address: Minerals Management Service, Vienna, Va.
2. U.S. Geological Survey, Denver, Co.
3. U.S. Geological Survey, Woods Hole, Mass.

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Abstract

A high-resolution seismic-reflection survey was run on the Mississippi River using marine common-depth-point (CDP), digital, and multichannel techniques in an attempt to locate a possible fault that had been interpreted by others from magnetic and land seismic data to be in the vicinity of Lock and Dam No. 26. The geologic feature is commonly known in the literature as the Cap au Gres Fault or Cap au Gres Uplift. A second objective was to demonstrate that the marine seismic system could be used successfully for making relatively deep penetration seismic-reflection surveys on inland waterways with shallow water depths (less than 10 meters) and organic sediments on the waterway bottom.

The survey was made by agreement between the U.S. Army Corps of Engineers (COE), St. Louis District, and the U.S. Geological Survey (USGS). The USGS used a specially equipped, trailerable, 38-ft aluminum boat for the work. The quality of the survey records can be classified as from fair to good. Seismic-reflection events could be interpreted in the upper 200 ms of data. Five reflecting horizons with little slope were recorded between Mississippi River Miles 195 and 210 without any evidence of faulting of the magnitude (50 to 100 m) suggested by the Shannon and Wilson report (1980). Minor faulting and buried channeling could be interpreted.

This survey demonstrated the value and economy of obtaining deeper penetration seismic data on inland water using an offshore marine, CDP, digital, multichannel seismic-reflection system. On-going modifications in field procedure, equipment configuration, equipment, and data processing will further improve the results obtained with such equipment. Future marine-style surveys conducted with the newly available hydraulic waterguns (80-, 200-, and 400-in^3) would probably produce data that are a significant improvement over data obtained with the 15-in^3 pneumatic watergun and 40-in^3 airgun used during the 1980 survey.

Introduction

This study was undertaken by the U.S. Geological Survey (USGS) as the result of a cooperative agreement between USGS and the U.S. Army Corps of Engineers (COE). The objective of the cooperative seismic-reflection study was to determine whether or not a fault that had been previously postulated as intersecting the Mississippi River could be detected and mapped using marine common-depth-point, seismic-reflection techniques. This work was performed as follow-on work to an earlier cooperative research effort conducted at Rend Lake, Ill., by the U.S. Bureau of Mines and the U.S. Geological Survey (Miller and others, 1981). The field work was performed in December 1980 to take advantage of the R/V NEECHO (a trailerable, 38-ft, aluminum research vessel equipped with highly specialized seismic-reflection equipment) which had been used for the Rend Lake study and which was already mobilized in the general area.

The survey covered an area between Alton, Illinois, and St. Louis, Missouri. Seismic lines were run from the mouth of the Missouri River up the Mississippi River to a distance approximately seven miles upriver from Lock and Dam No. 26 at Alton, Illinois (fig. 1).

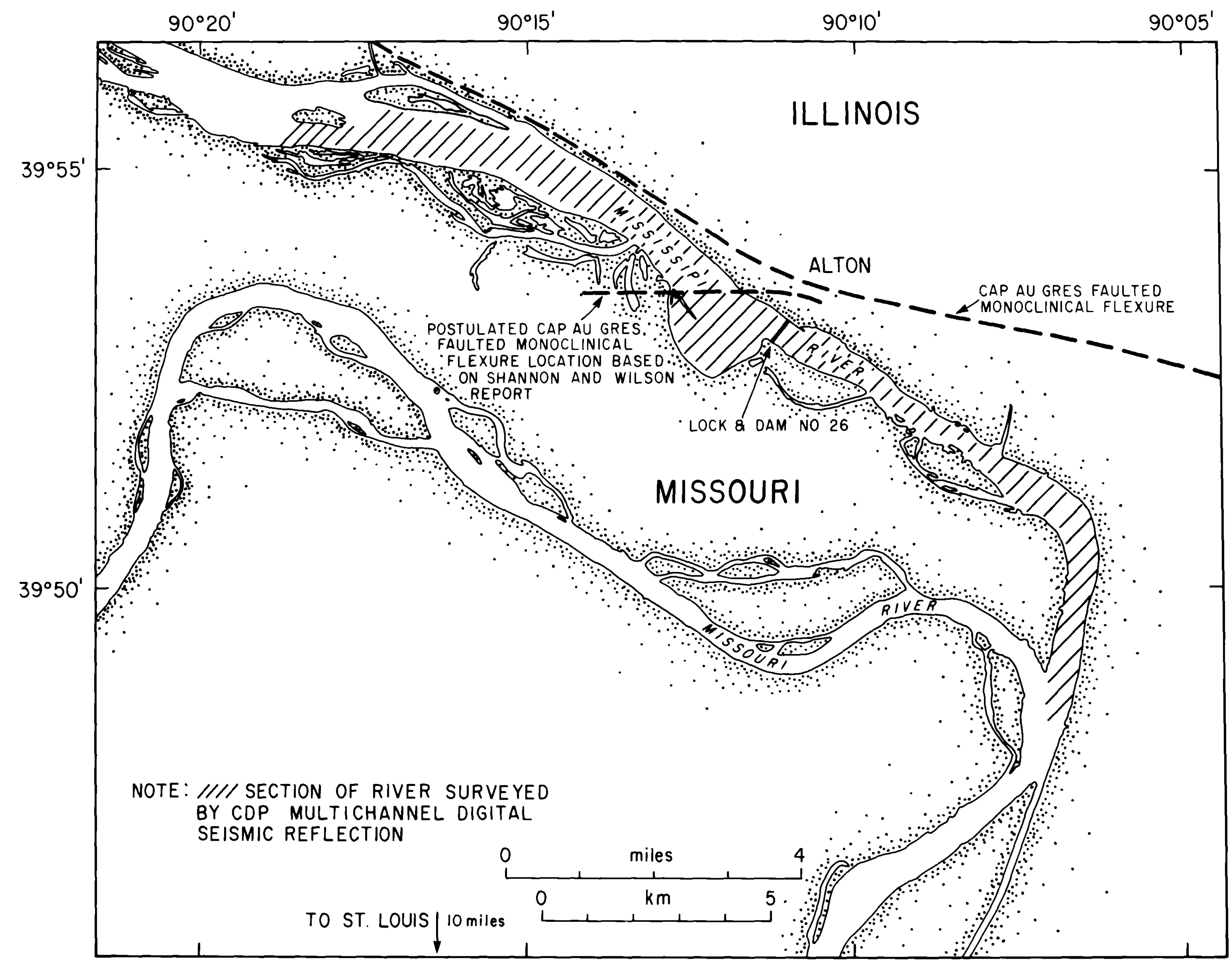

FIGURE 1: STUDY AREA

Additional survey lines were run upriver from Lock and Dam No. 25 between the dam and River Mile 244 in an attempt to record the Cap de Gres Fault (fig. 1) believed to cross the Mississippi River at this location. These data are not reported because mechanical problems developed with the larger (15-in^3 watergun and 40-in^3 airgun) sound sources used for the multichannel system. The penetration (which was limited to approximately 70 milliseconds two-way travel time) obtained with the small, 25-joule sparker did not show a recording of the fault.

Prior to this study, the COE had made shallow (i.e., less than 100-150 ft of penetration) seismic-reflection surveys in the area without recording a fault. It was thought that a more powerful marine seismic-reflection system would give greater penetration of seismic energy into the sediments and rock and, thus, could determine whether or not such a fault exists. The more powerful system was expected to seismically penetrate the earth in terms of hundreds of meters rather than to emphasize the high resolution with limited penetration normally used for engineering surveys.

Equipment

The multichannel digital seismic-reflection system consists basically of three component parts: a digital, field marine, multichannel, seismic recording system; a multichannel hydrophone array; and seismic energy sources.

The Digital Field System V (DFSV) is a modified multichannel, marine seismic-recording system manufactured by Texas Instruments Company. The system consists of the following main components:

a. 12 gain-ranging amplifiers, two nongain-ranging auxilliary amplifiers, multiplexer, and analog filters.
b. Analog-to-digital converter capable of digitizing the outputs of the amplifiers at any one of the following sample intervals: 0.5, 1.0, or 2.0 ms.
c. Two 9-track, magnetic-tape transports, each capable of automatically starting without interruption of recording when the other gets to the end of the tape.
d. Multichannel recording oscillograph and camera.
e. Twelve-volt DC power and battery system.
f. Data encoder and extended header electronics system capable of writing date, time, Loran C, and Miniranger navigation data directly into the record header of each shot. This highly desirable option assures that navigation data are permanently saved on tape with the recorded seismic data.
g. Electronics interfaces between all components.

The seismic array used with the DSFV recording system for this survey was manufactured by Fairfield Industries. A schematic of the spacing is shown on Figure 2. The system consists of an interface unit, 12-channel streamer array. The channel spacing was at a 10-meter group interval, and had 20 hydrophones per group. Each group was preamplifier coupled to the signal cable. Although three depth controllers can be used on the array to control its depth below the water's surface, they were not placed on the array for this particular survey. Instead, because the water was extremely shallow, the array was made slightly buoyant and towed as near the surface as possible to keep the active sections from dragging on the bottom.

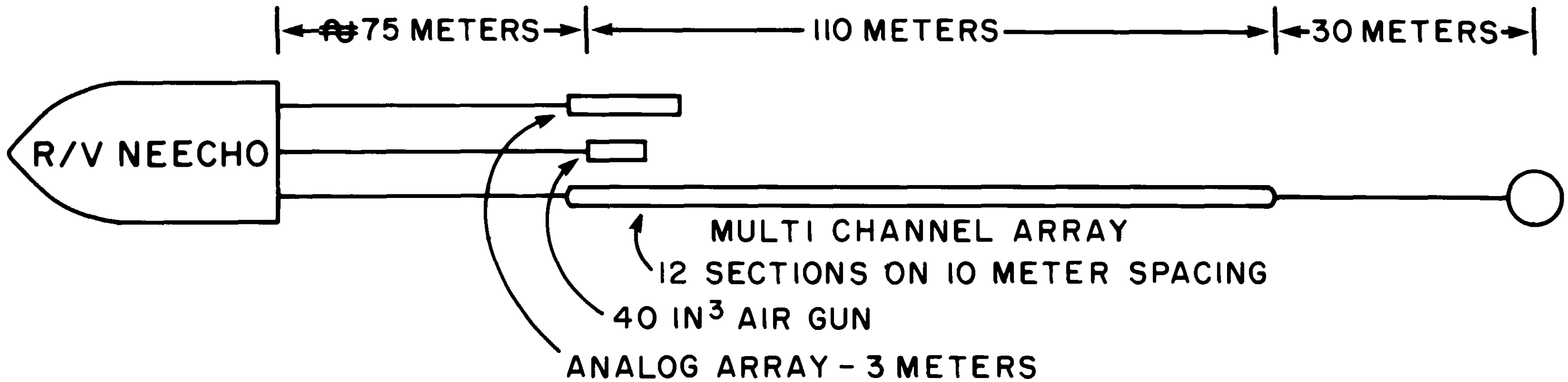

Figure 2.--Recording geometry of the seismic field system.

Two different types of pneumatic seismic-energy sources (airgun and watergun) were used during this survey. Both use high-pressure compressed air as a source of power, but they differ in the way the acoustic impulse is imparted to the water. The 40-in^3 airgun was used for most of the survey because the watergun malfunctioned in the cold and dirty water.

An airgun emits discrete pulses of acoustic energy into the water upon a signal from an electrical device such as the keying contact of a recorder or other timing unit. The pulses of acoustic energy are generated in the water by the sudden release of high-pressure air that has been stored in a suitable chamber in the water. Airguns are normally towed astern of the survey vessel with suitable flotation; the compressed air is supplied by a hose and the firing signal is initiated by a cable led back to the survey vessel. Acoustic energy derived from an airgun source is a function of the air pressure and volume of the air chamber. The airgun used for this survey was a Bolt Associates, Inc., Par Model 600B with a 40-in^3 air chamber operating at a pressure of approximately 1800 psig.

The watergun is a pneumatic seismic source that uses compressed air and can be interfaced with the same peripheral equipment as used for the airgun. Its theory of operation is that high pressure air is stored in a chamber behind a locked piston. The compressed air is used to drive a piston to propel a water jet that creates vacuum cavities which when imploded by the surrounding hydrostatic pressure emit a strong, bubble-free, high-frequency acoustic pulse. As in the case of the airgun, acoustic energy derived from a watergun source is a function of the air pressure and volume of the air chamber. Since the bubble pulse is eliminated by the watergun, the resolution is better than that of an airgun, but the penetration is not usually as great because of the loss in low frequency content. The watergun used for this survey was a Seismic Systems, Inc., 15-in^3 T-Watergun, operated with an air pressure of 1800 psig.

A small single-channel, 25-joule sparker seismic system was also on board during the survey and was used upriver from Lock and Dam No. 25. Part of the system was used to make a monitor record for the multichannel system from a single hydrophone group. The seismic-system units included: (1) an EPC Model-4100 graphic recorder which recorded data from one of the sections of the multichannel streamer or the output of the single-channel analog system; (2) an Innerspace Model 202 preamplifier/filter; (3) a 20-element, Innerspace Model-203 hydrophone streamer, which was used as a monitor phone during much of the survey because it could be streamed very near the acoustic source; (4) a small, 25-joule, Innerspace Technology Model-201 sparker, which was used as an acoustic sound source for the work above Lock and Dam No. 25 in the area of the Cap au Gres Fault when the watergun and airgun systems malfunctioned.

Field Procedures

The R/V NEECHO, a 38-ft aluminum vessel, was trailered to Portage des Sioux, Missouri, from Rend Lake, Illinois, and launched by a boat travel lift on 9 December 1980. The ship and crew returned to port at the end of each day's survey.

After the survey was completed on December 16th, the NEECHO was lifted out of the water and placed back on its trailer, and returned to Woods Hole.

Navigational control for this survey was accomplished by dead reckoning and radar ranges. The estimated position of the survey vessel is accurate to within 100 m at any time for the survey above and below Lock and Dam No. 26. However, the survey lines run above Lock and Dam No. 25 on 13 December were of little value as the local river buoys were used for the dead reckoning navigation. It was later learned that the positions of these buoys are not recorded, and so it is not possible to determine other than an approximate location of the survey line.

Data acquisition and reduction

For the geophysical survey, multichannel seismic-reflection lines were run using the 40-in^3 airgun. It was originally intended to use the 15-in^3 watergun for much of the survey, but this did not prove feasible as it was not possible to get the watergun to function continuously for any long period of time. The malfunction of the watergun was attributed to the cold and dirty river water. Some of the survey was run as single-channel analog using the 40-in^3 airgun or the 25-joule sparker as the sound source.

The operating parameters selected for multichannel digital shooting on the Mississippi River were based on experimental shooting done prior to this survey (Miller and others, 1981). The streamer was configured at a group interval of 10 m for a total active length of 115 m. The source-to-near-receiver section was kept to a minimum length in order to produce near-vertical reflections and thus simplify the monitoring of the near-trace channel in the shallow water. Twelve-fold recording with a source (shotpoint) interval of 5 m was used to give a good signal-to-noise ratio.

Both the waterguns and airguns developed operational problems at the start of the multichannel survey in the area above Lock and Dam No. 25, so most of this area was shot with the 25-joule Innerspace sparker with analog recording. The penetration of the subbottom was limited to about 75 milliseconds of two-way travel time. As stated earlier, the navigation data (buoy position) cannot be accurately correlated with the seismic-reflection data, but it is firmly believed that sparker lines crossed the reported location of the Cap au Gres fault.

Based on the quality of the sparker record at Lock and Dam No. 25, it was decided to record a single-channel, analog, monitor record with the Innerspace Technology array, filter, and preamplifier on the EPC flatbed recorder in addition to the multichannel digital record. The source-to-single-channel arrays were kept at a minimum length to produce a record of near vertical reflections. This system recorded penetration of up to 130 milliseconds and side reflections out to 1000 milliseconds.

The navigational data that constituted a position fix were plotted on Hydrographic Survey Maps of the Mississippi River (scale: 2 1/2" = 2000') along with date and time (figs. 3a, b). Shotpoint numbers and CDP data were recorded in 100-shotpoint increments on the maps. The line used for the composite profiles was drawn between the survey lines on each of the maps, and was used for constructing the two composite profiles (figs. 8, 9). The horizontal scale of the profiles is the same as that used to plot the navigation maps.

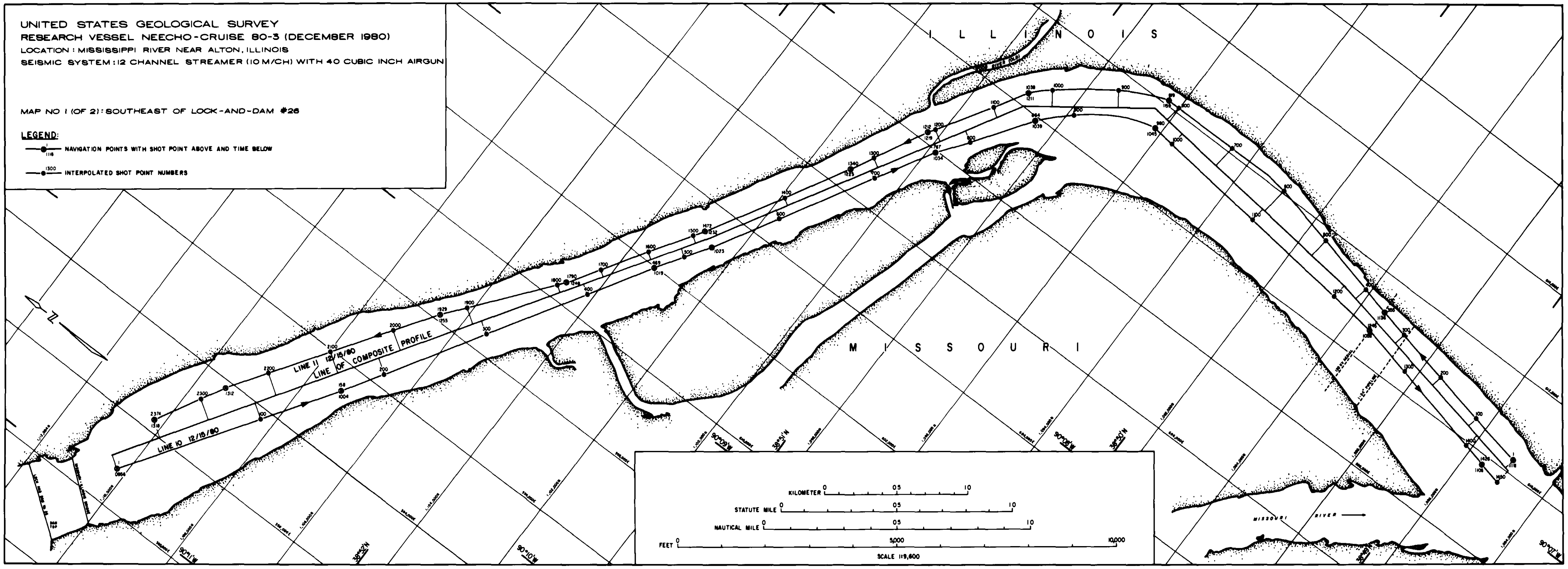

Figure 3a.--Navigation map downriver from Lock and Dam No, 26.

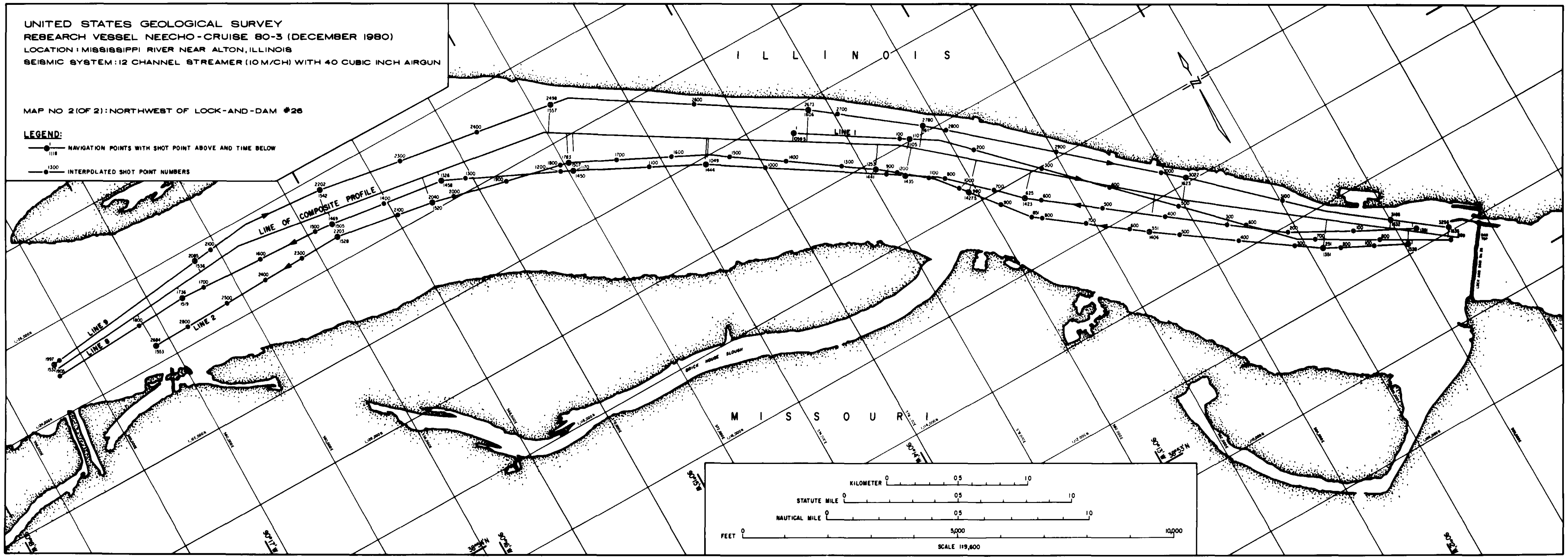

Figure 3b.--Navigation map upriver from Lock and Dam No. 26.

Sample analog records upriver and downriver from Lock and Dam No. 26 at Alton, Ill., are shown in figures 4 and 5. The analog records were used for constructing the lines for the river bottom, top of bedrock and the first horizon below the top of bedrock in the composite profiles. The depths of the profiles are shown in two-way reflection time rather than linear measurement because of the uncertainties in the velocities. The first horizon shown in the composite profiles below the river bottom is apparently the top of bedrock. Using depth to bedrock from the boring data at the Lock and Dam No. 26 Replacement Site, the calculated velocity in the unconsolidated sediments is approximately 6,000 ft/s. This is a reasonable velocity for glacial outwash and glacial ice-contact sediments having an "n" count greater than 25 as shown by the boring data.

Data Processing

Processing of the Mississippi River data was done in Denver, Colorado, on the USGS's DISCO (Digicon Interactive Seismic Computer), a dedicated seismic-data processing system that utilizes state-of-the-art seismic-data-processing software. The system hardware has been modified and marketed by Digicon Geophysical Corp. around the standard VAX 11/780 CPU built by Digital Equipment Corp. The VAX 11/780 configuration (fig. 6) consists of:

1. six (6) tri-density telex tape drives,
2. two (2) FPS 120B array processors,
3. three (3) 300-megabyte RM05 disk memory units,
4. four (4) megabytes main memory,
5. one (1) versatec ES plotter,
6. one (1) high-speed printer, and
7. DISCO state-of-the-art seismic-data-processing software.

The processed data were 12-channel, 12-fold digitally recorded data that were recorded at a 0.5-ms sample rate for one second in a SEGB seismic format. An initial line was processed in a standard processing flow (fig. 7); the results of the processing were poor due to the following:

1. poor signal-to-noise ratio, probably due in part to towing the streamer on the surface;
2. strong water-bottom multiples and airgun bubble pulses;
3. low-frequency strum on the far offset caused by the buoy on end of streamer;
4. over-driven near traces due to zero offset configuration.

After additional deconvolution testing, the initial line was reprocessed through common-depth-point (CDP) gathers; the results were similar to those of the initial processing. During this stage in processing, it was concluded that deconvolution (spiking) prior to stack only enhanced the multiple problem; therefore, deconvolution was dropped before stack. At this point, all CDP records were used to create a near-trace (trace 12 nearest the source) display, which is a single-fold cross section. This procedure was repeated for each of the 12 channels in order to determine which traces had problems. From this analysis, we found that trace 12 (nearest the source) had the strongest multiple problem, and that trace 11 had a similar, though not as strong, problem. This analysis also revealed that trace 1, the far trace, had a very low-frequency strum. A filter analysis was performed at this point to

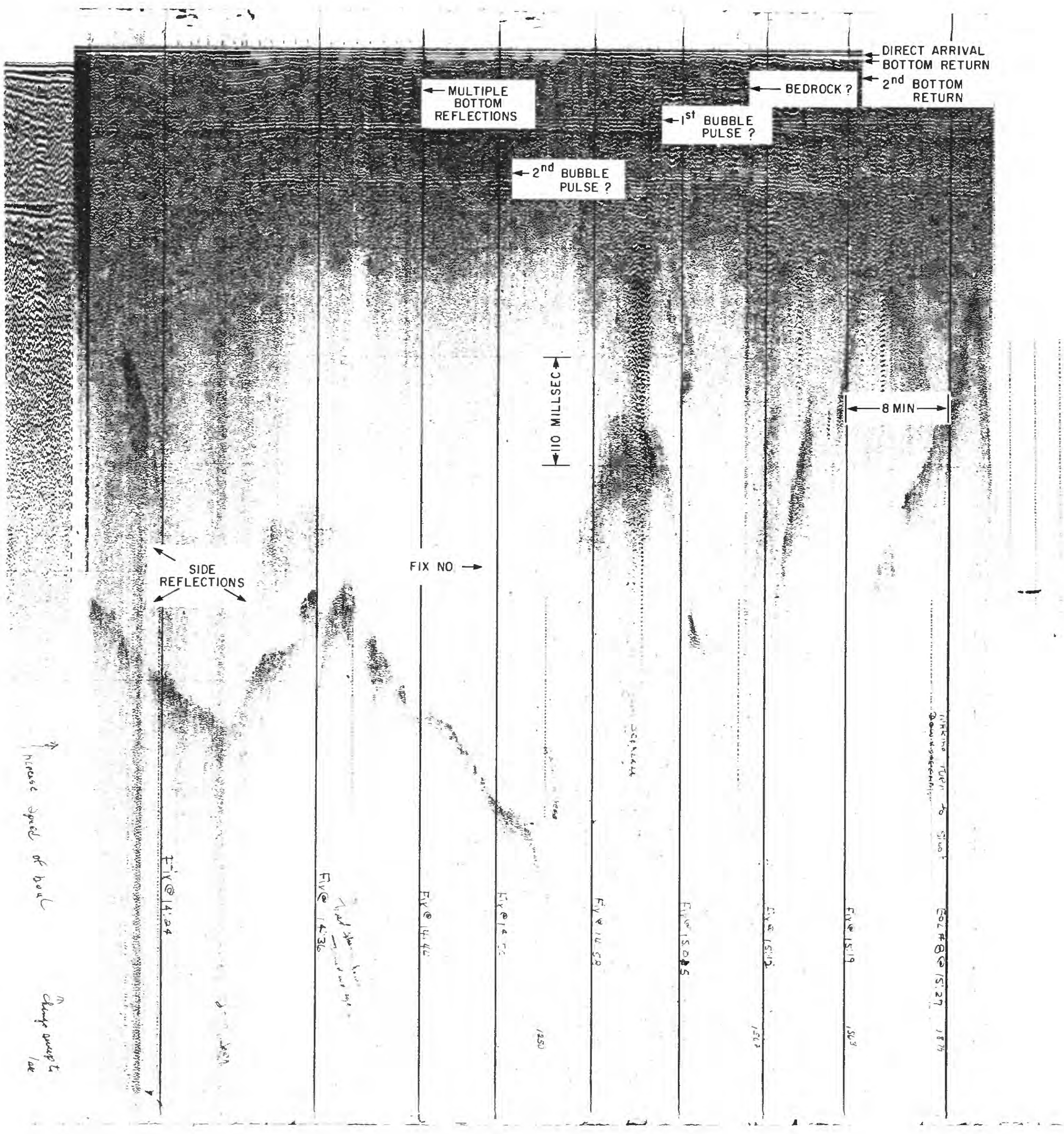

Figure 4.--Sample analog seismic-reflection record (line 8), north of Lock and Dam No. 26.

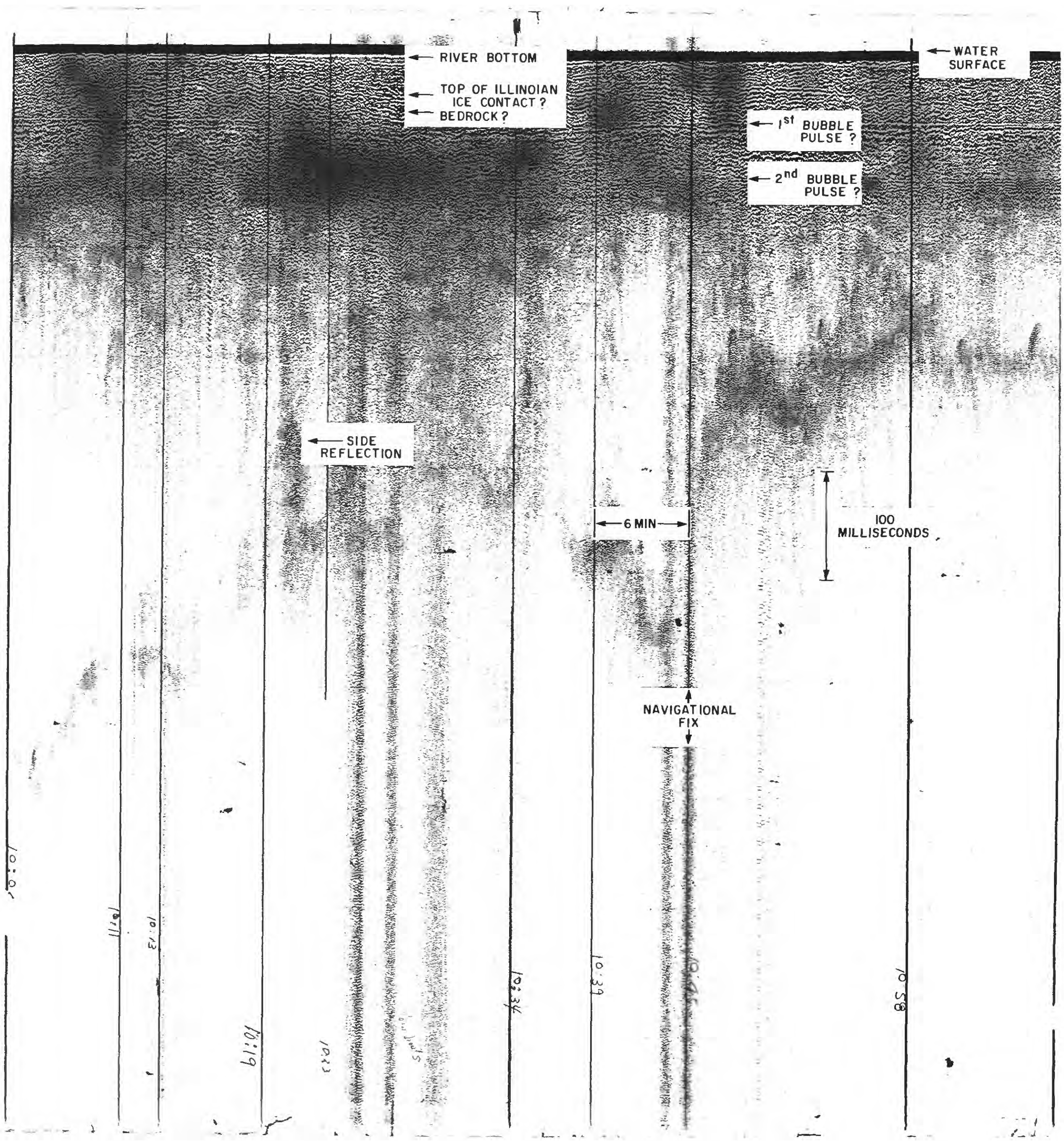

Figure 5.--Sample analog seismic-reflection record (line 10), below Lock and Dam No. 26.

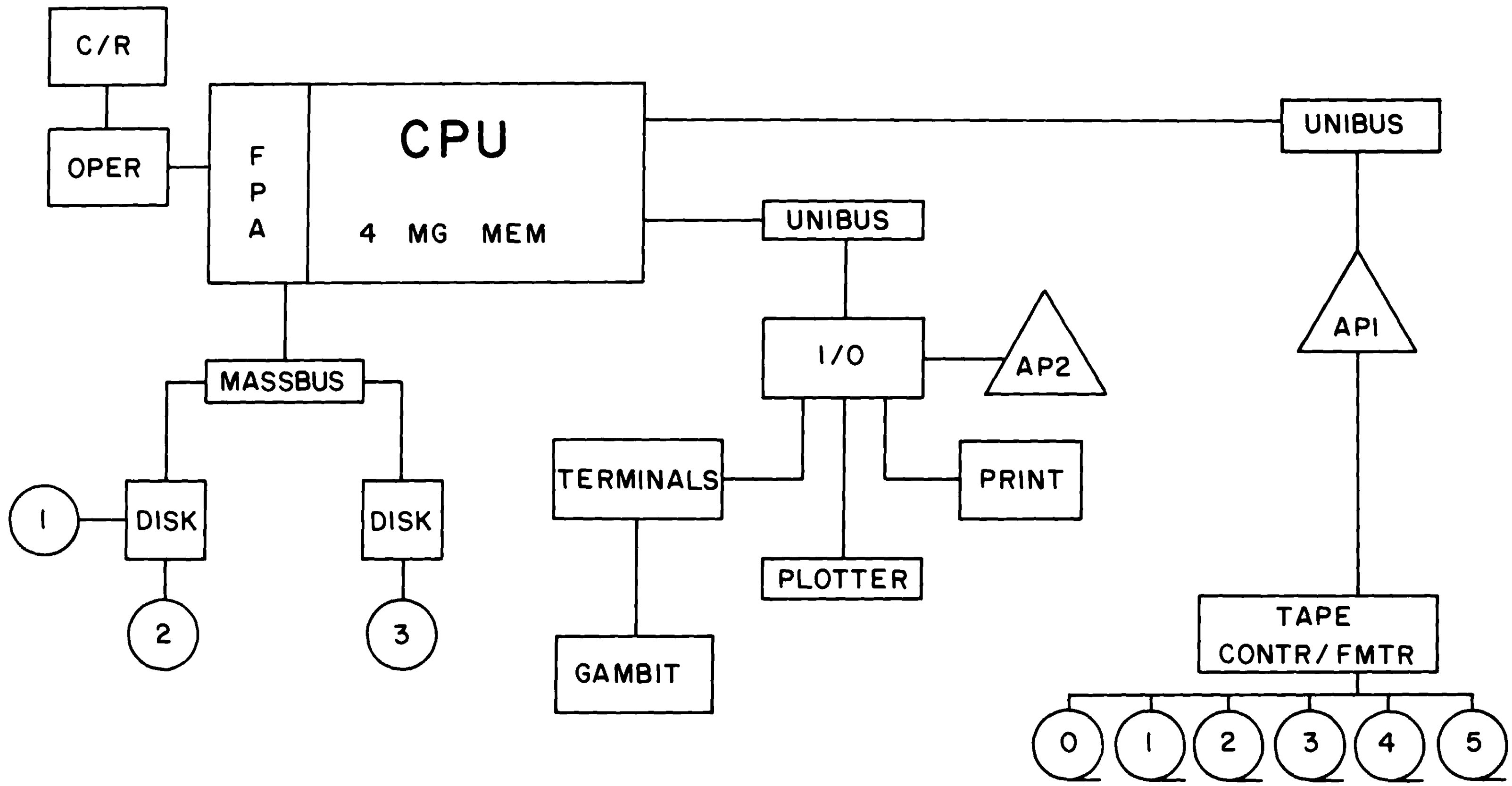

Figure 6.--USGS Digicon Interactive Seismic Computer (DISCO) System.

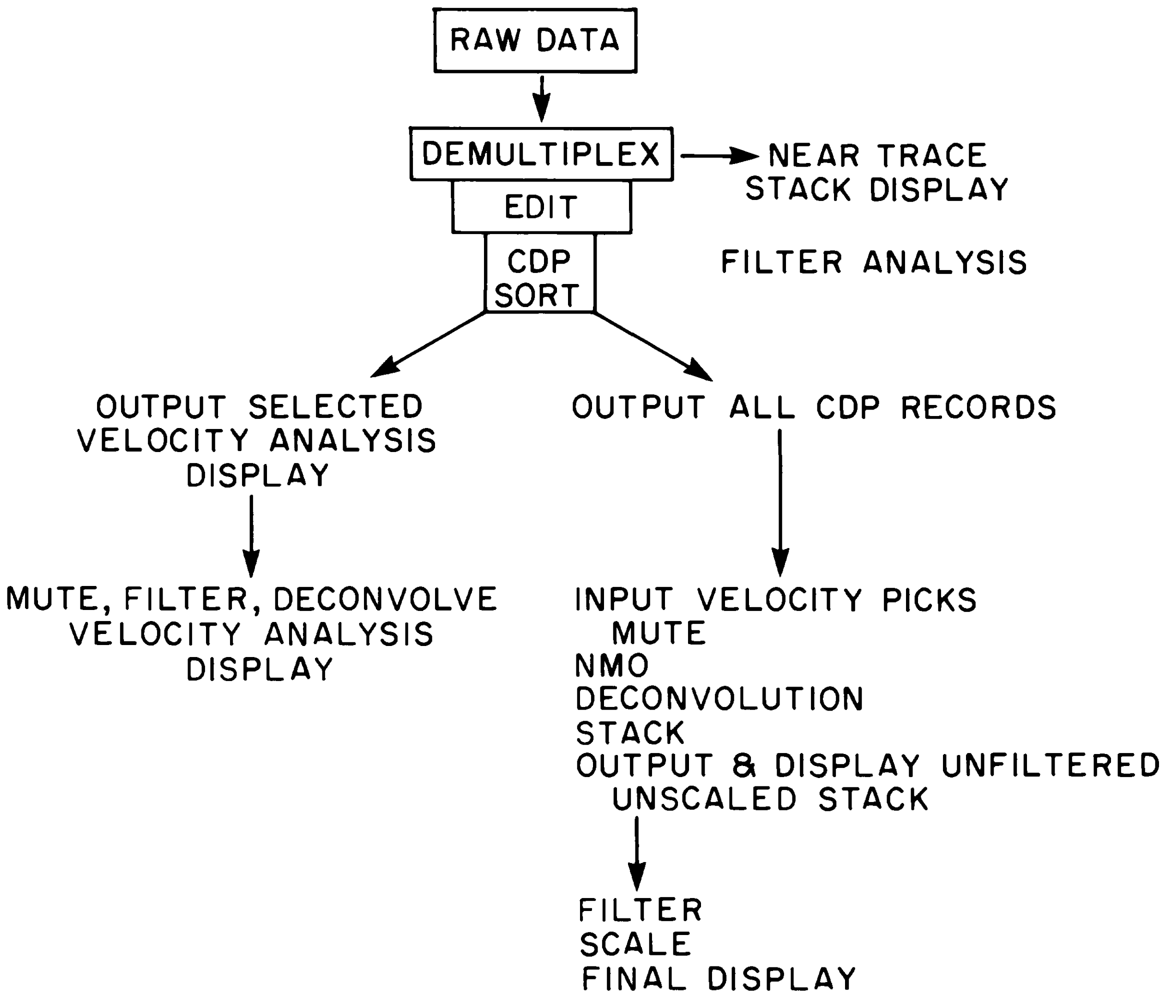

Figure 7.--Standard digital seismic-data processing flow schematic.

determine noise frequencies, frequency of far-offset strum, and frequency band of signal.

The filter tests on individual streamer channels established that the airgun bubble pulse was resonating at about 20 Hz and that other low-frequency low noise and water multiples were very strong below about 80 Hz. Final filters were selected with a taper from 150-300 Hz at the surface to 80-120 Hz below 0.3-second. A time-variant filter, interpreted from the filter analysis, was then applied.

Selected CDP records were chosen along the initial line, and velocity analysis was performed using semblance plots to determine stacking velocities. However, due to the initial geometry of acquisition, the normal velocity procedure was unacceptable because: 1) the deepest reflector occurred at 200 m on the near trace, but was not present on far 6 traces; 2) the moveout was too slight to give reliable velocity estimate; and 3) the near trace was overdriven by multiples.

A second velocity procedure, a constant velocity stack, resolved the problem of picking an apparent velocity function. By this method, velocities could be picked by choosing the velocity that stacked with the best coherency. A time-variant function was picked after many of these analyses were interpreted (best apparent stacking velocity for the data). During the initial processing, it was found that the normal stacking method was not acceptable due to the problems previously discussed, and it was determined that weighing the stacking summation was helpful. The following weights were applied before stacking:

Channel 1 = 0%	Channels 7-9 = 5%
Channel 2 = 1%	Channels 10-11 = 1%
Channels 3-6 = 20%	Channel 12 = 1%

The data were then corrected for normal moveout (NMO) with the best velocity information interpreted and stacked with positive results. This unfiltered, unscaled stack was bandpass filtered, deconvolved (predictive operator), and amplitude scaled, and the final result was displayed.

The geophysical profiles that resulted from the data processing described above were used to reconstruct the deeper layers in composite geophysical profiles. We were able to interpret the upper 40 ms to 200 ms of CDP data. However, the experience gained from this project indicates that modifying the field recording parameters will yield more velocity information and better signal-to-noise ratio, which would enhance the results.

Discussion

The Mississippi Valley is a large area of plains and low plateaus situated between the Appalachians and the Rocky Mountains. Basement is made up of Precambrian crystalline rocks and has an irregular surface; the closest sizeable surface outcropping is south of the study area, the St. Francis Mountains of eastern Missouri. Nearly everywhere, the valley is buried under Paleozoic and later sediments, generally several thousand feet thick.

Following deposition, the beds were flexed into broad, cratonic basins and broad domes, which constitute the major structural elements of the Mississippi Valley. The area of study is part of the separation between two of these major basins, the Eastern Interior Coal Basin and the Illinois Basin, which are separated in turn by a series of structures and by the Cap au Gres faulted flexture (Giles, 1939; Rubey, 1952). Rubey (1952) described the steeply dipping Cap au Gres flexure in detail and concluded that "narrow zones of deformation like the Cap au Gres are***structural features of greatest disturbance within the central Mississippi Valley region." The Cap au Gres flexure can be seen both east and west of the Mississippi River, but it disappears beneath the broad alluvial valley of the River (Rubey, 1952). Faults associated with it have offsets reported to be as great as 300 feet (Shannon and Wilson, 1980).

The results from the seismic-reflection survey upriver and downriver from Lock and Dam No. 26 were similar. Quality of the multichannel seismic data can be classified as fair to good between 40-200 ms of two-way travel time in the subbottom. Since the purpose of the survey was to detect faults by using CDP seismic-reflection methods, a detailed interpretation of the stratigraphy in the unconsolidated sediments using the single-channel, analog monitor record was not made. The resolution of the single-channel monitor record is limited due to the low-frequency output of the airgun seismic source, low-frequency filtering, and the slow sweep speed of the analog recorder. It was not possible to resolve any reflections in the first 30 to 40 milliseconds of recording because of the streamer (hydrophone array) length.

A composite geophysical profile (fig. 8) was constructed using the single-channel analog data from Lines 8 and 9 and the CDP data from Lines 1, 2, 8 and 9. The data from which the profile of the river bottom and the next two lower horizons were drawn were from the analog records, and the data used to interpret the three deeper reflecting horizons were taken from the CDP reflection profiles (Winget and Tirey, 1984). As can be seen from the CDP profiles and the composite profile (fig. 8), there is no indication of a fault of the magnitude previously interpreted and suggested by Shannon and Wilson (1980): a 50-100-m displacement in the upper 180-200 ms of two-way reflection time. Assuming a conservative velocity of 3,000 m/s for this section, there were no large displacements detected in the upper 300 m of the geological column. The analog data indicate some buried channeling and perhaps minor faulting in the area. Strong bottom multiples were recorded on the analog record in several places, indicating organic mud or silt deposits on the river bottom at these locations.

Considerable high-frequency, coherent side-reflection energy was recorded on the analog-monitor record with a two-way travel time that ranged from 100 millisecond to more than one second (figs. 4, 5). The test zig-zag analog line that was run indicated that these side reflections came from the north side of the river. It is difficult to speculate on the origin of the reflections, but they are more irregular than would be expected from the river bank itself.

Two possible explanations are: (1) the fault line with the up-throw on the north side parallels the river (i.e., the direction and flow of the river is fault controlled) and side reflection come from the uplift face; or (2) the side reflections come from point reflectors along the north edge of the river bank. The latter is the most likely explanation.

As stated earlier in the report, an analog 25-joule sparker survey was run upstream immediately above Lock and Dam No. 25. These data were not reported due to the lack of accurate navigational control above the dam. A reflecting horizon was recorded over all the area at a depth of approximately 80 milliseconds two-way travel time, and appears to correspond with the strong reflector recorded at a depth of approximately 90-ms two-way travel time in the vicinity of Lock and Dam No. 26, assuming that the difference in upper pool levels at the two dams was approximately 5 meters. Further assuming an average velocity of 3,000 m/s for the two-way travel time of the reflected energy, the depth to this horizon is approximately 10 m above mean sea level. From the Shannon and Wilson (1980) report and Laclede Gas Company (St. Louis, Mo.) unpublished data, this reflecting horizon is believed to be the base of the Salem Limestone.

A composite geophysical profile for a single line down the river from Lock and Dam No. 26 was made (fig. 9) by combining the data from Lines 10 and 11. The method of construction was the same as that described for the line above Lock and Dam No. 26. The data from below the dam are very similar to the data upriver from the dam with some exceptions. Downriver, the deeper CDP reflection data were "noisier" than the data upriver because the river was narrower and there were stronger side reverberations and reflections below the dam. From the analog monitor record, the penetration and resolution of the unconsolidated sediment data were much better downriver. There was an absence of strong multiple bottom reflections, indicating an absence of thick organic silt deposits on the bottom downriver from the dam.

Conclusions

It is possible to interpret seismic-reflection events in the upper 200 ms of data. In the upper 200 ms of data, there is no evidence of faulting of the magnitude suggested by the Shannon and Wilson (1980) report and by the information provided to COE by Laclede Gas Company, St. Louis, Mo. This does not eliminate the possibility that faulting deeper in the section could have occurred earlier in geologic time. In our study, five reflecting horizons were recorded more or less continuously on the river between Miles 195 and 210. The reflecting horizons showed very little slope or structure. There is a few milliseconds of relief in some areas. Minor faulting (less than 5 to 10 m) can be detected in some places, and a couple of buried stream channels are cut in the bedrock more or less perpendicular to the direction of the river. The analog monitor record upriver from Lock and Dam No. 26 has many strong multiple bottom reflections that are not present downriver from Lock and Dam No. 26, which indicates that considerably more organic mud or silt has been deposited upriver from the lock.

This survey has demonstrated the value and economy of obtaining deeper penetration seismic data by using a multichannel, digital seismic system on inland water ways rather than conventional land-seismic techniques. With some modifications in operating proceedures, technique, and equipment, it should be possible to improve the results obtained here for penetration and signal-to-noise ratio by several orders of magnitude. The new all-hydraulic waterguns (80-, 200-, and 400-in^3), which require a much smaller power source in terms of physical size and weight, will make more powerful seismic-energy sources easier to use from small boats. The limitations imposed by shallow towing depths for the source and streamer, lack of streamer maneuverability in

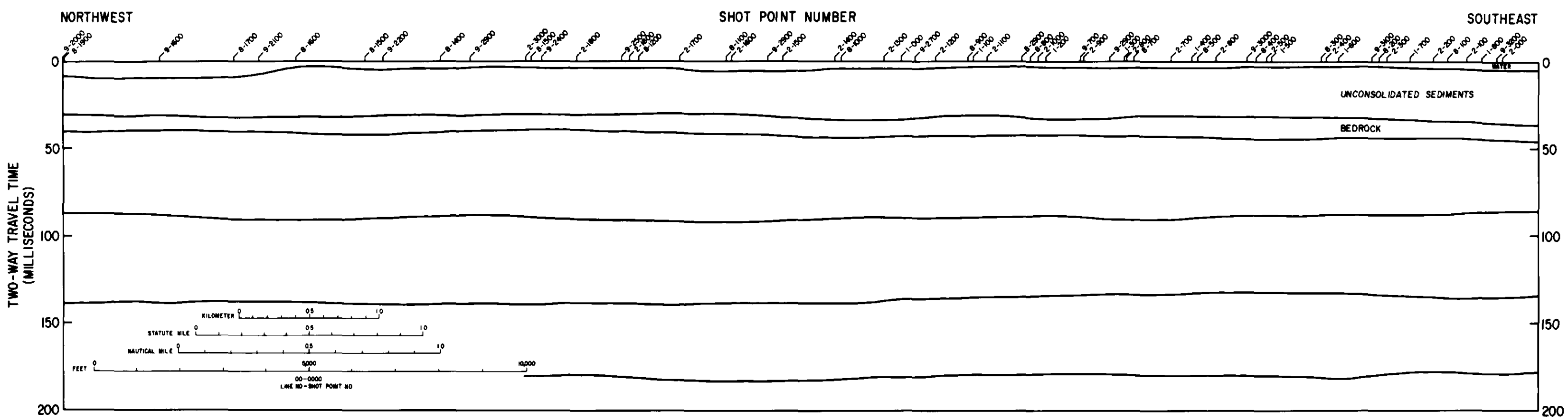

Figure 8.--Composite profile upriver from Lock and Dam No. 26, Mississippi River.

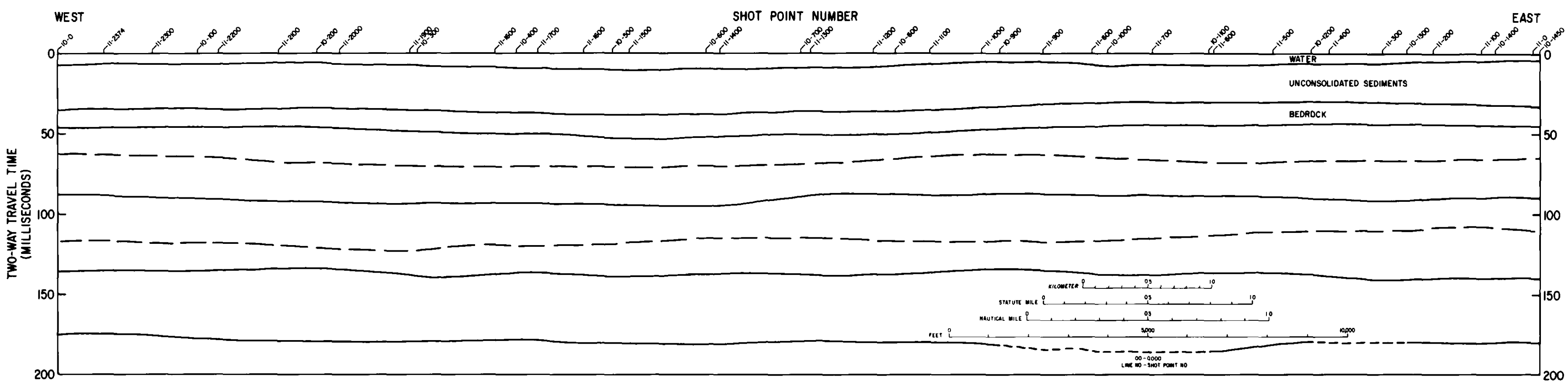

Figure 9.--Composite profile downriver from Lock and Dam No. 26, Mississippi River.

confined areas, and background noise resulting from side reflections from the river banks and other structures in the water will be more difficult to overcome.

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