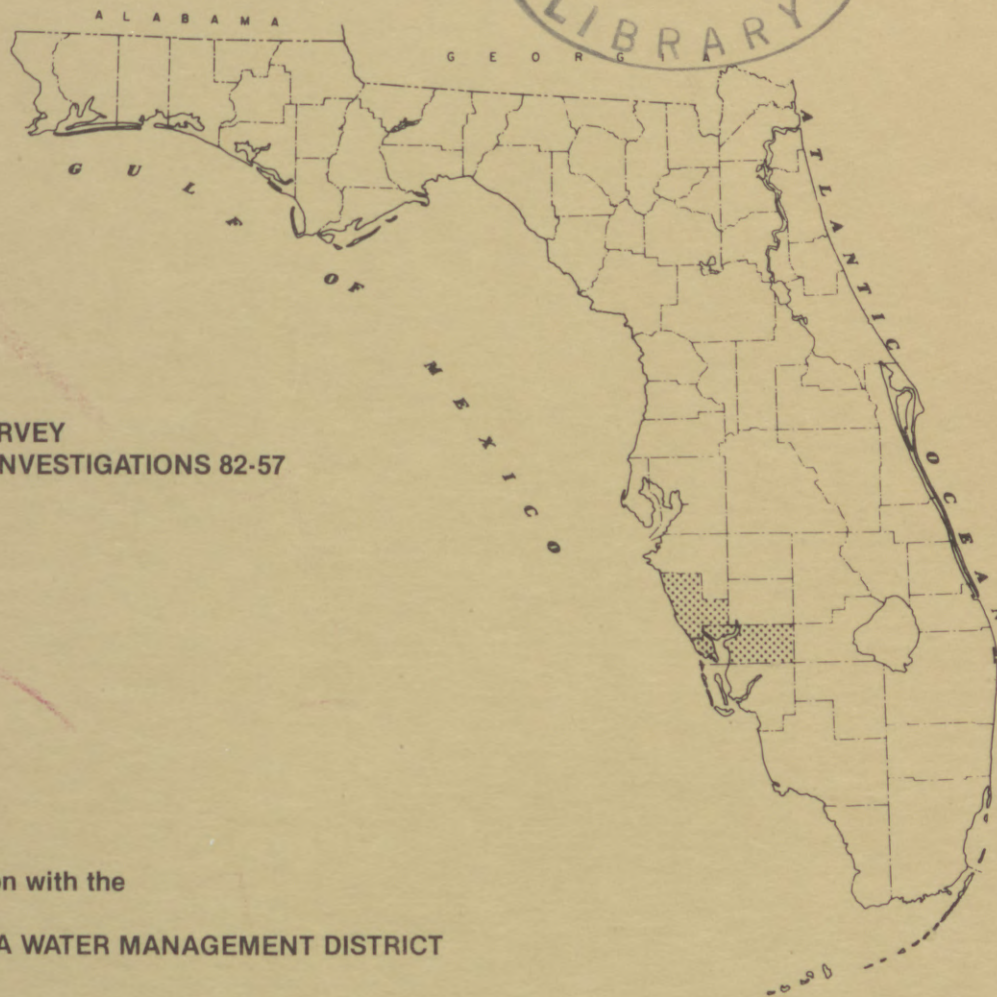
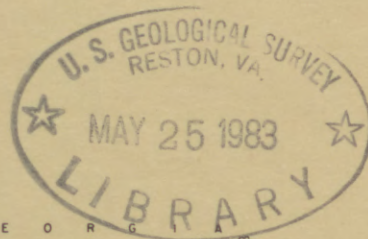


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CONTINUOUS SEISMIC-REFLECTION SURVEY DEFINING SHALLOW SEDIMENTARY LAYERS IN THE CHARLOTTE HARBOR AND VENICE AREAS, SOUTHWEST FLORIDA



U.S. GEOLOGICAL SURVEY
WATER-RESOURCES INVESTIGATIONS 82-57

Prepared in cooperation with the
SOUTHWEST FLORIDA WATER MANAGEMENT DISTRICT



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U.S. GEOLOGICAL SURVEY

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SOUTHWEST FLORIDA WATER MANAGEMENT DISTRICT

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UNITED STATES DEPARTMENT OF THE INTERIOR

JAMES G. WATT, Secretary

GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information write to:

U.S. Geological Survey
Suite 3015, Hobbs Federal Building
227 North Bronough Street
Tallahassee, Florida 32301

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ABBREVIATIONS AND CONVERSION FACTORS

Factors for converting inch-pound units to International System of units (SI) and abbreviation of units

<u>Multiply</u>	<u>By</u>	<u>To obtain</u>
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
foot per second (ft/s)	0.3048	meter per second (m/s)
pound per square inch (lb/in ²)	6.8948x10 ³	Newton per square meter (N/m ²)

* * * * *

National Geodetic Vertical Datum of 1929 (NGVD of 1929).--A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called mean sea level. NGVD of 1929 is referred to as sea level in the text of this report.

* * * * *

CONTINUOUS SEISMIC-REFLECTION SURVEY DEFINING SHALLOW SEDIMENTARY LAYERS IN THE CHARLOTTE HARBOR AND VENICE AREAS, SOUTHWEST FLORIDA

By R. M. Wolansky, F. P. Haeni, and R. E. Sylvester

ABSTRACT

A continuous marine seismic-reflection survey system was used to define the configuration of shallow sedimentary layers underlying the Charlotte Harbor and Venice areas, southwest Florida. Seismic profiling was conducted over a distance of about 57 miles in Charlotte Harbor, on the Peace and Myakka Rivers, and on the Intracoastal Waterway near Venice using a uniboom (high-resolution boomer) whose energy was capable of penetrating 200 feet of sediments with a resolution of 1 to 3 feet.

Five stratigraphic units defined from the seismic record include sediments of Holocene to early Miocene age. All seismic-profile records are presented, along with geologic sections constructed from the records. Seismic-reflection amplitude, frequency, continuity, configuration, external form, and areal association were utilized to interpret facies and depositional environments of the stratigraphic units. The depositional framework of the units ranges from shallow shelf to prograded slope. The seismic-stratigraphic units are correlated with the surficial aquifer and intermediate artesian aquifers, and permeable zones of the aquifers are related to the seismic record.

INTRODUCTION

In much of Sarasota, southwestern De Soto, and Charlotte Counties, the surficial and intermediate aquifers (shallow aquifers) are the principal sources of potable water, as ground water in the underlying Floridan aquifer system is not potable. Between 1979 and 1981, an investigation was undertaken to define the hydrogeologic framework of these shallow aquifers in Sarasota, Charlotte, and part of De Soto Counties. Part of that investigation included a study to determine the feasibility of using a continuous high-resolution seismic-reflection survey to help define the configuration of the shallow (less than 200 feet deep) sedimentary layers. In February 1980, about 57 miles of seismic profiles were obtained for Charlotte Harbor, the Peace and Myakka Rivers, and the Intracoastal Waterway near Venice (fig. 1). The purpose of this report is to describe the application of the seismic-reflection technique to a hydrogeologic problem in southwest Florida and to present the seismic records and the hydrogeologic interpretation of these records.

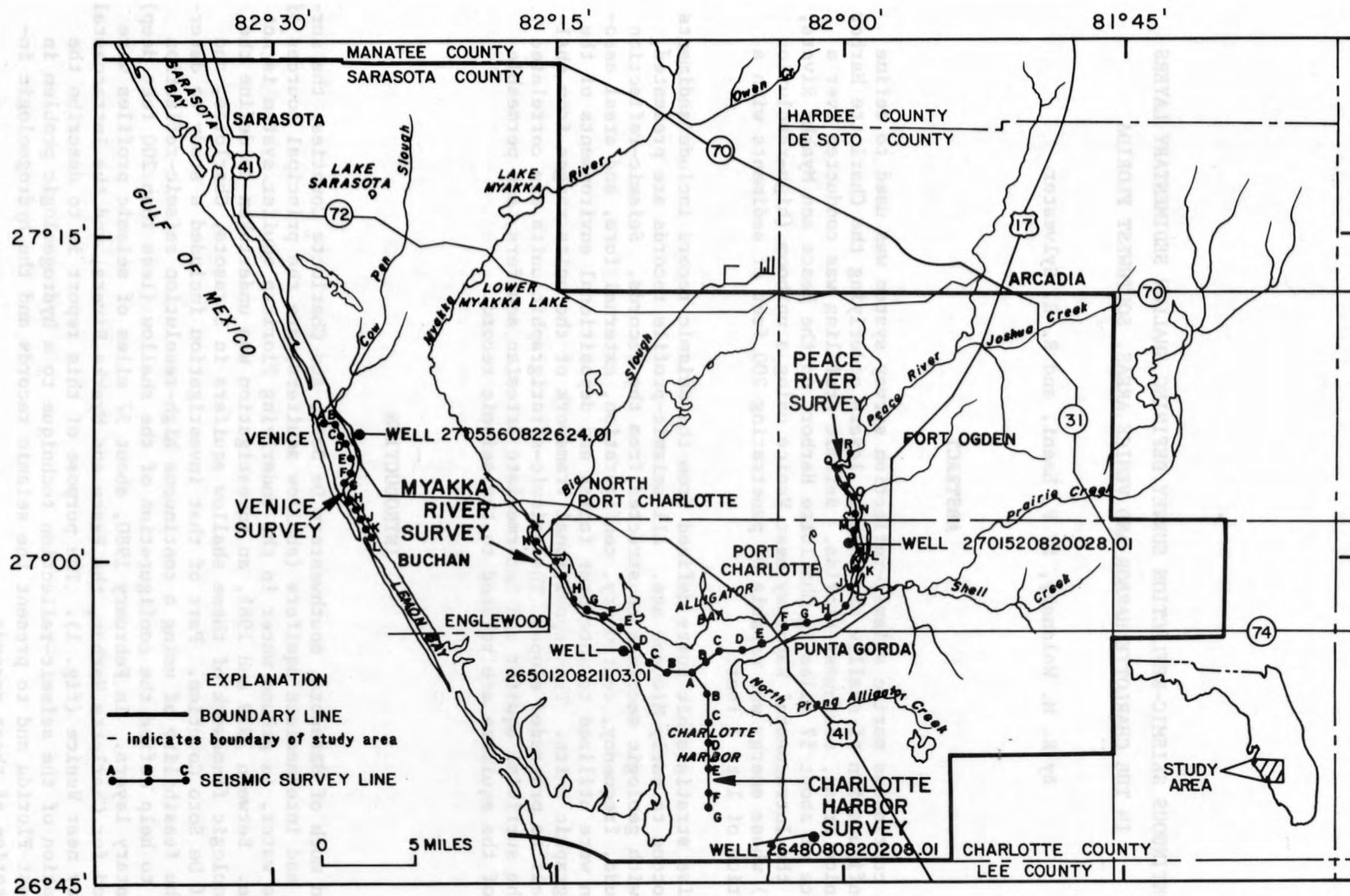


Figure 1.--Area of investigation and locations of seismic profiles.

Acknowledgments

The assistance and cooperation of the U.S. Geological Survey Office of Marine Geology, Woods Hole, Mass., which provided the equipment and aided in field work, is sincerely appreciated. Andrew D. Smith and Derick A. Roby, U.S. Geological Survey, Tampa, assisted in the diagrammatic interpretations of the seismic records.

Description of Area

The northern part of Charlotte Harbor is in Charlotte County in southwestern Florida (fig. 1). Continuous seismic profiling was conducted in the harbor from Alligator Bay to a point 8 miles to the south (Charlotte Harbor survey), from Alligator Bay 22 miles up the Peace River to Fort Ogden (Peace River survey), from Alligator Bay 14 miles up the Myakka River to Myakka Shores (Myakka River survey), and from Venice 13 miles south on the Intracoastal Waterway to Buchan (Venice survey) (fig. 1). Water depths along the routes of the seismic profiles ranged from 2 to 20 feet.

METHOD OF INVESTIGATION

Two basic seismic exploration techniques are seismic-refraction and seismic-reflection (Dobrin, 1976). The main difference between the two techniques is that with the refraction method, energy arrives at the receiver after traveling through, and in some cases along, rock layers; in the reflection method, the energy is received after it has reflected from a subsurface layer. The seismic-reflection method was used in this investigation because it is more suitable for distinguishing detailed sediment layers and structure. Reflection data can be collected on land and water; however, the continuous-reflection technique can only be used on water. The continuous-reflection method offers a means for studying the structure of unconsolidated and consolidated sediments on and beneath the bottom of water-covered areas. Because data are collected continuously over great distances, this technique can be used to interpret the geology and hydrology of a large area in a short period of time.

A brief explanation of the continuous reflection technique is given below. More detailed treatment of this subject is available in Leenhardt (1969), Missimer and Gardner (1976), EG and G Environmental Equipment (1977), Van Overeem (1977), and Sangree and Widmier (1979).

The principle of seismic reflection is that an acoustic signal transmitted from a sound source is reflected at air-water, water-sediment, or sediment-sediment interfaces due to change in acoustic impedance at these interfaces. The acoustic impedance is the product of the seismic velocity of the sediment and the sediment bulk density. The reflectance at each interface is a function of the acoustic impedance and the angle of incidence of the impinging seismic-wave train. For a large contrast in acoustic impedance, such as at the air-water interface, most of the normally incident energy is reflected. The reflected energy at a sediment-sediment interface decreases as the acoustic impedances on either side of the interface become nearly equal, and, if they are equal, energy will be transmitted through the interface without reflection.

The continuous reflection technique requires a boat to tow an energy source that emits acoustical impulses or pressure waves at regular intervals. The transmitted impulse, or seismic wave, is reflected from layer interfaces having different acoustic characteristics, such as the water bottom and subsurface layers. The reflected acoustic waves are received by a line of hydrophones that convert them to electrical signals and transmit them to an amplifier and band-pass filter before being displayed on a variable-density analog recorder (fig. 2). The recorder display is a permanent paper record of the reflected signals that shows the bottom and subbottom in cross-sectional view.

The main advantage of the continuous-reflection technique is that reflected signals are almost continuously correlated due to emission of acoustical impulses at regular, short intervals (4 to 8 per second). The display is, therefore, a continuous delineation of subsurface density changes, greatly aiding the interpretation of geological formations, structure, and contacts between geologic units. Another advantage of this geophysical technique is that the data can be collected very rapidly.

The various sound sources used in continuous-reflection profiling, and some of their characteristics, are listed in table 1. Because this investigation addressed the hydrogeology of shallow aquifers that generally occur at depths of less than 400 feet below land surface, the uniboom^{1/} (high-resolution boomer) was selected as the sound source for this study. The uniboom produces a seismic wave capable of penetrating to a depth of 200 feet or more in some types of subbottoms with a resolution of 1 to 3 feet. The uniboom consists of an electrical coil magnetically coupled to a plate. When energy contained in electrical storage capacitors is discharged into the coil, the result is a sudden movement of the plate, causing a sharp pressure pulse. The implosive force of water rushing to fill the void left behind the plate as it moves creates an acoustical impulse.

To conduct profiling operations in very shallow water and in restricted canals and waterways, a 22-foot fiberglass workboat was used for this study (fig. 3). The boat was powered by a 200-horsepower outboard motor that required a minimum water depth of 2 feet and consequently allowed access to all but the shallowest areas. A canvas shelter was installed on the forward half of the boat to protect the operating personnel and the electronic equipment from rain and spray. A 4.5-kilowatt gasoline-powered generator provided 100 volts of alternating current for the sound-source power supply and the electronic equipment.

Both the sound source and the hydrophone were towed alongside the boat--one on each side. The horizontal separation of the source and receiver was, therefore, about 10 feet.

The hydrophone array was made up of 12 nonlinearly spaced elements connected in parallel. The elements were enclosed in a plastic tube filled with mineral oil, so that the entire unit was almost neutrally buoyant. The hydrophone array was towed as close to the water surface as possible, without actually breaking the surface. The array was positioned 2 to 3 feet away from the side of the boat by an outrigger on the bow.

^{1/} The use of the brand name in this report is for identification purposes only and does not imply endorsement by the U.S. Geological Survey.

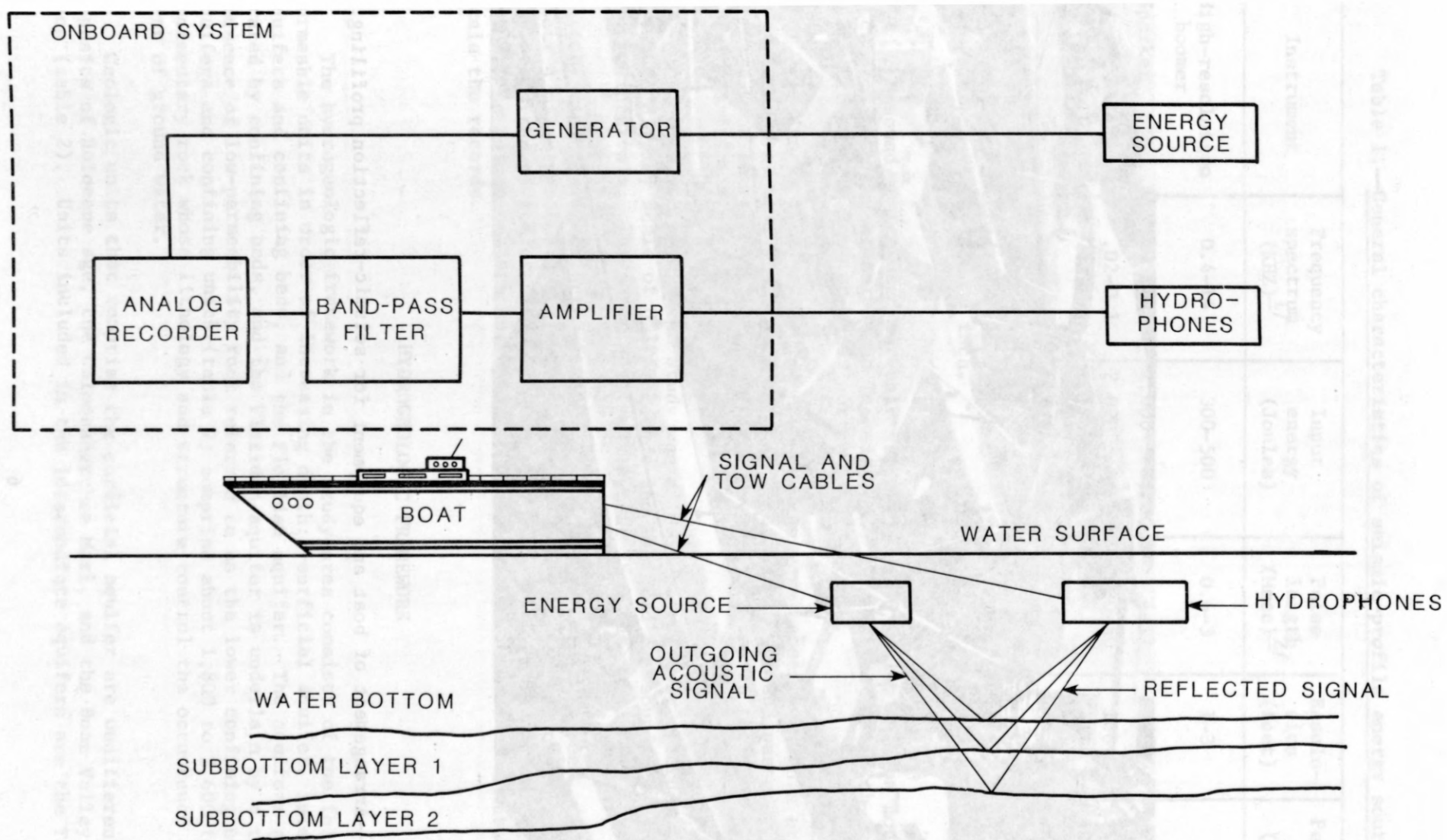


Figure 2.--Continuous marine seismic-reflection profiling system.



Figure 3.--Arrangement of boat and equipment for seismic-reflection profiling.

Table 1.--General characteristics of seismic-profile energy sources

Instrument	Frequency spectrum (KHZ) ^{1/}	Input energy (Joules)	Pulse length (Msec) ^{2/}	Resolution (feet)	Penetration (feet)
High-resolution boomer	0.4-14	300-500	0.6-3	1-3	>200
Sparker	.05-5	1,000-100,000	4-11	2-50	15,000
Air gun	.02-0.1	2,000 psi ^{3/} compressed air	30-50	100	>15,000

^{1/} KHZ = kilohertz.

^{2/} Msec = millisecond.

^{3/} psi = pounds per square inch.

The sound source used for this study was a 300 joules uniboom mounted on a catamaran. The catamaran was lashed to the side of the boat with the top of the source just below the water surface (see fig. 3).

The signals received from the hydrophone were passed through a preamplifier and filter unit and simultaneously recorded on tape and passed to a recorder. The records shown in this report were produced in the field with the band-pass filter set at 200 to 4,000 hertz.

The recorder used in the study was a 19-inch dry-paper recorder. It was set on a display scale of 0.125 seconds and it fired the sound source at 0.5-second intervals. The paper speed was set at 75 lines per inch.

Profiling was conducted by maintaining a constant boat speed, usually about 4 miles per hour, between plotted navigational aids or prominent landmarks. Although the exact speed for each survey was not known, the starting and ending points of each survey were known and were used to horizontally scale the records.

HYDROGEOLOGIC FRAMEWORK

The hydrogeologic framework in the study area consists of the following permeable units in order of increasing depth: surficial aquifer, intermediate aquifers and confining beds, and the Floridan aquifer. The aquifers are separated by confining beds, and the Floridan aquifer is underlain by a thick sequence of low-permeability rock referred to as the lower confining unit. The aquifers and confining units (table 2) comprise about 1,800 to 2,600 feet of sedimentary rock whose lithology and structure control the occurrence and movement of ground water.

Geologic units that comprise the surficial aquifer are undifferentiated deposits of Holocene age, the Caloosahatchee Marl, and the Bone Valley Formation (table 2). Units included in the intermediate aquifers are the Tamiami

Table 2.--Generalized stratigraphic section and hydrogeologic description

Series	Stratigraphic unit	Aquifer	Seismic-stratigraphic unit	Thickness (feet)	Lithology
Holocene	Undifferentiated sediments	Surficial aquifer	Unit 1	0-60	Nonmarine, light gray to yellow, fine- to medium-grained quartz sand; underlain by marine terrace deposits of sand, marl including clay, shell, and peat deposits.
Pleistocene	Caloosahatchee Marl			0-50	Shallow marine, gray, tan, or cream, unconsolidated sandy marl, marl and shell beds, hard sandy limestone; some phosphate.
Pliocene	Bone Valley Formation			0-20	Mostly nonmarine, very light gray to gray, clayey sand and sandy clay, with lens-like beds of light gray, fine- to medium-grained quartz sand, with a considerable amount of land vertebrate fossil fragments, some marine fossil fragments, and phosphate nodules and quartz pebbles.
Lower Pliocene	Tamiami Formation	Confining bed	Unit 2	0-150	Shallow marine, green to gray, sandy, calcareous clay, gray marl, gray sandstone, and slightly consolidated tan to light gray limestone; all units with some phosphate.
		Tamiami-upper Hawthorn aquifer			
Middle Miocene	Hawthorn Formation	Confining bed	Unit 3	200-400	Marine, interbedded layers of buff, sandy, clayey, phosphatic limestone and dolomite; gray, fine to medium sand, gray to greenish-blue sandy clay, with abundant phosphate nodules.
		Lower Hawthorn-Tampa aquifer	Unit 4		
Lower Miocene	Tampa Limestone	Confining bed	Unit 5	150-300	Marine, white to light gray, sandy, often phosphatic, clayey limestone, silicified in part, with many molds of pelecypods and gastropods; often interbedded with light gray clay and sandy clay. A residual mantle of green to greenish-blue calcareous clay is often developed.

Oligo- cene	Suwannee Limestone	Floridan aquifer	200-300	Marine, cream to buff, often soft, granular limestone composed of loosely cemented foraminifers.
Upper Eocene	Ocala Limestone		200-300	Marine, white to cream, often soft and finely granular, limestone, grading near the bottom into tan limestone with beds of grayish-brown dolomite.
Middle Eocene	Avon Park Limestone		600-700	Marine, cream to tan, soft to hard, granular to chalky, highly fossiliferous limestone interbedded with grayish-brown to dark brown highly fractured dolomite; some carbonaceous and clayey zones; some intergranular gypsum and anhydrite near the bottom in places.
	Lake City Limestone	Lower confin- ing bed	300-500	Marine, green to tan, slightly carbonaceous and cherty limestone, and grayish to dark brown dolomite; both with varying amounts of intergranular gypsum and anhydrite.

and Hawthorn Formations and parts of the Tampa Limestone not in hydraulic contact with the Floridan aquifer. Underlying the intermediate aquifers and confining beds are parts of the Tampa, Suwannee, Ocala, and Avon Park Limestones of the Floridan aquifer. Underlying the Floridan aquifer is the lower confining bed, a part of the Avon Park or Lake City Limestones that are impregnated with evaporites.

Geologic Formations

The Lake City Limestone of middle Eocene age consists primarily of limestone and dolomite with varying amounts of evaporites. Thickness of the Lake City varies from 300 to 500 feet in thickness. The Avon Park of middle Eocene age consists primarily of limestone interbedded with dark brown, highly fractured dolomite. Thickness of the Avon Park varies from 600 to 700 feet. The Ocala Limestone of late Eocene age is a relatively pure limestone that grades into a dolomite near the bottom. Thickness of the Ocala varies from 200 to 300 feet. The Suwannee Limestone of Oligocene age is a granular limestone that varies from 200 to 300 feet in thickness. The Tampa Limestone is a sandy, phosphatic limestone with varying amounts of interbedded sand and clay near the bottom. Thickness of the Tampa varies from 150 to 300 feet.

The Hawthorn Formation of middle Miocene age unconformably overlies the Tampa Limestone. The Hawthorn Formation consists principally of beds of sandy, phosphatic limestone and dolomite, and sandy, chalky to granular, phosphatic clay. The Hawthorn thickens toward the south and ranges in thickness from about 200 to 400 feet.

The Hawthorn Formation is unconformably overlain by the Tamiami Formation of early Pliocene age. The Tamiami is comprised of clays, marls, sands, and thin beds of limestone. All the rock types, including the limestone, are slightly consolidated and slightly phosphatic. The Tamiami ranges in thickness from zero to 150 feet and is present in most of the area.

The Bone Valley Formation of Pliocene age unconformably overlies the Hawthorn Formation in part of the study area. The Bone Valley Formation consists of a lower unit composed of phosphate nodules, sand, and clay and an upper unit that is predominantly clayey sand with minor amounts of phosphate nodules. The formation ranges in thickness from zero to 20 feet. It is present only in the northern part of the study area and was not recognized in the area of the seismic survey.

The Caloosahatchee Marl of Pliocene and Pleistocene age unconformably overlies the Tamiami Formation in the southern part of the study area. Typically, Caloosahatchee sediments consist of unconsolidated shell beds; light gray, sandy, shelly marl; marl; and thin beds of hard, sandy limestone. The marl varies laterally from very shelly to very sandy and silty. The Caloosahatchee Marl ranges in thickness from zero to 50 feet.

Pleistocene terrace deposits are included in the undifferentiated deposits (table 2) and unconformably overlie the Caloosahatchee Marl. The terrace deposits are predominantly fine-to-medium, well-sorted, pale yellow-orange sand with some marl, peat, and shell. Thickness and areal distribution of the

Pleistocene terrace deposits are more variable than the overlying Holocene deposits. Pleistocene deposits range in thickness from zero to 40 feet. Holocene deposits are included in the undifferentiated deposits (table 2) and consist of fine-to-medium, light gray, quartz sand with minor beds of marl and peat. Holocene deposits are present throughout most of the area and range in thickness from zero to 20 feet.

Aquifers and Confining Beds

The surficial aquifer consists of permeable beds in the Bone Valley Formation and younger deposits. The surficial aquifer is generally unconfined; locally, however, water in lenses of sand, marl, and limestone is semiconfined where these rocks are overlain by thin clay beds. Underlying the surficial aquifer is the uppermost intermediate aquifer that consists of the Tamiami Formation and the upper part of the Hawthorn Formation (Tamiami-upper Hawthorn aquifer). This aquifer is equivalent to zones 1 and 2 as defined by Joyner and Sutcliffe (1976). The lowermost intermediate aquifer consists of the lower part of the Hawthorn Formation and the upper permeable parts of the Tampa Formation (lower Hawthorn-upper Tampa aquifer) that are in hydraulic contact with the Hawthorn Formation and not the Floridan aquifer. The lower Hawthorn-upper Tampa aquifer is equivalent to zone 3 as used by Joyner and Sutcliffe (1976). The two intermediate aquifers are separated from the surficial aquifer by clayey confining beds that are part of the Tamiami Formation and from each other by confining beds that are part of either the Tampa Limestone or the Hawthorn Formation, or both (table 2). Facies change within the confining bed can cause local hydraulic connection between the two intermediate aquifers or the uppermost intermediate aquifer and the surficial aquifer.

The confining beds that overlie the Floridan aquifer consist of marl or sand and clay within the Tampa Limestone (Wilson, 1977). Locally, beds of limestone and dolomite in the Tampa or Suwannee Limestones have low permeability either because they are not fractured or, if they are, the fractures are filled with clay. In these cases, the low-permeability limestones and dolomites also are treated as confining beds. These confining beds retard vertical movement of ground water between the overlying aquifers and the Floridan aquifer. Facies change within the confining beds can cause local hydraulic connection between the Floridan and surficial or intermediate aquifers. Within the study area, the confining beds are generally assumed to be areally extensive and range from 5 to 30 feet in thickness.

The thickness of the surficial aquifer is variable, generally ranging from about 50 feet in the northwest to about 100 feet in the eastern and southern parts of the study area. Thickness of the surficial and intermediate aquifers and their intervening confining beds also increases toward the south. The combined thickness of these aquifers and confining beds ranges from about 100 to about 700 feet. The altitude of the top of the Tamiami-upper Hawthorn aquifer (uppermost intermediate aquifer) ranges from about 50 feet below sea level in the north to about 125 feet below sea level in the south. Its thickness ranges from about 75 feet in the north to about 150 feet in the south. The altitude of the top of the lower Hawthorn-upper Tampa aquifer (lowermost intermediate aquifer) ranges from about 150 feet below sea level in the north to about 200 feet below sea level in the south. Its thickness ranges from about 200 feet in the north to about 350 feet in the south. Thickness of the limestone and dolomite beds of the Floridan aquifer increases toward the south and ranges from about 1,400 to 1,900 feet. The altitude of the top of the Floridan ranges from about 100 feet below sea level in the north to about 650 feet below sea level in the south.

HYDROGEOLOGIC INTERPRETATION OF SEISMIC-REFLECTION PROFILE DATA

Continuous lateral definition of sedimentary layers by seismic reflection aids in interpretation of geologic formations and contacts between geologic units. Interpretation of seismic data requires knowledge of local geology, based on regional studies, lithologic and geophysical logs, and knowledge of the average seismic velocities for geologic units penetrated.

To determine the depths to stratigraphic units (variations in materials) from reflection times, it is necessary to know the average seismic velocity for each unit. One method used to determine the approximate average velocity for the units is to correlate known depths to marked changes in lithology with reflectors on the seismic record. The seismic profile record has a vertical scale of two-way traveltime (the time required for a seismic wave to reach a unit and return). The two-way traveltime is related to the average velocity in the following manner:

$$\text{Average velocity} = \frac{\text{Depth of unit}}{\frac{\text{Two-way traveltime to unit}}{2}}$$

For example, if the one-way traveltime for a stratigraphic unit (or type of material) penetrated is 0.01 second (as read from the seismic profile), and lithologic logs near the site show the material to be at a depth of 50 feet below the reference point, the average velocity for the unit is the depth (50 feet) divided by its one-way traveltime (0.01 second), or 5,000 ft/s.

Numerous geophysical and geologists' logs from wells adjacent to the seismic profiles were used to determine depths to reflecting units. A summary of estimated average seismic velocities for the materials penetrated near the four survey sites is given in table 3. The materials penetrated can be grouped into five seismic-stratigraphic units.

Seismic-profile records and diagrammatic presentations of seismic-stratigraphic units for the Charlotte Harbor, Peace River, Myakka River, and Venice surveys are shown in figures 4, 5, 6, and 7, respectively. Geologic sections constructed from the seismic records for the above surveys are shown in figures 8, 9, 10, and 11, respectively. Lithologic logs from wells near each survey are shown in figure 12.

The configuration of the sediment-water interface and five seismic-stratigraphic units have been interpreted from the seismic profiles by tracking distinctive reflecting beds across the seismic record. The five seismic-stratigraphic units are, from bottom to top: sand and clay of the Tampa Limestone (the upper confining unit of the Floridan aquifer, unit 5); limestone and dolomite of the Hawthorn Formation (unit 4); limestone conglomerate or marl and clay of the Tamiami Formation (unit 3); clay and clayey sand, clay and sand, or sand and limestone of the Tamiami Formation (unit 2); and undifferentiated surficial deposits, Caloosahatchee Marl, and Bone Valley Formation combined (unit 1).

Table 3.--Estimated seismic velocities of penetrated materials

- Unit 1 - Sand of surficial deposits and Caloosahatchee Marl, undifferentiated
 Unit 2 - Clay and clayey sand, clay and sand, or sand and limestone of the Tamiami Formation
 Unit 3 - Limestone conglomerate or marl and clay of Tamiami Formation
 Unit 4 - Limestone and dolomite of Hawthorn Formation
 Unit 5 - Sand and clay of Tampa Limestone

Predominant lithology	Description	Seismic stratigraphic unit	Calculated average seismic velocity (ft/s)
Charlotte Harbor survey			
Water			4,900
Sand	Fine to medium quartz sand with varying amounts of marl shell, clay, phosphate, and limestone stringers.	Unit 1	5,000
Clay and clayey sand	Gray to green calcareous clay with quartz sand, phosphate and shell.	Unit 2	6,500
Limestone conglomerate	Sandy limestone with abundant phosphate pebbles and limestone fragments.	Unit 3	8,500
Limestone and dolomite	Interbedded layers of phosphate limestone and dolomite.	Unit 4	11,000
Peace River survey			
Water			4,900
Sand	Fine to medium quartz sand with varying amounts of marl, shell, clay, phosphate, and limestone stringers.	Unit 1	5,000
Clay and sand	Gray to green calcareous clay with quartz sand, marl, phosphate, and shell.	Unit 2	9,000
Limestone conglomerate	Sandy limestone with abundant phosphate pebbles and limestone fragments.	Unit 3	10,000
Limestone and dolomite	Interbedded layers of phosphatic limestone and dolomite.	Unit 4	11,000

Table 3.--Estimated seismic velocities of penetrated materials - Continued

Predominant lithology	Description	Seismic stratigraphic unit	Calculated average seismic velocity (ft/s)
Peace River survey - continued			
Sand and clay	Sand and clay unit of Tampa Limestone consisting of interbedded layers of gray to green clayey sand and sandy clay with clayey limestone.	Unit 5	11,000
Myakka River survey			
Water			4,900
Sand	Fine to medium quartz sand with varying amounts of marl, shell, clay, phosphate, and limestone stringers.	Unit 1	5,000
Clay and sand	Gray to green calcareous clay with quartz sand, marl, phosphate, and shell.	Unit 2	6,500
Limestone conglomerate and limestone	Sandy limestone with abundant phosphate pebbles and limestone fragments changing to marl at the northern end of the run.	Unit 3	11,000
Limestone and dolomite	Interbedded layers of phosphatic limestone and dolomite.	Unit 4	11,000
Venice survey			
Water			4,900
Sand and limestone	Fine to medium quartz sand and sandy, marly limestone.	Unit 1	7,500
Clay and marl limestone	Gray marl and sandy limestone stringers.	Unit 2	9,000
Marl and clay	Gray marl and green to gray, sandy calcareous clay.	Unit 3	9,000
Limestone and dolomite	Interbedded layers of phosphatic limestone and dolomite.	Unit 4	11,000

Locations of wells where average seismic velocity calculated shown in figure 1.

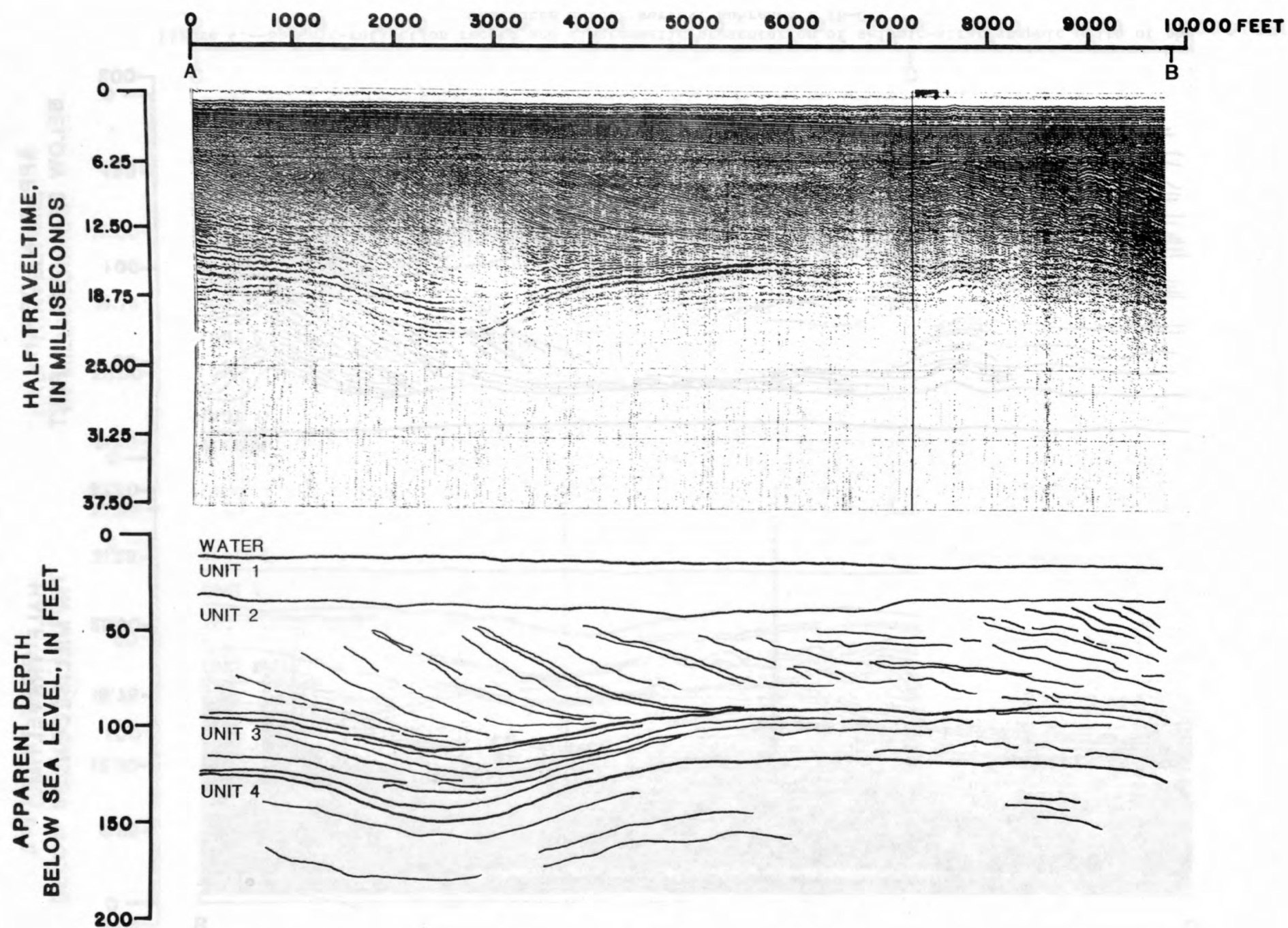


Figure 4.--Seismic-reflection record and diagrammatic presentation of seismic-stratigraphic units of the Charlotte Harbor survey, subreach 1 (A-B).

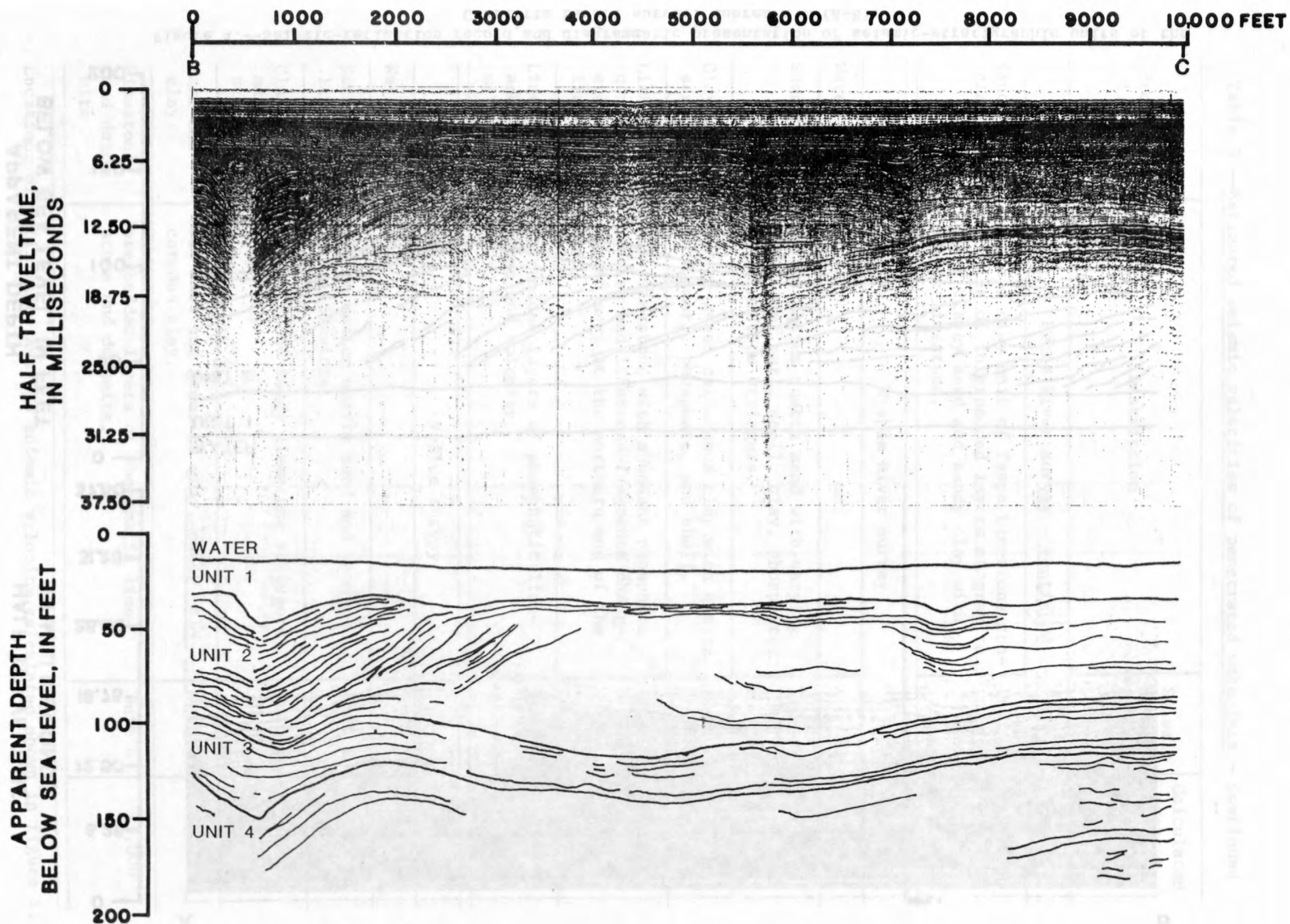


Figure 4.--Seismic-reflection record and diagrammatic presentation of seismic-stratigraphic units of the Charlotte Harbor survey, subreach 2 (B-C).

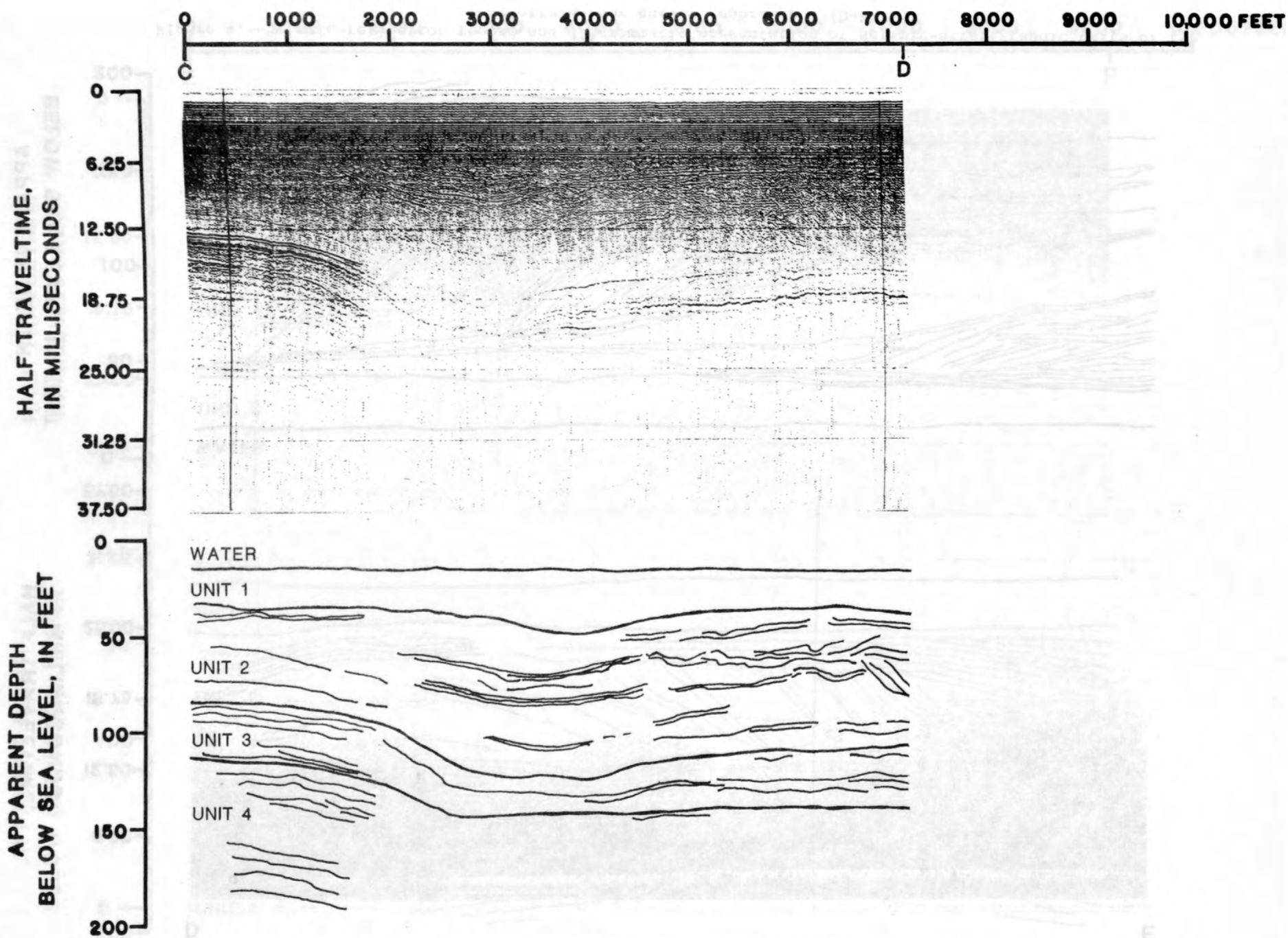


Figure 4.--Seismic-reflection record and diagrammatic presentation of seismic-stratigraphic units of the Charlotte Harbor survey, subreach 3 (C-D).

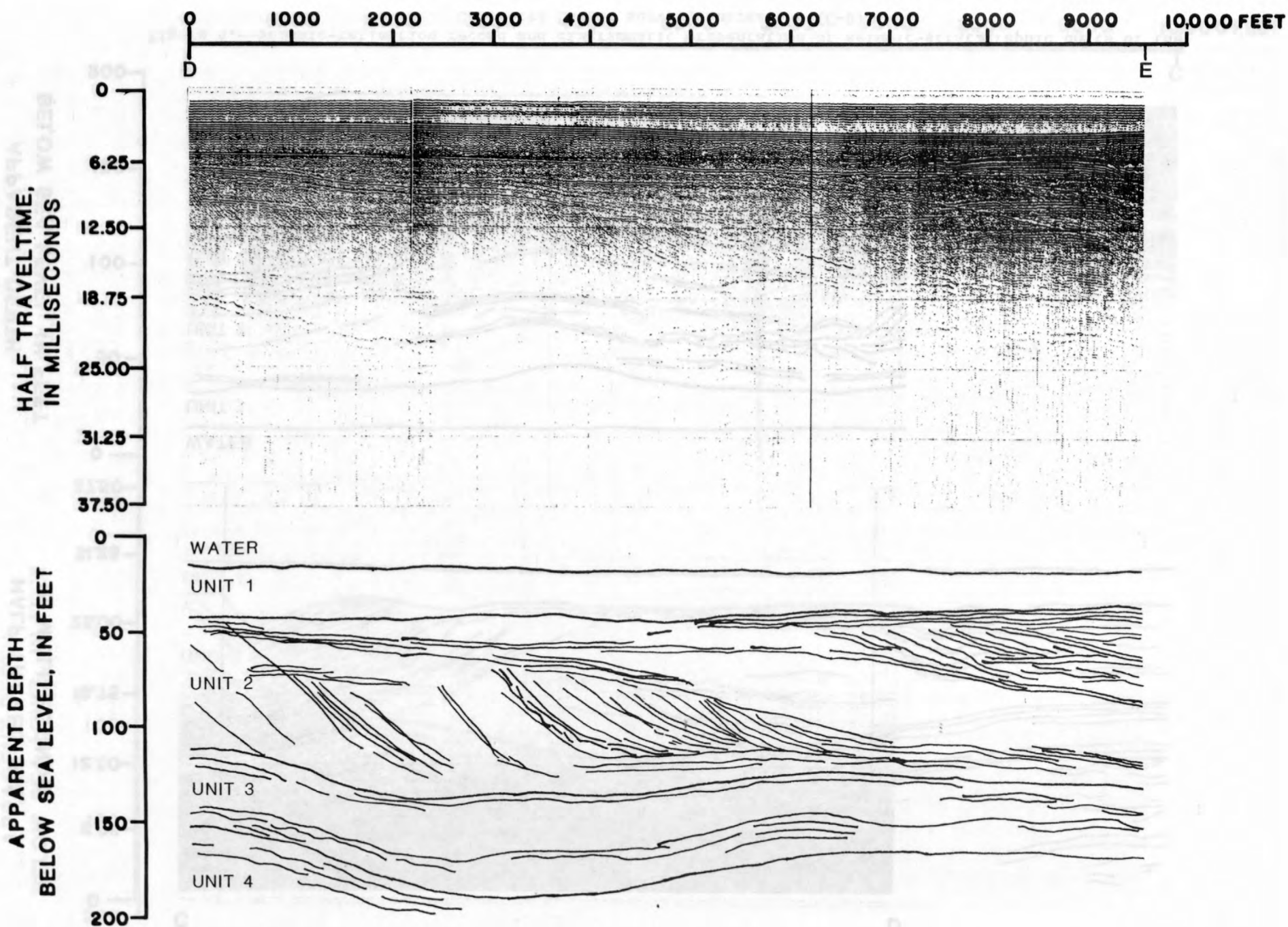


Figure 4.--Seismic-reflection record and diagrammatic presentation of seismic-stratigraphic units of the Charlotte Harbor survey, subreach 4 (D-E).

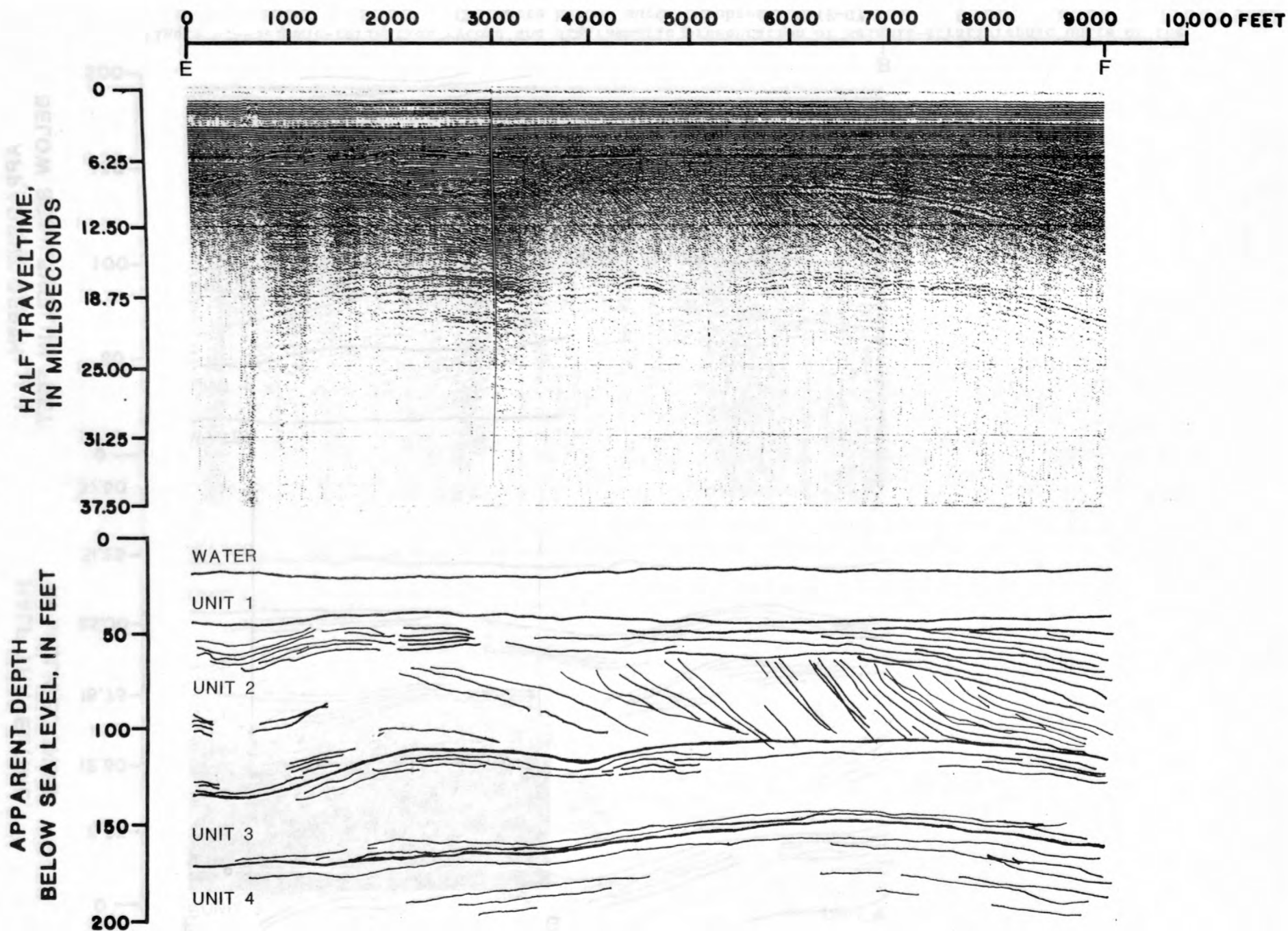


Figure 4.--Seismic-reflection record and diagrammatic presentation of seismic-stratigraphic units of the Charlotte Harbor survey, subreach 5 (E-F).

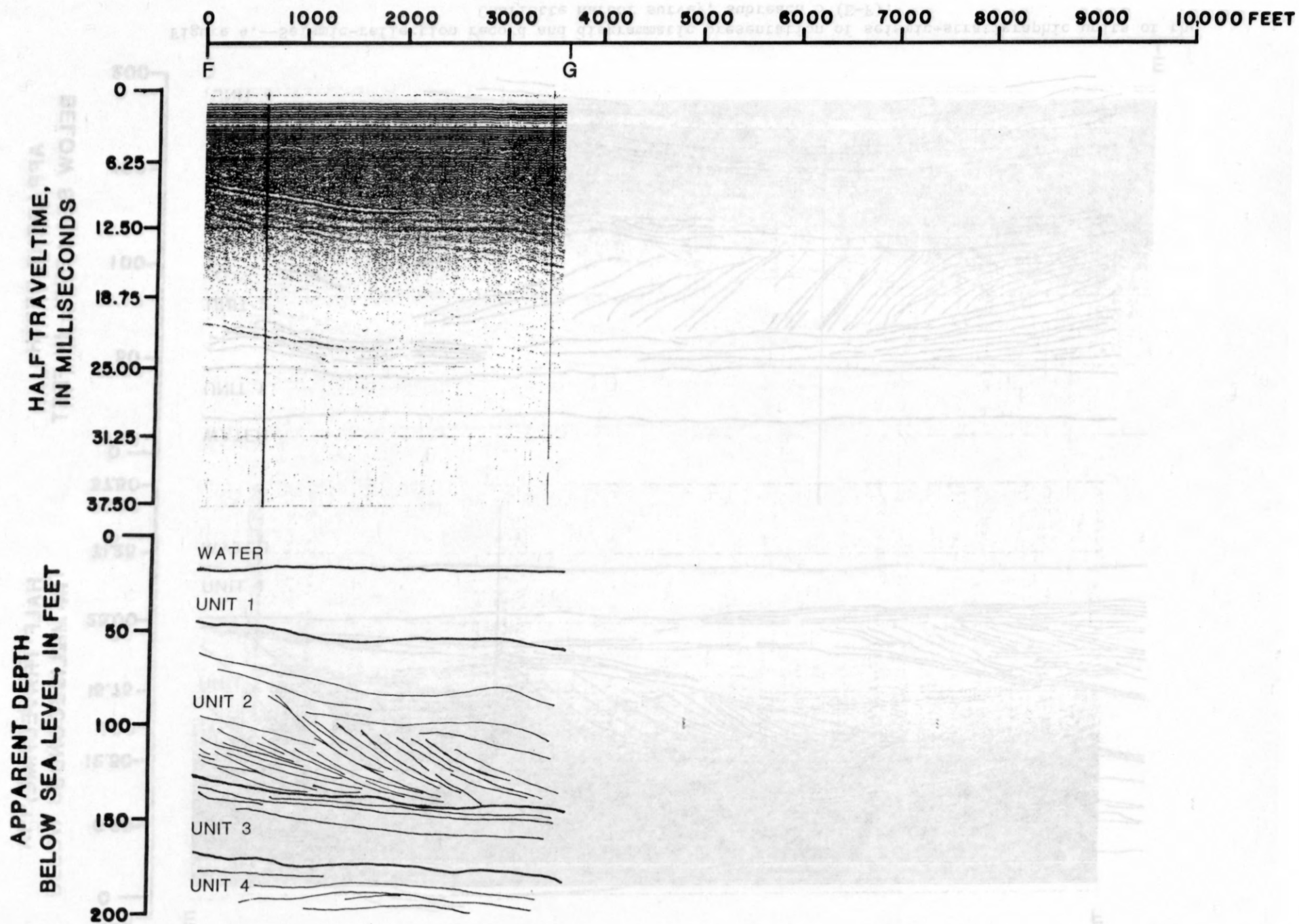


Figure 4.--Seismic-reflection record and diagrammatic presentation of seismic-stratigraphic units of the Charlotte Harbor survey, subreach 6 (F-G).

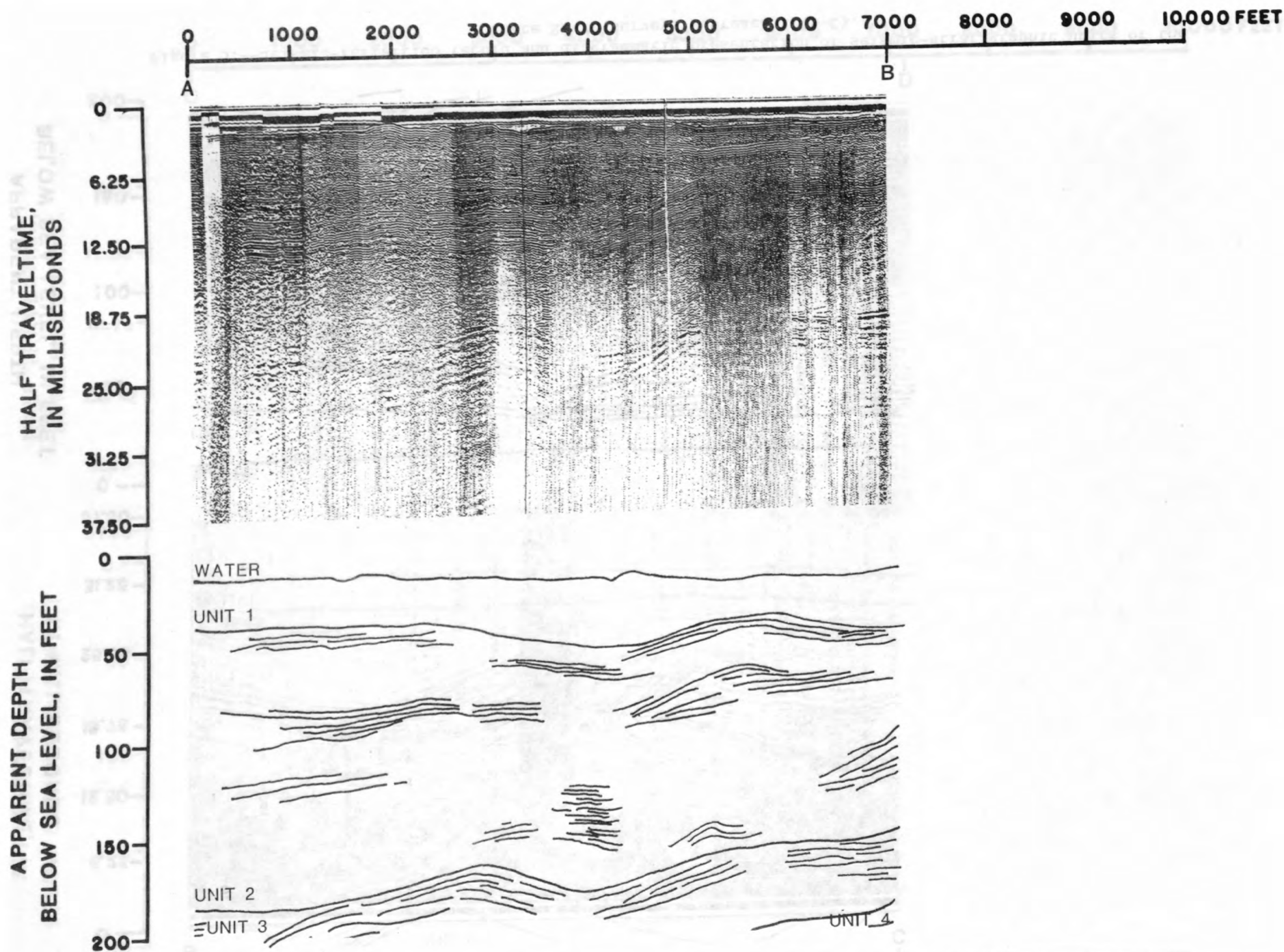


Figure 5.--Seismic-reflection record and diagrammatic presentation of seismic-stratigraphic units of the Peace River survey, subreach 1 (A-B).

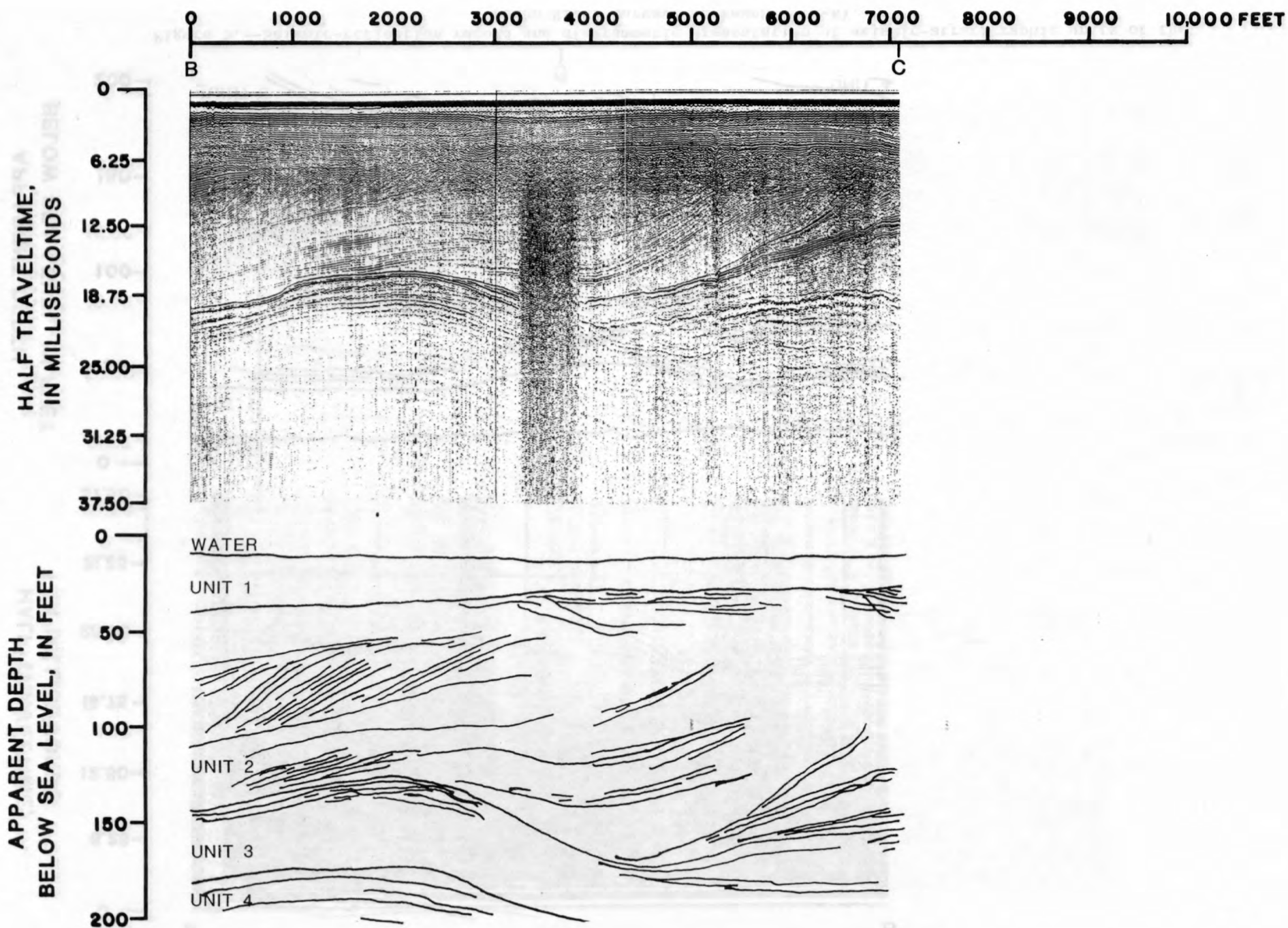


Figure 5.--Seismic-reflection record and diagrammatic presentation of seismic-stratigraphic units of the Peace River survey, subreach 2 (B-C).

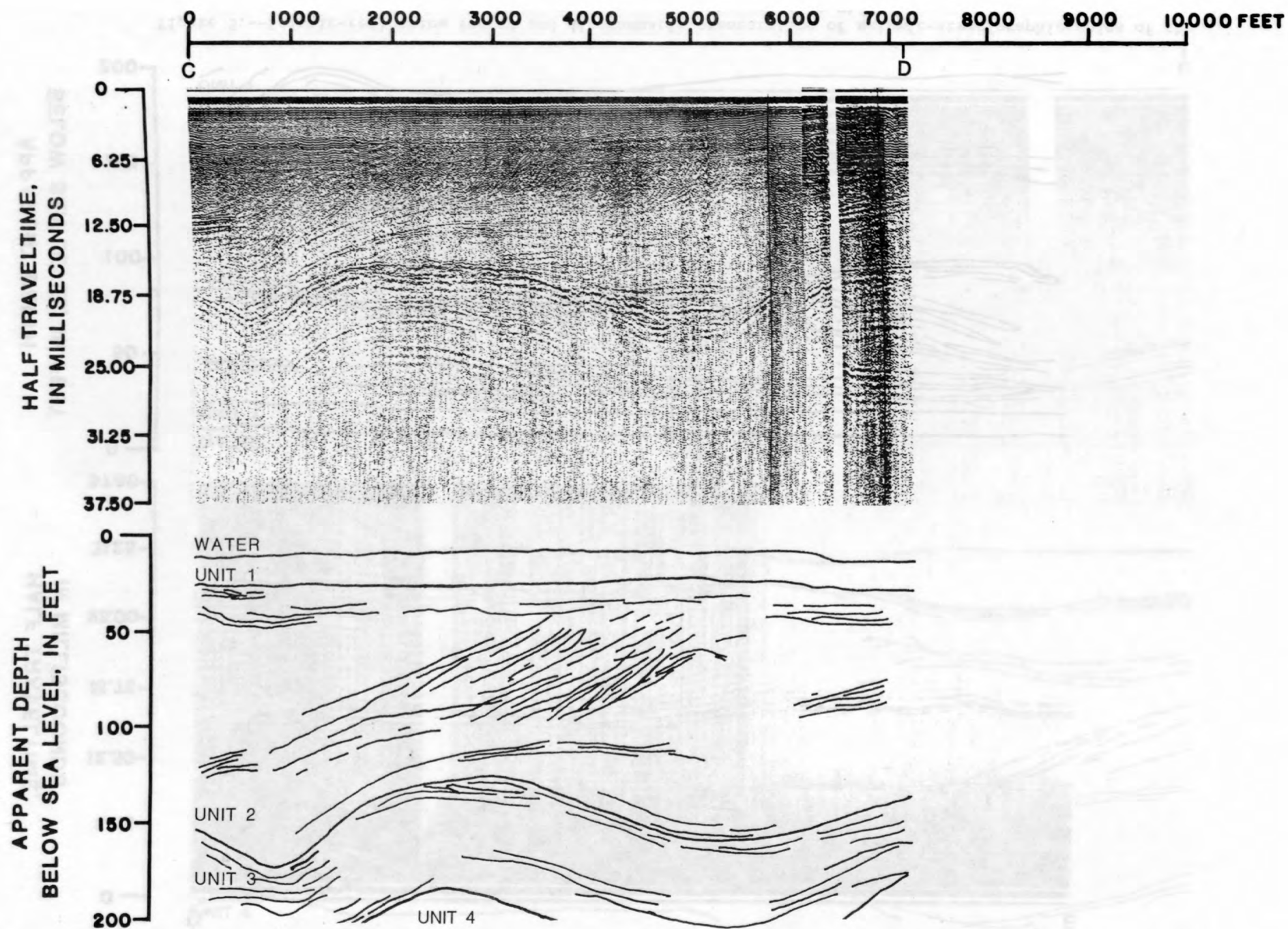


Figure 5.--Seismic-reflection record and diagrammatic presentation of seismic-stratigraphic units of the Peace River survey, subreach 3 (C-D).

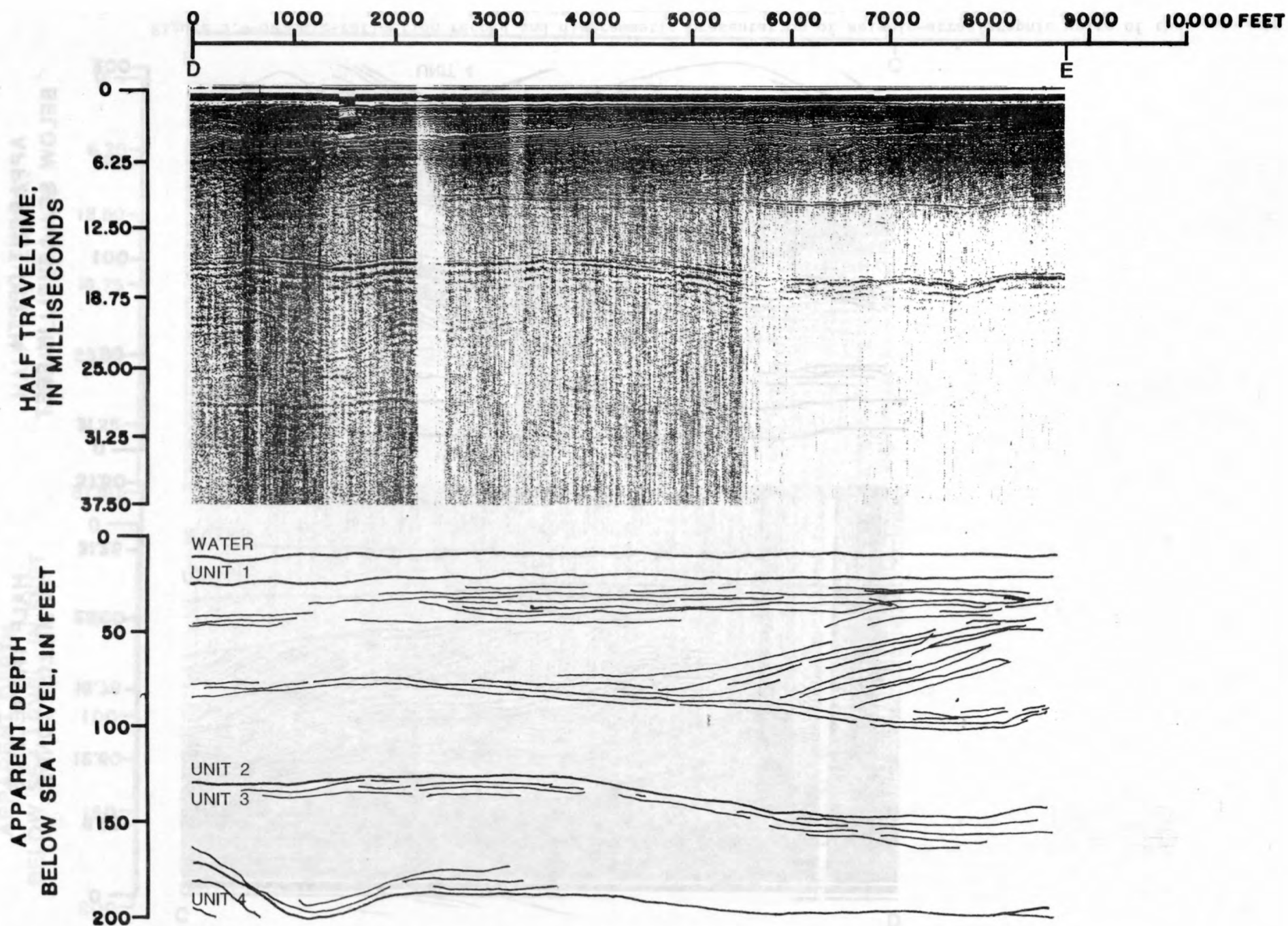


Figure 5.--Seismic-reflection record and diagrammatic presentation of seismic-stratigraphic units of the Peace River survey, subreach 4 (D-E).

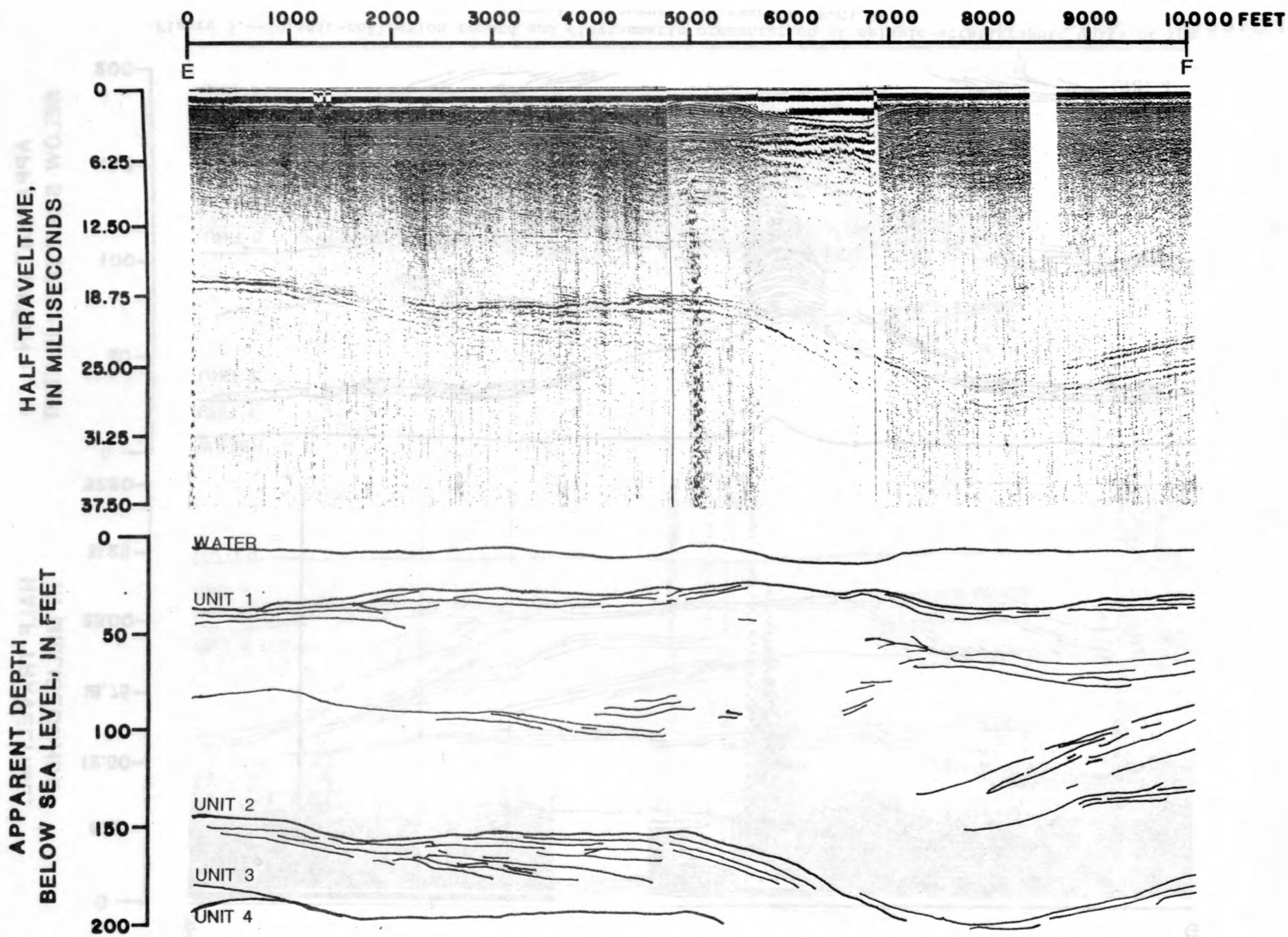


Figure 5.--Seismic-reflection record and diagrammatic presentation of seismic-stratigraphic units of the Peace River survey, subreach 5 (E-F).

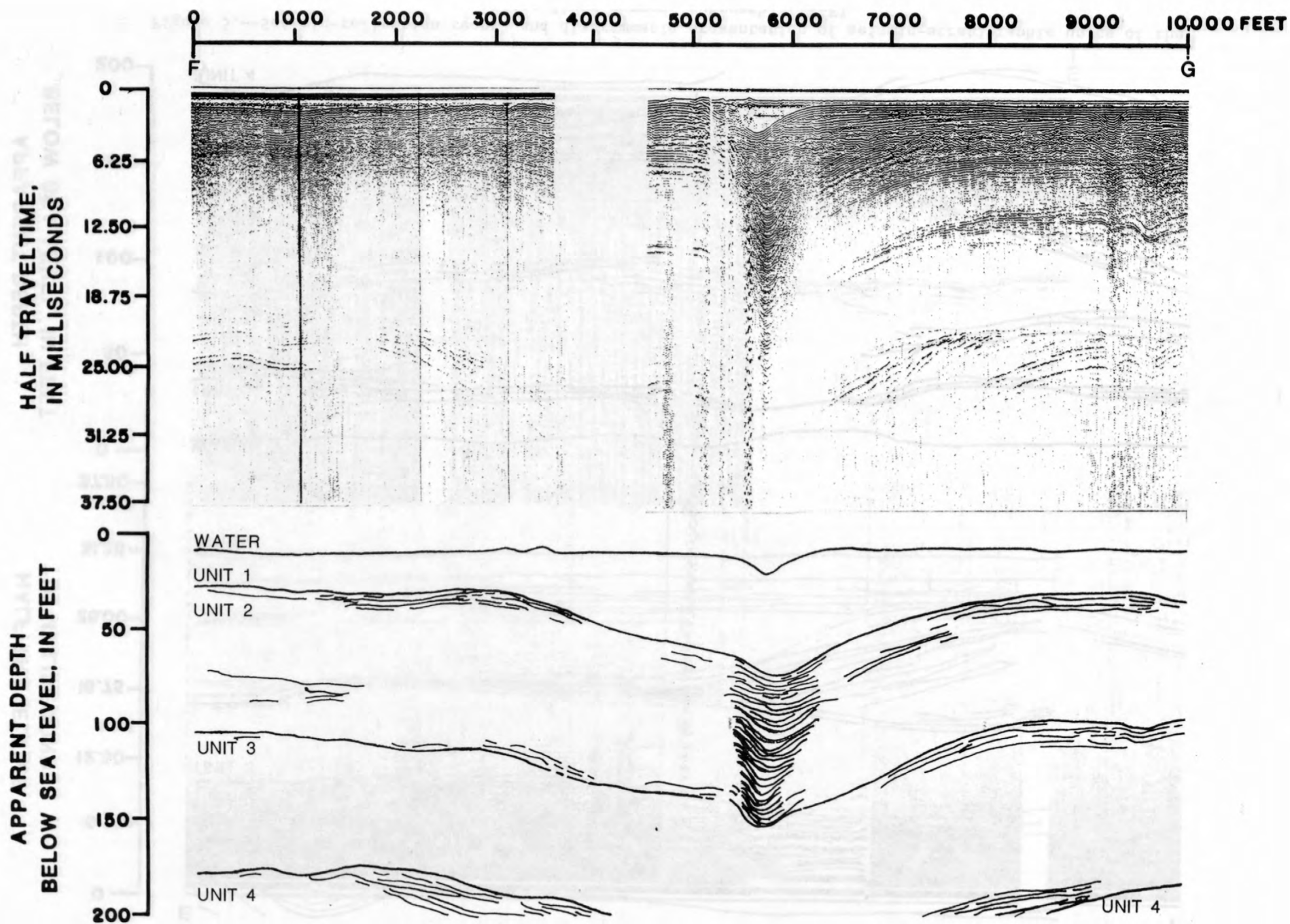


Figure 5.--Seismic-reflection record and diagrammatic presentation of seismic-stratigraphic units of the Peace River survey, subreach 6 (F-G).

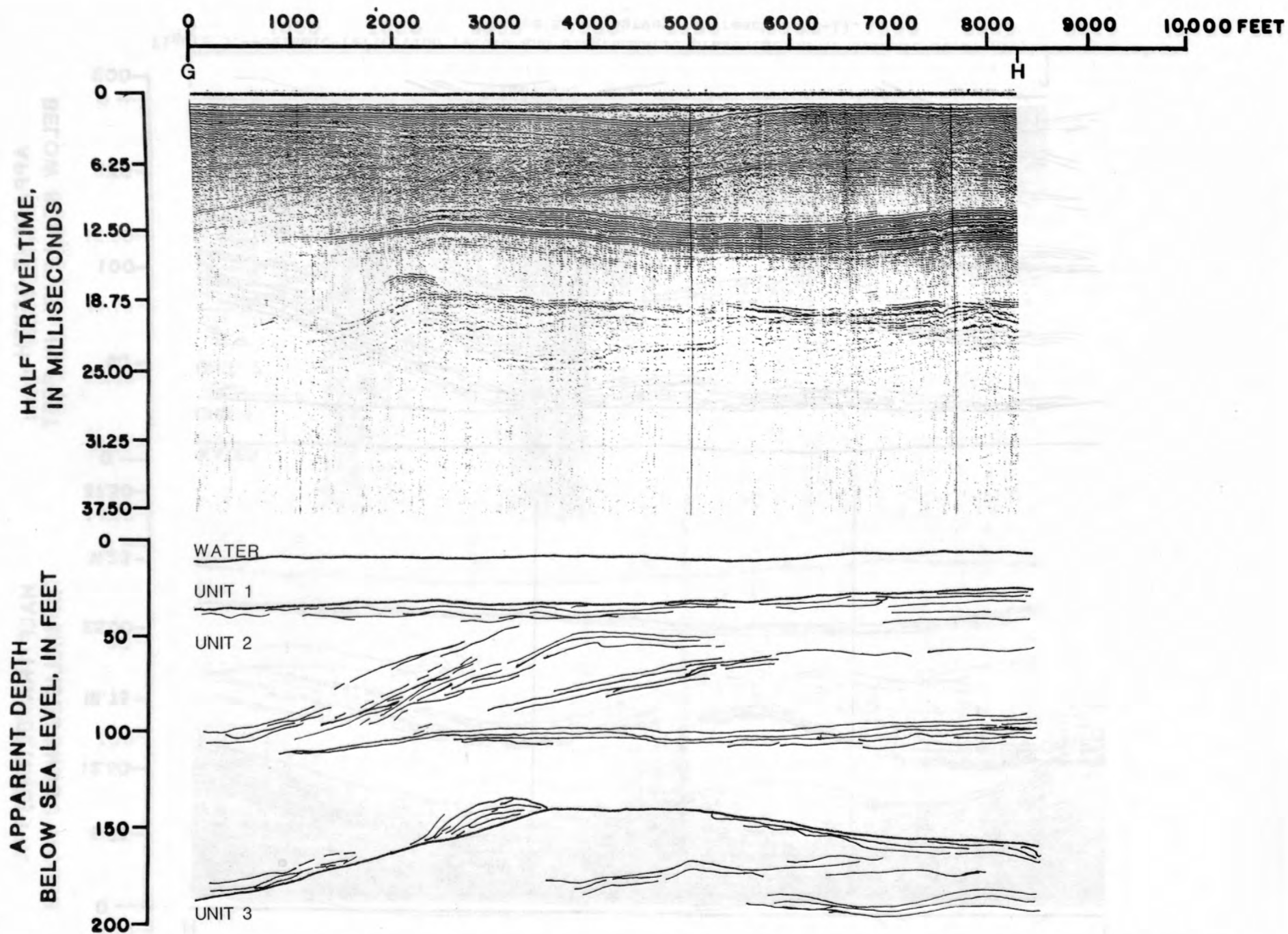


Figure 5.--Seismic-reflection record and diagrammatic presentation of seismic-stratigraphic units of the Peace River survey, subreach 7 (G-H).

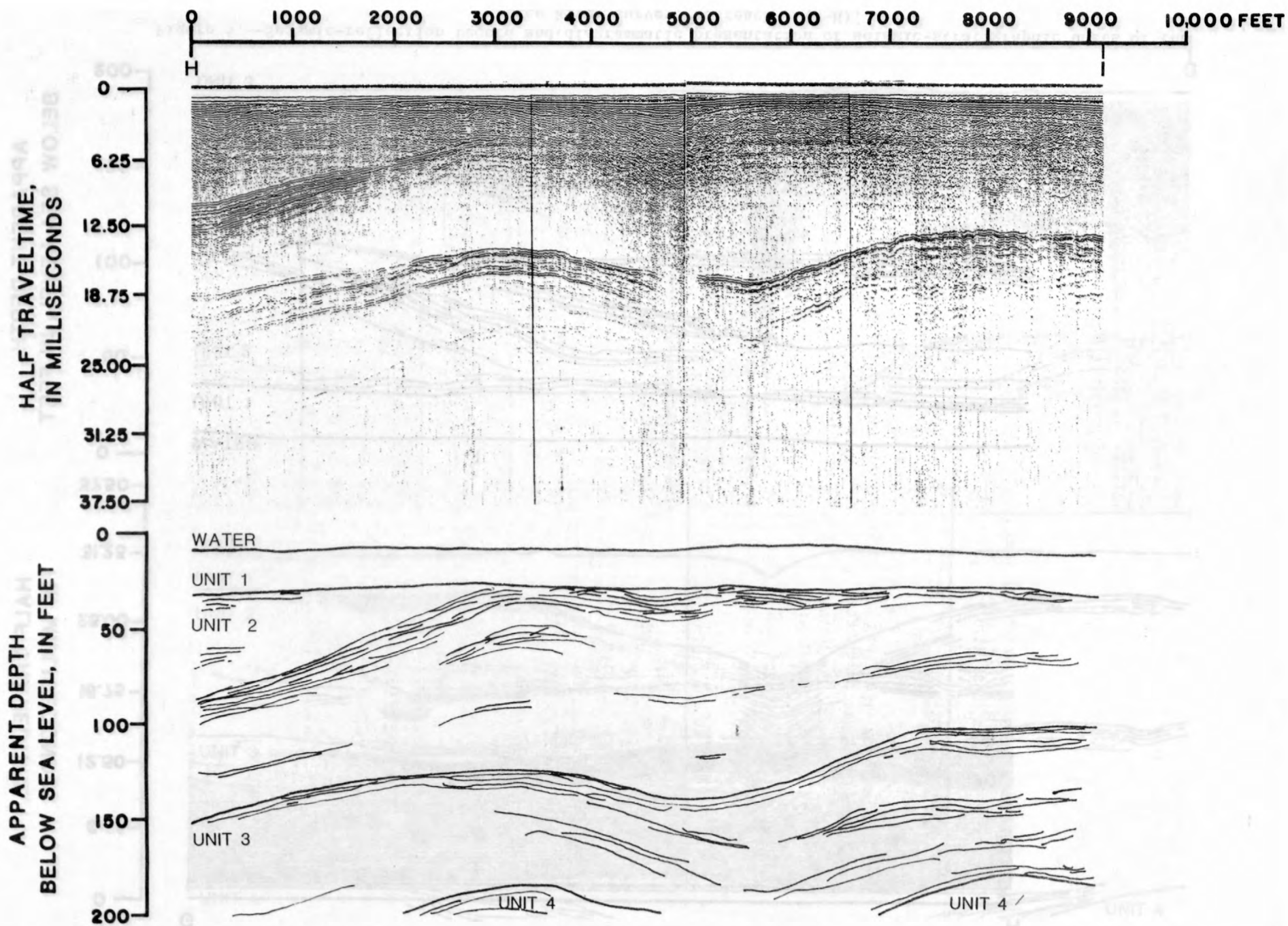


Figure 5.--Seismic-reflection record and diagrammatic presentation of seismic-stratigraphic units of the Peace River survey, subreach 8 (H-I).

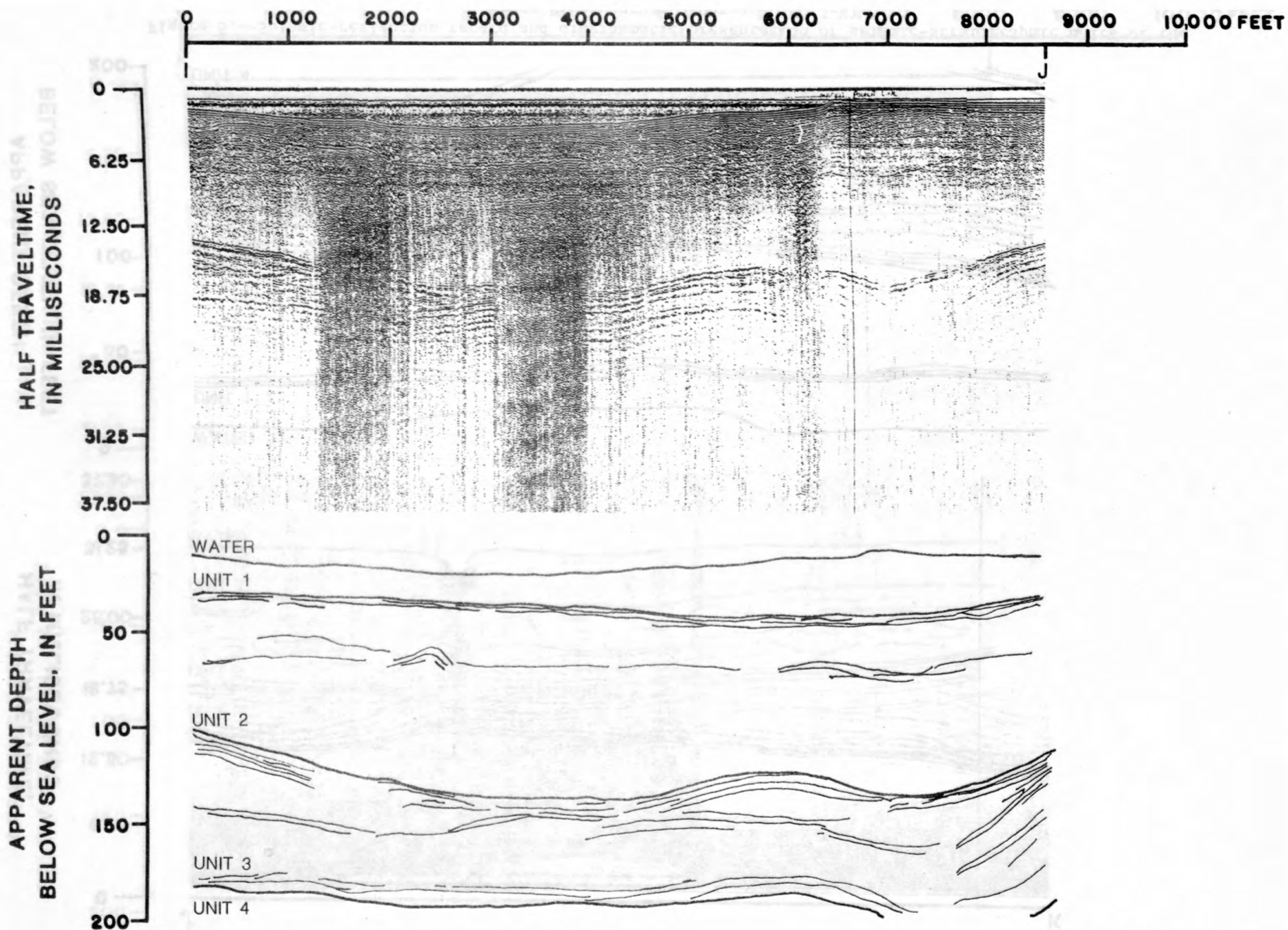


Figure 5.--Seismic-reflection record and diagrammatic presentation of seismic-stratigraphic units of the Peace River survey, subreach 9 (I-J).

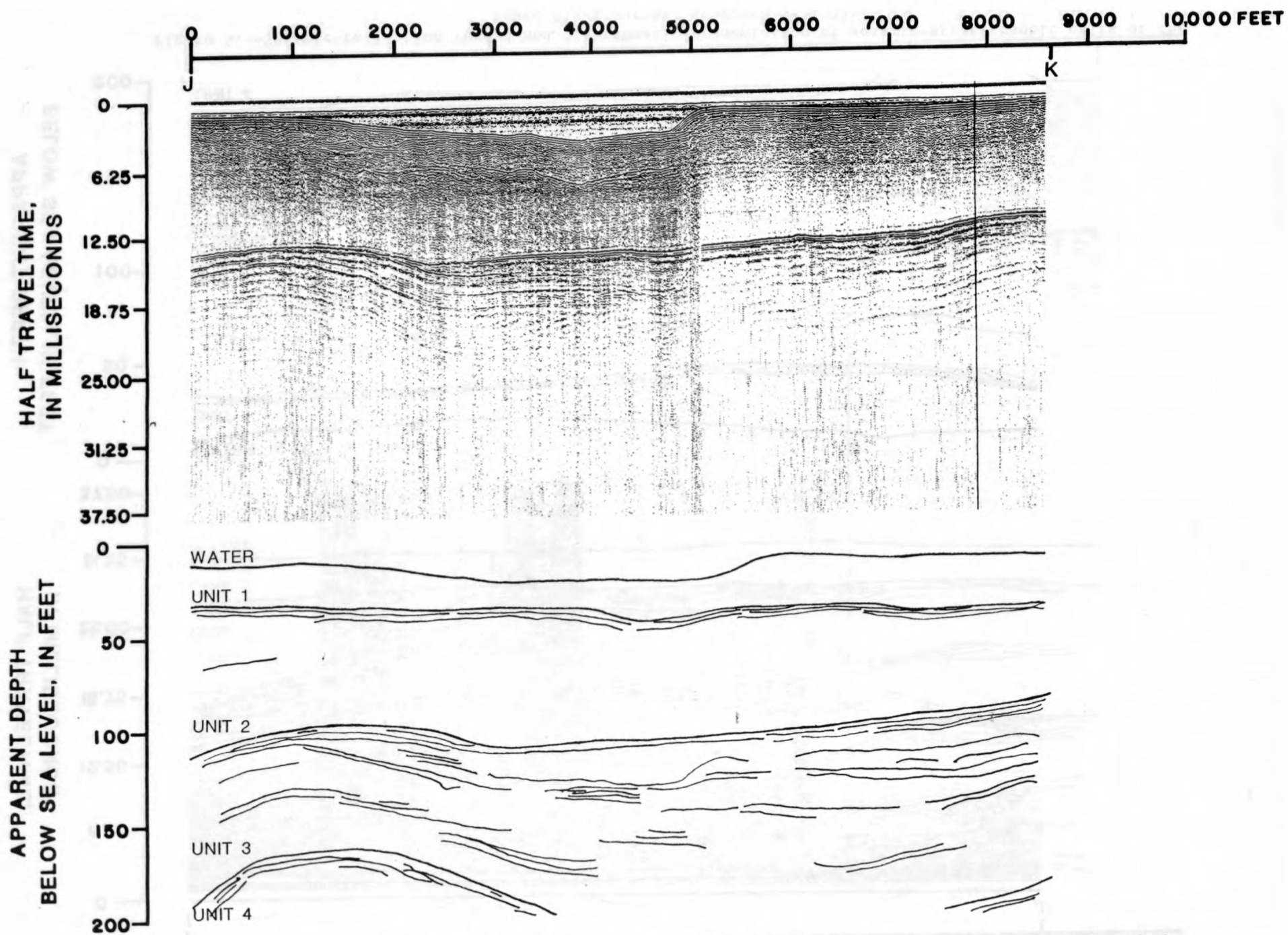


Figure 5.--Seismic-reflection record and diagrammatic presentation of seismic-stratigraphic units of the Peace River survey, subreach 10 (J-K).

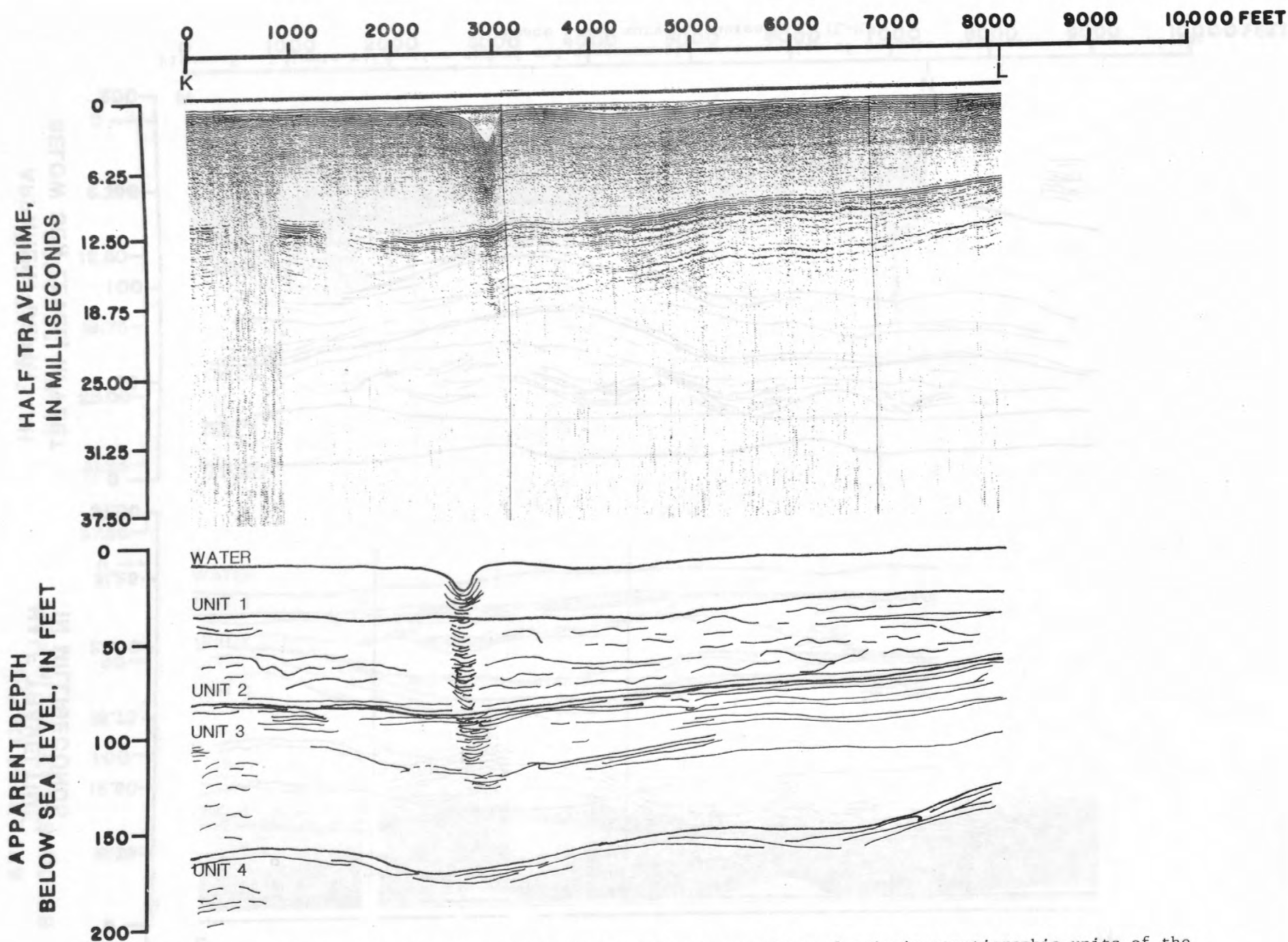


Figure 5.--Seismic-reflection record and diagrammatic presentation of seismic-stratigraphic units of the Peace River survey, subreach 11 (K-L).

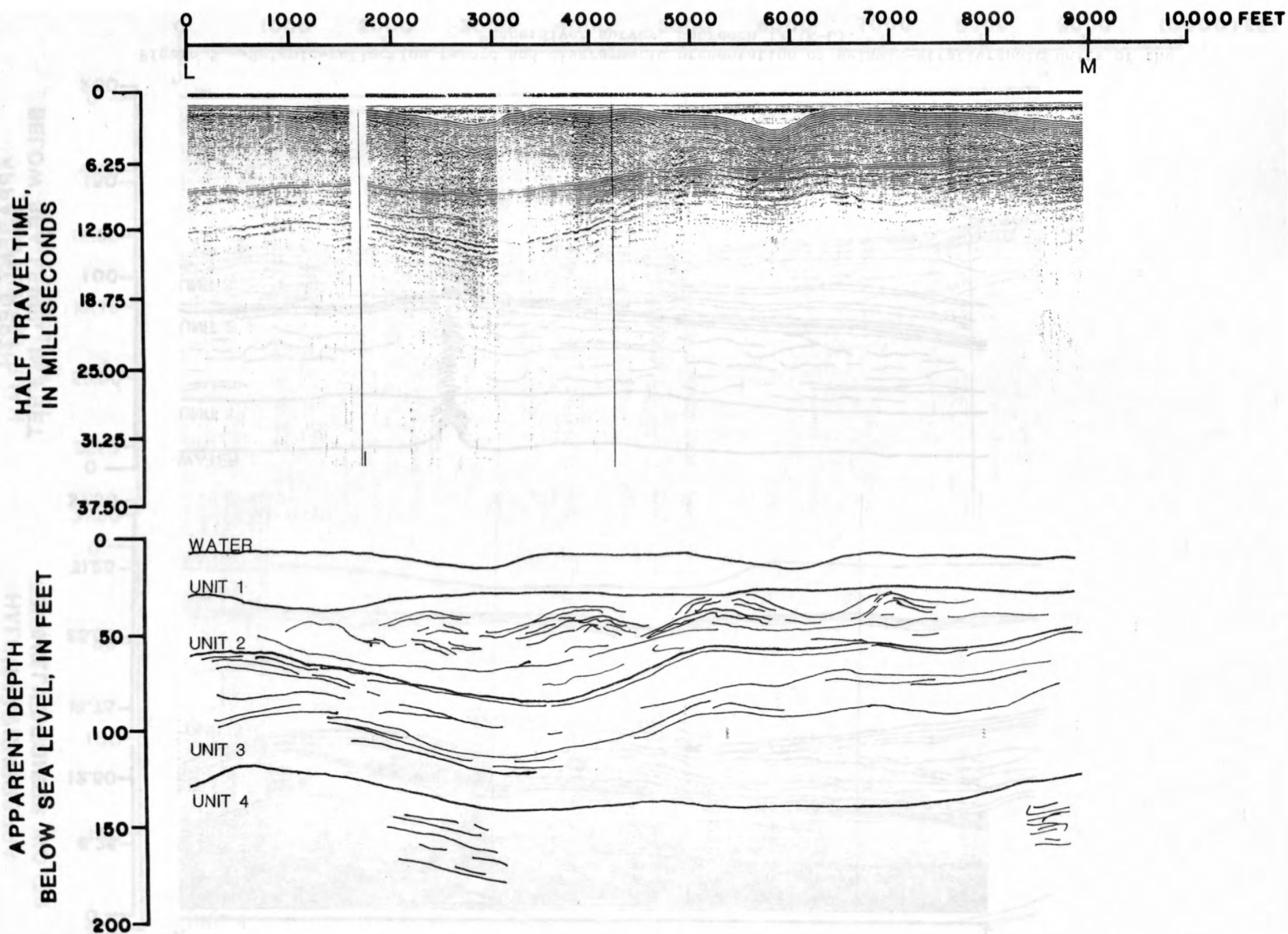


Figure 5.--Seismic-reflection record and diagrammatic presentation of seismic-stratigraphic units of the Peace River survey, subreach 12 (L-M).

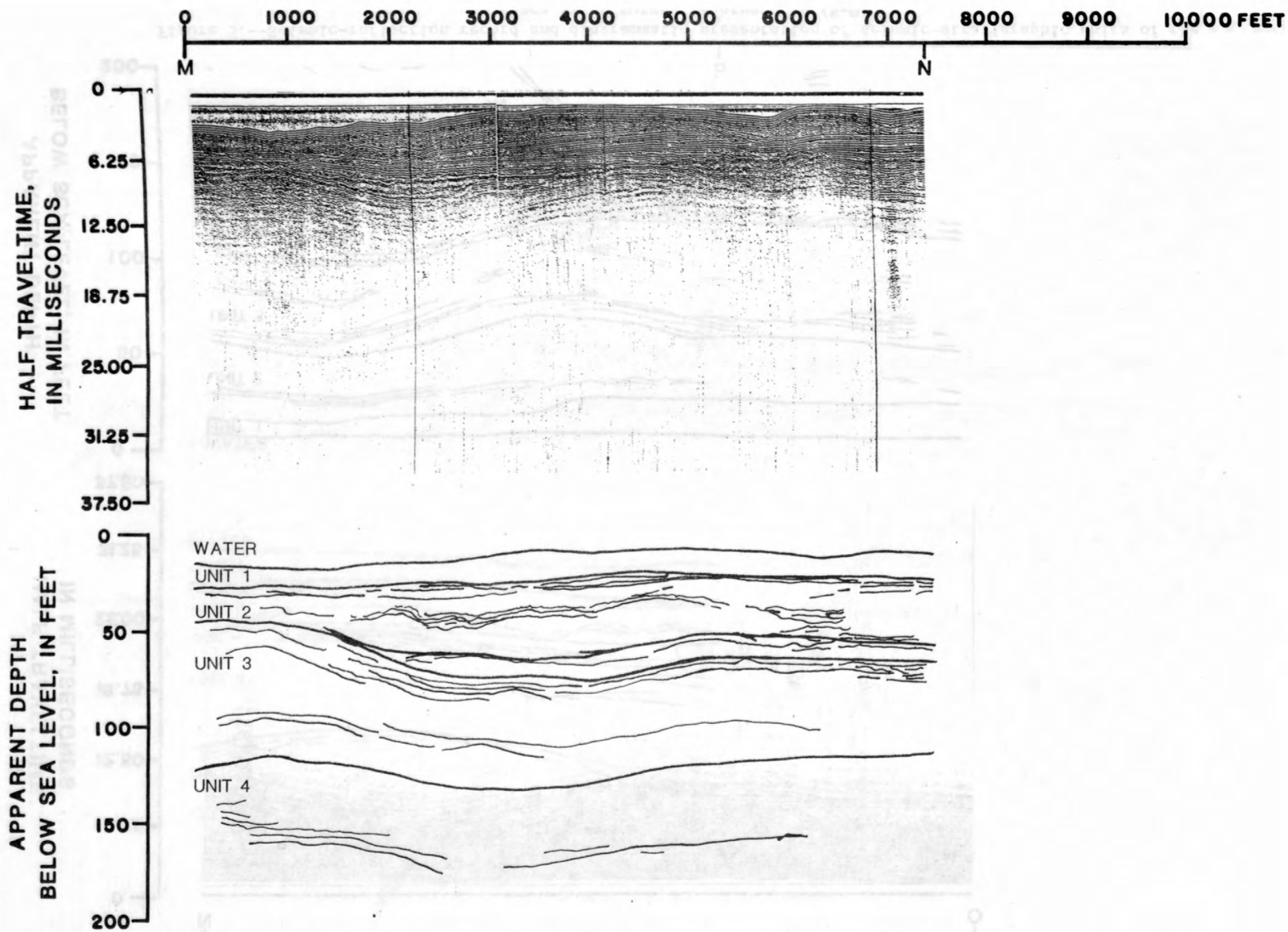


Figure 5.--Seismic-reflection record and diagrammatic presentation of seismic-stratigraphic units of the Peace River survey, subreach 13 (M-N).

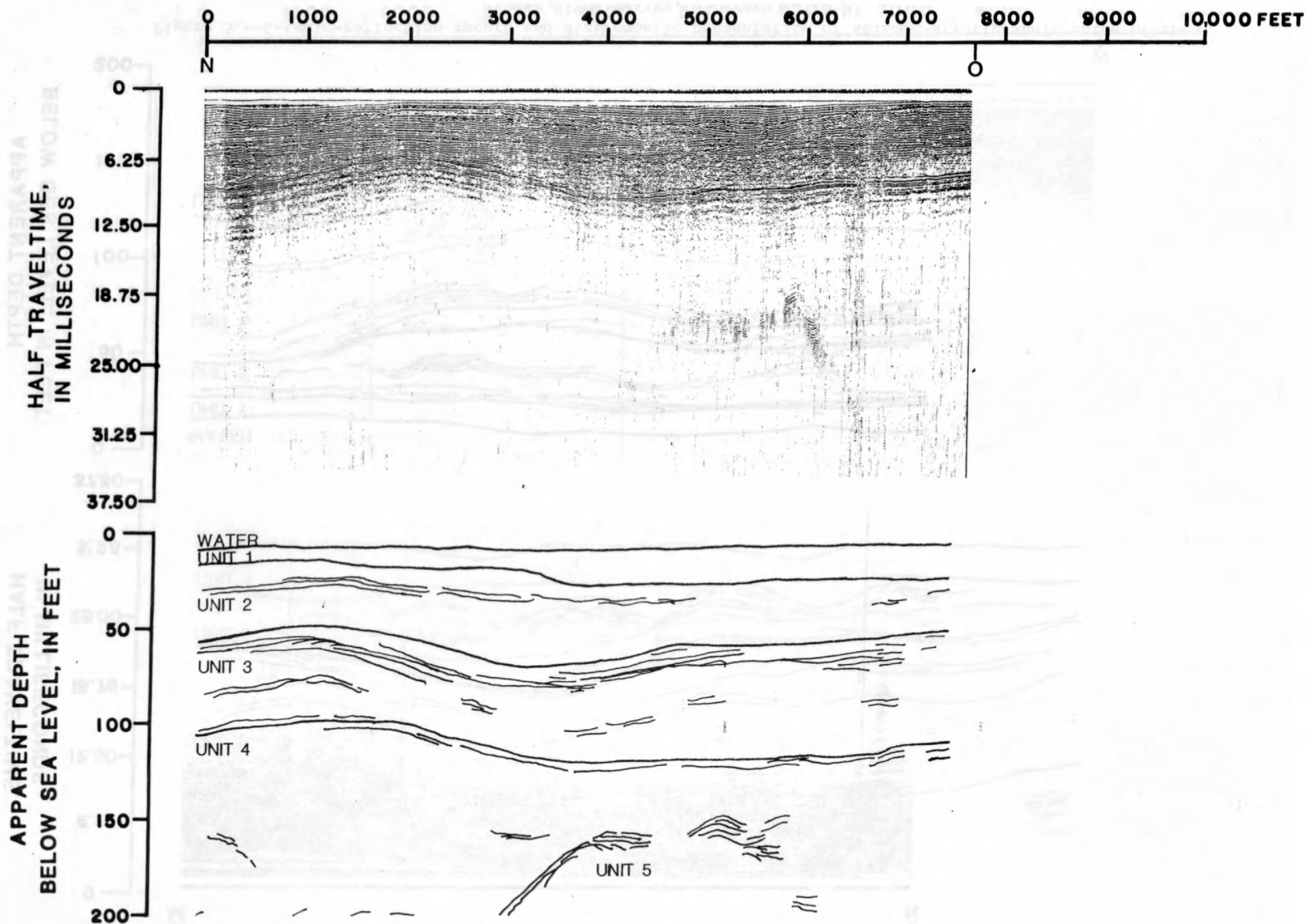


Figure 5.--Seismic-reflection record and diagrammatic presentation of seismic-stratigraphic units of the Peace River survey, subreach 14 (N-O).

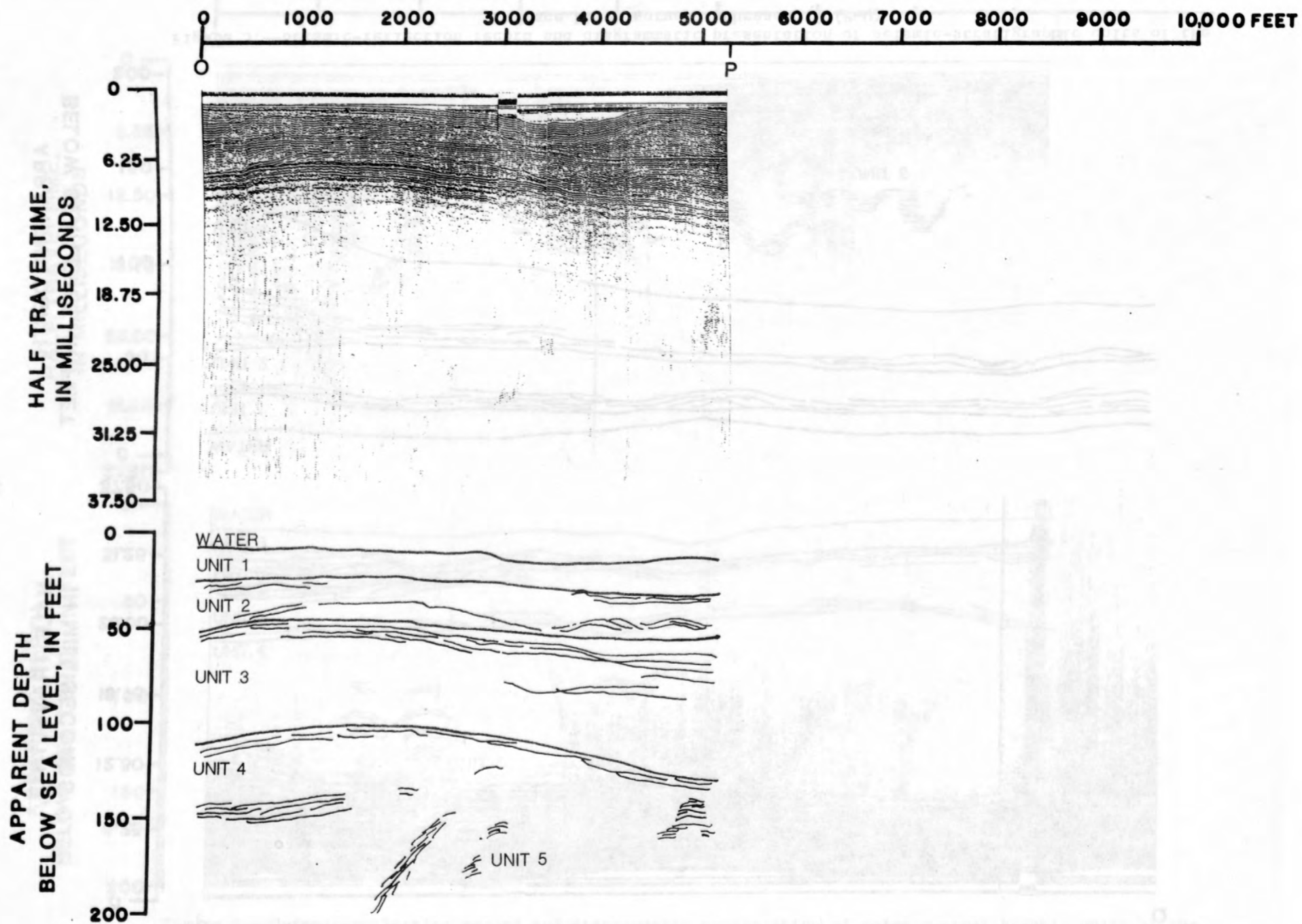


Figure 5.--Seismic-reflection record and diagrammatic presentation of seismic-stratigraphic units of the Peace River survey, subreach 15 (O-P).

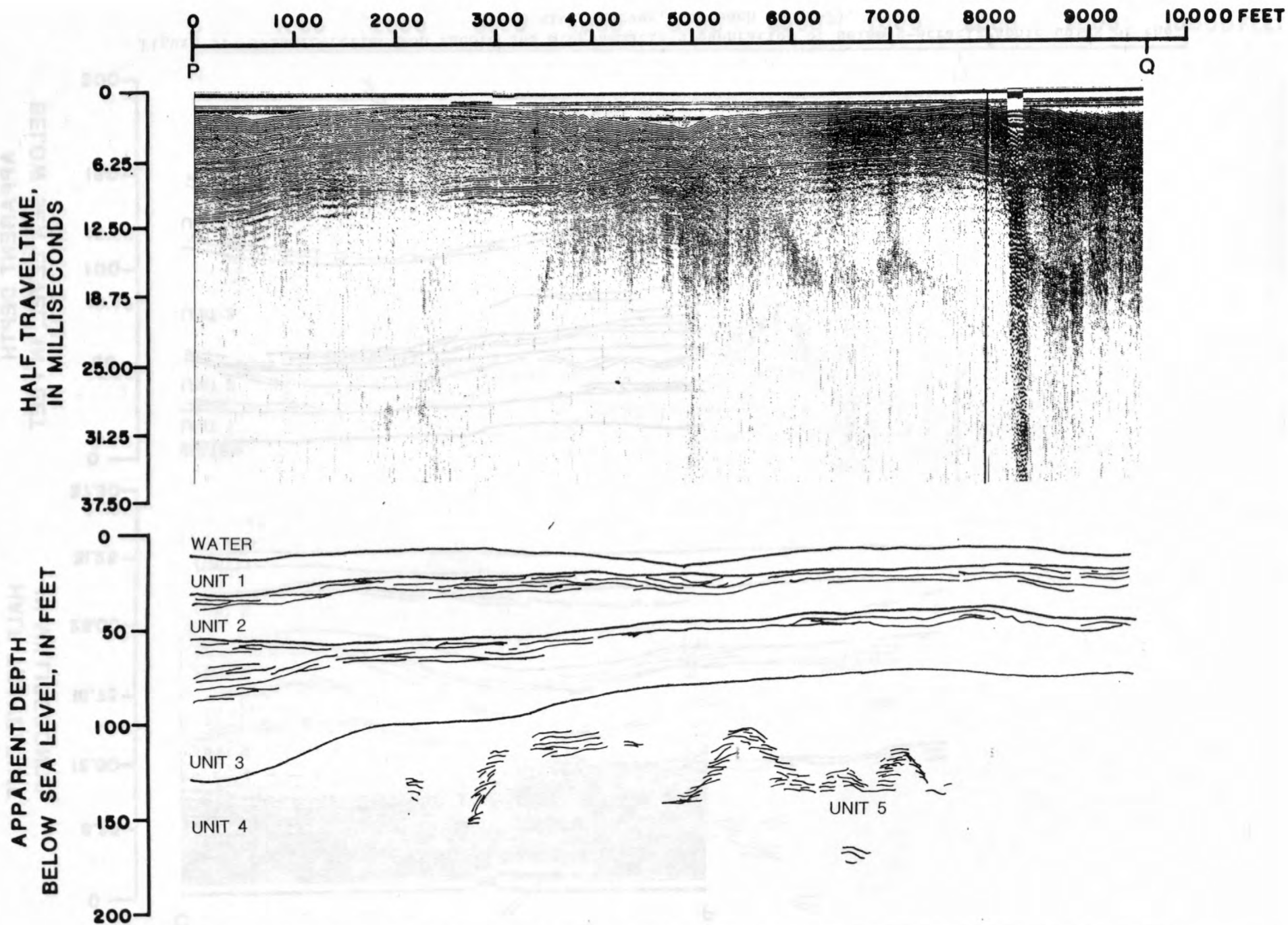


Figure 5.--Seismic-reflection record and diagrammatic presentation of seismic-stratigraphic units of the Peace River survey, subreach 16 (P-Q).

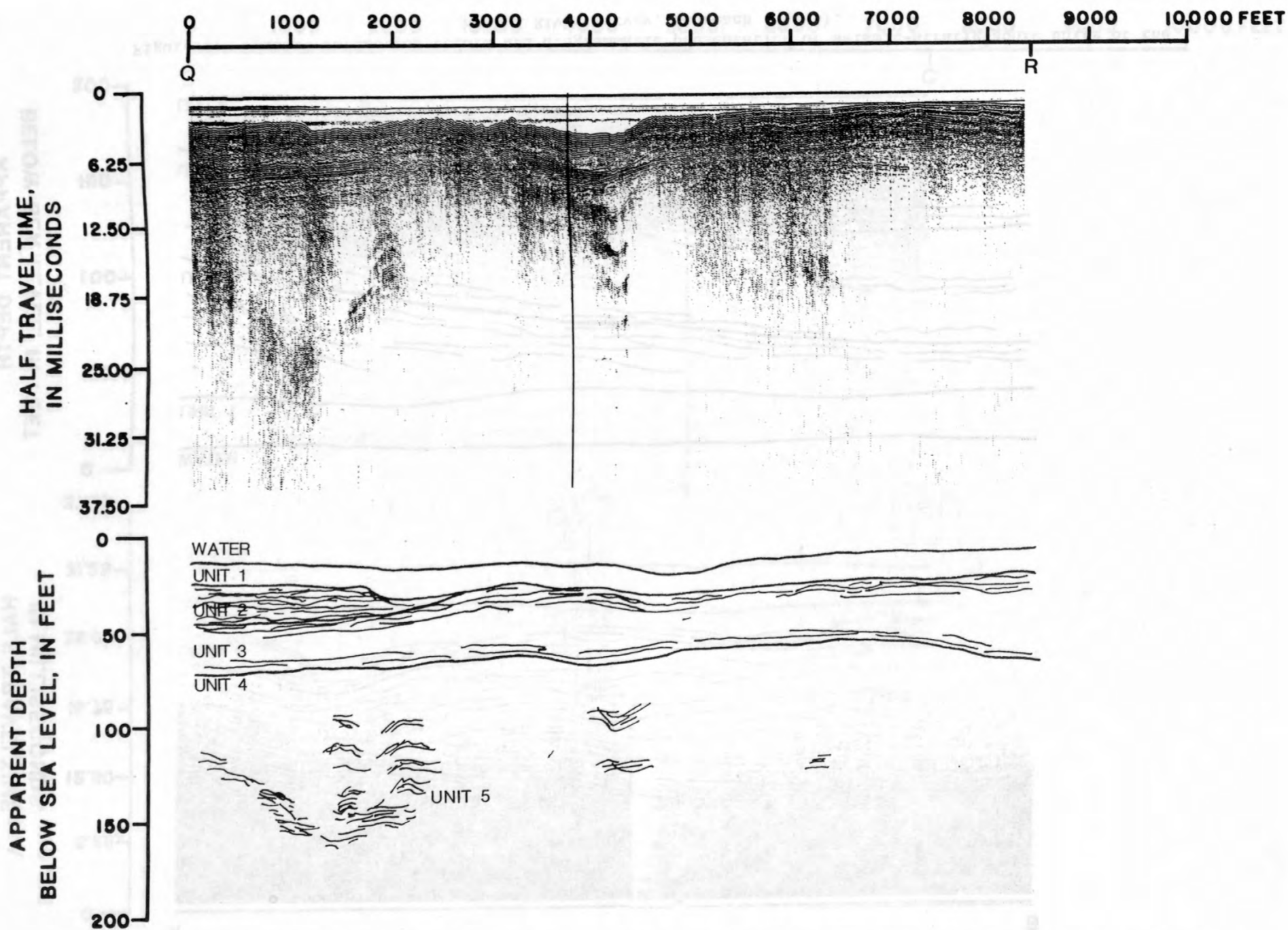


Figure 5.--Seismic-reflection record and diagrammatic presentation of seismic-stratigraphic units of the Peace River survey, subreach 17 (Q-R).

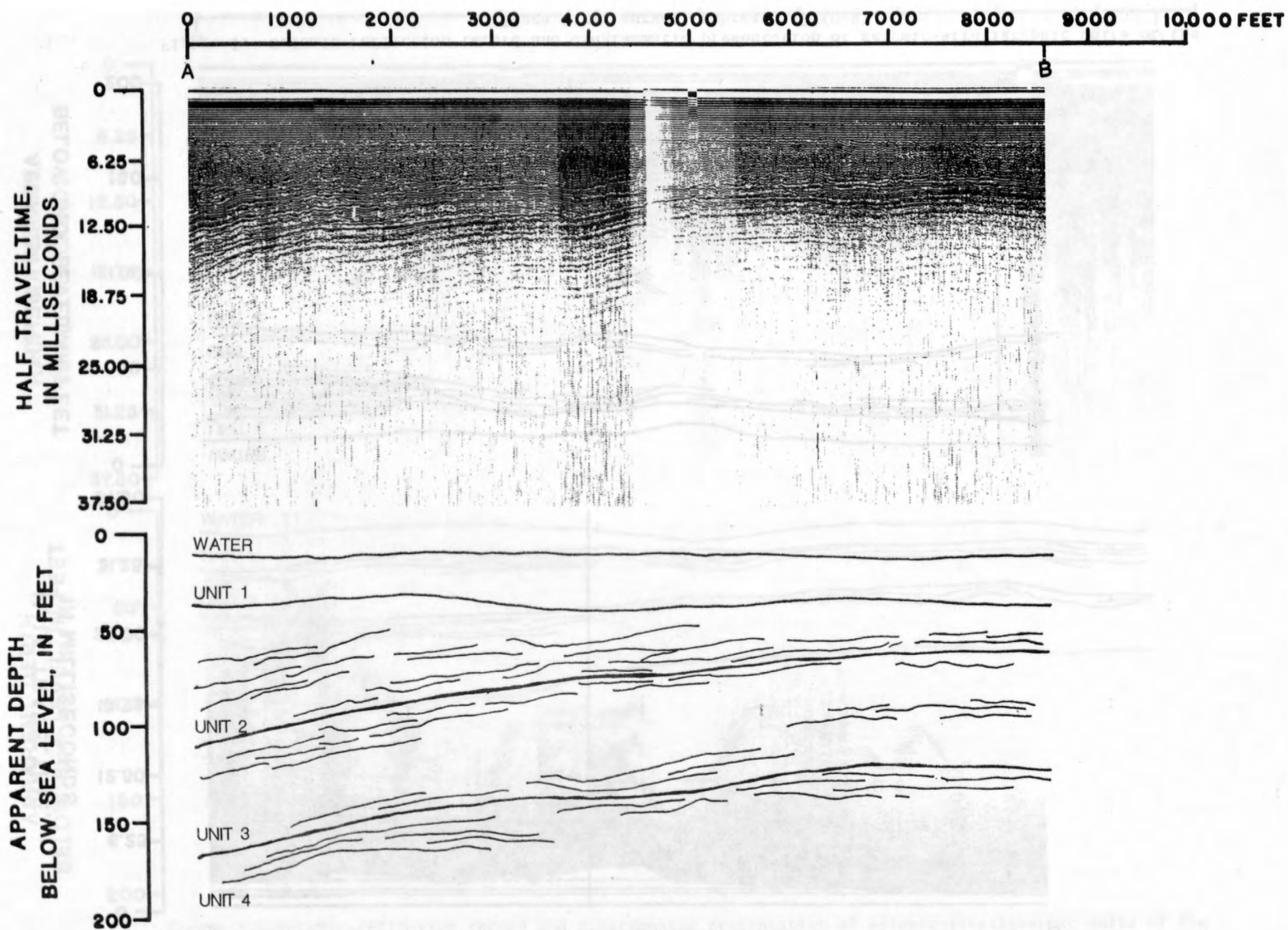


Figure 6.--Seismic-reflection record and diagrammatic presentation of seismic-stratigraphic units of the Myakka River survey, subreach 1 (A-B).

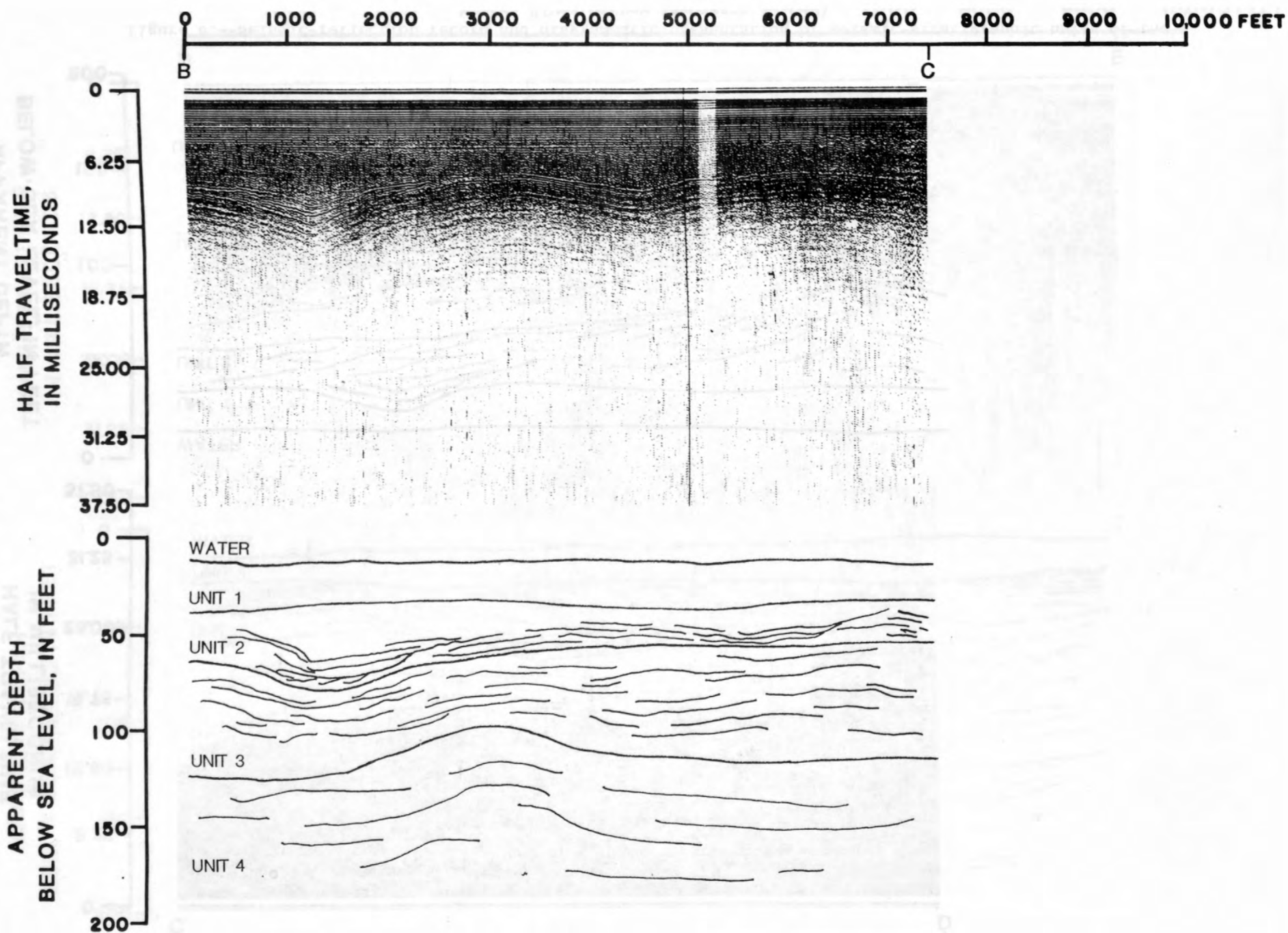


Figure 6.--Seismic-reflection record and diagrammatic presentation of seismic-stratigraphic units of the Myakka River survey, subreach 2 (B-C).

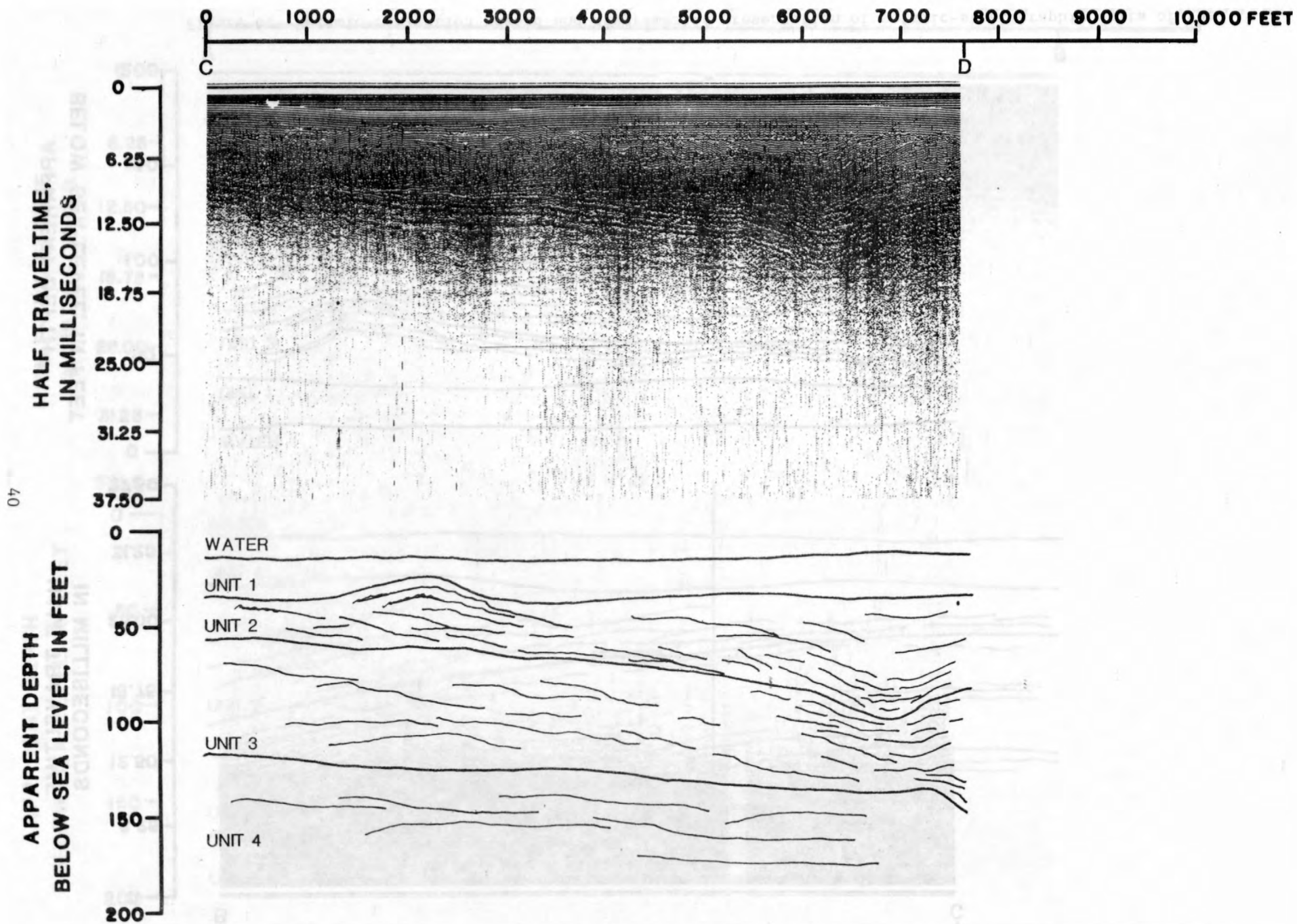


Figure 6.--Seismic-reflection record and diagrammatic presentation of seismic-stratigraphic units of the Myakka River survey, subreach 3 (C-D).

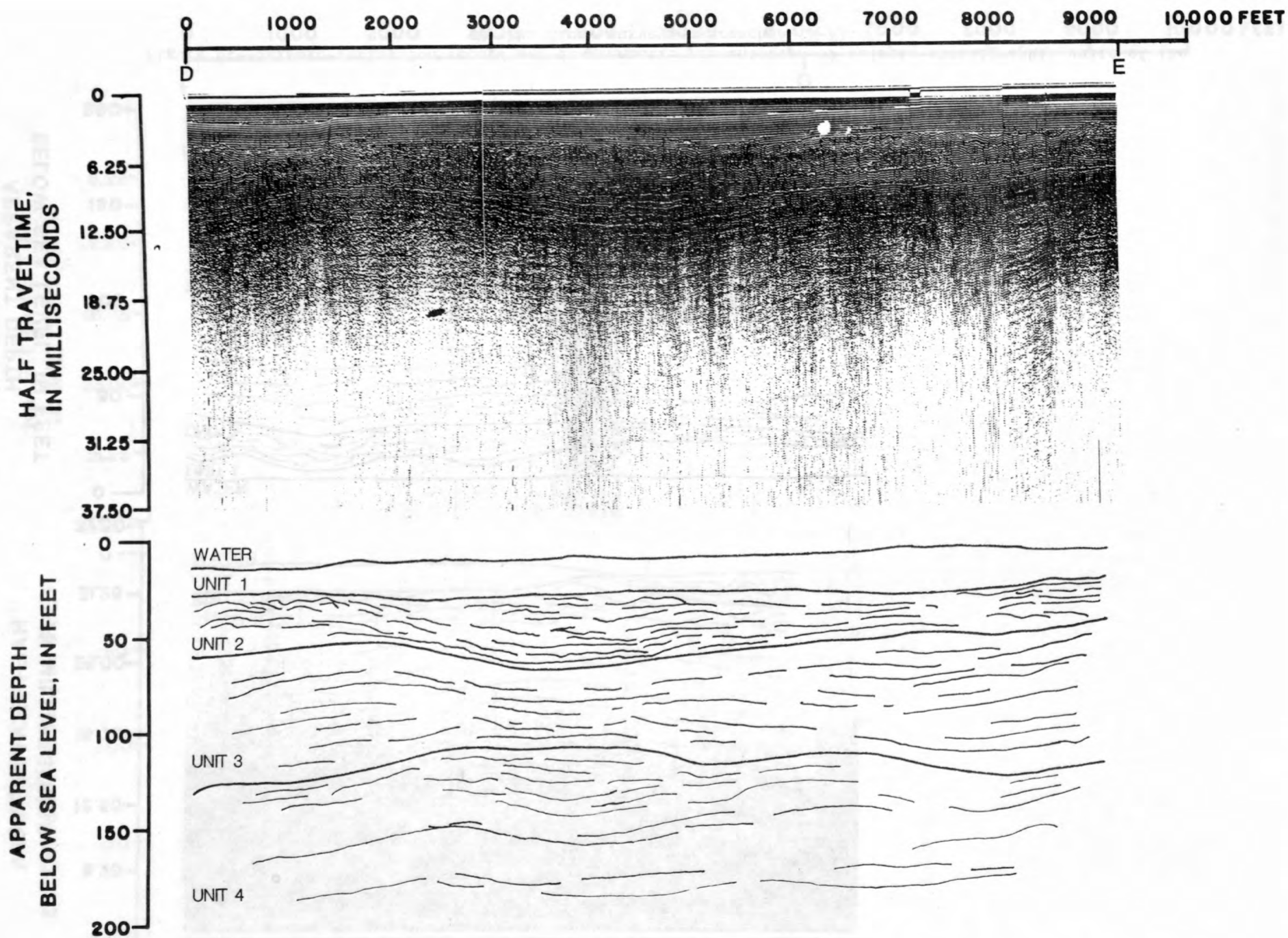


Figure 6.--Seismic-reflection record and diagrammatic presentation of seismic-stratigraphic units of the Myakka River survey, subreach 4 (D-E).

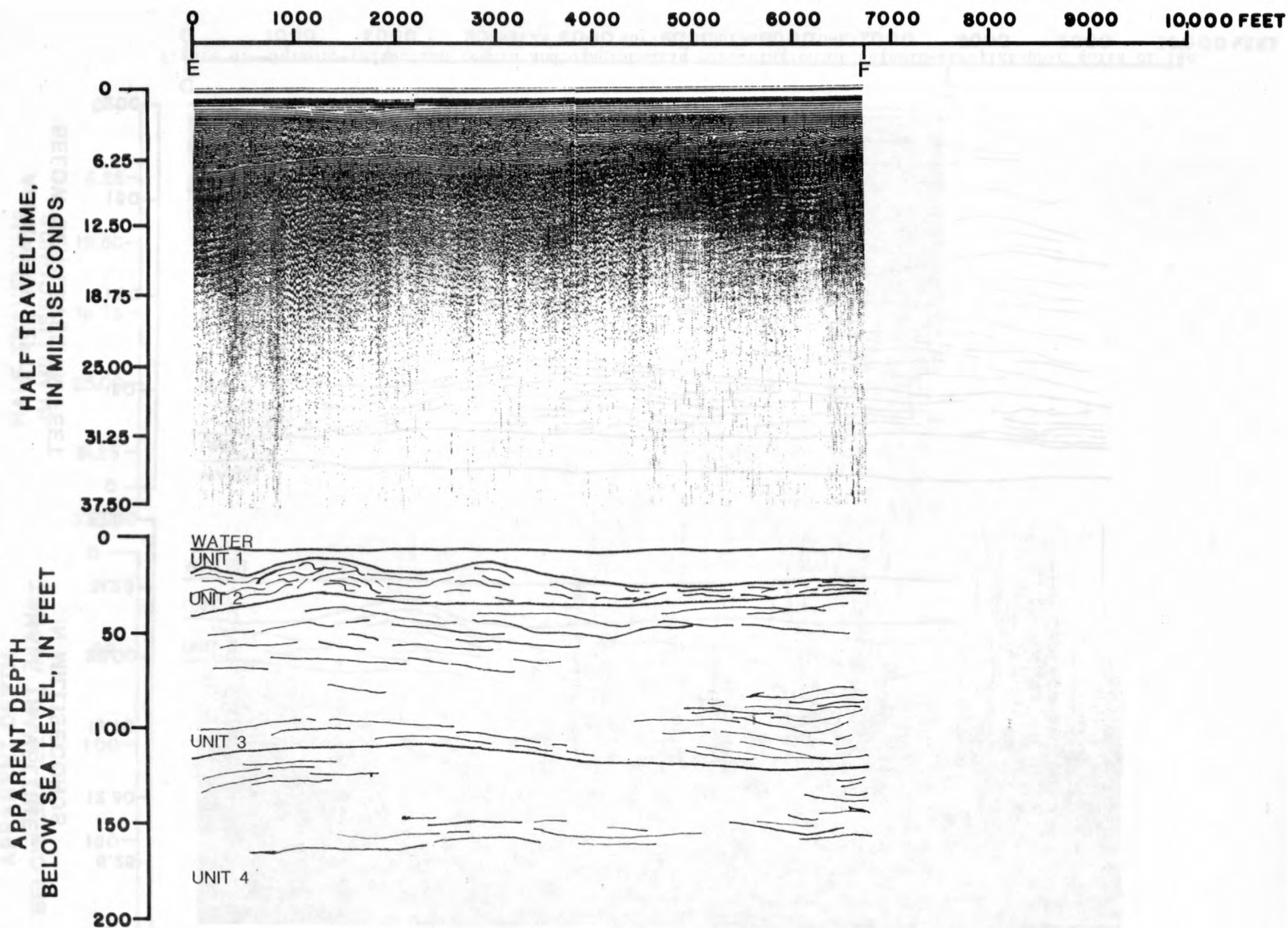


Figure 6.--Seismic-reflection record and diagrammatic presentation of seismic-stratigraphic units of the Myakka River survey, subreach 5 (E-F).

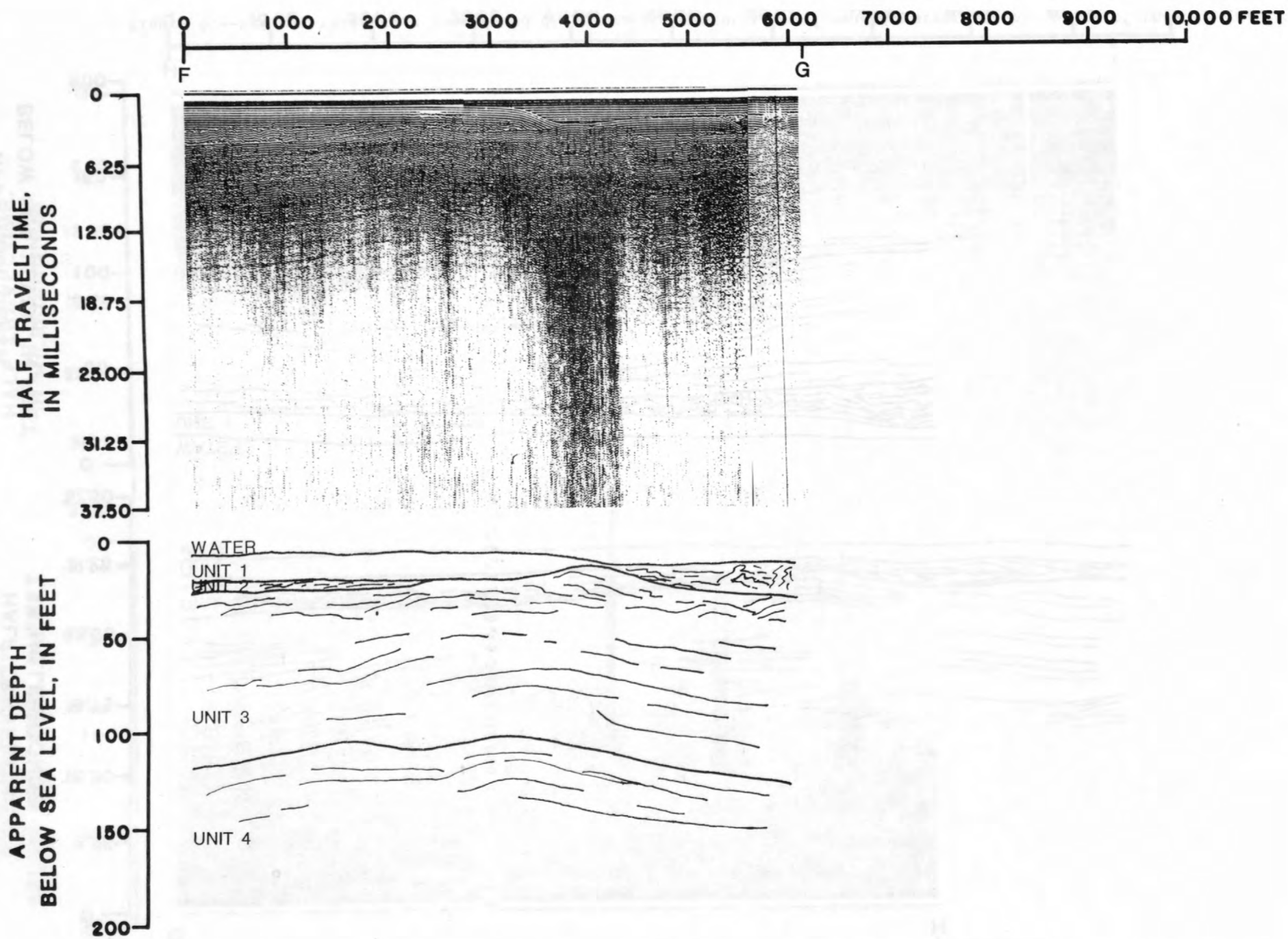


Figure 6.--Seismic-reflection record and diagrammatic presentation of seismic-stratigraphic units of the Myakka River survey, subreach 6 (F-G).

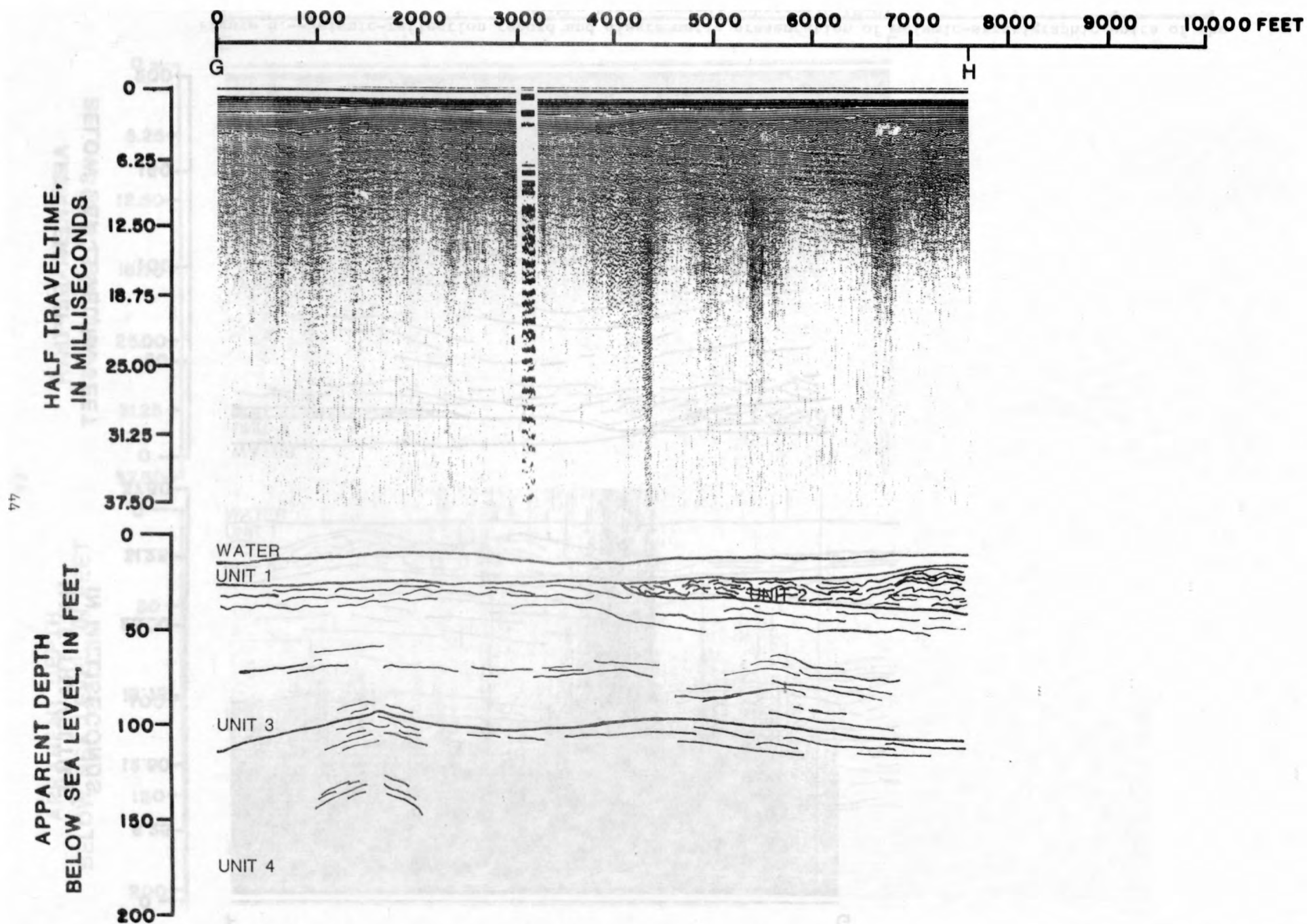


Figure 6.--Seismic-reflection record and diagrammatic presentation of seismic-stratigraphic units of the Myakka River survey, subreach 7 (G-H).

APPARENT DEPTH
BELOW SEA LEVEL, IN FEET

HALF TRAVELTIME,
IN MILLISECONDS

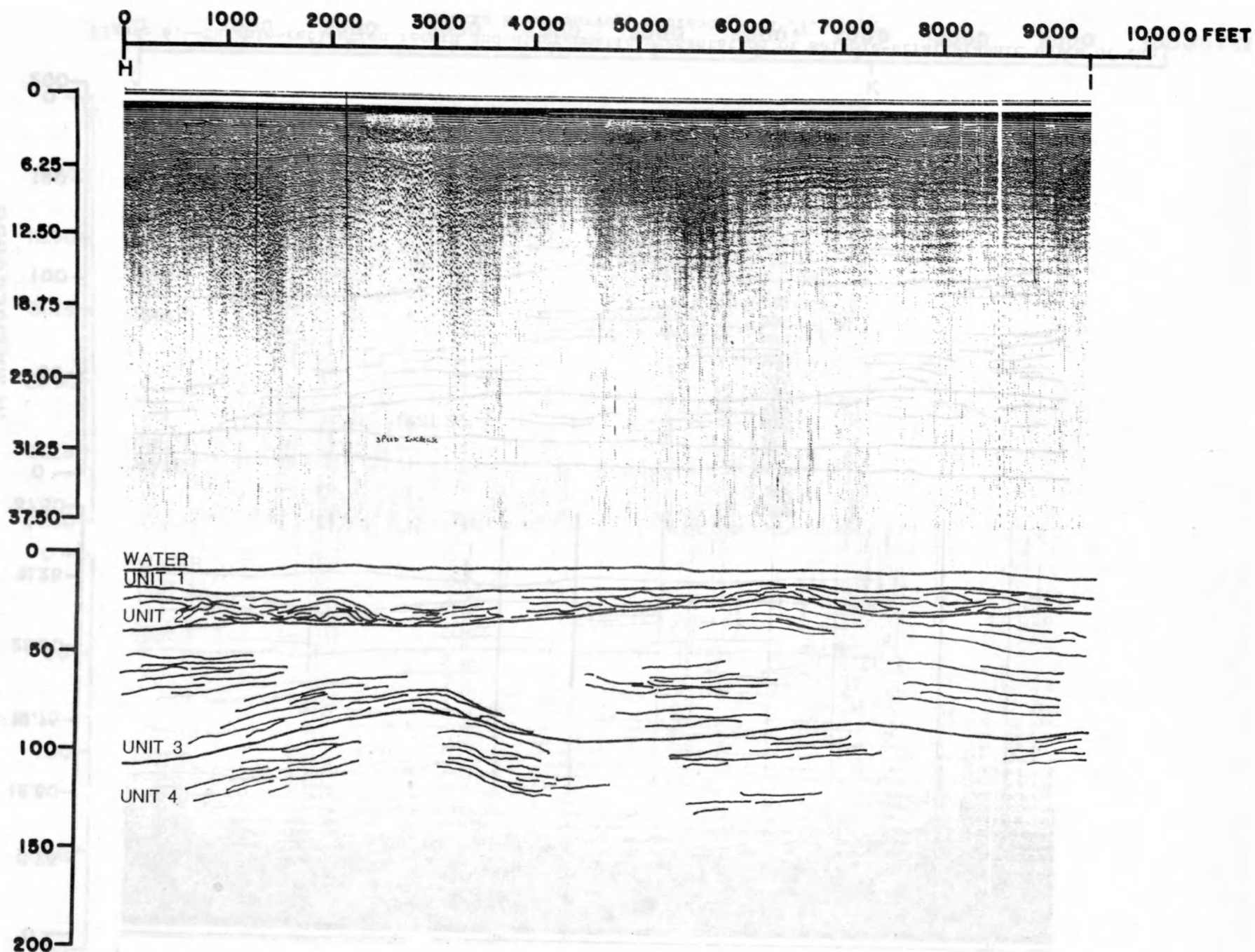


Figure 6.--Seismic-reflection record and diagrammatic presentation of seismic-stratigraphic units of the Myakka River survey, subreach 8 (H-I).

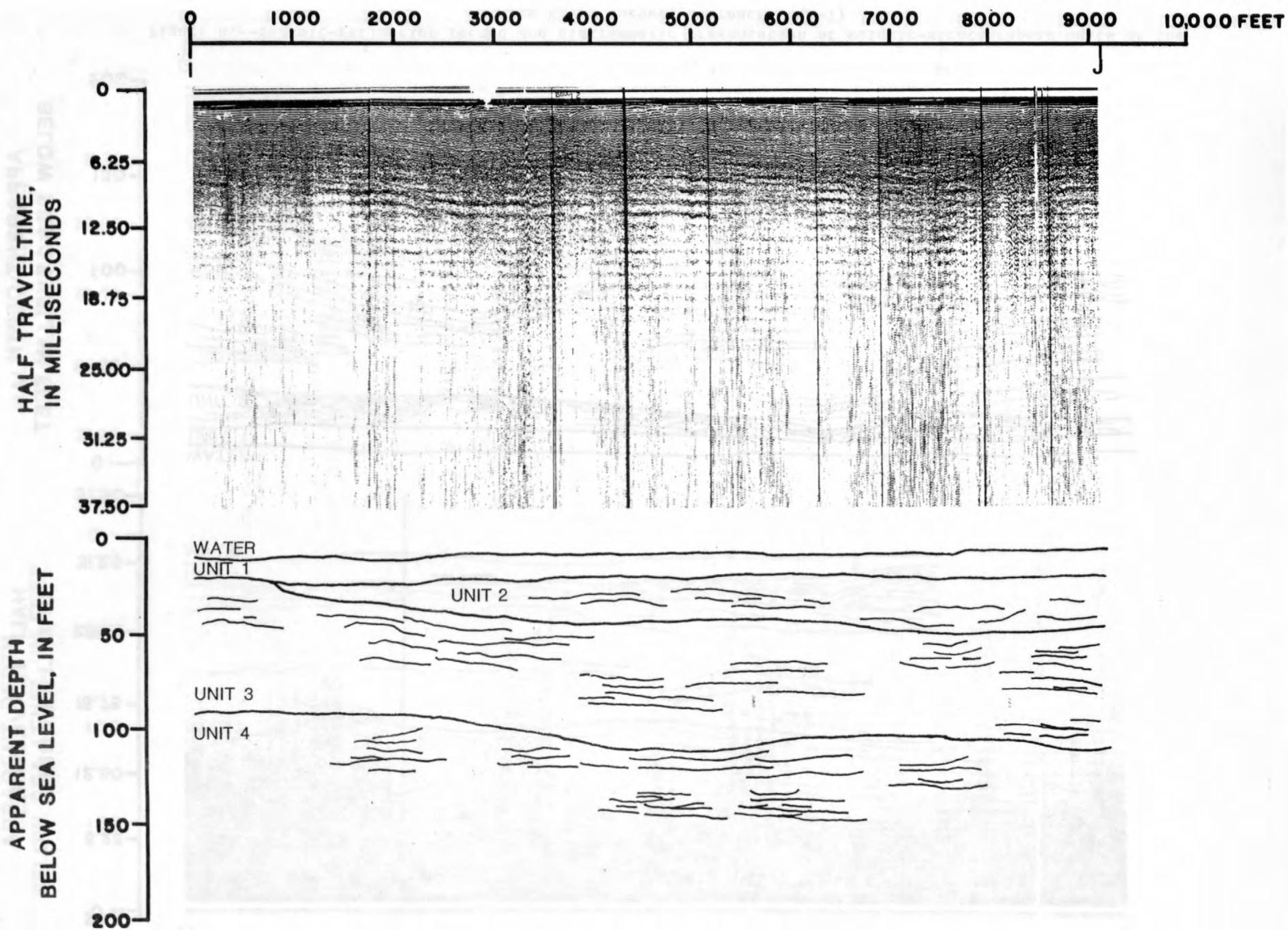


Figure 6.--Seismic-reflection record and diagrammatic presentation of seismic-stratigraphic units of the Myakka River survey, subreach 9 (I-J).

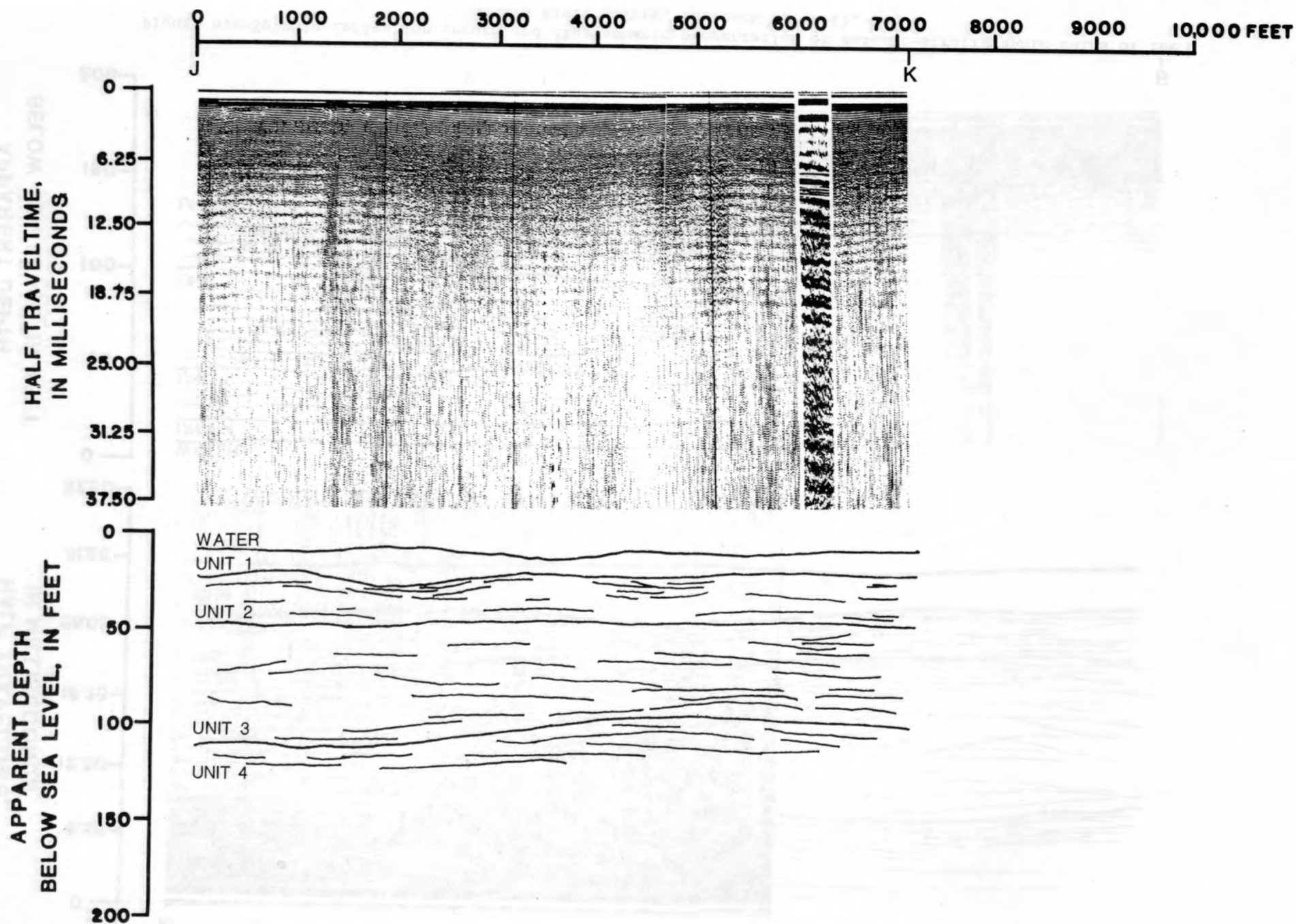


Figure 6.--Seismic-reflection record and diagrammatic presentation of seismic-stratigraphic units of the Myakka River survey, subreach 10 (J-K).

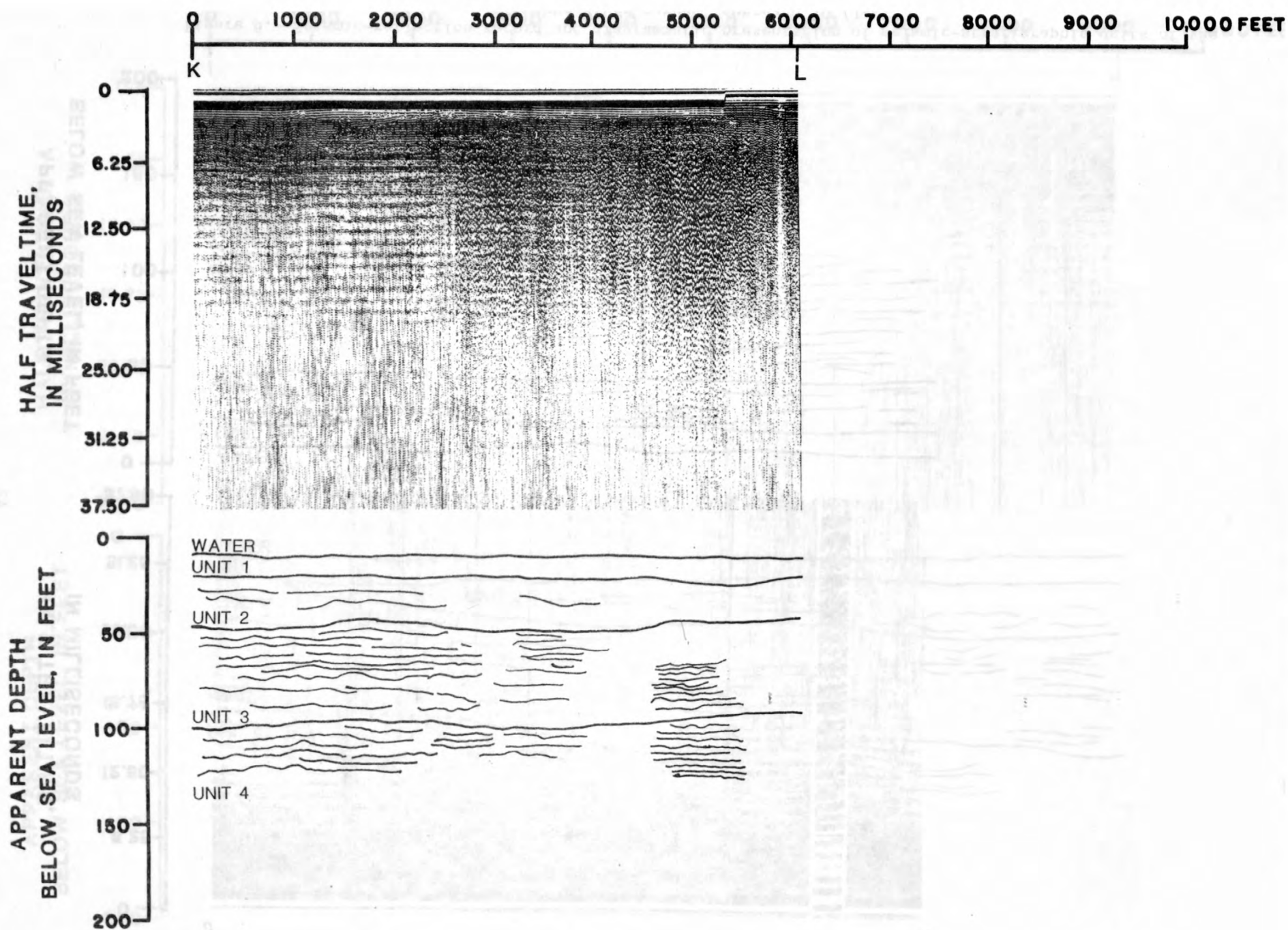


Figure 6.--Seismic-reflection record and diagrammatic presentation of seismic-stratigraphic units of the Myakka River survey, subreach 11 (K-L).

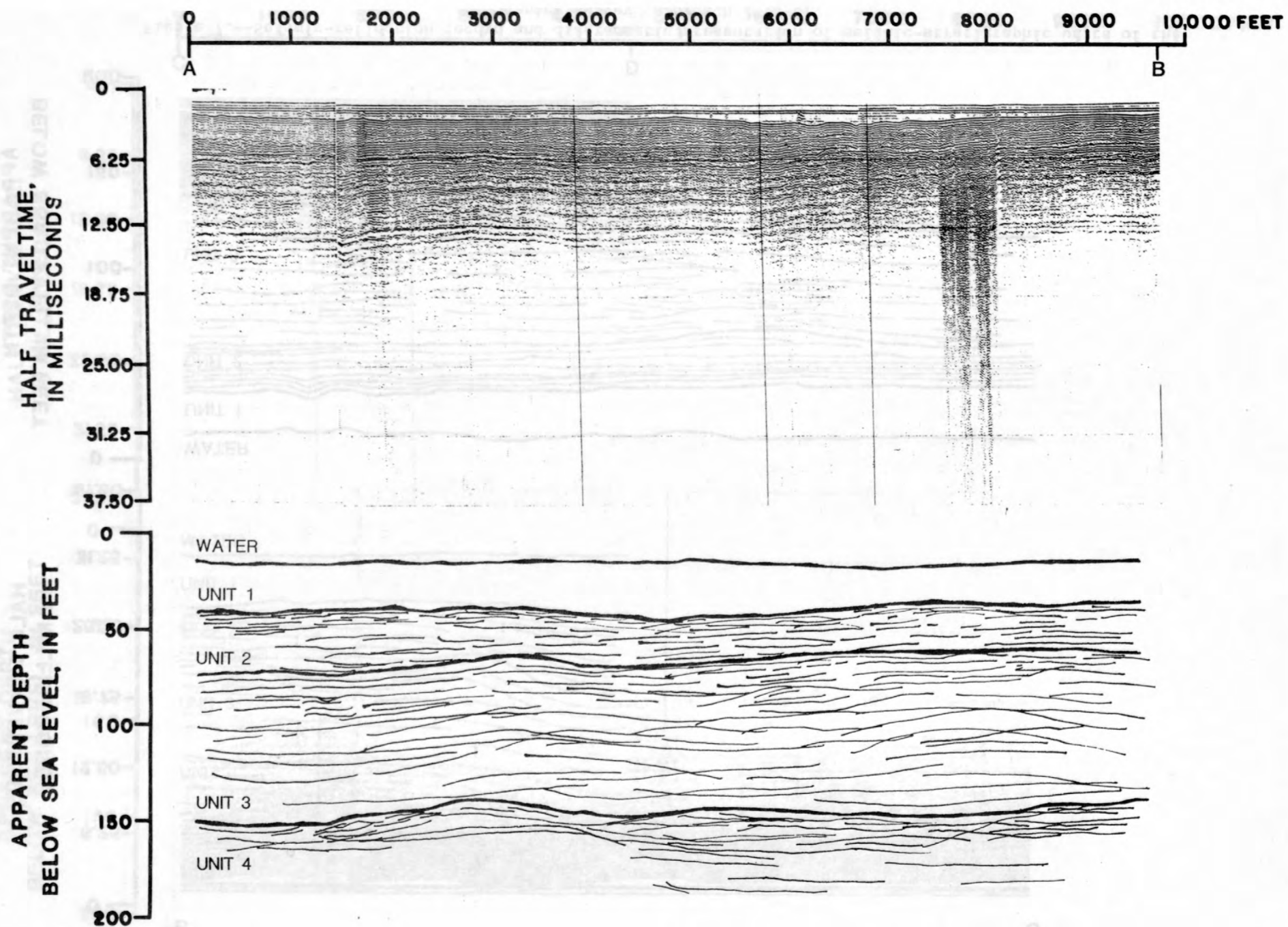


Figure 7.--Seismic-reflection record and diagrammatic presentation of seismic-stratigraphic units of the Venice survey, subreach 1 (A-B).

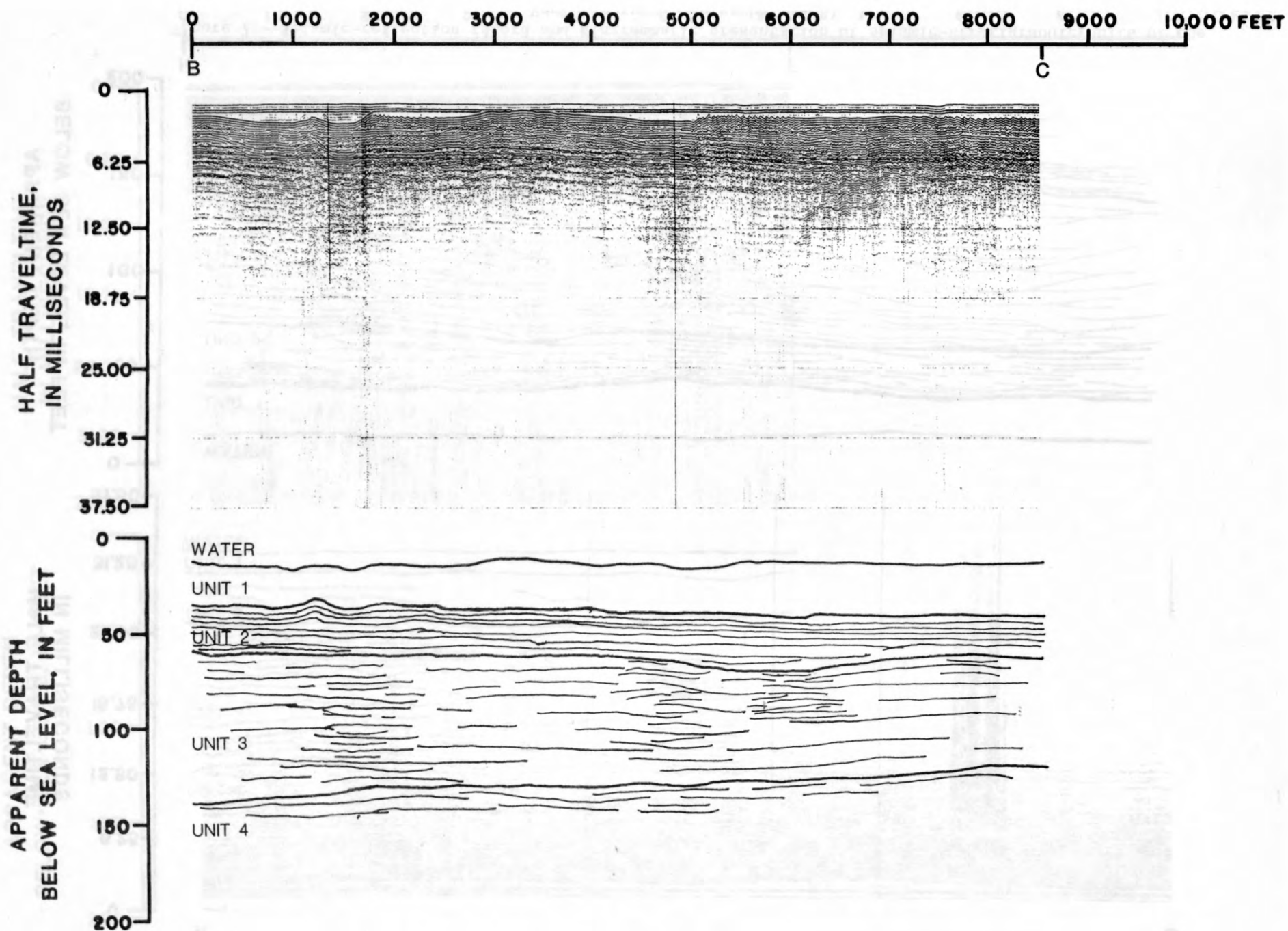


Figure 7.--Seismic-reflection record and diagrammatic presentation of seismic-stratigraphic units of the Venice survey, subreach 2 (B-C).

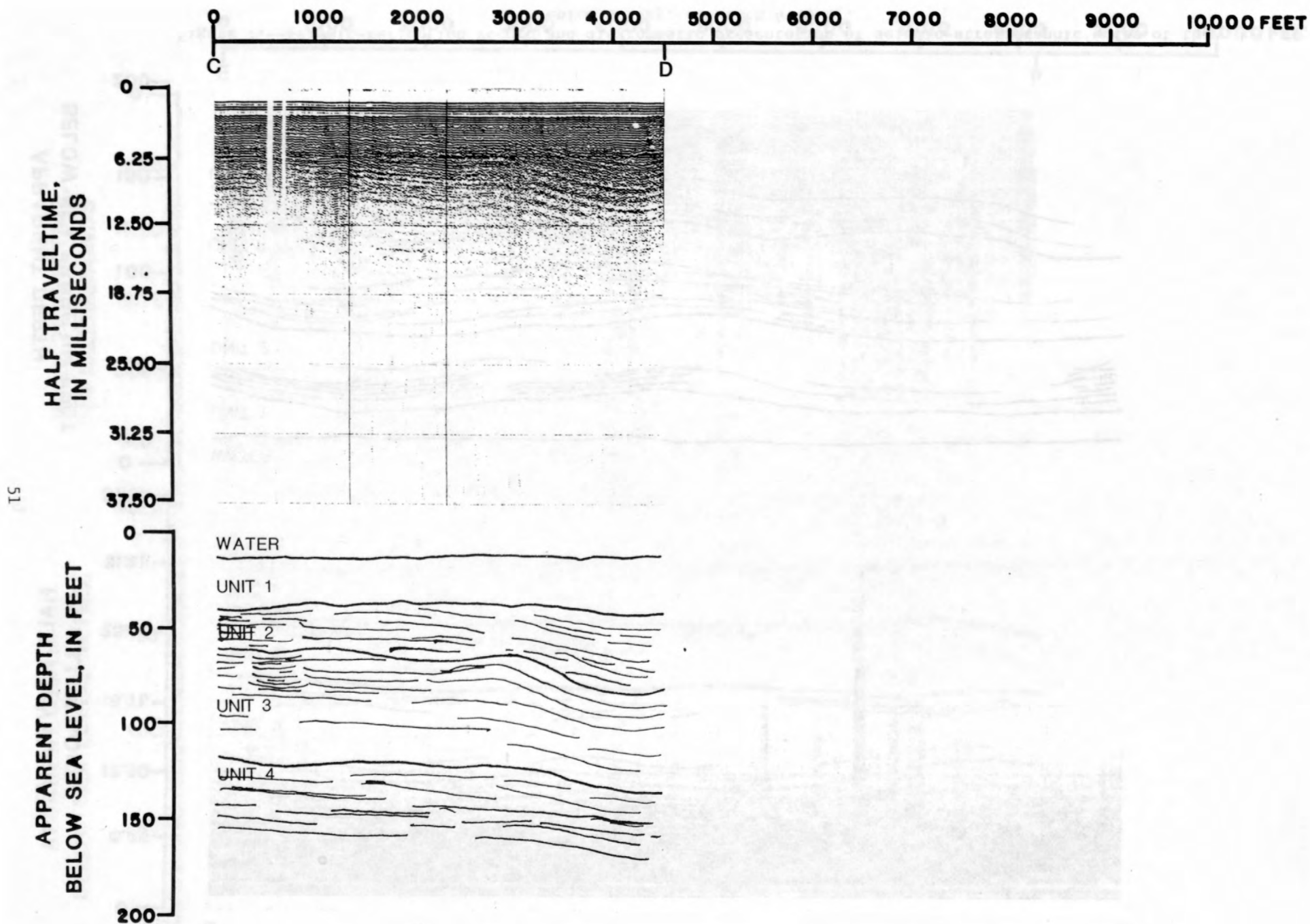


Figure 7.--Seismic-reflection record and diagrammatic presentation of seismic-stratigraphic units of the Venice survey, subreach 3 (C-D).

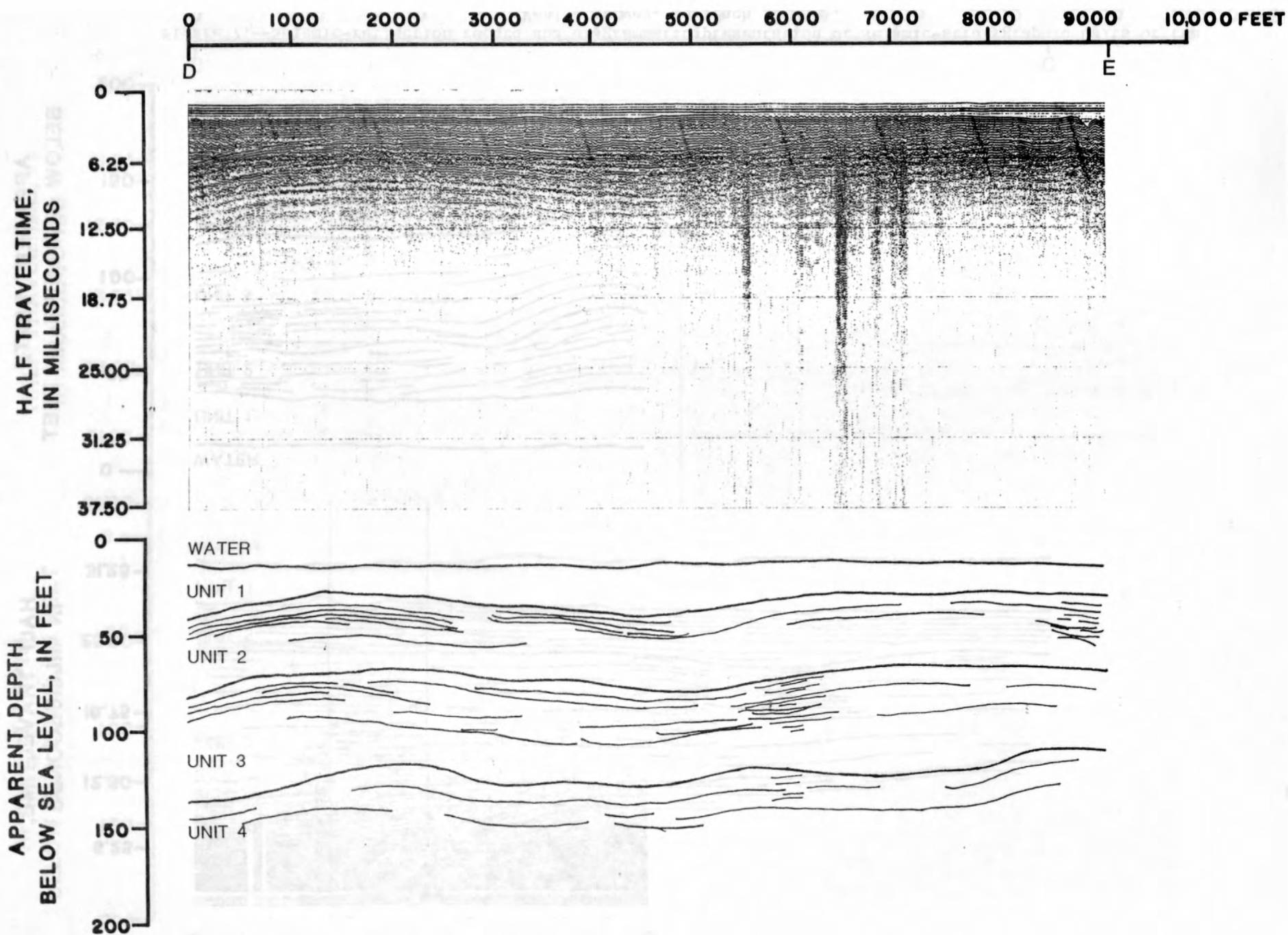


Figure 7.--Seismic-reflection record and diagrammatic presentation of seismic-stratigraphic units of the Venice survey, subreach 4 (D-E).

APPARENT DEPTH
BELOW SEA LEVEL, IN FEET

HALF TRAVELTIME,
IN MILLISECONDS

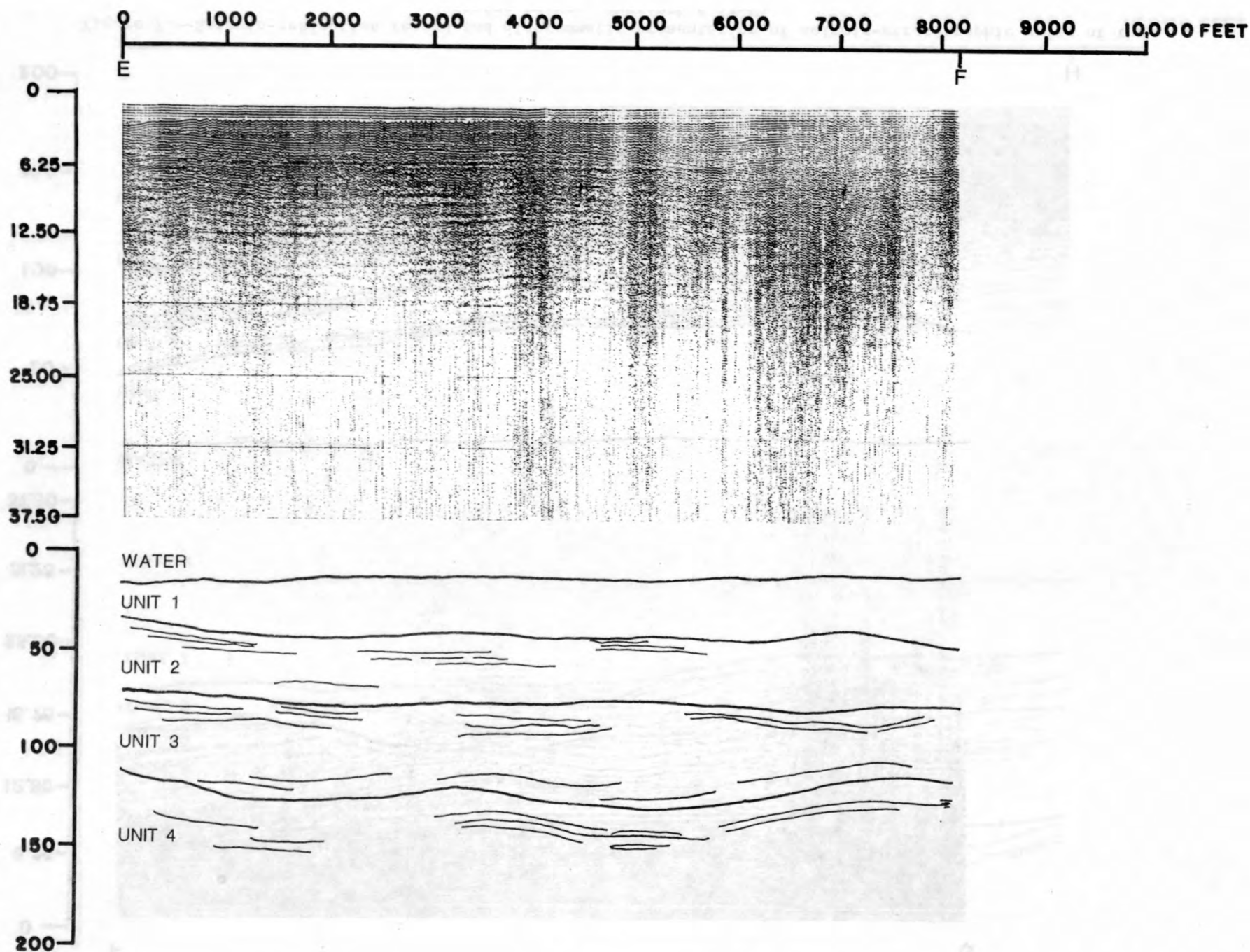


Figure 7.--Seismic-reflection record and diagrammatic presentation of seismic-stratigraphic units of the Venice survey, subreach 5 (E-F).

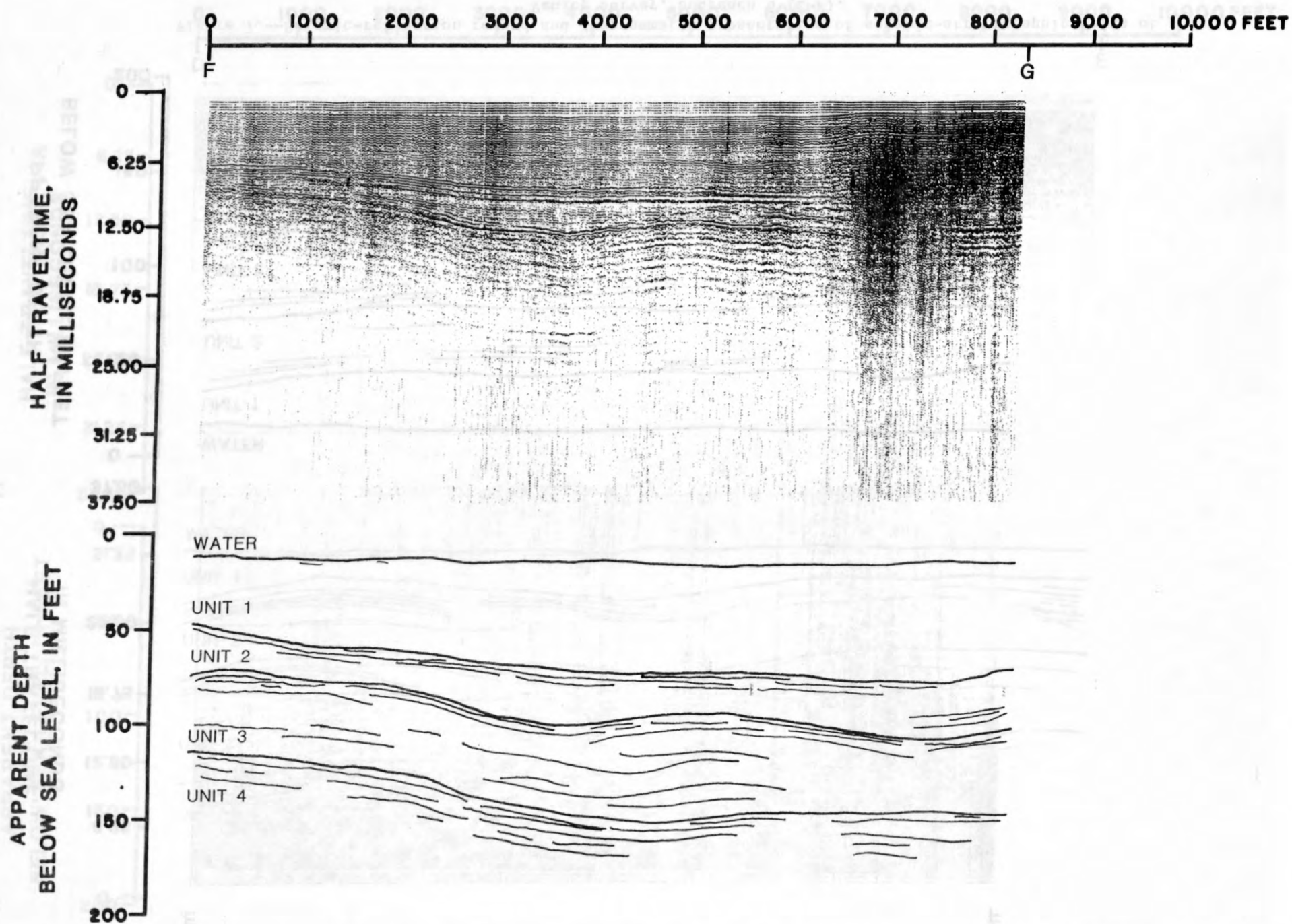


Figure 7.--Seismic-reflection record and diagrammatic presentation of seismic-stratigraphic units of the Venice survey, subreach 6 (F-G).

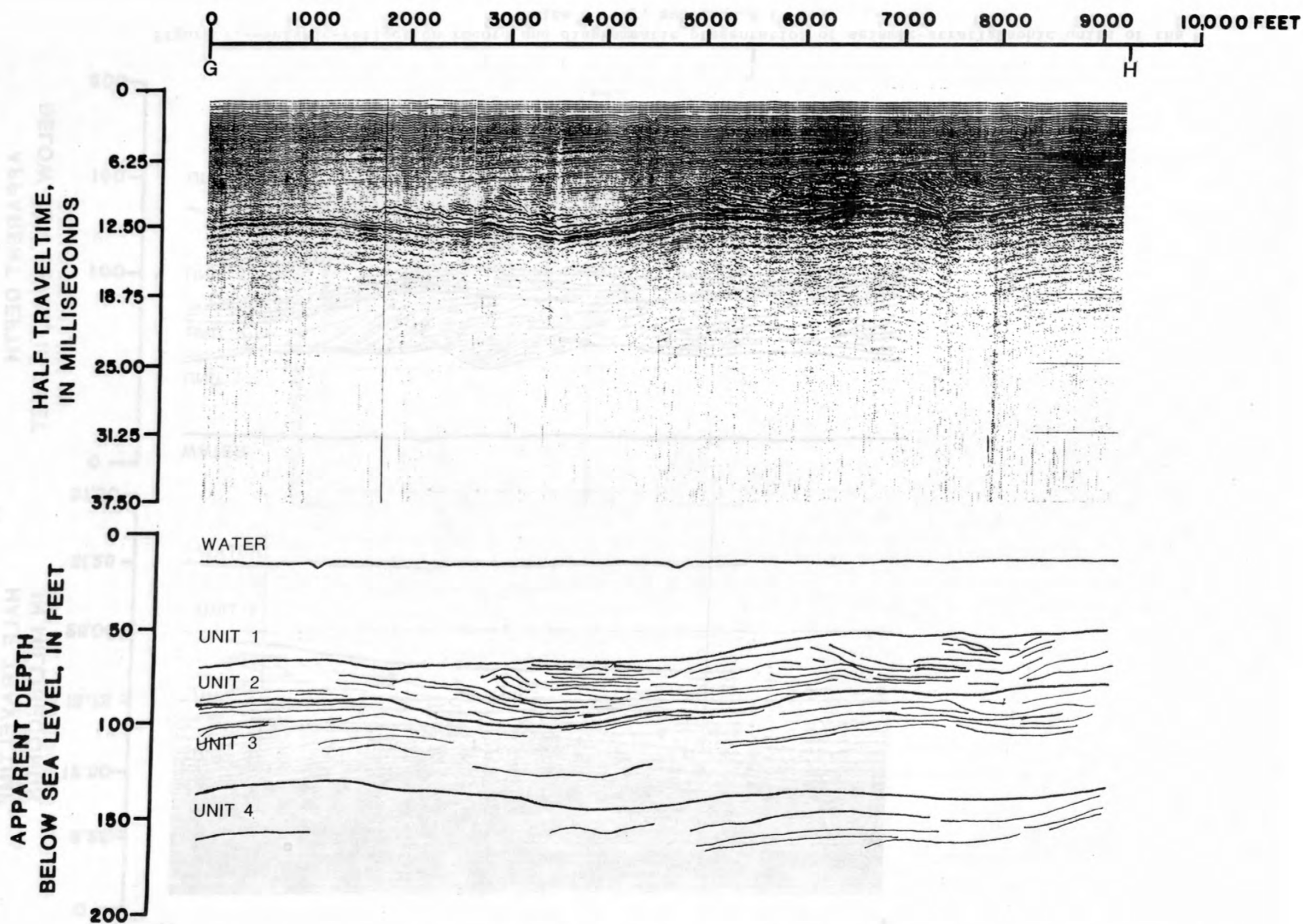


Figure 7.--Seismic-reflection record and diagrammatic presentation of seismic-stratigraphic units of the Venice survey, subreach 7 (G-H).

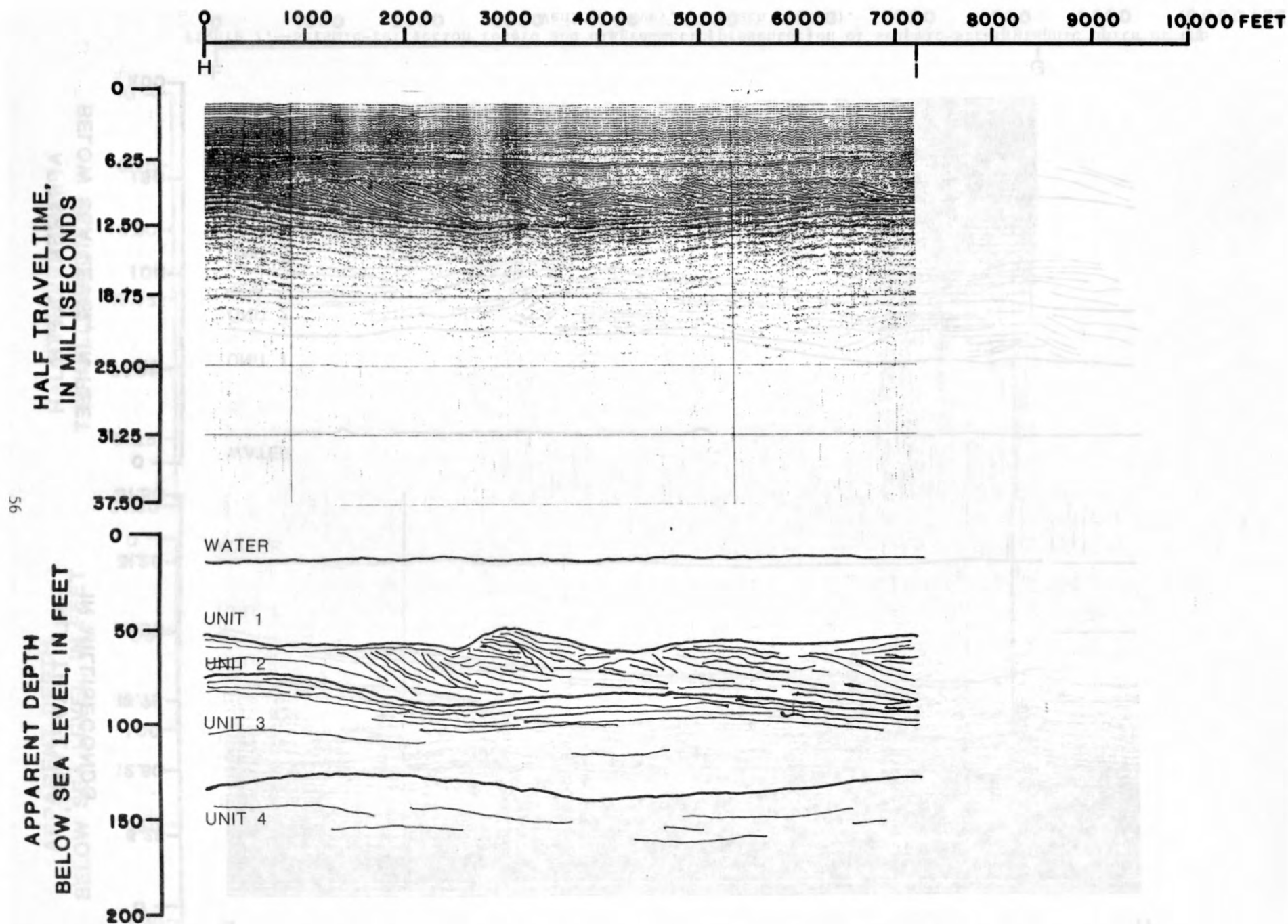


Figure 7.--Seismic-reflection record and diagrammatic presentation of seismic-stratigraphic units of the Venice survey, subreach 8 (H-I).

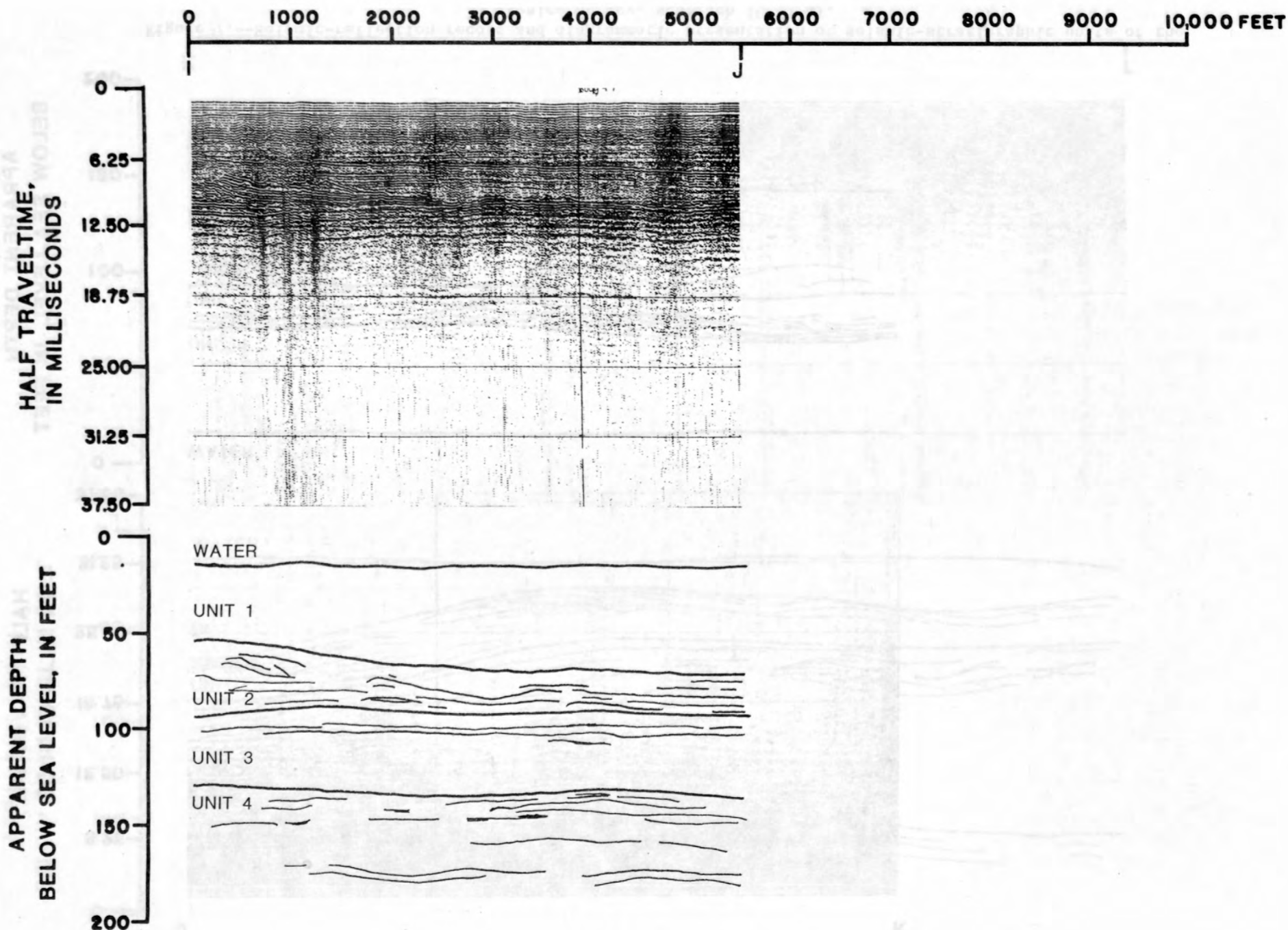


Figure 7.--Seismic-reflection record and diagrammatic presentation of seismic-stratigraphic units of the Venice survey, subreach 9 (I-J).

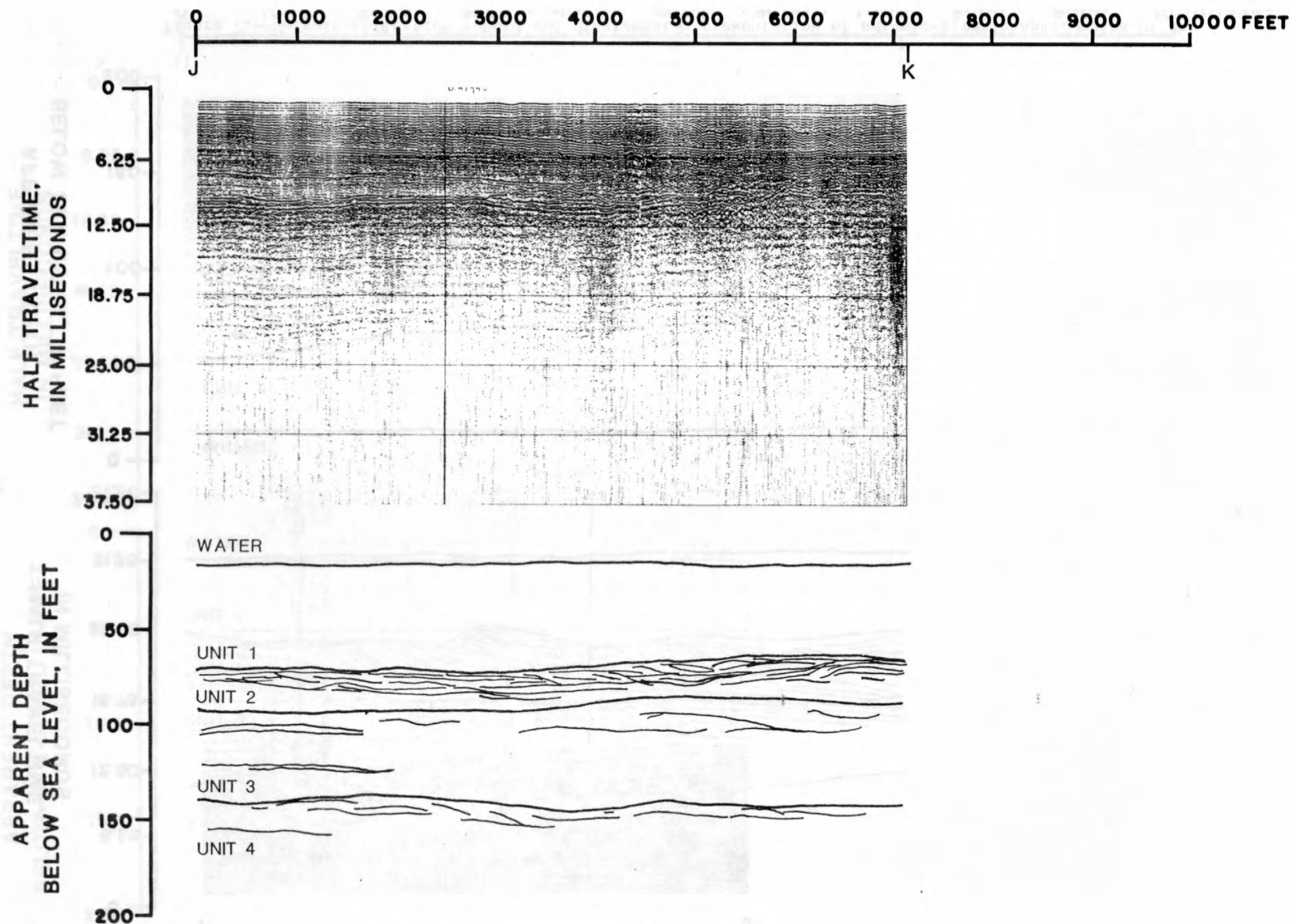


Figure 7.--Seismic-reflection record and diagrammatic presentation of seismic-stratigraphic units of the Venice survey, subreach 10 (J-K).

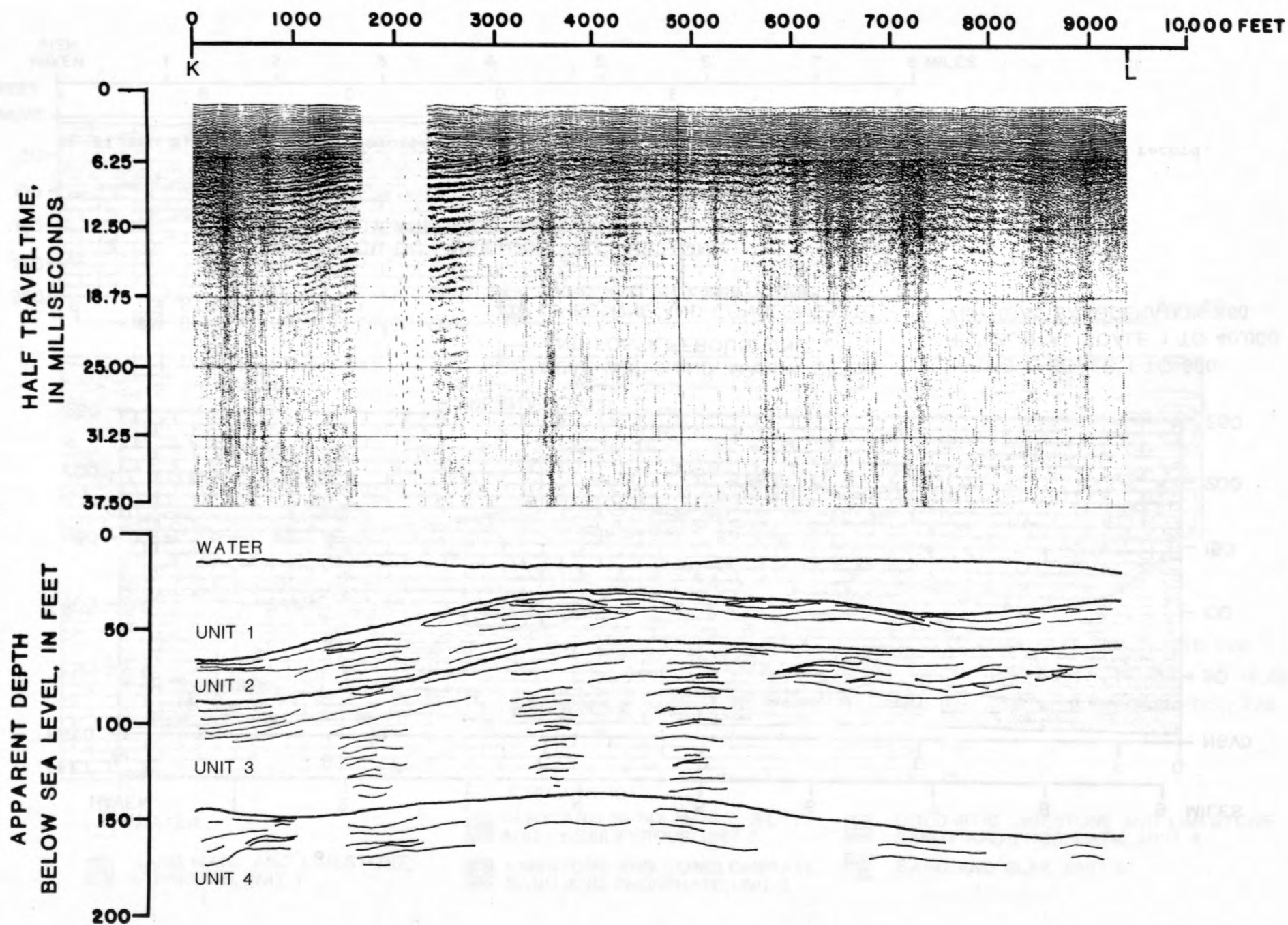


Figure 7.--Seismic-reflection record and diagrammatic presentation of seismic-stratigraphic units of the Venice survey, subreach 11 (K-L).

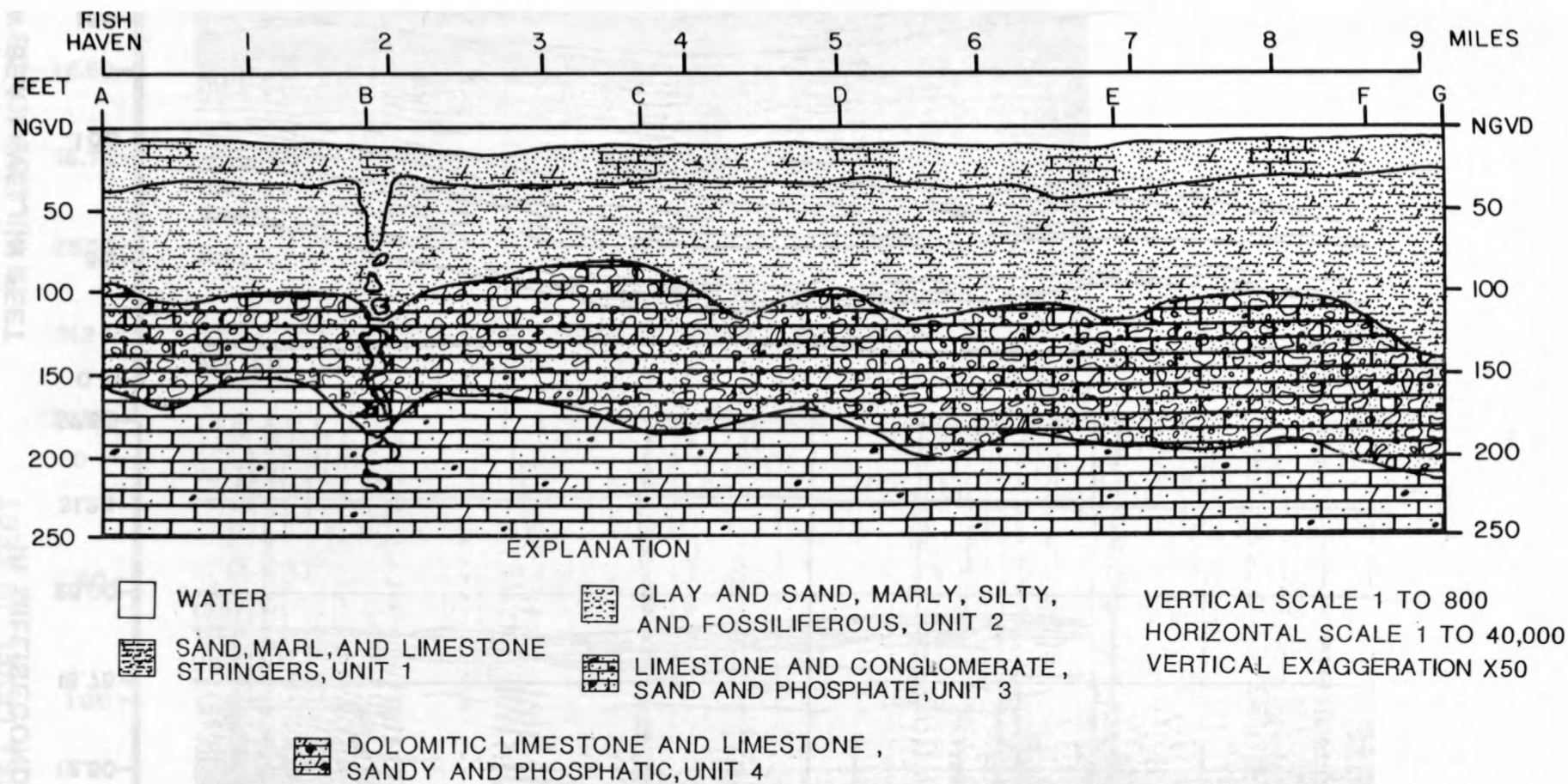


Figure 8.--Generalized geologic section of the Charlotte Harbor survey defined from the seismic record.

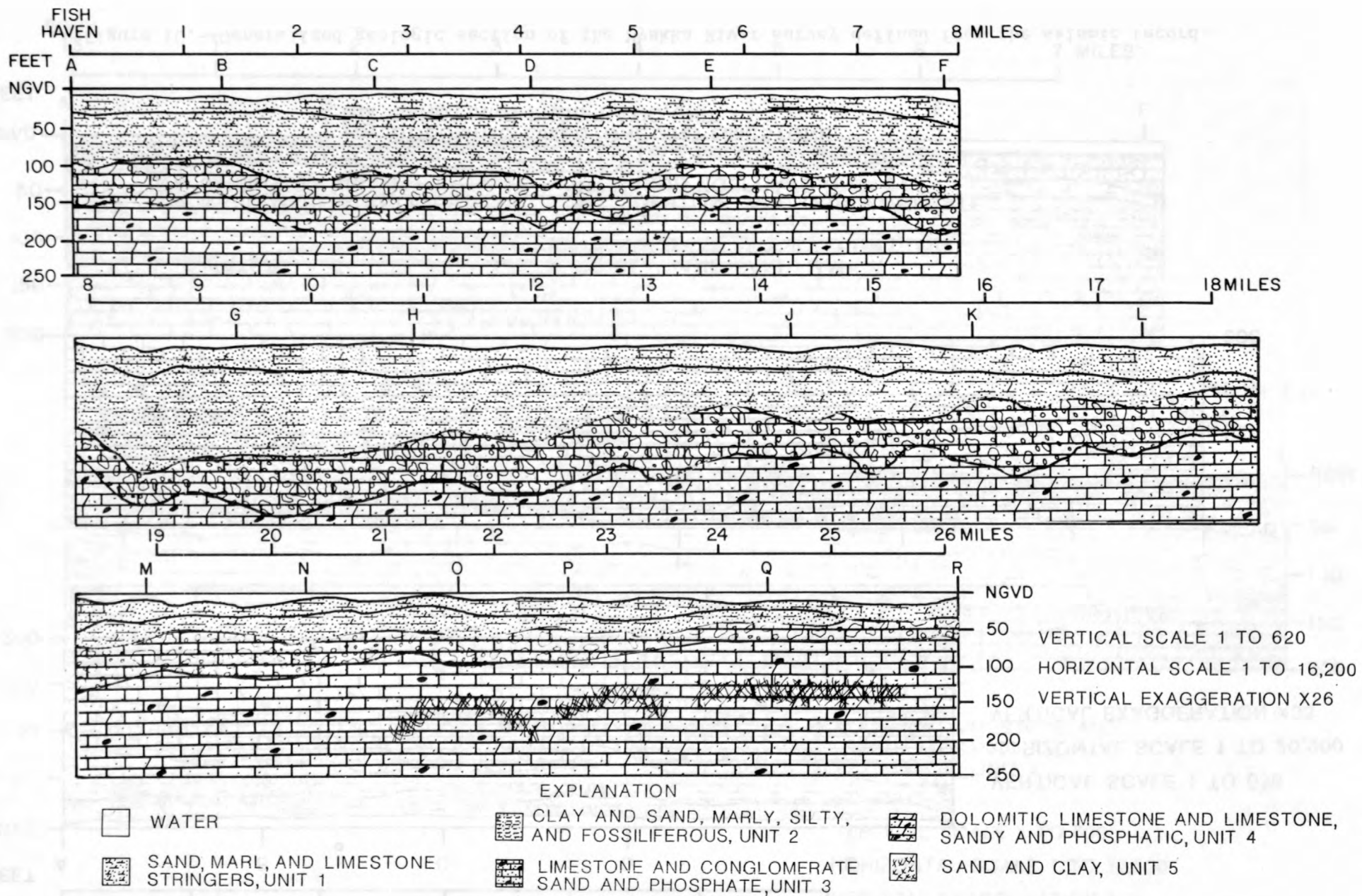


Figure 9.--Generalized geologic section of the Peace River survey defined from the seismic record.

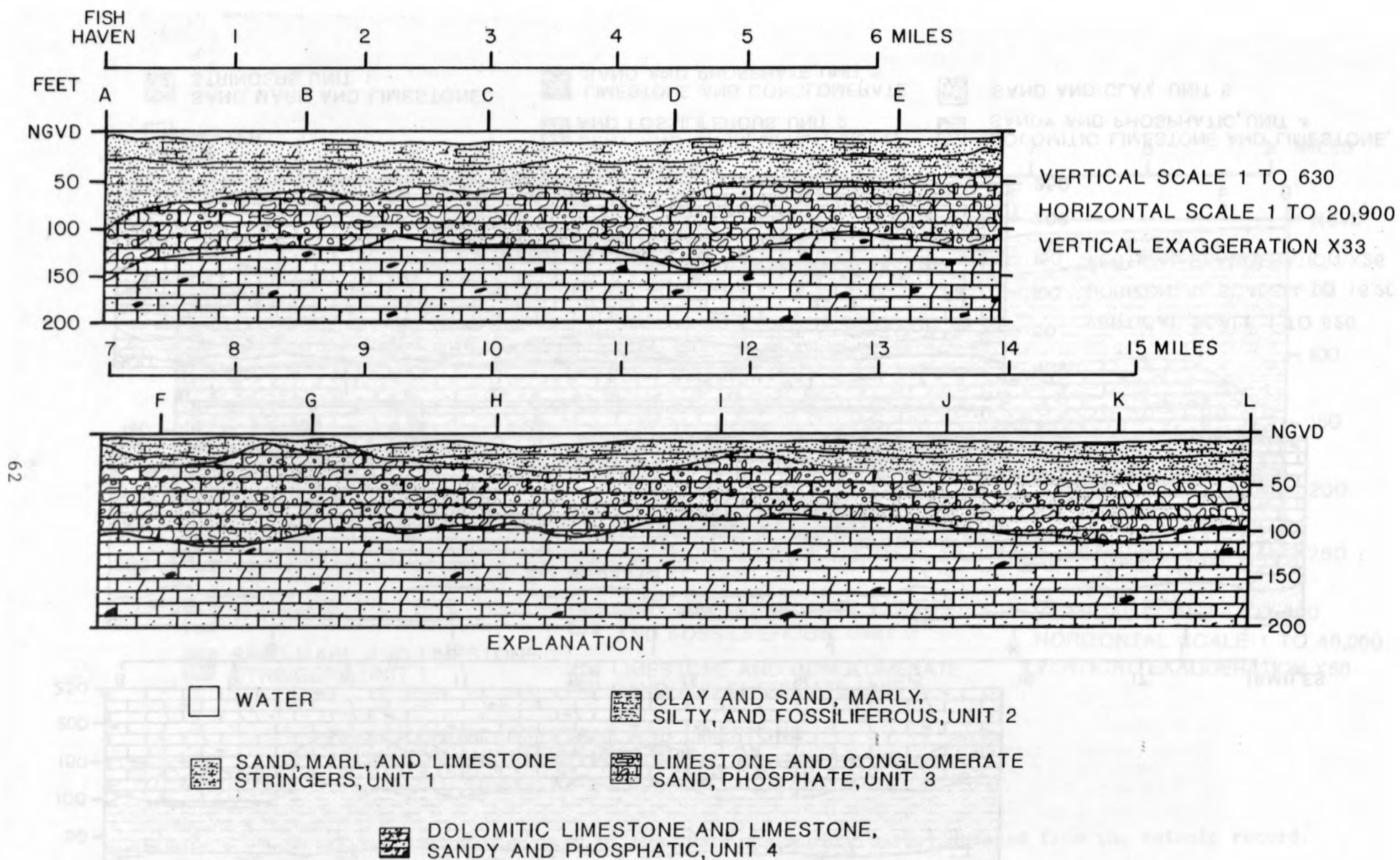
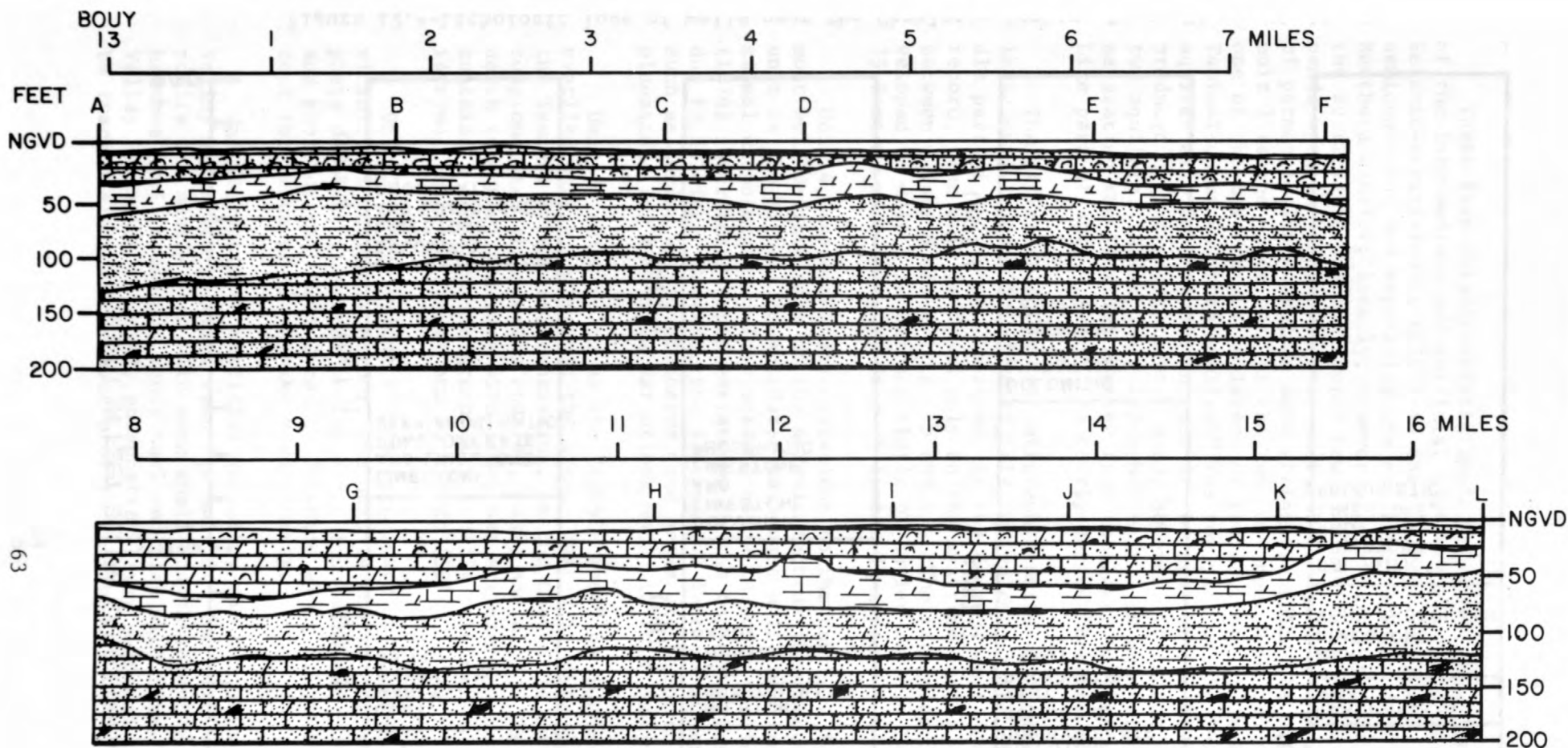
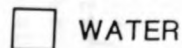


Figure 10.--Generalized geologic section of the Myakka River survey defined from the seismic record.



EXPLANATION



WATER



MARL AND LIMESTONE
STRINGERS, UNIT 2



DOLOMITIC LIMESTONE AND
LIMESTONE, SANDY AND
PHOSPHATIC, UNIT 4



LIMESTONE, SANDY,
MARLY, AND SHELLY,
UNIT 1



MARL AND CLAY,
SANDY, UNIT 3

VERTICAL SCALE 1 TO 600

HORIZONTAL SCALE 1 TO 12,500

VERTICAL EXAGGERATION X21

Figure 11.--Generalized geologic section of the Venice survey defined from the seismic record.

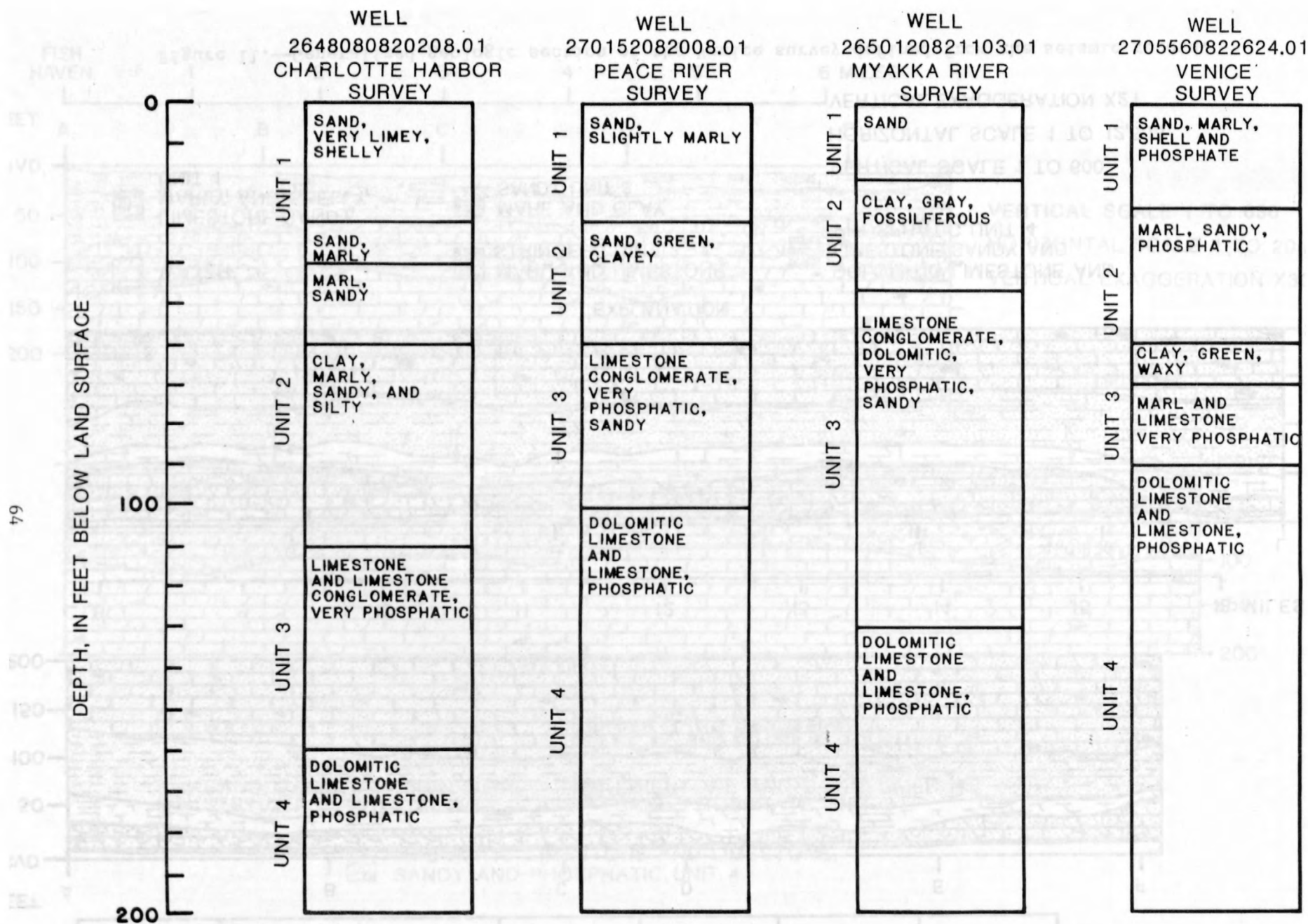


Figure 12.3—Lithologic logs of wells near the Charlotte Harbor, Peace River, Myakka River, and Venice surveys.

These five seismic-stratigraphic units are equivalent to hydrologic units of the intermediate and surficial aquifers and their associated confining beds. Seismic-stratigraphic unit 1 is the surficial aquifer. Unit 2 generally is the semiconfining bed separating the surficial aquifer from the Tamiami-upper Hawthorn aquifer; locally, however, where highly permeable, it is part of either the surficial or Tamiami-upper Hawthorn aquifers. Where unit 2 is placed depends upon the amount of fine sediment in the unit and the presence or absence of permeable limestone and sand stringers within the unit. Seismic-stratigraphic unit 3 is the upper part of the Tamiami-upper Hawthorn aquifer and is generally one of the more permeable layers of the aquifer. Unit 4 is the lower part of the Tamiami-upper Hawthorn aquifer. The top part of the lower Hawthorn-upper Tampa aquifer also is included in unit 4. Because of the limited depth of penetration produced by the energy source used, however, it is not possible to separate these two aquifers. Seismic-stratigraphic unit 5 is equivalent to the confining bed separating the Floridan aquifer from the lower Hawthorn-upper Tampa aquifer. Like part of unit 4, unit 5 is poorly defined because of limited penetration.

The different seismic-stratigraphic units also generally correspond to geologic units. Unit 5, approximately equivalent to the clays and sand of the middle part of the Tampa Limestone, is the deepest unit detectable from the seismic record. The unit is found only on the upstream end of the Peace River survey, between points N and R (figs. 5 and 9). The irregular surface apparently developed in unit 5 is characteristic of buried karst. Depths to the unit vary 75 feet or more in 1,000 feet of linear distance.

Unit 4, approximately equivalent to the Hawthorn Formation, is the lowermost well-defined unit on the seismic records throughout most of the area. This unit is the highest consolidated carbonate unit, and its top is probably an erosional unconformity. In a seismic study in south Florida, Missimer and Gardner (1976) interpreted depth variations to the top of carbonate reflectors as being due to folding. However, the alternative interpretations stated in their report, such as buried karst, biotherms, and banks are believed to be more plausible explanations for the depth variations noted in this study.

Unit 3, referred to as the "rubble zone" by Missimer and Gardner (1976), overlies unit 4 throughout the area. Unit 3 is equivalent to the lower part of the Tamiami Formation, consisting, in the Charlotte Harbor area, of limestone conglomerate, phosphorite nodules, sand, and clay. These rocks grade to the north into marl and clay with limestone stringers. In the Venice area, unit 3 contains a dark grayish-green clay locally referred to as the "Venice clay" of informal usage by Joyner and Sutcliffe (1976).

Unit 2 is equivalent to the upper part of the Tamiami Formation. In the vicinity of Charlotte Harbor, the unit is mostly clay with sand, marl, and phosphate pebbles; it grades to the north into marl and limestone with minor sand and phosphorite. Unit 2 can be detected along all seismic-profile sections except for parts of the Myakka River survey.

Undifferentiated surficial deposits, the Caloosahatchee Marl, and the Bone Valley Formation together comprise unit 1. The undifferentiated surficial deposits are mostly sand with some shell and phosphorite, whereas the Caloosahatchee Marl is usually sandy marl and clay with limestone stringers. The Bone Valley Formation is mostly phosphatic clayey sand and sandy clay. Unit 1 can be tracked along all seismic-profile sections.

A significant erosional feature is apparent on the Charlotte Harbor seismic record (fig. 4, subreach 2). A sinkhole several hundred feet in diameter is located near point B. The sinkhole penetrates the Hawthorn Formation (unit 4) and possibly is developed also in underlying formations. It probably formed by the development of large solution openings in the limestone and dolomite of the Hawthorn and underlying formations, followed by collapse of the roofs of these openings.

INTERPRETATION OF DEPOSITIONAL ENVIRONMENT AND HYDROGEOLOGIC PROPERTIES FROM SEISMIC-REFLECTION DATA

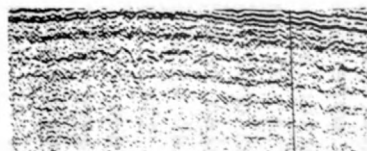
The facies relations and depositional environment of a stratigraphic unit can be interpreted from seismic-reflection data through an understanding of the effects of lithology and bed thickness on reflection amplitude, frequency, continuity, configuration, and external form and areal association. Once the geologic character of the stratigraphic unit is known, certain assumptions about its hydrologic properties can be made. The following geologic interpretations can be made from the reflection parameters (Sangree and Widmier, 1979):

Reflection amplitude -----	Velocity-density contrast at interface, bed thickness and interbedding, degree of consolidation of beds
Reflection frequency -----	Bed thickness
Reflection continuity -----	Bedding continuity, depositional processes
Reflection configuration -----	Bedding patterns, depositional processes, erosion and paleotopography, grain size
External form and areal association -----	Gross depositional environment, sediment source, geologic setting, grain size

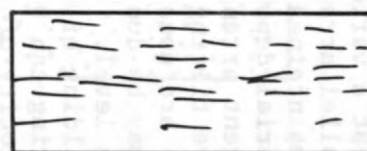
Amplitude variation is due principally to velocity-density contrast at bedding interfaces. Large velocity-density contrasts, such as those at the contact of unconsolidated sediment with consolidated rock, cause high amplitude reflections, whereas small velocity-density contrasts, such as those at the contact of unconsolidated sediment with semiconsolidated rock, cause low amplitude reflections. However, high amplitude reflections can also be due to constructive addition of the response in thick beds rather than large velocity-density contrasts.

Frequency is primarily dependent upon the character of the seismic pulse. However, it is also strongly influenced by thickness of the beds. Other geologic factors, such as spacing of reflecting beds or changes in velocity within an interval, will influence frequency.

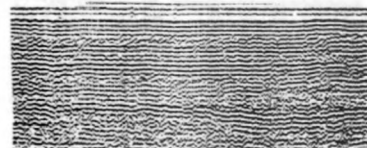
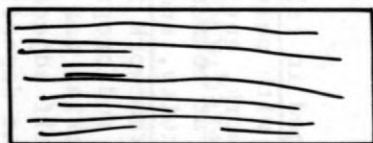
Seismic reflections generally parallel bedding surfaces within the resolution of a seismic cycle. Therefore, reflection continuity suggests continuity of bedding and lateral continuity of lithology. Figure 13 shows examples of seismic records with high and low amplitude and frequency and with continuous and discontinuous reflection patterns from the study area.



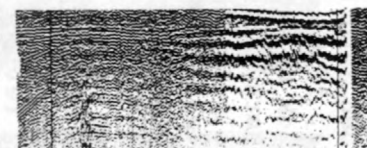
HIGH-AMPLITUDE REFLECTIONS



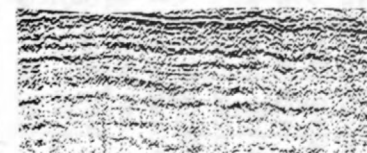
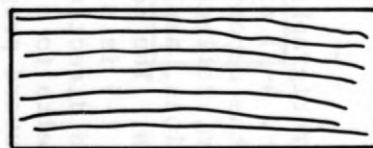
LOW-AMPLITUDE REFLECTIONS



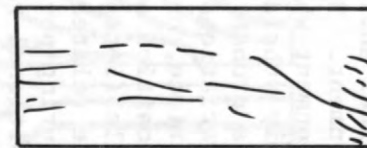
HIGH-FREQUENCY REFLECTIONS



LOW-FREQUENCY REFLECTIONS



CONTINUOUS REFLECTION PATTERNS



DISCONTINUOUS REFLECTION PATTERNS

Figure 13.--Amplitude, frequency, and continuity variations in reflection character (modified from Sangree and Widmier, 1979).

Reflection configuration can be divided into three principal types of reflection, as shown in figure 14 (Roksandic, 1978). The three types are: (1) reflection-free type, which indicates a lack of reflecting surfaces and uniform lithology; (2) layered-reflection type, characterized as simple-layered, parallel or divergent reflections that are relatively continuous or as complex-layered cross, oblique, and sigmoid reflections; and (3) chaotic-reflection type, characterized by discontinuous, contorted, and diffracted patterns.

Certain depositional environments can be inferred from reflection configurations. For example, reflection-free configurations indicate relatively homogeneous beds. In carbonate rock, however, reflection-free configuration could indicate a massive reef environment. Layered configurations suggest a varied depositional environment. Simple-layered configurations with parallel arrangement imply an environment where uniform rates of deposition were maintained on a stable or uniformly subsiding surface and indicate that the material deposited on such a surface is probably fine grained. Simple-layered divergent arrangements imply areal variations in the rate of deposition, progressive tilting of the depositional surface, or both. Complex-layered configurations are usually associated with deposition on prograded slope. Oblique layering may be due to outbuilding of middle (foreset) beds during a period of stable sea level. Sigmoid layering may be related to simultaneous outbuilding and upbuilding of upper (topset) beds during periods of rising sea level. Cross layering can be produced in a depositional environment where the direction and velocity of water currents changes rapidly. Cross layering indicates the presence of coarse-grained material.

Specific reflection patterns can be separated into seismic-stratigraphic units by identifying the termination of reflection patterns at the upper and lower unit boundaries. The character and variety of cycle termination at seismic-unit boundaries are shown in figure 15. The upper boundary of a unit may exhibit a truncated or concordant surface. Truncated cycles at the upper boundary, usually associated with oblique configurations, represent toplap termination or erosional truncation. The lower boundary of a unit may also exhibit a discordant or concordant surface. Discordant cycle termination at the lower boundary is defined as baselap, which is separated into onlap and downlap. Both oblique and sigmoid reflections are characterized by downlapping terminations at the lower boundary. The character of boundary cycle termination probably represents local changes in sediment source or depositional environment, or regional changes in sea level.

The seismic-stratigraphic units defined in table 3 and tracked throughout the study area (figs. 4-7) are correlated with seismic-facies units in table 4. Table 4 also shows the depositional framework, environment of deposition, lithology, external form, reflection geometry at boundaries, reflection configuration, lateral relations, amplitude, continuity, and frequency for the different seismic-facies units. The depositional framework interpretation for seismic-stratigraphic units 1-5 is a shelf-margin and prograded slope. The environment varies, in a seaward direction, from subaerial and subaqueous delta platform to delta slope to prodelta to a carbonate shelf adjacent to the delta system. Figure 16 shows the seaward progression of the depositional environments of a deltaic sequence, along with the facies characteristic of each environment and the expected reflection configuration of each facies.

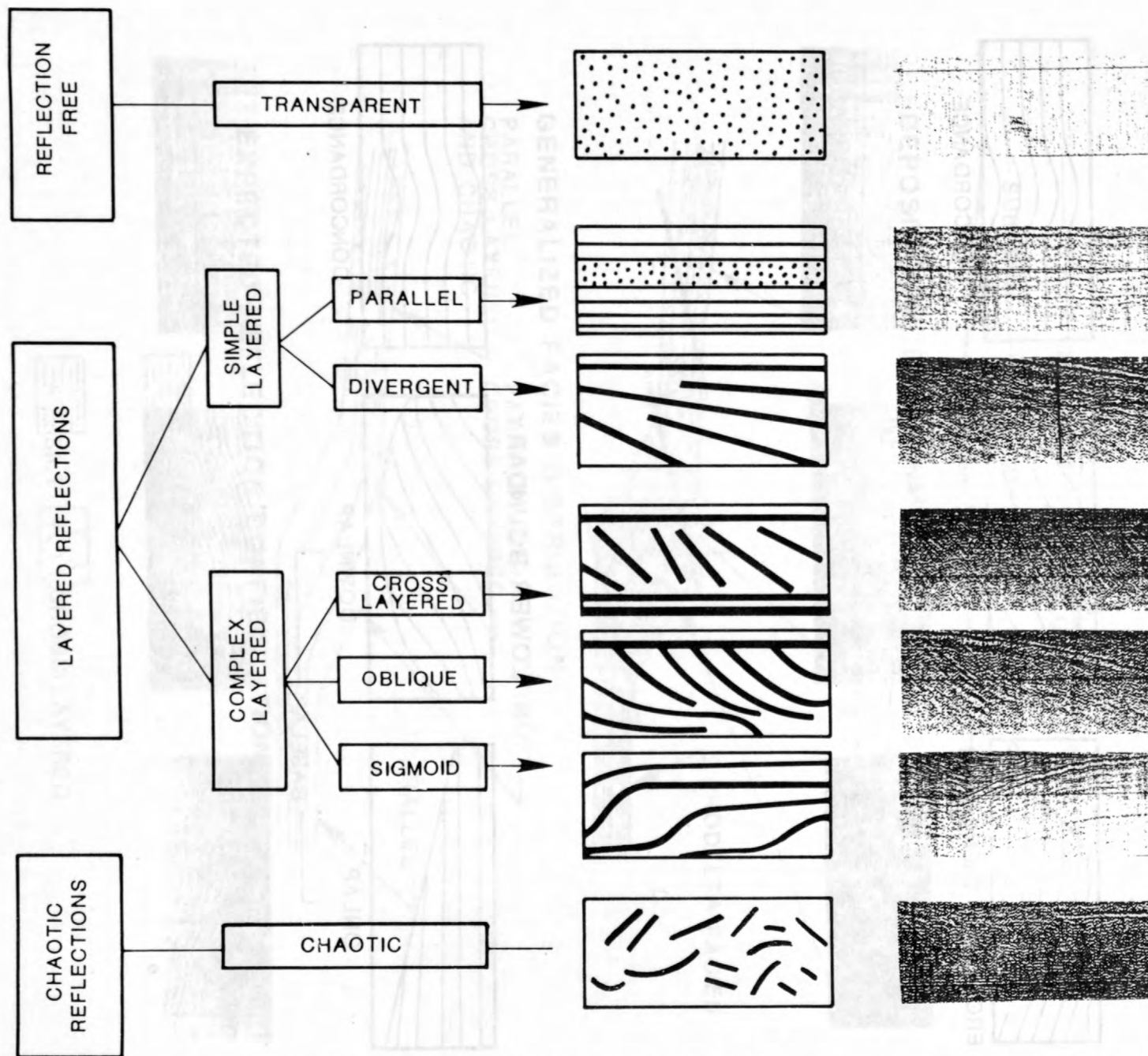


Figure 14.--Characteristic types of reflection configuration (modified from Roksandic, 1978).

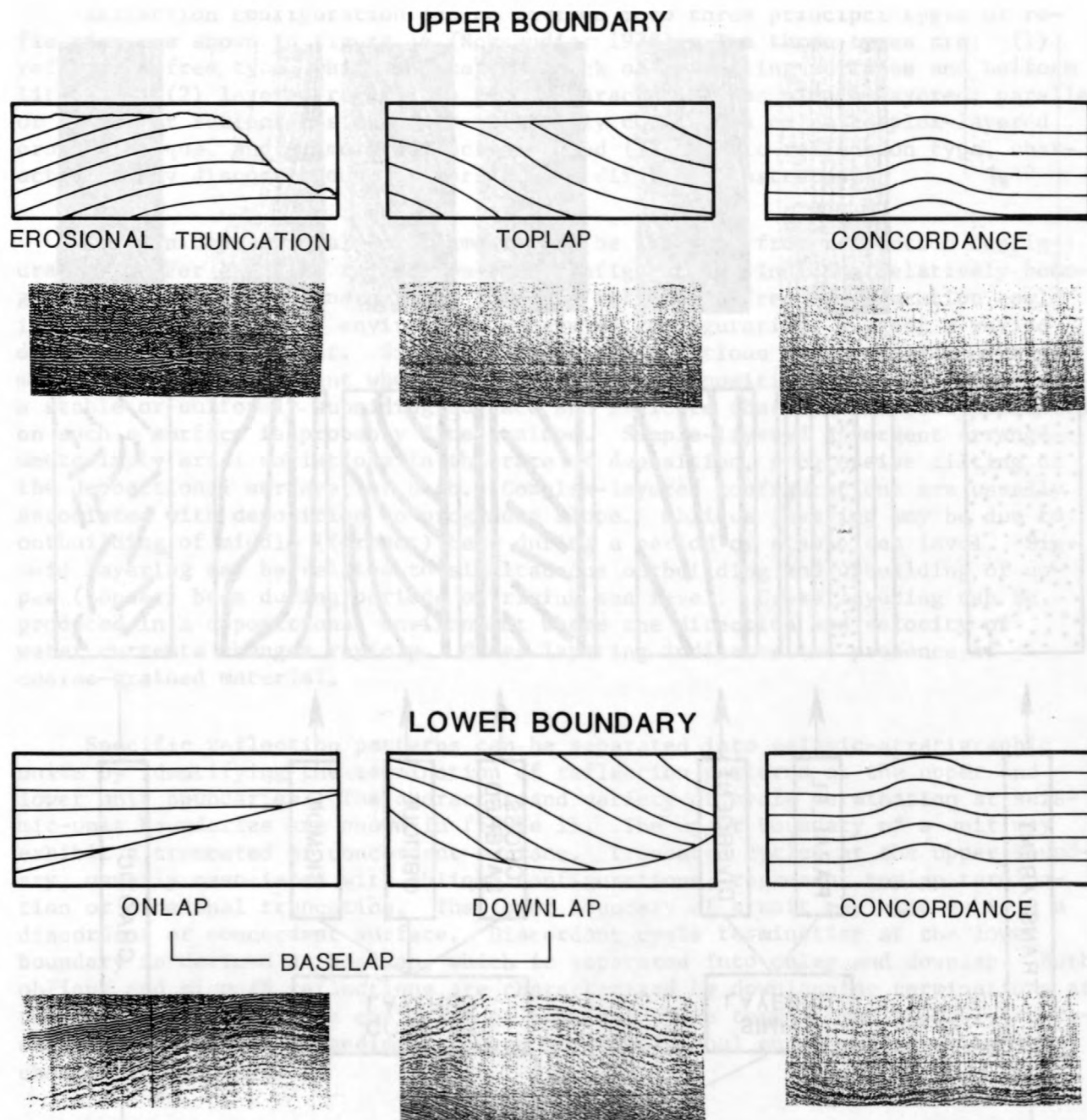


Figure 15.--Character of cycle terminations at boundaries of seismic facies unit (modified from Sangree and Widmier, 1979).

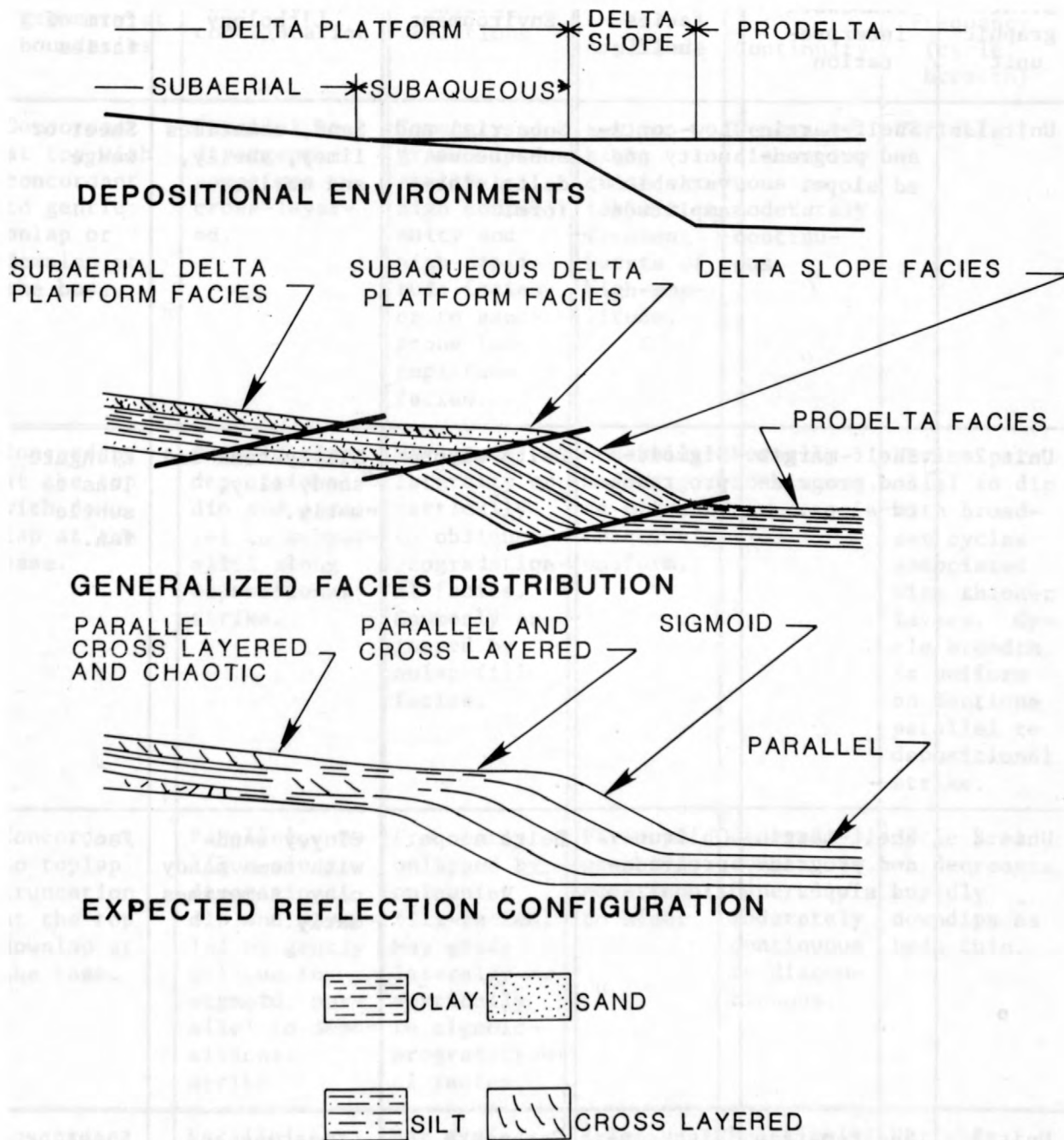


Figure 16.--Depositional environments, generalized facies distribution, and expected reflection configuration of a deltaic sequence (modified from Roksandic, 1978).

Table 4.--Relation of seismic facies characteristic

[Modified from Sangree

Seismic-stratigraphic unit	Depositional framework interpretation	Seismic-facies unit	Environment	Lithology	External form of facies
Unit 1	Shelf-margin and prograded slope.	Low-continuity and variable amplitude.	Subaerial and subaqueous delta platform.	Sand, sometimes limey, shelly, and marly.	Sheet or wedge.
Unit 2	Shelf-margin and prograded slope.	Sigmoid-progradational.	Delta slope.	Clayey sand and sandy clay, marly.	Elongate lens to subtle fan.
Unit 2	Shelf-margin and prograded slope.	Oblique-progradational.	Delta slope.	Clayey sand with some sandy clay, sometimes marly.	Fan.
Unit 3	Shelf-margin and prograded slope.	High-continuity and high-amplitude.	Carbonate shelf adjacent to a delta system.	Limestone and limestone conglomerate, very phosphatic.	Sheet or wedge.

to sedimentary environments and facies in study area
and Widmier, 1979]

Reflection geometry at boundaries	Reflection configuration	Lateral relations	Other seismic-facies parameters		
			Amplitude	Continuity	Frequency (cycle breadth)
Concordant at top with concordant to gentle onlap or downlap at the base.	Parallel to divergent, sometimes cross-layered.	Commonly grades laterally to high continuity and high-amplitude facies or to sand-prone low-amplitude facies.	Low to high, quite variable with frequent bursts of high-amplitude.	Generally discontinuous to moderately continuous.	Variable.
Concordant at the top with downlap at the base.	Sigmoid along depositional dip and parallel to subparallel along depositional strike.	May grade laterally or vertically to oblique-progradation facies. Commonly onlapped by onlap-fill facies.	Generally moderate to high, relatively uniform.	Normally continuous.	Varies parallel to dip with broadest cycles associated with thicker layers. Cycle breadth is uniform on sections parallel to depositional strike.
Concordant to toplap truncation at the top downlap at the base.	Parallel, oblique along depositional dip and parallel or gently oblique to sigmoid, parallel to depositional strike.	Frequently onlapped by onlapping fill-facies. May grade laterally or vertically to sigmoid-progradation facies.	Variable generally. Moderate to high.	Generally continuous. Generally moderately continuous to discontinuous.	Cycle breadth decreases rapidly downdips as beds thin.
Concordant at top with concordant to gentle onlap or downlap at the base.	Parallel to divergent.	May grade laterally to all other shelf facies or to slope-progradation facies.	Relatively high, but variable.	Relatively continuous.	Variable, some broad cycles.

Table 4.--Relation of seismic facies characteristic to

Seismic-stratigraphic unit	Depositional framework interpretation	Seismic-facies unit	Environment	Lithology	External form of facies
Unit 4	Shelf-margin and prograded slope.	High-continuity and high-amplitude.	Carbonate shelf adjacent to a delta system.	Dolomitic limestone and limestone, phosphatic.	Sheet or wedge.
Unit 5	Shelf-margin and prograded slope.	High-amplitude.	Prodelta.	Sandy clay and clayey sand.	Fan.

The subaerial part of a delta platform is usually formed of sediments of various grain sizes that have been deposited simultaneously. Sand is deposited in distributary channels, silt in the levees that flank these channels, and silt and clay in flood basins and lagoons behind the levees. In contrast, the subaqueous part is composed primarily of sand. On the delta slope, silt is the predominant deposit, grading seaward into clay on the prodelta. The expected reflection configuration varies for different parts of the deltaic sequence. The subaerial part of the delta platform should show oblique- or chaotic-reflection configurations in the distributary channels, cross-layered configuration in the flanking levees, and parallel configuration in flood basins and lagoons. The subaqueous part of the platform should usually show a discontinuous parallel and cross-layered configuration, rarely an oblique configuration. The delta slope usually exhibits a sigmoid-reflection configuration, whereas, the prodelta shows a parallel configuration.

Seismic-stratigraphic unit 1, a low-continuity variable-amplitude seismic-facies unit, was deposited on a subaerial and subaqueous delta platform. Unit 2 has two expressions: an oblique and a sigmoid-progradation seismic-facies unit, both deposited on a delta slope. Units 3 and 4, high-continuity and amplitude seismic-facies units, were deposited on a carbonate shelf adjacent to a delta system. Although both units 3 and 4 exhibit parallel-reflection configuration, they are separated by a zone of higher amplitude at this contact. Unit 5, a high-amplitude seismic-facies unit, was deposited in a prodelta environment.

sedimentary environments and facies in study area--Continued

Reflection geometry at boundaries	Reflection configuration	Lateral relations	Other seismic-facies parameters		
			Amplitude	Continuity	Frequency (cycle breadth)
Concordant at top with concordant to gentle on-lap or down-lap at the base.	Parallel to divergent.	May grade laterally to all other shelf facies or to unda-form portion of slope-pro-gradational facies.	Relative-ly high, but vari-able.	Relatively continuous.	Variable, some broad cycles.
Concordant at top with concordant to gentle on-lap or down-lap at the base.	Parallel to divergent.	May grade laterally to all other shelf facies or to unda-form portion of slope-pro-gradational facies.	Relative-ly high, but vari-able.	Relatively continuous.	Variable, some broad cycles.

Determining the depositional environment of the seismic-stratigraphic units aids in interpreting the hydrogeologic properties. For example, unit 5 is interpreted as having been deposited in a prodelta environment where clay is the dominant lithology. Wilson (1977) stated in his paper that the material included in unit 5 hydraulically separates the Floridan aquifer from a shallow, secondary, confined aquifer and that the material grades into a sandy limestone in southwest De Soto County. The first occurrence of unit 5 along the Peace River correlates with Wilson's map of the Tampa Limestone sand and clay unit, a confining bed.

Units 3 and 4 are interpreted as having been deposited on a carbonate shelf adjacent to a delta system. Accordingly, terrestrial, estuarine, and shallow marine environments existed side by side and interfinger. The dominant lithology is carbonate rock in both units 3 and 4. Clay is present in variable amounts due to the proximity of the adjacent delta system. The upper parts of units 3 and 4 often contain permeable zones. Strong discontinuous reflectors within these units probably correlate with relatively permeable beds of limestone and sandstone that could possibly yield significant quantities of water.

Unit 2 is interpreted as having been deposited on a delta slope where fine-textured sediments are often predominant. The sigmoid pattern expressed by unit 2 in places indicates low depositional energy and the presence of clay, whereas the oblique pattern shown by the unit in other places is characteristic of high-energy depositional conditions and indicates the presence of sand. A discontinuous strong reflector near the top of unit 2 between points G and H on the Peace

River survey (figs. 1 and 5) suggests a zone of hard limestone that may be water-bearing. This limestone is often present in the study area. However, it is discontinuous and does not always show as a strong reflector.

Unit 1 is interpreted as having been deposited on a subaerial and subaqueous delta platform where sand is the predominant lithology. A discontinuous reflector in the seismic record at the base of unit 1 possibly represents stringers of limestone that could be water bearing.

SUMMARY AND CONCLUSIONS

High-resolution continuous marine seismic-reflection profiling is a rapid and accurate method to define shallow sedimentary layers and shallow aquifers. In the Charlotte Harbor and Venice areas of Florida, the uniboom (high-resolution boomer) was found to be the equipment best suited for identifying seismic-stratigraphic and seismic-facies units in the shallow sediments and, hence, aquifers. The geologic formations delineated with the aid of the seismic-reflection profiling method include, from oldest to youngest, the Hawthorn, Tamiami, and Bone Valley Formations, the Caloosahatchee Marl, and the undifferentiated surficial deposits.

The five seismic-stratigraphic units defined from the seismic record are, from bottom to top: sand and clay of the Tampa Limestone (unit 5); limestone and dolomite of the Hawthorn Formation (unit 4); limestone conglomerate or marl and clay of the Tamiami Formation (unit 3); clay and clayey sand, clay and sand, or sand and limestone of the Tamiami Formation (unit 2); and undifferentiated surficial deposits, the Bone Valley Formation, and the Caloosahatchee Marl (unit 1). Unit 1 is equivalent to the surficial aquifer. Unit 2 is equivalent in places to the semiconfining bed separating the surficial aquifer from the Tamiami-upper Hawthorn aquifer or, in other places, is part of the surficial or Tamiami-upper Hawthorn aquifers, depending upon the amount of fine sediment in the unit and the location of permeable limestone and sand stringers. Unit 3 is part of the Tamiami-upper Hawthorn aquifer and is generally a relatively permeable layer within that aquifer. Unit 4 is generally part of the Tamiami-upper Hawthorn aquifer. The top part of the lower Hawthorn-Tampa aquifer is probably included in the unit. However, because the depth of penetration of the energy source used was limited to about 200 feet, it is not possible to separate the two aquifers everywhere. Unit 5 is equivalent to the confining bed separating the lower Hawthorn-Tampa aquifer from the underlying Floridan aquifer.

Facies and environments of deposition of the seismic-stratigraphic units are interpreted from seismic-reflection amplitude, frequency, continuity, configuration, external form, areal association, and the nature of cycle terminations at the boundaries of seismic-facies units. The depositional framework interpretation for stratigraphic unit 1 is a subaerial and subaqueous delta platform. Segments of unit 2 are equivalent to sigmoid- and oblique-progradation seismic-facies units, both of which were deposited on a delta slope. Units 3 and 4 are equivalent to a high-continuity and amplitude seismic-facies unit that was deposited on a carbonate shelf adjacent to a delta system. Unit 5 is equivalent to a high-amplitude seismic-facies unit deposited in a prodelta environment.

Seismic-reflection profiling greatly aided the interpretation of the geology and hydrology of the study area. Geologic and geophysical logs of nearby wells provided data necessary for interpretation and verification of the seismic record.

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