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HIGH-RESOLUTION SEISMIC REFLECTION PROFILING FOR MAPPING SHALLOW AQUIFERS IN LEE COUNTY, FLORIDA

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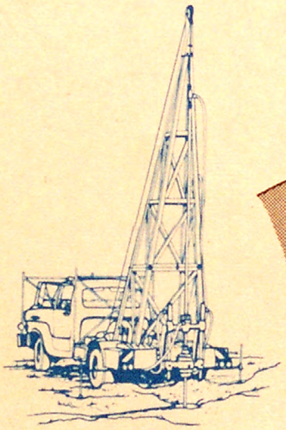

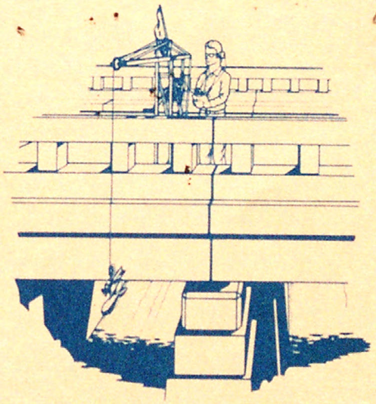

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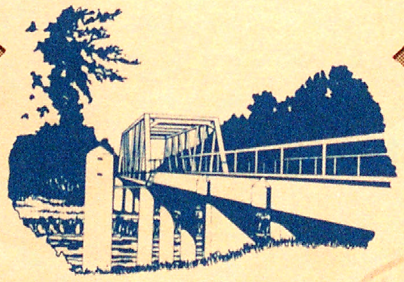

Prepared in cooperation with the
COUNTY COMMISSIONERS OF LEE COUNTY
and the
FLORIDA DEPARTMENT OF ENVIRONMENTAL REGULATION

U.S. DEPARTMENT OF THE INTERIOR MARCH 3, 1849

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By T. M. Missimer and R. A. Gardner

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CONTENTS

	Page
Abstract	1
Introduction	1
Purpose	3
Acknowledgments	3
Description of report area	3
Method of investigation	3
Principles of seismic reflection profiling	5
Selection and use of the equipment	8
Hydrogeologic setting	11
Results of investigation	14
Seismic velocities	14
Stratigraphy and geologic structure	18
Hydrologic implications	23
Problems involving interpretation of seismic reflection profile data	28
Summary and conclusions	28
References	30

ILLUSTRATIONS

Figure 1.--Map of Lee County showing the area of investigation	2
2.--Maps of the lower Caloosahatchee River estuary showing the locations of the seismic profiles made in the investigation	4
3.--Sketch showing principles of reflected and refracted seismic wave trains	6
4.--Sketch showing the principal components of a seismic exploration system	7
5.--Schematic diagram of a continuous reflection seismic profiling system	9
6.--Geologic column showing lithology, formations, and aquifers underlying the Caloosahatchee River estuary in Lee County	12
7.--Lithologic and gamma-ray logs of well L-1180 and the corresponding portion of the boomer seismic record	15
8.--Lithologic and gamma-ray logs of well L-1820 and the corresponding portion of the boomer seismic record	17
9.--Stratigraphic section of the lower Caloosahatchee River estuary as derived from the seismic record	19
10.--Approximate 1.5-mile section of the boomer seismic record showing folds in the Hawthorn Formation	21

ILLUSTRATIONS (Continued)

Page

Figure 11.--Approximate 6-mile section of the sparker seismic record showing folds in the Hawthorn Formation 22

12.--Approximate 1.5-mile section of the boomer seismic record illustrating cross-bedding in the green clay unit of the Tamiami Formation . . 24

13.--Approximate 1.5-mile section of the boomer seismic record showing folds in the Tamiami Formation and the Holocene, Pleistocene, and the Pliocene strata. 25

14.--Approximate 2-mile section of the boomer seismic record showing paleochannels 26

TABLES

Table 1.--Estimated seismic velocities of penetrated materials. 16

For use of those readers who may prefer to use metric units rather than English units, the conversion factors for the terms used in this report are listed below:

Multiply English unit	By	To obtain metric unit
feet (ft)	0.3048	meters (m)
miles (mi)	1.609	kilometers (km)
feet per mile (ft/mi)	0.189	meters per kilometer (m/km)

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ABSTRACT

High-resolution continuous seismic reflection profiling equipment was utilized to define the configuration of sedimentary layers underlying part of Lee County, Florida. About 45 miles (72 kilometers) of profile were made on the Caloosahatchee River Estuary and San Carlos Bay. Two different acoustic energy sources, a high resolution boomer and a 45-electrode high resolution sparker, both having a power input of 300 joules, were used to obtain both adequate penetration and good resolution.

The seismic profiles indicated that much of the strata of middle Miocene to Holocene age apparently are extensively folded but not faulted. Initial interpretations indicate that: (1) the top of the Hawthorn Formation (which contains the upper Hawthorn aquifer) has much relief due chiefly to apparent folding; (2) the limestone, sandstone, and unconsolidated sand and phosphorite, which together compose the sandstone aquifer, appear to be discontinuous; (3) the green clay unit of the Tamiami Formation contains large scale angular beds dipping eastward; and (4) numerous deeply cut alluvium-filled paleochannels underlie the Caloosahatchee River.

INTRODUCTION

Lee County, (fig. 1) an area of rapidly increasing population, faces continually increasing demands for potable water, which presently is obtained mostly from ground-water sources. To properly manage the ground-water resources it is necessary to understand in detail the subsurface hydrology including thickness and depth to the various aauifers, their internal structure and characteristics, and the quality of water in each.

The geology of Lee County is complex and although correlations of stratigraphic units from well to well have proved useful, many questions are left unanswered. Structural trends, internal characteristics (facies and lithology), and the location of individual rock units are not well known.

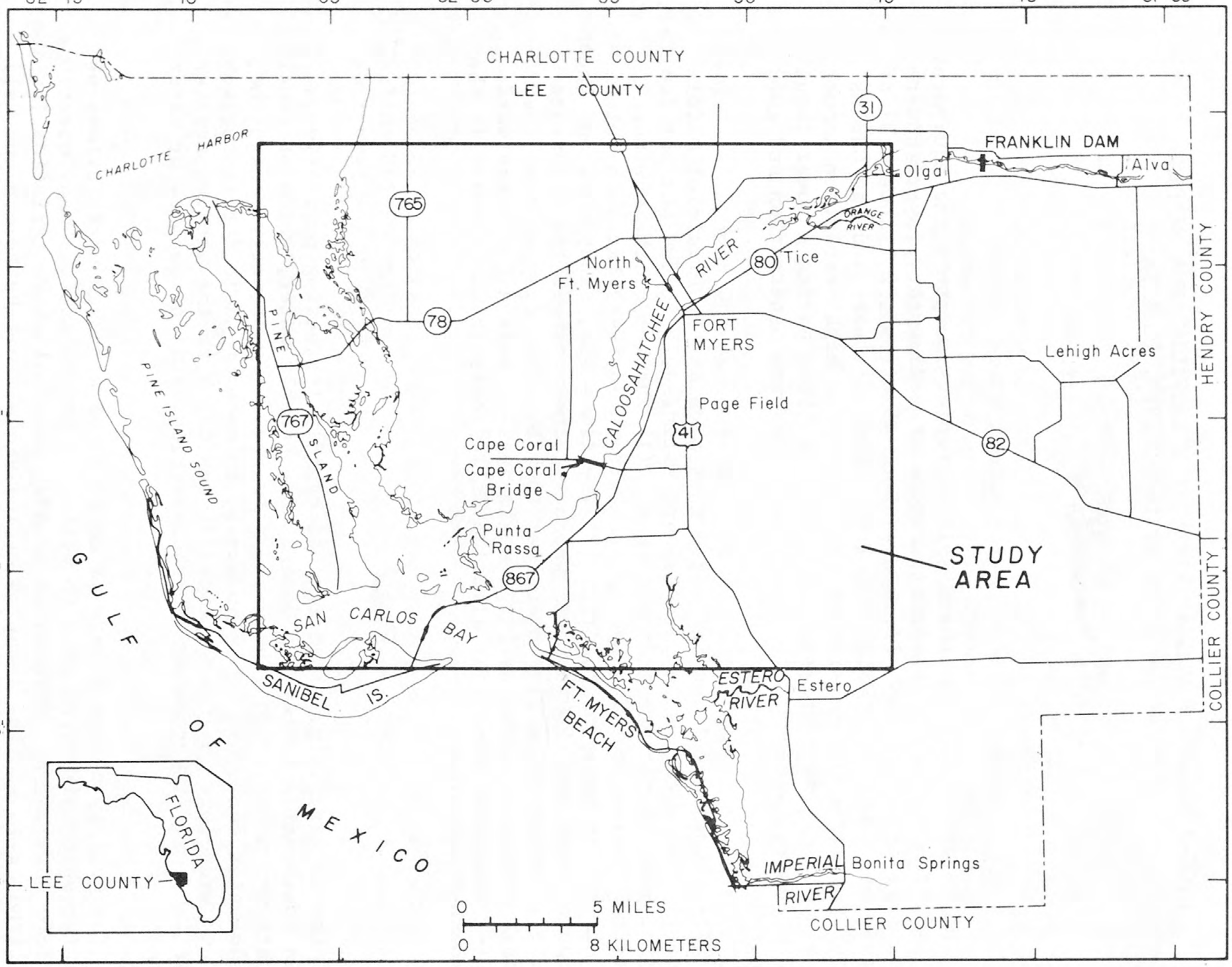


Figure 1.--Lee County, Florida showing the area of investigation.

PURPOSE

The purpose of this report is twofold: (1) to illustrate the use of high-resolution seismic reflection profiling for defining the configuration and position of strata that constitute certain aquifers and (2) to briefly discuss some of the principles and limitations of seismic reflection profiling that affect such interpretations.

ACKNOWLEDGMENTS

This study was aided by geophysical and lithologic logs from adjacent areas provided by Mobil Oil Corporation and the Florida Department of Natural Resources, Bureau of Geology. The investigation was made as part of a continuing program of hydrologic investigations in cooperation with the Board of County Commissioners of Lee County, and the Florida Department of Environmental Regulation.

DESCRIPTION OF REPORT AREA

The investigation was limited to the main channel of the Caloosahatchee River Estuary and San Carlos Bay. Continuous seismic reflection profiles were made beginning at a point about 1 to 2 miles (1.6 to 3.2 kilometers) downstream, from the confluence to the Orange River downstream to and around San Carlos Bay (fig. 2). About 45 miles (72 kilometers) of profile was made.

The bathymetry of the lower Caloosahatchee River is very irregular: water depths along the profile vary between 4 and 25 feet (1.2 and 7.6 meters). Tidal fluctuation at the Franklin Dam tidal gage during the profiling was less than 2 feet (0.6 meter) (U.S. Department of Commerce, 1973).

Water salinity in the river probably was fairly uniform from San Carlos Bay upstream to the Orange River due to minimal freshwater discharge into the river during the profiling. Water temperature was about 22°C with no evidence from periodic measurements of significant vertical gradients.

METHOD OF INVESTIGATION

The method used in this investigation is commonly referred to by such names as high resolution seismic surveying, subbottom profiling, continuous seismic profiling, seismic reflection surveying and others. As indicated by these names, the technique enables the investigator to

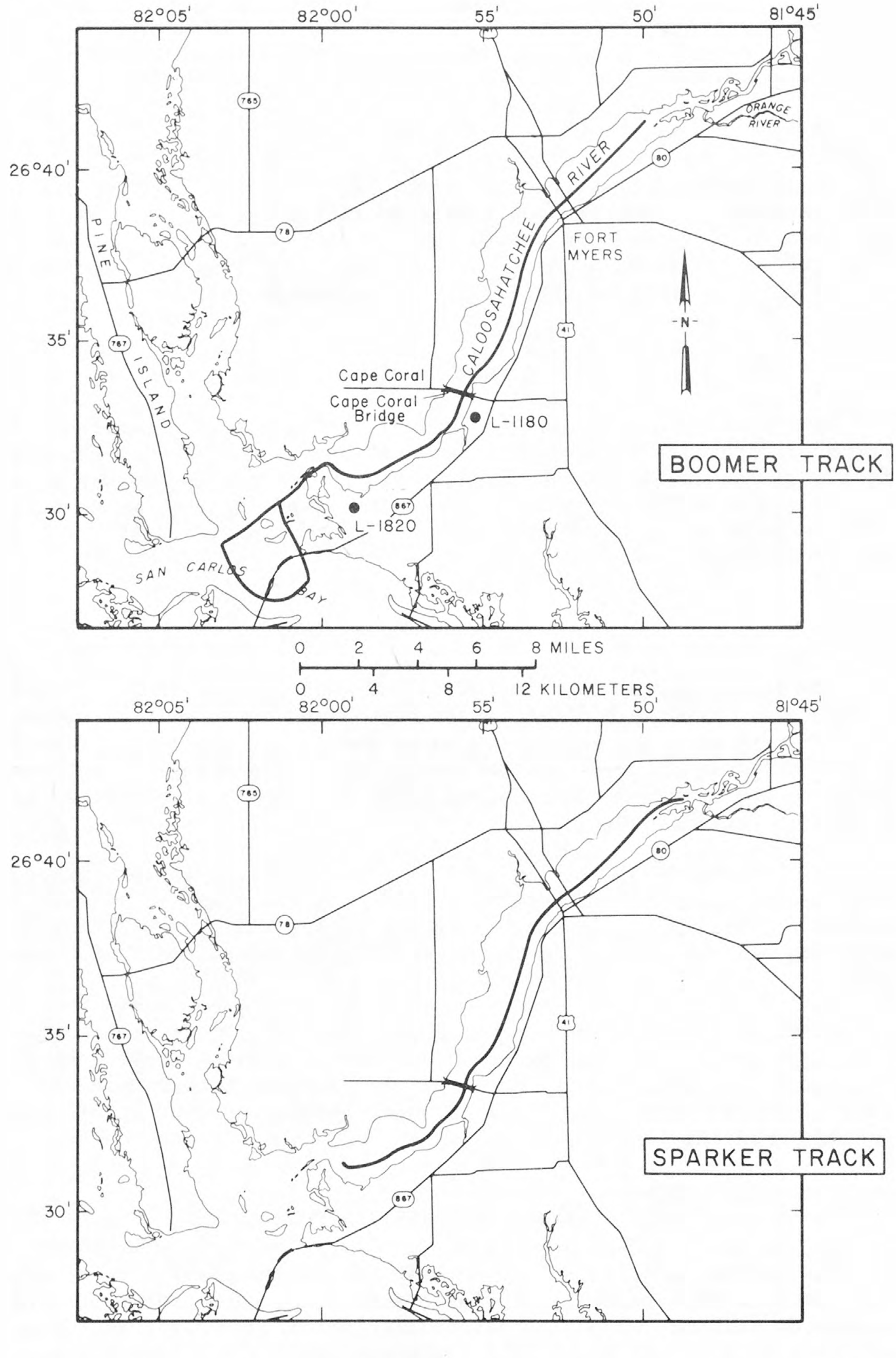


Figure 2.--Lower Caloosahatchee River estuary showing the locations of the seismic profiles made in the investigation.

obtain a virtually continuous record of reflected seismic waves from buried acoustic-reflecting surfaces, which can often be defined with a high degree of resolution depending upon the type of equipment and sound source. The record obtained is similar to the record produced by a recording fathometer except that in addition to a reflection from the bottom recorded by the fathometer some subbottom features are also recorded. The method is limited to areas where the survey can be conducted on water (seismic reflection data can also be collected on land, but not continuously).

Principles of Seismic Reflection Profiling

When an energy source initiates a seismic wave train within a homogenous and isotropic medium, the wave train radiates outward from the source in all directions and the amplitude of the waves decreases with distance from the source. If the medium is composed of layers having different acoustic characteristics, some of the energy will be reflected at layer interfaces back to the surface and some of the energy will be refracted horizontally as shown in figure 3.

The principal components of a seismic surveying system are shown in figure 4. An energy source generates a seismic wave train at A. If a receiver (hydrophone) is located close to A, as at B, so that the reflected waves are recorded (R_n), the depth to the reflecting surface can be computed if the seismic velocity of the wave train is known. This configuration was used to obtain the profiles discussed in this paper. In other applications, a receiver may be located at some point distant enough (C) that the refracted wave G_n is the first identified and the velocity of the wave train with certain assumptions can be determined.

In a multiple-layered system with horizontal layering in which the individual layers, L1, L2, ...Ln, have velocities of V1, V2, ...Vn, part of the wave train will be reflected from each layer interface. The number of layers reflecting energy to the surface and the strength of the returned energy wave depend on the strength and frequency of the energy source, the degree of reflectivity at the interfaces,and scattering, spreading, and absorption losses.

The reflectance of the various horizons is a function of the acoustic impedance and the angle of incidence of the impinging seismic-wave train. Acostic impedance in turn is the product of the seismic velocity of the rock and its density. Reflection may occur within a single velocity layer (all one lithology) if the density within the layer changes enough to produce a change in the acoustic impedance. Numerous factors can affect the density of the rocks and hence the acoustic impedance. Therefore, it is sometimes possible to record, with proper equipment, the detailed internal structure of a single velocity layer.

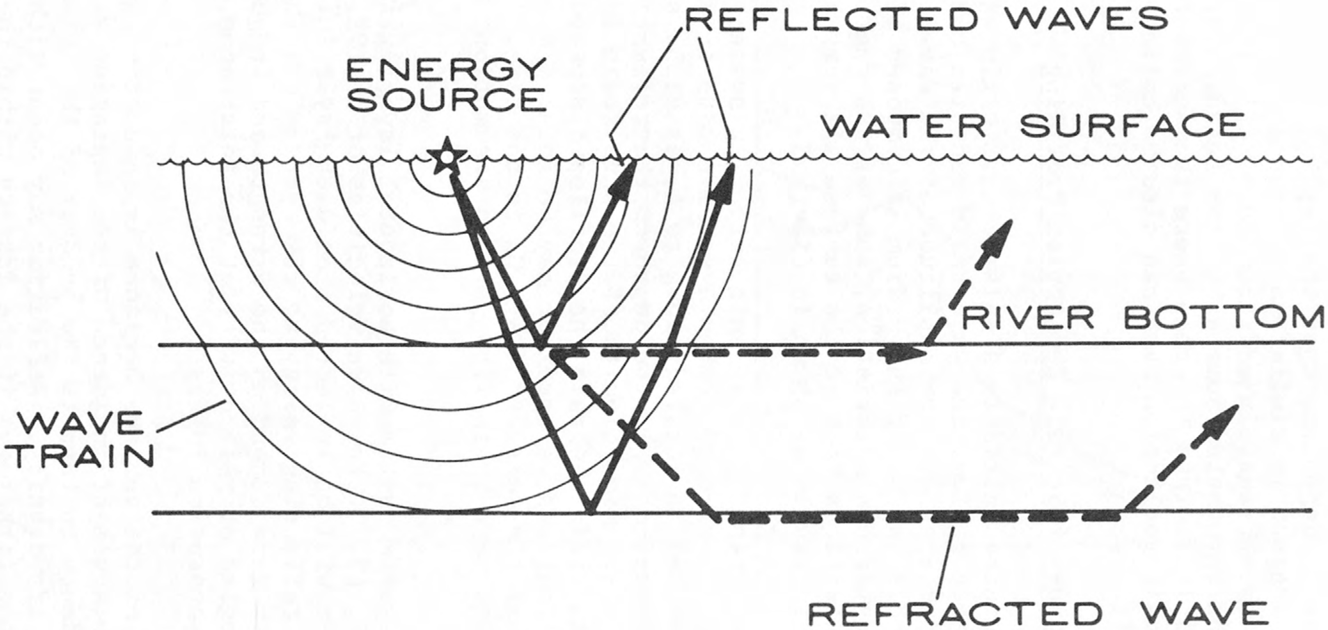


Figure 3.--Sketch showing principles of reflected and refracted seismic wave trains.

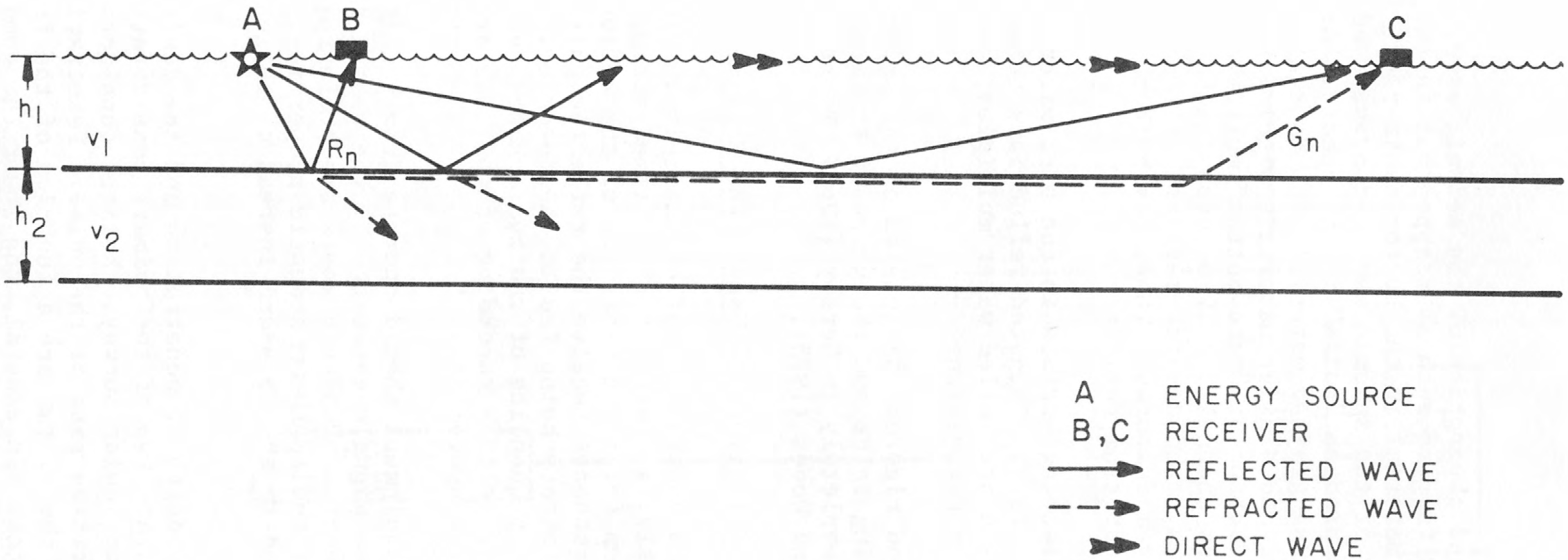


Figure 4.--Sketch showing the principal components of a seismic exploration system.

Scattering and absorption of the seismic waves can occur as the result of several factors such as trapped gas in the accumulations of decaying organic material in the bottom sediments. The gas bubbles may absorb the energy of the seismic wave and prevent adequate penetration and reflection or produce "noise" in the record. Accumulations of oyster shell, coarse-grained material such as that sometimes deposited in river channels, and similar materials within the rock section may result in the production of "hard bottom" multiples, which can obscure the record. Narrow channels, rock outcrops along the channel, and similar features may produce side-reflections that appear on the record as phantom subbottom features. These may both confuse the record and obliterate real subbottom reflections.

The best reflecting surface in the air, water, sediment sequence is the water-air interface. Repeated reflections between the bottom and water surface, which are called water multiples, can obliterate many or all other subbottom reflections.

A detailed and rigorous discussion of the principles of seismic reflection profiling is beyond the scope of this report. This subject is treated more completely in Hersey (1963), Moore (1968), Tucker and Yorston (1973), and Woods (1975).

Selection and Use of the Equipment

In order for a continuous reflection seismic profiling system to function effectively, a source of rapid timed firing of short energy pulses and a system for rapid recording of the reflected energy pulses is required. Hydrophones receive the reflected pulse, which is amplified and filtered before being fed to the recorder. Timing of the firing rate, gain, sequencing of the hydrophones, and selection of the filter band pass as well as recording of the data are accomplished within the recording system (fig. 5).

Ideally the equipment should operate from a reasonably "quiet" vessel. Extraneous signals generated by the vessel and its equipment can obscure the record. Wooden vessels are preferred over steel hull vessels because of their quieter acoustic properties. That is, the wooden vessels tend to absorb sound instead of reflecting or creating acoustic waves.

The effective depth of penetration and the desired resolution of subbottom features are two of the primary considerations when selecting equipment for a particular survey. Related considerations involve the duration and repetition rate of the pulse. Penetration and the resolving capability of the system are a function of the frequency spectrum of the energy source. In general, the lower the dominant frequency of an energy source the deeper the effective or useful penetration; the higher

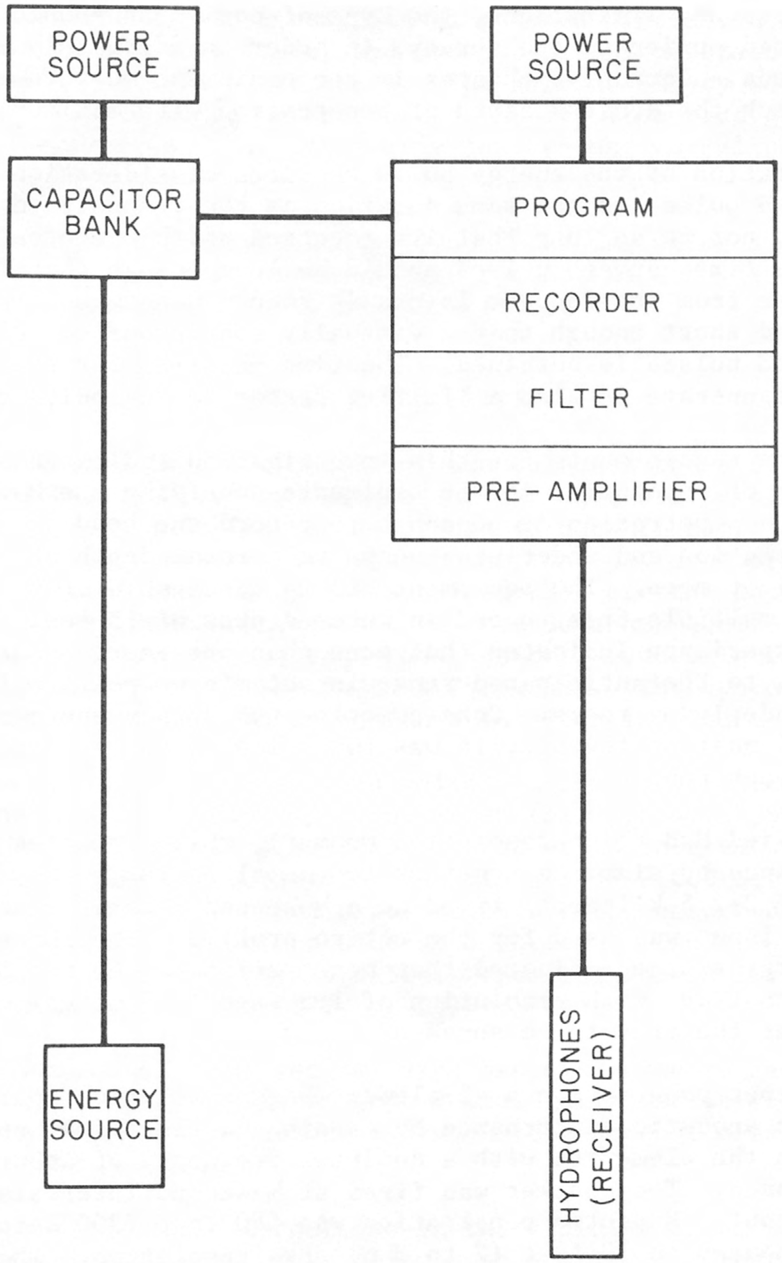


Figure 5.--Schematic of a continuous reflection seismic profiling system.

the dominant frequency, the greater the resolution obtained. Because of these frequency limitations, the type of equipment should be carefully selected, prior to the survey, in order to adequately meet specific data needs. Commonly, changes in the equipment must be made in the field to reach the desired depth of penetration with maximum resolution.

The duration of the energy pulse requires consideration in that the reflected pulse has the same duration as the transmitted pulse. The pulse should not be so long that its recorded width obscures required detail. The time between pulses should be long enough that the reflected pulse from the deepest layers is recorded between transmission of pulses and short enough that a virtually continuous correlation of the reflected pulses is obtained. The time required for the power source to regenerate is also a limiting factor to the pulse rate.

The data requirements for this investigation indicated a need for a high order of resolution in the sediments overlying the Hawthorn Formation and penetration deep enough to record the bedding of the Hawthorn Formation and underlying rocks to a total depth of 660 feet (200 meters) or more. The equipment had to be capable of producing a virtually multiple-free record in water depths of 15 feet (5 meters) or less. Experience indicated that more than one energy source was needed owing to the anticipated range in seismic velocities in the sequence of underlying rocks. Consequently, two energy sources were selected amd most of the profile was run twice, using a different energy source for each run.

A modified HRB (high resolution boomer), which intiates an acoustic disturbance by slamming together two metal plates,with a dominant frequency of 2-2.5 kilohertz fired at a ½-second repetition rate with a 300-joule input was used for the entire profile. The characteristics of this energy source indicated that penetration to the top of the Hawthorn Formation, with resolution of 1.5 feet (0.5 meter), could be expected over the area to be surveyed.

For deeper penetration a 45-element high resolution sparker, which initiates an acoustic disturbance by causing an electrical spark to jump between the elements, with a dominant frequency of about 0.7 kilohertz, was used. The sparker was fired at ½-second intervals with a 300-joule input. Expected penetration was 660 feet (200 meters) or more with about 6 to 10 feet (2 to 3 meters) resolution. The reflected wave was filtered to pass the 80-hertz to 4-kilohertz band with the HRB and 60-hertz to 1.5-kilohertz band with the sparker. The energy source and the hydrophones were towed near the water surface behind the survey vessel. The energy source was positioned 30 feet (10 meters) behind the vessel and the hydrophones in a line at 13-foot (4-meter) intervals behind the energy source.

The vessel was a twin screw, diesel powered cruiser, wood-hulled, with a 5-foot (1.5-meter) draft, and was capable of maintaining course in the surveyed waters on one screw. The average survey water speed was 4.5 to 5 statute miles per hour (2.8 to 3.1 kilometers per hour). Auxiliary power was used for the energy sources and vessel power for the recording equipment and accessories.

Positioning was accomplished by dead reckoning using a standard nautical chart. The time at which each channel marker was passed was noted to horizontally scale the seismic record.

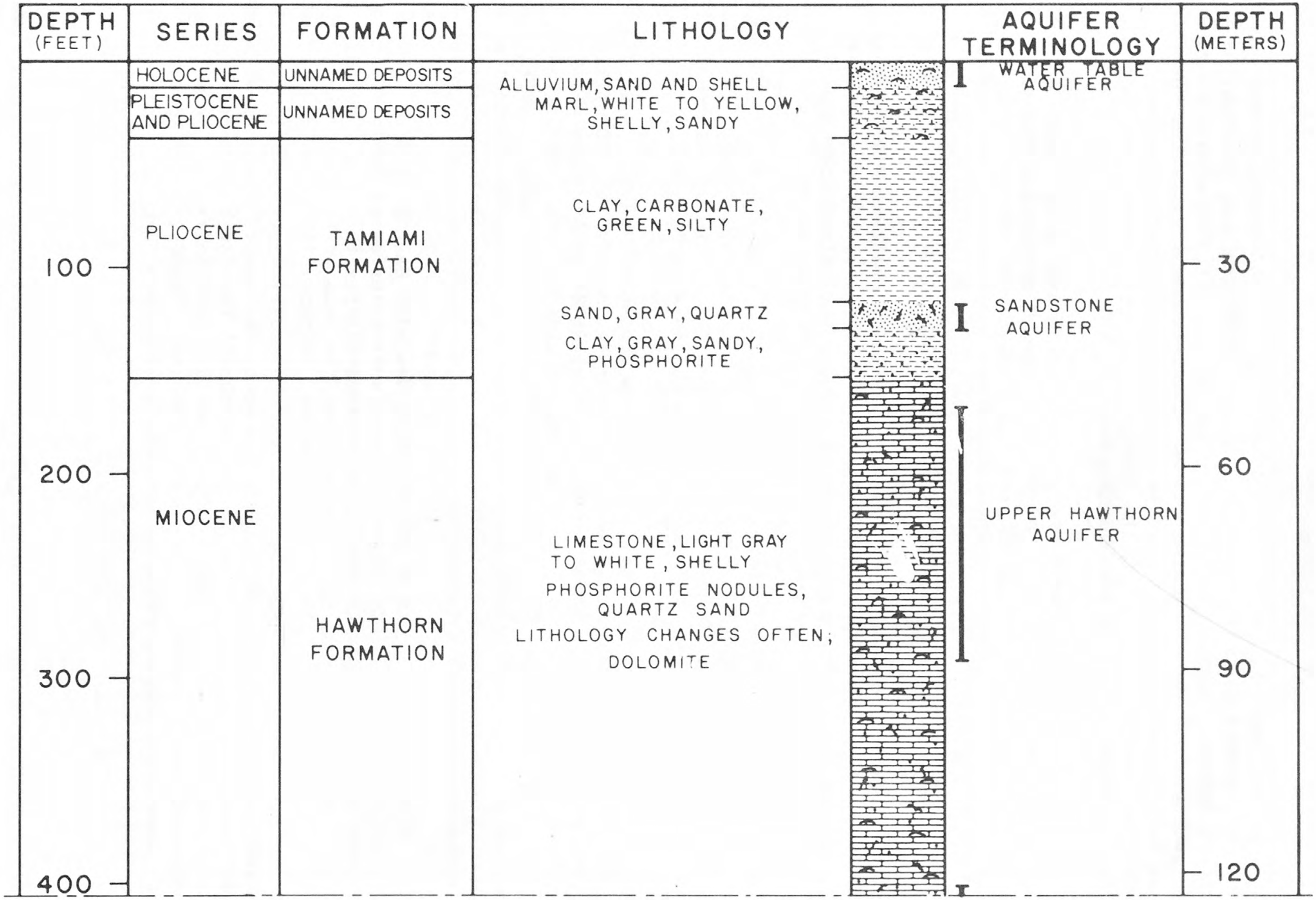
HYDROGEOLOGIC SETTING

The subsurface in the vicinity of the Caloosahatchee River Estuary presents numerous unsolved hydrologic and geologic problems. At least four major aquifers underlie the area; one is unconfined (the water-table aquifer) and three are artesian. The confined aquifers as described by Sproul and others (1972, p. 15-22), are the upper Hawthorn aquifer, the lower Hawthorn aquifer, and the Suwannee aquifer. A minor artesian aquifer known as the sandstone aquifer, occurs in the "rubble zone" in the lower part of the Tamiami Formation. The approximate stratigraphic position of these aquifers is given in figure 6.

Extreme variation in dissolved solids concentration occurs within the artesian aquifers. Highly saline water (as much as 19,000 milligrams per liter of dissolved solids) is present in an area where the water normally would be expected to contain around 2,000 milligrams per liter of dissolved solids. One explanation for the occurrence of the saline water is that a fracture zone or a series of faults provides a connection between deeper highly saline zones and the shallower artesian aquifers (Sproul and others 1972, p. 25).

Recent faulting in the general area has also been suggested by Tanner (1965, p. 41). He stated that a fault oriented at about N. 50° E., active in the last 10,000 years, is responsible for the offset in the coastline of Lee County.

The tops of geologic formations in the vicinity of the Caloosahatchee River vary considerably in depth below mean sea level. There is as much as 50 feet (16 meters) of relief on the top of the Hawthorn Formation and even more relief on the tops of other geologic units. It is not known whether the sediment sequence is faulted (Tanner, 1965; Sproul and others, 1972), contains extensively eroded unconformities in the subsurface, or possibly is folded. Regardless of origin, the vertical variations are real and have not been explained adequately.



DEPTH (FEET)
SERIES
FORMATION
LITHOLOGY
AQUIFER TERMINOLOGY
DEPTH (METERS)
HOLOCENE
UNNAMED DEPOSITS
PLEISTOCENE AND PLIOCENE
UNNAMED DEPOSITS
ALLUVIUM, SAND AND SHELL
MARL, WHITE TO YELLOW, SHELLY, SANDY
WATER TABLE AQUIFER
PLIOCENE
TAMIAMI FORMATION
CLAY, CARBONATE, GREEN, SILTY
SAND, GRAY, QUARTZ
CLAY, GRAY, SANDY, PHOSPHORITE
SANDSTONE AQUIFER
MIOCENE
HAWTHORN FORMATION
LIMESTONE, LIGHT GRAY TO WHITE, SHELLY
PHOSPHORITE NODULES, QUARTZ SAND
LITHOLOGY CHANGES OFTEN;
DOLOMITE
UPPER HAWTHORN AQUIFER
100
200
300
400
30
60
90
120

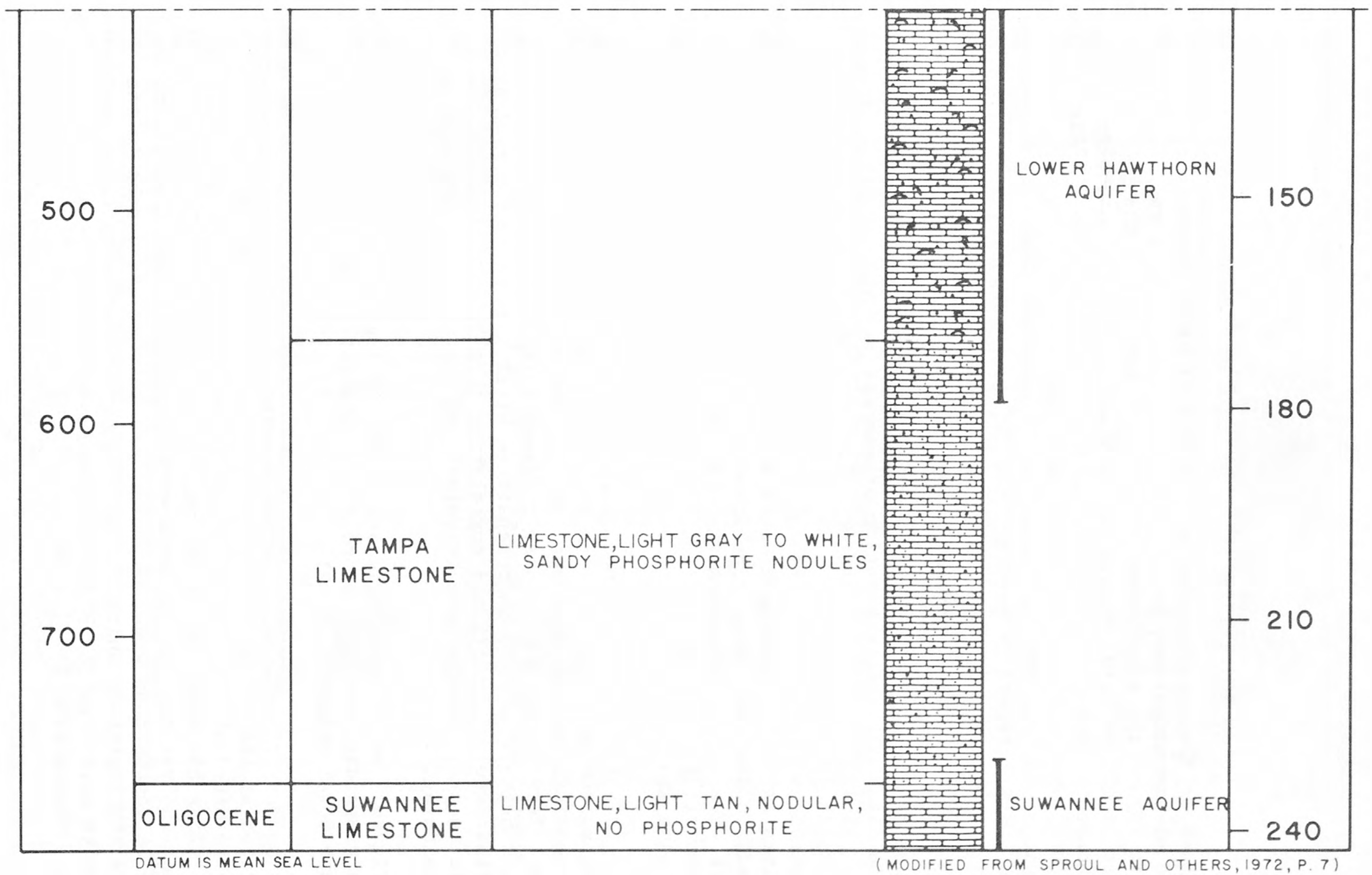


Figure 6.--Geologic column showing lithology, formations, and aquifers underlying the Caloosahatchee River estuary in Lee County.

RESULTS OF INVESTIGATION

Because the main purpose of this report is to demonstrate a method of investigation, only a small part of the data collected is used to report the significant results. A segment of HRB record, extending from the Cape Coral bridge to the mouth of the Caloosahatchee River, was chosen for detailed analysis due to its proximity to excellent data reference points. This record was analyzed for seismic velocities, geologic structure, and stratigraphy. A 6-mile (9.7 kilometer) portion of the sparker record is used for illustrative purposes.

Seismic Velocities

One of the more difficult parts of interpreting continuous seismic profile data is the determination of average seismic velocities for the various geologic units penetrated. Ideally, test borings should be made close to the profile to determine the depth to reflecting interfaces. The petroleum industry commonly measures "absolute" seismic velocities for given strata by placing a sound source at a known depth in a freshly drilled, mudded test hole. The sound source is triggered, initiating a shock wave which propogates through the overlying strata and is recorded upon arrival at land surface. The average velocity is then calculated using time and the distance traveled.

In this investigation, numerous geophysical logs and known geologic sequences from wells adjacent to the seismic profiles were used to determine the distance from mean sea level to reflecting horizons. Several well drillers in Lee County also provided data on the depth of various geologic units along the Caloosahatchee River. By using known depths to certain geologic units and correlating them to reflectors on the seismic record, average seismic velocities for certain lithologic units were calculated.

Figure 7 shows lithologic and gamma-ray logs for well L-1180 and the corresponding seismic record for a calibration point southwest of the Cape Coral bridge (fig. 2).

A summary of estimated average seismic velocities for the materials penetrated at the calibration site is given in table 1. These velocities were determined at a calibration point just southwest of the Cape Coral bridge along the track using the high resolution boomer record (fig. 7). To check the validity of the determined values, a point near the mouth of the Caloosahatchee River was used. At this point, depths to the various stratigraphic units as derived from the seismic record were compared with well logs (L-1820) to determine accuracy of the predicted depths. (See fig. 8.)

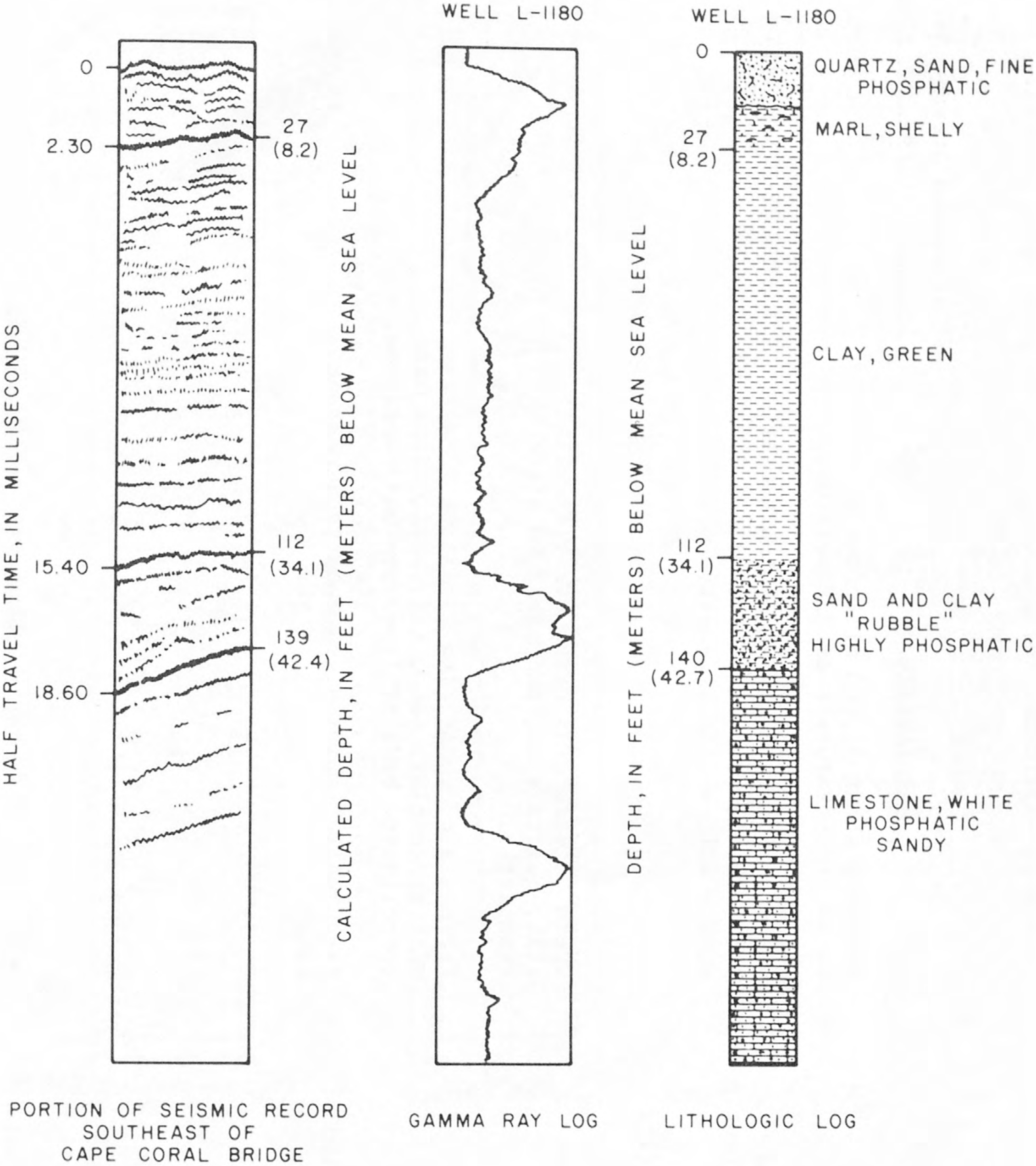


Figure 7.--Lithologic and gamma ray logs of well L-1180 and the corresponding portion of the boomer seismic record.

Table 1.--Estimated seismic velocities of penetrated materials.

Material	Description	Calculated Average Seismic Velocity (feet per second)
Water	Salinity about 31,000 miligrams per liter, temperature near 22° Celsius.	4,900
Undifferentiated, Holocene, Pleistocene and Pliocene	Fine to medium quartz sand with some fine semi-consolidated carbonate material. Marl with shell, variable density.	7,500
Alluvium and marl		
Tamiami Formation	Green to dark gray carbonate clay with silt, quartz sand, and shell in minor quantities.	6,500
Green clay		
"Rubble"	Fragments of underlying limestone formation with green clay, sand, and shell. Some hard consolidated beds of limestone and sandstone.	8,500
Hawthorn Formation	Hard, well lithified, phosphatic limestone, sandy.	11,000

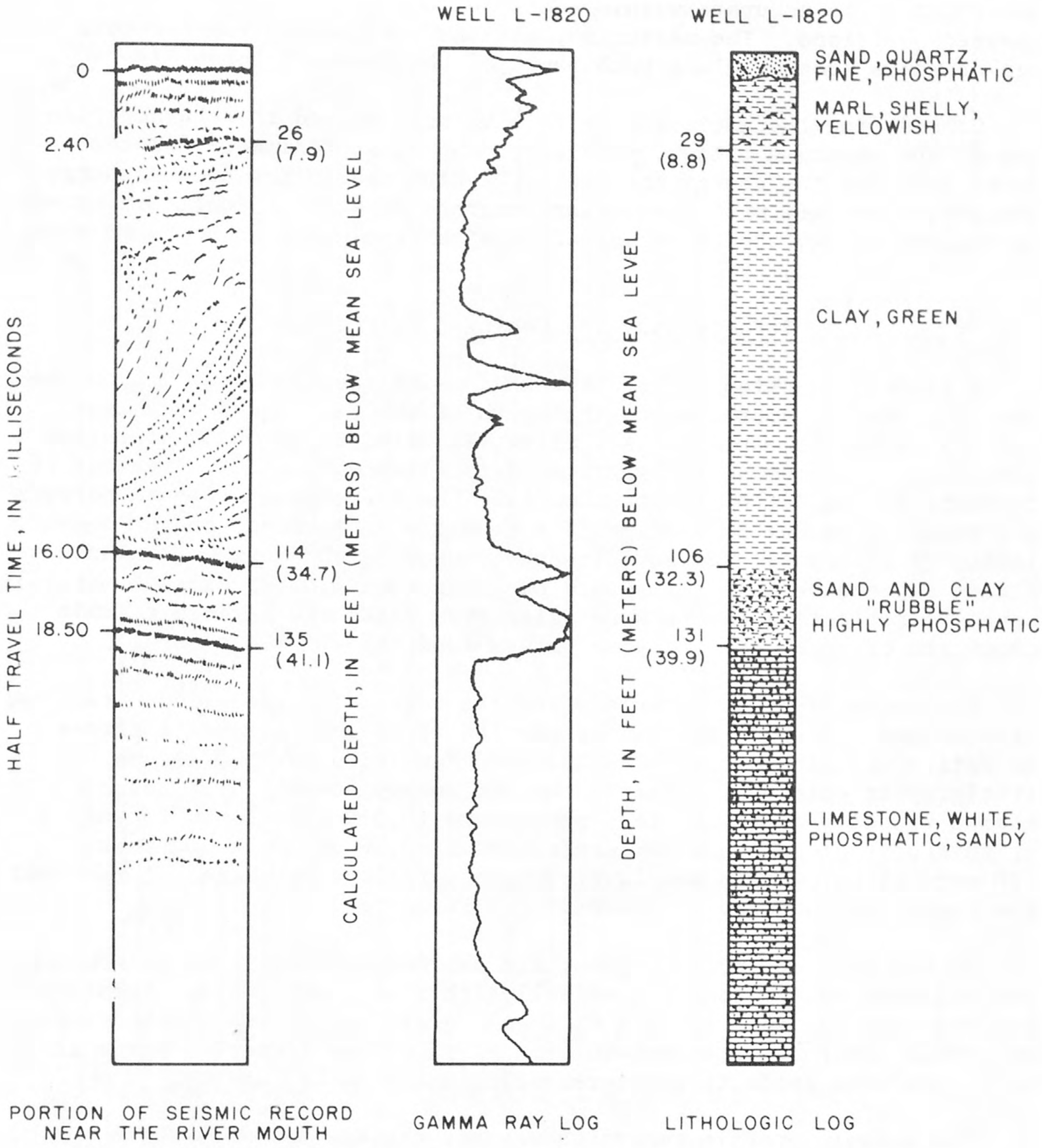


Figure 8.--Lithologic and gamma ray logs of well L-1820 and the corresponding portion of the boomer seismic record.

Interpreted depths to the top of the geologic units studied herein were found to be accurate within about 10 feet (3 meters) of several measured positions. The measured positions were taken from numerous logs of wells located along both banks of the Caloosahatchee River.

Considering the estimated seismic velocities and the characteristics of the instrumentation, resolution can be approximated for the record from the two energy sources. The high resolution boomer energy source yielded data with resolution accurate to about 1 foot (0.3 meter). The sparker energy source yielded data with resolution accurate to about 3 feet (0.9 meter).

Stratigraphy and Geologic Structure

A geologic section was constructed, using the HRB record, from the Cape Coral bridge southwest to the mouth of the Caloosahatchee River. Figure 9 shows the approximate 7 miles (11 kilometers) of this section which was derived using 103 vertical data alinements, the equivalent of correlating a series of 103 test wells. The horizontal distance between data points from the seismic profile record was dependent on the complexity of the penetrated stratigraphy; however, the maximum distance between successive data alinements was less than 1,000 feet (300 meters). Depths to reflecting layers were calculated using the derived seismic velocities of each unit and time values from the seismic record.

The sediment-water interface and the four major geologic units were defined in detail by tracing particular reflecting strata across the entire seismic record. The Hawthorn Formation was the deepest stratigraphic unit penetrated by the HRB energy source. The assumed seismic velocity of 11,000 feet per second (3,350 meters per second) for this unit gives a maximum useful penetration of about 400 feet (120 meters) below mean sea level. Energy reflections were not received from formations underlying the Hawthorn Formation.

In the area of investigation, the Hawthorn Formation as determined from adjacent wells, consists of well-lithified, hard, white limestone that contains variable amounts of shell, quartz sand, and phosphorite. The porous nature of the rock in some parts of the formation makes it one of the most productive water-bearing units in Lee County.

The seismic profile record shows that the Hawthorn Formation apparently is folded along the entire section studied. Although the depth variation to the reflectors is interpreted as folding in this report, the alternative interpretations, such as buried karst, bioherms, or banks, could be made. However, the linear nature and continuity of the features, as discovered when a roughly rectangular profile was made in San Carlos Bay (fig. 2), points toward the folding hypothesis. The

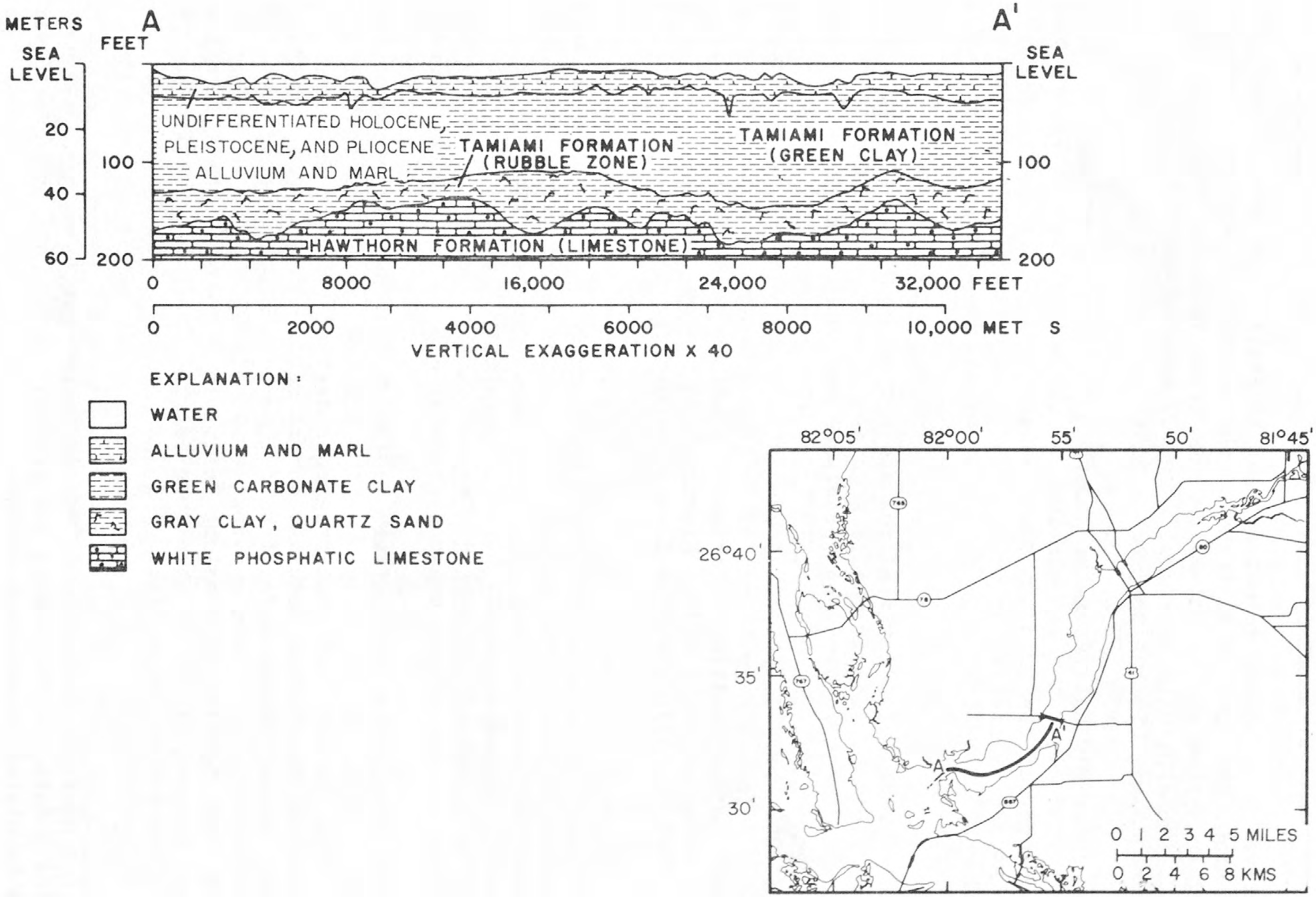


Figure 9.--Stratigraphic section of the lower Caloosahatchee River Estuary as derived from the seismic record.

alternative explanations do not involve generally extensive linear features. Also, the structural trend of the apparent folded area is subparallel to other structural alinements (that is Ocala Uplift area) in Florida. The apparent folding is probably related to differential subsidence caused by tensional basal displacement.

The geometric nature of the apparent folds is illustrated in figures 10 and 11, which are portions of the boomer and sparker record[1]. Maximum slopes of the fold limbs are as great as 312 feet per mile (59 meters per kilometer) or up to about 4 degrees. Maximum relief measured vertically from trough to apex of any fold in about 130 feet (40 meters).

Faults were not identified and are not believed to be present in any portion of the seismic record studied. Previous suggestions of faults extending upward to the top of the Hawthorn Formation of middle Miocene age (Sproul and others, 1972, p. 12) or even into Pleistocene (Tanner, 1965, p. 41) cannot be substantiated by data from this investigation. Although no evidence of faults was found in this survey, some evidence for faulting in deeper formations remains. Apparently, faulting ended prior to middle Miocene time as was found by Bermes and others (1963, p. 37) in Putnam County in northern Florida.

The contact between the Hawthorn Formation and the overlying Tamiami Formation is an unconformity with much relief due to erosion and apparent folding. The apparent folds occur primarily in the underlying limestone, but in some places the unconformity apparently is deformed by folding (fig. 10). The unconformity has about 40 to 50 feet (12 to 17 meters) of vertical relief in the section studied. This relief obscures the slight seaward regional dip of the Hawthorn Formation.

A relatively thin unit of the Tamiami Formation, referred to as the "rubble zone," immediately overlies the Hawthorn Formation. The "rubble zone" consists of rock fragments derived from the Hawthorn Formation and phosphorite nodules, quartz sand, and gray-green carbonate clay. Discontinuous beds of hard limestone of calcareous sandstone are also present. The unit apparently is folded, but not as extensively as the underlying limestone unit. In Lee County the discontinuous sandy portion of the "rubble zone" of the Tamiami Formation is known as the sandstone aquifer.

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[1]All lines shown in the seismic profile record represent time and not distance. Both the horizontal and vertical scales are non-linear with regard to distance.

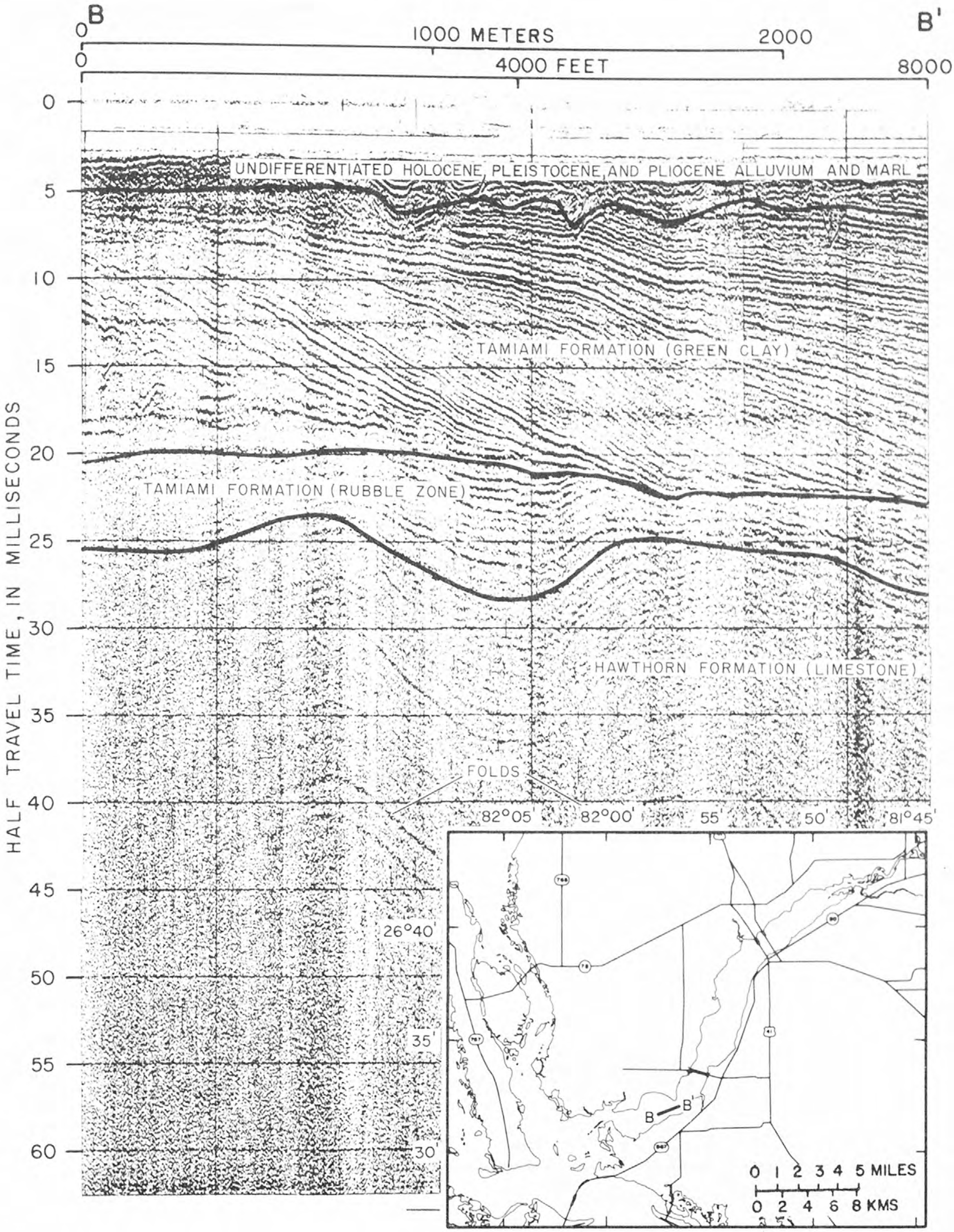

Figure 10.--Approximate 1.5-mile (2.4-kilometer) section of the boomer seismic record showing folds in the Hawthorn Formation.

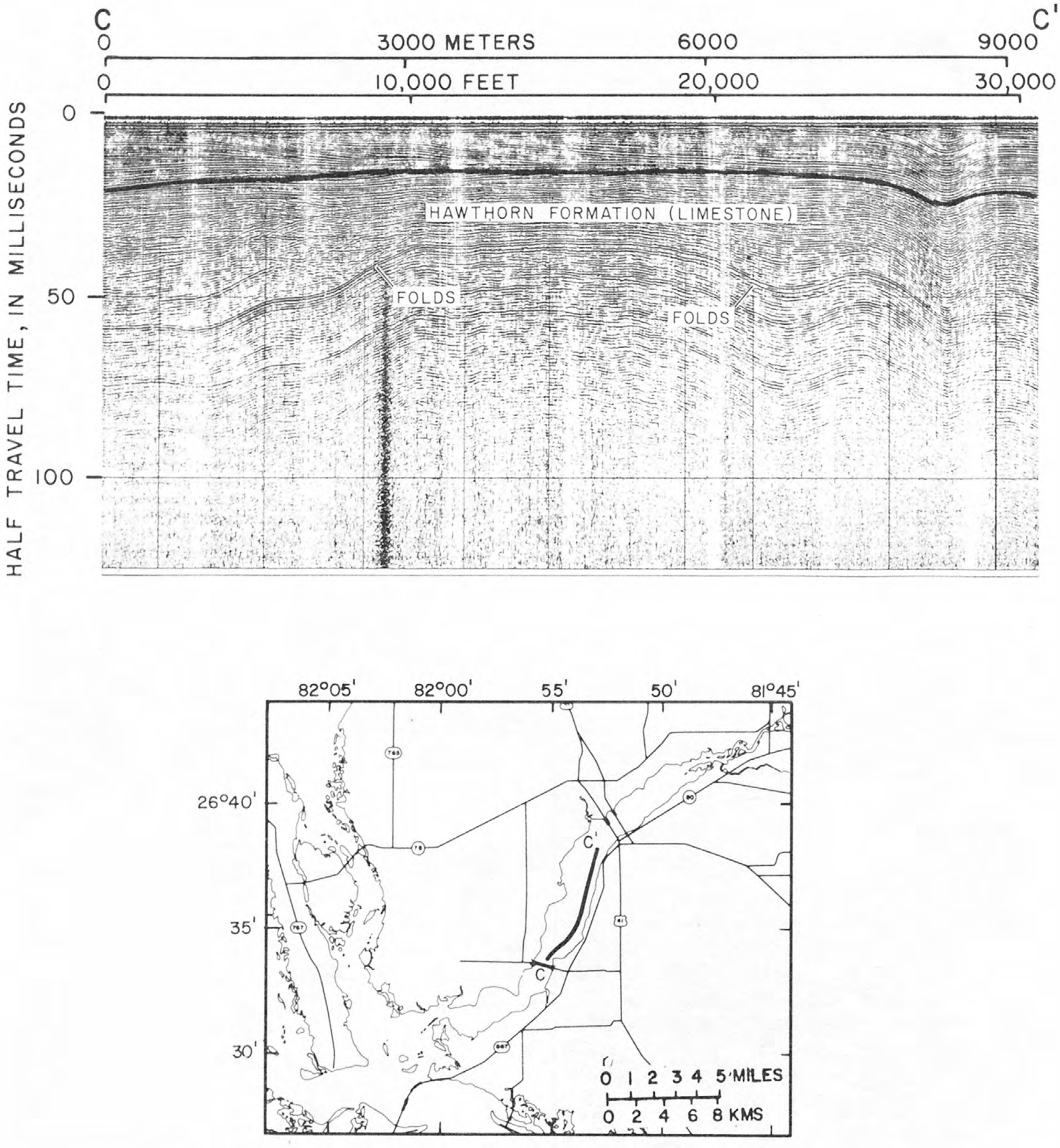

Figure 11.--Approximate 6-mile (9.7-kilometer) section of the sparker seismic record showing folds in the Hawthorn Formation.

A dark green carbonate clay unit, containing some fine quartz sand and shell conformably overlies the "rubble zone." This unit is also part of the Tamiami Formation. The seismic record suggests large scale, angular bedding dipping eastward (fig. 12) which may be of deltaic origin. The seismic reflection record along with test drilling and electric logs suggests the possibility of lateral and vertical grading of grain size in the angular beds. The unit is folded in some areas, but not extensively as the underlying Hawthorn sediments. Portions of the boomer record show some areas of small apparent folds occurring completely through the Tamiami (fig. 13). This unit has very low permeability and is the major confining unit above the upper Hawthorn aquifer and the sandstone aquifer.

The areal distribution and composition of the various sediment facies within the Tamiami Formation were probably controlled by structural movements during deposition (Missimer, 1974).

Undifferentiated Pliocene, Pleistocene and Holocene sediments lie unconformably on the green clay unit. Units included in this sequence are the Caloosahatchee Marl, the Fort Thompson Formation, Pleistocene marine terrace sands, and Caloosahatchee River alluvium. Numerous lithologies occur within this sequence, but it consists chiefly of soft, white to yellow marl, shell, and quartz sand. Individual formations were not differentiated because they are extremely thin and discontinuous. In many places, they are not separated by a traceable reflecting horizon.

The seismic record revealed several localities where undifferentiated Holocene, Pleistocene and Pliocene strata are apparently folded, one of which is shown in figure 13. The apices of the apparent folds extend well up into the unit.

During earlier times when sea level was lower than at present, tributaries to the Caloosahatchee River cut below the bed of the river into the Tamiami Formation. Remnant paleochannels of these streams are now filled with alluvium (fig. 14).

Hydrologic Implications

The seismic reflection profiles significantly increase the knowledge of the geology of the area, which is an aid in interpreting the ground-water hydrology. The top of the Hawthorn Formation is an erosional surface (unconformity), that apparently was subjected to folding. The upper part of this formation contains the upper Hawthorn aquifer and the seismic profiles show why the depth to this aquifer varies so markedly in wells throughout Lee County.

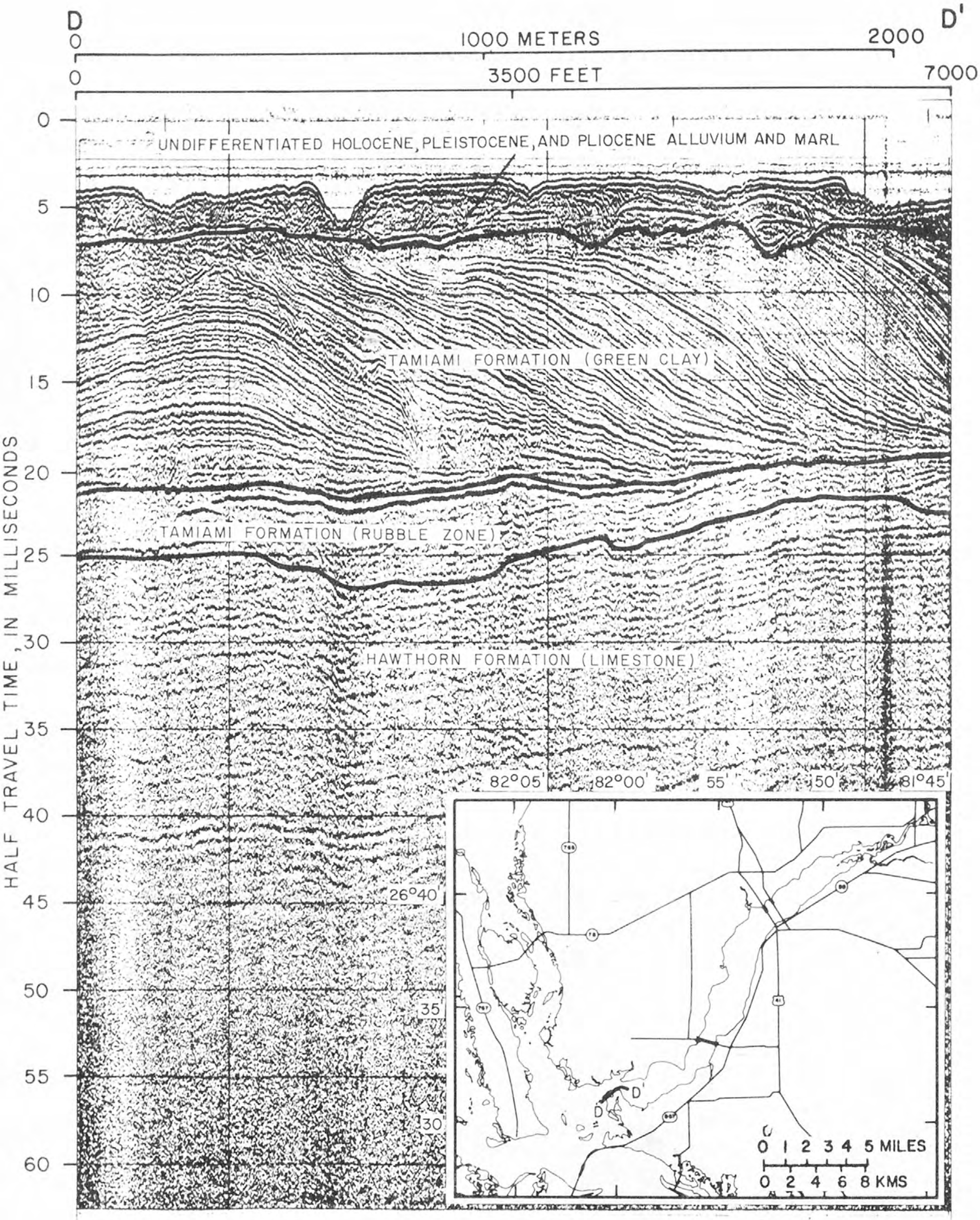

Figure 12.--Approximate 1.5-mile (2.4-kilometer) section of the boomer seismic record illustrating cross-bedding in the green clay unit of the Tamiami Formation.

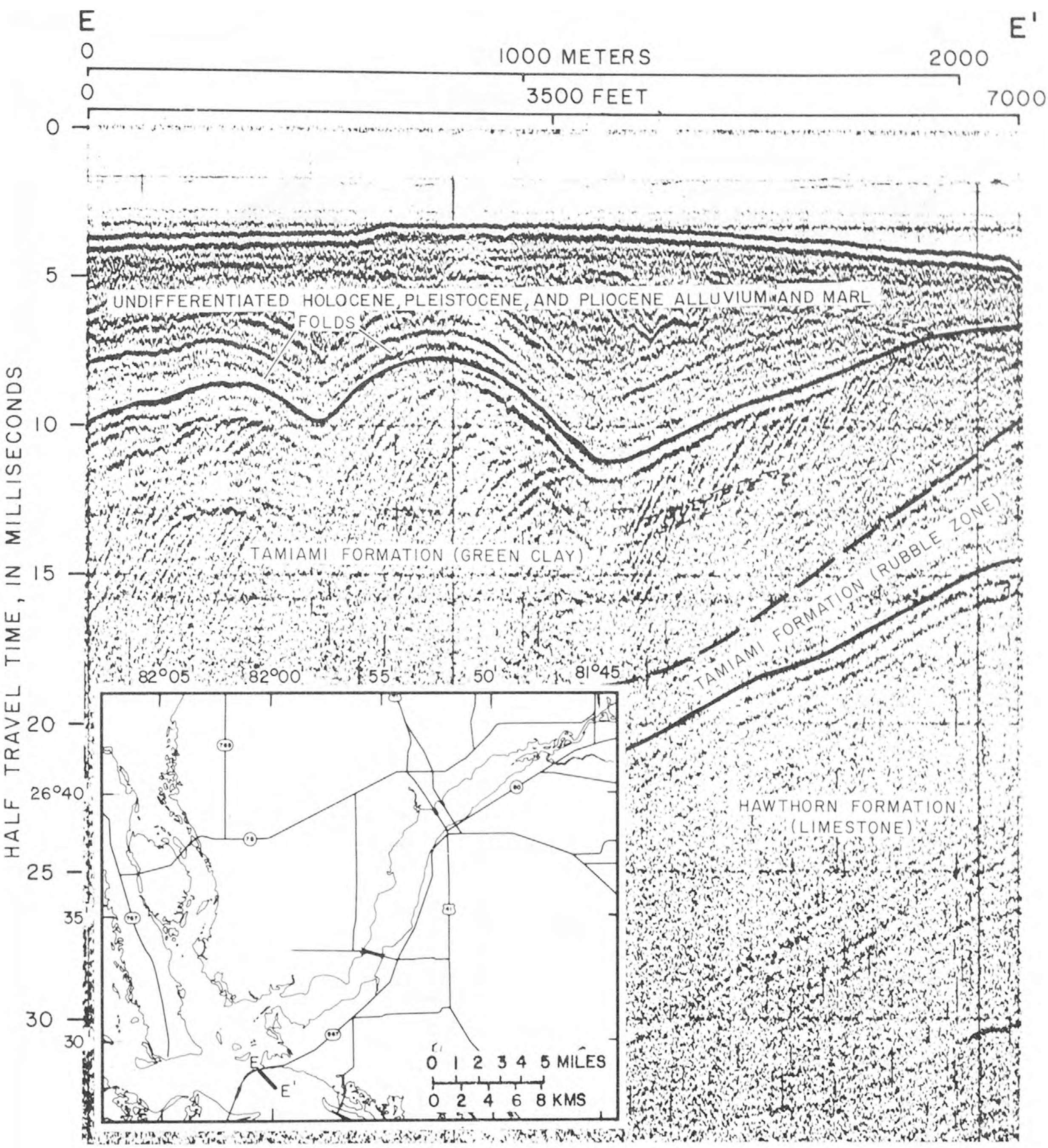

Figure 13.--Approximate 1.5-mile (2.4-kilometer) section of the boomer seismic record showing folds in the Tamiami Formation and the Holocene, Pleistocene, and the Pliocene strata.

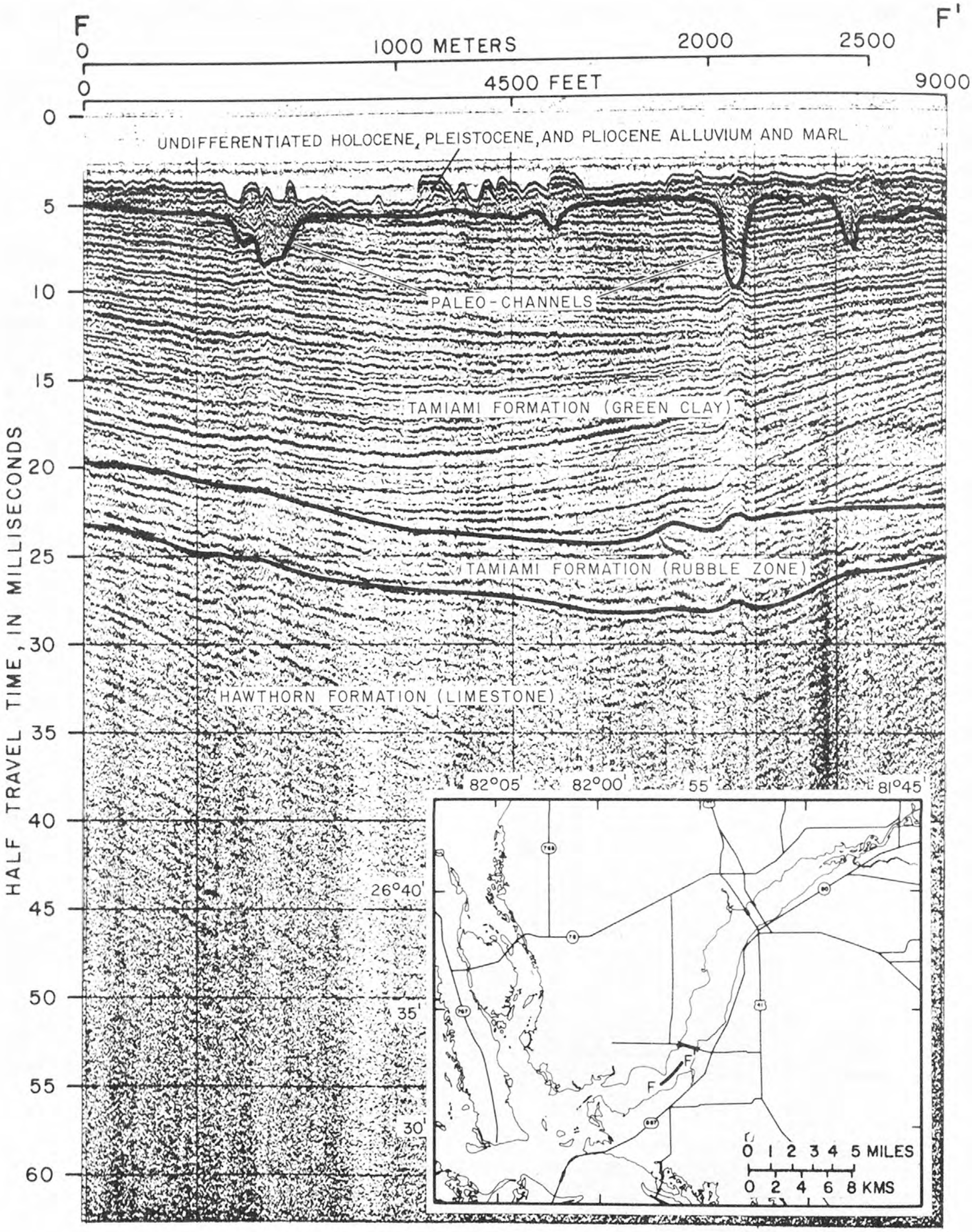

Figure 14.--Approximate 2-mile (3.2-kilometer) section of the boomer seismic record showing paleochannels.

The apparent folding and lack of faulting in the Hawthorn Formation also have hydrologic implications. Since bedding planes would have been folded in the limestone, a preferred direction of flow should be parallel to the axis of the apparent folds. The apparent lack of faults, which can act as permeable vertical conduits for the leakage of saline water from depth, indicates that such leakage occurs in a different manner. Leakage of saline water from below into this aquifer is caused principally by improper cased wells according to Sproul and others (1972, p. 24).

Geologic characteristics of the "rubble zone" of the Tamiami Formation vary significantly along the profiled area. The greater part of this unit consists of sandy phosphatic clay, which yields little or no water. Strong, discontinuous reflectors within this unit suggest beds of sandstone and limestone, which could possibly yield significant quantities of water. A 5-to 10-foot (1.5-to 3-meter) thick zone of unconsolidated quartz sand mixed with phosphorite gravel, known as the sandstone aquifer, commonly exists as a discontinuous unit within the "rubble zone." The sandstone aquifer is not specifically identified in any of the illustrations shown, because of its discontinuous nature.

The green clay unit of the Tamiami Formation is a zone of very low permeability that effectively confines the underlying artesian aquifers. Angular bedding within this unit, as shown on figure 12, suggests possible vertical grading with regard to grain size. Several drillers have reported that localized parts of this unit yield significant quantities of water. The presence of certain discontinuous seismic reflectors within the green clay unit suggests the presence of sand lenses that potentially could yield some water.

A discontinuous reflector in the seismic record for the base of the Holocene, Pleistocene, Pliocene sequence suggests a thin zone of hard limestone or sandstone. This zone may be correlative to water-yielding strata occurring in the Cape Coral area at a similar depth. Little is known about this thin zone other than it contains highly saline water.

Holocene and Pleistocene marine terrace quartz sands and Caloosahatchee River alluvium occur at the top of the stratigraphic sequence. These sediments constitute the water-table aquifer. In close proximity to the river, the water is saline due to tidal flow of water from the Gulf of Mexico. In some areas, paleochannels filled with alluvium are cut deeply below the river bed. Where these paleochannels extend inland and are filled with permeable sediments, the potential yield of water should be high.

PROBLEMS INVOLVING INTERPRETATION OF SEISMIC REFLECTION PROFILE DATA

High resolution continuous seismic reflection profiling can provide detailed stratigraphic and structural information. However, accurate determination of stratigraphic positions from the seismic record requires supporting geologic data. A test hole as near to the profiled area as possible will provide needed geologic data, as it can be used as a calibration point for the seismic record. Seismic velocities can be estimated for the various rock or sediment types penetrated by using depths determined from the test hole log. At least one other check point (test hole or well) is needed to determine the accuracy of the predicted depths.

Even with sufficient background data, problems are encountered in areas where the stratigraphy is complex. Good reflectors disappear with lateral changes in lithology. One of the most easily traceable subsurface features is an unconformity, especially where beds are truncated at distinguishable angles.

Where a dense stratigraphic unit occurs near the top of a sediment sequence, the seismic wave reflecting from it may cause multiple reflection lines to appear on the record. Such reflections may obscure deeper reflectors. If multiple reflections are interpreted as reflecting layers, the geologic interpretations will be in error.

SUMMARY AND CONCLUSIONS

Continuous high resolution seismic reflection profiling can be used under specific conditions to obtain an accurate continuous record of subsurface geologic features. By using different acoustic energy sources and varying the power input and frequency, differing degrees of useful penetration and resolution can be obtained.

The method basically involves continuous recording of the time required for an energy pulse (seismic wave train) to go from a surface source to some subsurface interface of contrasting acoustic impedance and be reflected back to the surface. At the various subsurface reflection interfaces part of the energy pulse is refracted downward until it is reflected upward at some deeper interface, or until scattering causes total dissipation of energy. The product is a graphic tracing of subsurface reflectors and other reflecting surfaces.

Certain factors tend to limit the use of the method. The method is useful in areas where the survey can be conducted over water. Even so, water bodies with accumulations of organic material along the bottom are not suited to the method. Small gas bubbles trapped in decaying organic material in bottom sediments may cause dispersion and absorption of the energy pulse before it can penetrate to a useful depth. Also, if the geometry of the water body being profiled is very narrow, side reflections may obscure the record. If the vessel used is noisy the record may be obscured by the boat noise.

The seismic record obtained during this investigation provides evidence of apparent extensive subsurface folding. No faulting was identified in sediments of middle Miocene to Holocene age. The record shows that the contact between the Hawthorn Formation and the Tamiami Formation is unconformable and with much relief, presumably because of erosion and apparent folding, thus explaining the variability in depth from land surface to the upper Hawthorn aquifer. Other significant interpretations from the record include: the sandstone aquifer appears to be discontinuous along the tract investigated; the green clay unit of the Tamiami Formation shows large-scale angular beds dipping generally from west to east; and several narrow alluvium-filled paleochannels exist in the Caloosahatchee River bed.

Seismic reflection profiling is beneficial in interpreting the geology and hydrology of Lee County. Background data were available which materially helped interpretation of the record.

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