Miocene Aquiclude Mapping Project:

Phase - I Findings Report

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Prepared in cooperation with
Georgia Southern University, Applied Coastal Research Laboratory
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Atlanta
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PROJECT REPORT 39

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Prepared in cooperation with
Georgia Southern University, Applied Coastal Research Laboratory
(GSU Offshore Seismic Studies Contract # 10-21-6-15-120-317)
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EXECUTIVE SUMMARY

This Phase-I Findings Report provides the Georgia Department of Natural Resources, Environmental Protection Division with the results of Phase I, Tasks #1 - #4 of the Miocene Aquiclude Mapping Project under Contract 10-21-6-15-120-317 with the Georgia Southern University Applied Coastal Research Laboratory.

The project concerns the geophysical mapping of Tertiary and Quaternary strata overlying the Upper Floridan aquifer (UFA) to determine potential sites of saltwater intrusion in the estuarine and nearshore region between Wassaw Sound, GA, and St. Helena Sound, SC. The study area includes the intracoastal and inner shelf areas and encompasses the northeastern portion of a regional cone of depression on the potentiometric surface of the UFA that is centered on Savannah, GA.

In accordance with Phase I objectives, published and unpublished seismic and geological data were reviewed, evaluated, and synthesized. Eight hundred miles of high-resolution seismic-reflection data, collected between 1970 and 1997, were compiled and interpreted using standard methods of analysis. Borehole lithology-log and gamma-log data were used to ground-truth the seismic-stratigraphic interpretations and to provide additional control in areas where seismic coverage was limited. The seismic data set forms the primary basis upon which the observations made in this Phase I report are based.

Coverages of past geophysical surveys were summarized, and representative cross-sections show stratigraphic relationships, depths to the top of the UFA, and the thickness of the Miocene aquiclude. Appropriate maps summarize the structure on the top of the UFA, highlight areas where the Miocene aquiclude is thin or absent, and indicate where saltwater intrusion sites are likely to occur. This database will be used to determine the sites and/or areas where new geophysical surveys should be carried out as part of Phase II.

Based on the thinness or absence of the Miocene aquiclude (the confining unit), the potentiometric value within the UFA, and the salinity of the overlying water column, five (5) potential sites of saltwater intrusion were designated and ranked (highest to lowest) as Areas of Concern (AOC):

1. *Hilton Head High* centered approximately 10 miles southeast of Hilton Head Island.
2. *Skull Creek/Calibogue Sound* immediately west of Hilton Head Island.
3. *Colleton/Chechessee Rivers*, tributaries to the Broad River.
4. *Broad River* near SC Highway 170 bridge.
5. *Beaufort River* from its mouth to the City of Beaufort.

It is strongly recommended that these AOCs and the region bounded by St. Helena Sound, Port Royal Sound, St. Helena Island, and Beaufort be investigated in detail during Phase II.

PART 1: STUDY DESCRIPTION

INTRODUCTION

The purpose of this draft "findings" report is to provide the Georgia Department of Natural Resources, Environmental Protection Division (EPD) with the information described in the SCOPE OF SERVICES, Phase I, Tasks #1 - #4, Contract 10-21-6-15-120-317 with the Georgia Southern University (GSU) Applied Coastal Research Laboratory (ACRL). Tasks #1 - #4 contain the following elements:

1. Review, evaluation and synthesis of published and unpublished geological and seismic data in both the public and private (files/archives) domains.

2. Generation of (1) an isopach map showing the thickness of aquiclude strata overlying the Floridan aquifer; (2) color-coded maps showing the tracklines of all previous surveys; and (3) stratigraphic cross-sections showing where the overlying strata appear to be breached, thin, or missing.

3. Identification of areas that are susceptible to salt-water intrusion.

The study includes the nearshore and estuarine areas between Wassaw Sound, Georgia, and St. Helena Sound, South Carolina (Fig. 1-1). It essentially encompasses the northeastern portion of a regional cone-of-depression on the potentiometric surface of the Upper Floridan aquifer (UFA). The cone of depression is centered on Savannah and is caused primarily by the long-term heavy pumpage of groundwater from the UFA in the Savannah area.

The principal objectives of the study are to determine where: (1) the strata overlying the UFA may be breached, thin, or missing; and (2) the overlying water column is saline. Such areas may be sites of salt water intrusion into the UFA leading to contamination of drinking water wells and degradation of water quality, in general.

Based on the information provided by Tasks #1 - #4, the final task of Phase I (Task #5) will be to develop a plan of new geophysical surveys adequate to confirm the existence or non-existence of the most probable sites of salt-water intrusion. The final phase of the study, Phase II, will be to collect and analyze new field data and prepare a final report that will include appropriate isopach and structural contour maps and stratigraphic cross-sections.

GEOLOGIC FRAMEWORK

The stratigraphic-hydrogeologic units involved in this study are shown in Table 1-1 and briefly described below.

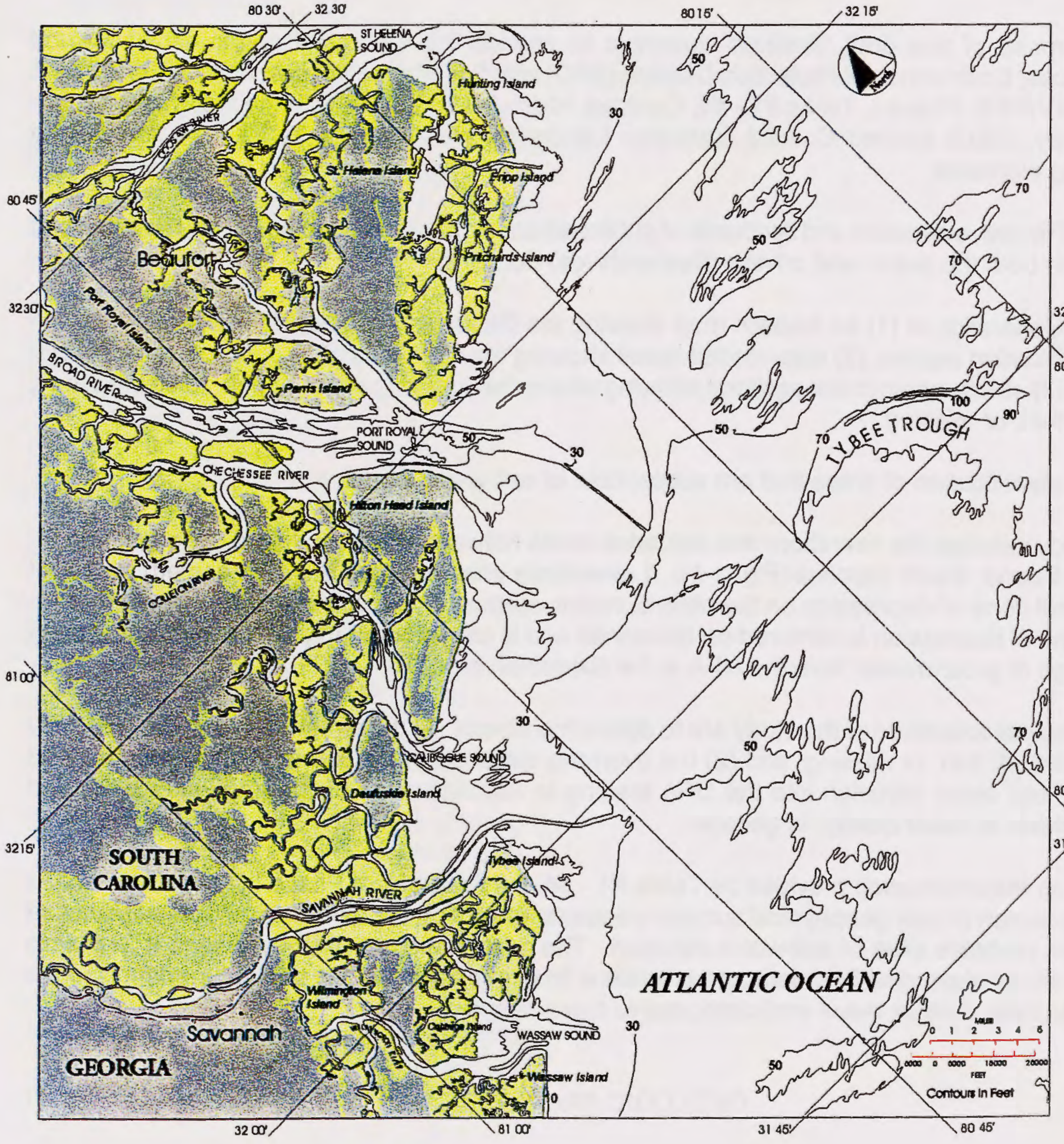

Figure 1-1 Map showing location of the study area on the Georgia-South Carolina inner shelf and coastal zone.

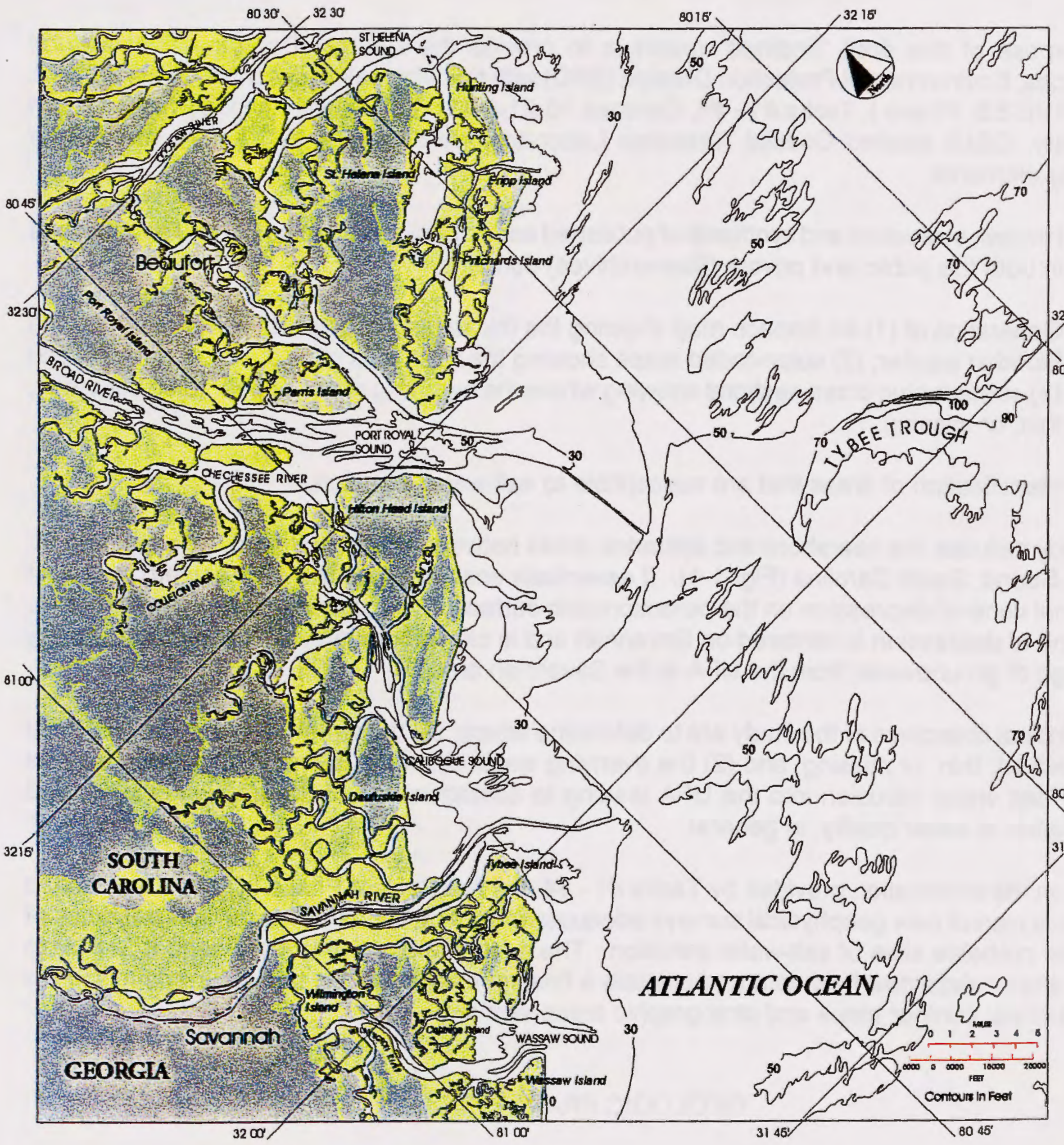

Figure 1-1 Map showing location of the study area on the Georgia-South Carolina inner shelf and coastal zone.

Table 1-1 Stratigraphic-hydrogeologic units of the study area on the Georgia-South Carolina inner shelf and coastal zone
Pliocene - Holocene Recent sediments Plio-Pleistocene aquifer (surficial aquifer)
Miocene Aquiclude upper Miocene = Coosawhatchee Formation (Miocene-A) middle Miocene = Marks Head Formation (Miocene-B) lower Miocene = Tampa Limestone or Tampa Limestone equivalent
Upper Floridan Aquifer Oligocene unit (uppermost unit) = Suwanee Limestone Ocala Limestone (Late (Jackson) Eocene)

Throughout the study area, the entire stratigraphic package above the UFA is generally less than 200 feet in thickness. The following descriptions of the principal stratigraphic-hydrogeologic units are adapted from the U.S. Army Corps of Engineers (1998):

<u>Pliocene-Holocene Unit</u>. Holocene deposits are characterized by sand, clay and lesser amounts of gravel; Pleistocene deposits by arkosic sand and gravel containing discontinuous clay beds; and Pliocene deposits by phosphatic, micaceous and clayey sand. The Pliocene-Holocene units are also characterized by numerous in-filled channels, some of which extend into and through the Miocene aquiclude. In areas where the Miocene deposits are absent or thin, these channels may provide permeable pathways for salt-water intrusion into the UFA. It is important to note that in the Calibogue Sound-Port Royal Sound-Beaufort area, the UFA is locally exposed on the sea bed to saline and/or brackish water in areas where modern tidal currents have removed overlying (post-Oligocene) strata.

<u>Miocene Aquiclude (Confining Unit)</u>. Composed of mainly clastic deposits containing low-permeability clays, silts, clayey silts and sandy or silty clays that act as confining units in the study region. The Miocene deposits range in thickness from over 100 ft in the Savannah area to being locally absent, or nearly so, off Hilton Head Island and in the Beaufort area.

<u>Upper Floridan Aquifer (UFA)</u>. Composed of highly permeable limestones of Oligocene and Late Eocene age that supply most of the public drinking water in the study region. The top of the UFA ranges from -260 ft MSL just to the south of Savannah to -80 ft MSL in the Hilton Head Island area to -20 ft MSL in the Beaufort area.

PART 2: DATA ACQUISITION AND PROCESSING

ARCHIVE SEISMIC DATA

Data Sources

Eight hundred miles of pre-existing high-resolution seismic-reflection (boomer and airgun) data were compiled for Phase 1 of this two-phase project. Figure 2-1 shows the trackline locations and Table 2-1 summarizes information on line coverage and quality. These data were collected between 1970 and 1997 and form the primary basis upon which the observations and recommendations made in this Phase 1 report are based.

The majority of the data, approximately 700 miles, were obtained from archives at the Georgia Southern University Applied Coastal Research Laboratory (GSU-ACRL). These data were collected during several studies in 1972-1976, 1979-1980, 1985, and 1989 in coastal South Carolina (Jasper and Beaufort Counties), coastal Georgia (Chatham County), and on the Atlantic inner shelf in areas west and south of the Tybee Trough (Fig. 2-1). About fifty-five miles of data from coastal South Carolina were provided by the South Carolina Department of Health and Environmental Control (DHEC) from a 1970 survey conducted in the Port Royal Sound area of Beaufort County (South Carolina Water Resources Commission, 1972). Approximately forty miles of data from coastal Georgia were provided by the U.S. Army Corps of Engineers from a 1997 survey conducted in the Savannah River and Navigation Channel (U.S. Army Corps of Engineers, 1998; Ocean Surveys Inc., 1998).

Within the study area, the intracoastal areas of Georgia and South Carolina are covered by approximately 360 miles of data, while the inner shelf is covered by the remaining 440 miles of data. Eighty percent (630 miles) of the data was of sufficient quality to permit interpretation for the purposes of this project (Fig. 2-1). Interpretable data were generally confined to depths within 200 ft of Mean Sea Level (MSL). Of the 20% low-quality data, over half was collected with a deep-penetration, low-resolution airgun system (Fig. 2-1, Table 2-1; lines GS5-1, GS6-1, GS6-2, and GS6-20).

Data Reduction and Presentation

Reflectors 1 through *5* on the seismic records (see Seismic Stratigraphy) were sampled for elevations at horizontal intervals of 750 - 1000 ft and at all points of significant elevation change. In areas where the stratigraphy had a simple "layer-cake" character, the records were sampled approximately every 1500 - 3000 ft. For each sample location, the survey time mark was noted and the two-way-travel times to the seabed and to *Reflectors 1* through *5* were measured. The geographic location (distance along the profile line) of each sample "site" was then calculated using trackline plots that showed timed position fixes. All data were then tabulated into a Corel QuattroPro spreadsheet, where a routine was run to convert acoustic travel times (milliseconds) into depths (feet). Distance versus depth cross-sections were then generated (see Study Findings). Data points from these cross sections were transferred to 1:100,000-scale mylar smooth-sheets to show elevations of the top of the Oligocene/Eocene aquifer and thicknesses of the Miocene aquiclude along each trackline. These data points were then hand contoured, photo-reduced, and scanned into CorelDraw to produce full-size 1:100,000-scale maps (~30" x 32") and reduced, page-size (~8.5 x 11"), versions at a scale of approximately 1:400,000.

Data in this report are graphically presented in Part 3 in two formats. Geologic cross-sections generated in QuattroPro show structural and stratigraphic information for *Reflectors 1* through *5* in coast-parallel and coast-normal orientations. Maps generated in CorelDraw show existing seismic trackline coverages across the coastal zone and inner shelf (Fig. 2-1), the thickness of the Miocene aquiclude, and the topography of the top-aquifer unconformity.

Data Accuracy

The positional accuracy of the data presented in maps and cross-sections in this report has limitations imposed by the marine positioning systems used when the data were collected, primarily during the 1970s and 1980s. Each reflector on the cross-sections and maps has inherent vertical (elevation) and horizontal (latitude/longitude) errors.

Vertical Accuracy

Several sources of potential vertical (Z) error arise when the graphic printouts showing survey time (abscissa) versus acoustic travel time (ordinate) are converted to geologic cross sections showing location (latitude-longitude) versus depth (feet). The principal potential sources of error in calculating the depth of a specific reflector are, in order of importance:

1. Acoustic Velocity Variation: The vertical travel time to a given reflector on the graphic printouts (a known quantity) is converted to depth to that reflector using an acoustic velocity (generally an estimated quantity). For this study, an average acoustic velocity of 4922 ft/sec was inferred for the water column. An average velocity of 5578 ft/sec was inferred for the sediment column down to the top of the aquifer (*Reflector 4*). An average velocity of 6955 ft/sec was inferred for Oligocene strata in those areas where they were preserved between *Reflectors 4 and 5*. These values were based on best-fit comparisons between borehole data (or published structure maps) and seismic records, as well as on previous seismic-reflection work conducted on the South Atlantic Bight (Duncan, 1972; Henry and Idris, 1992; Ocean Surveys, Inc., 1998; U.S. Army Corps of Engineers, 1998). Acoustic velocities in the water column are known to generally range from 4922 to 4987 ft/sec (Pickard and Emery, 1982) and tend to increase with temperature (13 ft/sec/degree C), salinity (5 ft/sec/salinity unit) and depth (0.02 ft/sec/foot). Acoustic velocities in the sediment column can also show similar variation depending on the lithology present and on the degree of induration of the sediments (e.g., hard limestone layers in the Miocene would have higher velocities than adjacent sands). A 150 ft/sec variation from the mean acoustic velocity used in time-to-depth conversions can yield a vertical error of +/- 5 feet.

2. Tidal Effects: The relative elevation of the survey vessel during surveying is controlled by the tidal stage. Between successive surveys, this dependence can result in vertical offsets of a given reflector of as much as +/-4 .5 feet relative to mean sea level, depending on the tidal stage during surveying. This effect can be greatest during spring tides but generally decreases in a seaward direction and during neap tides.

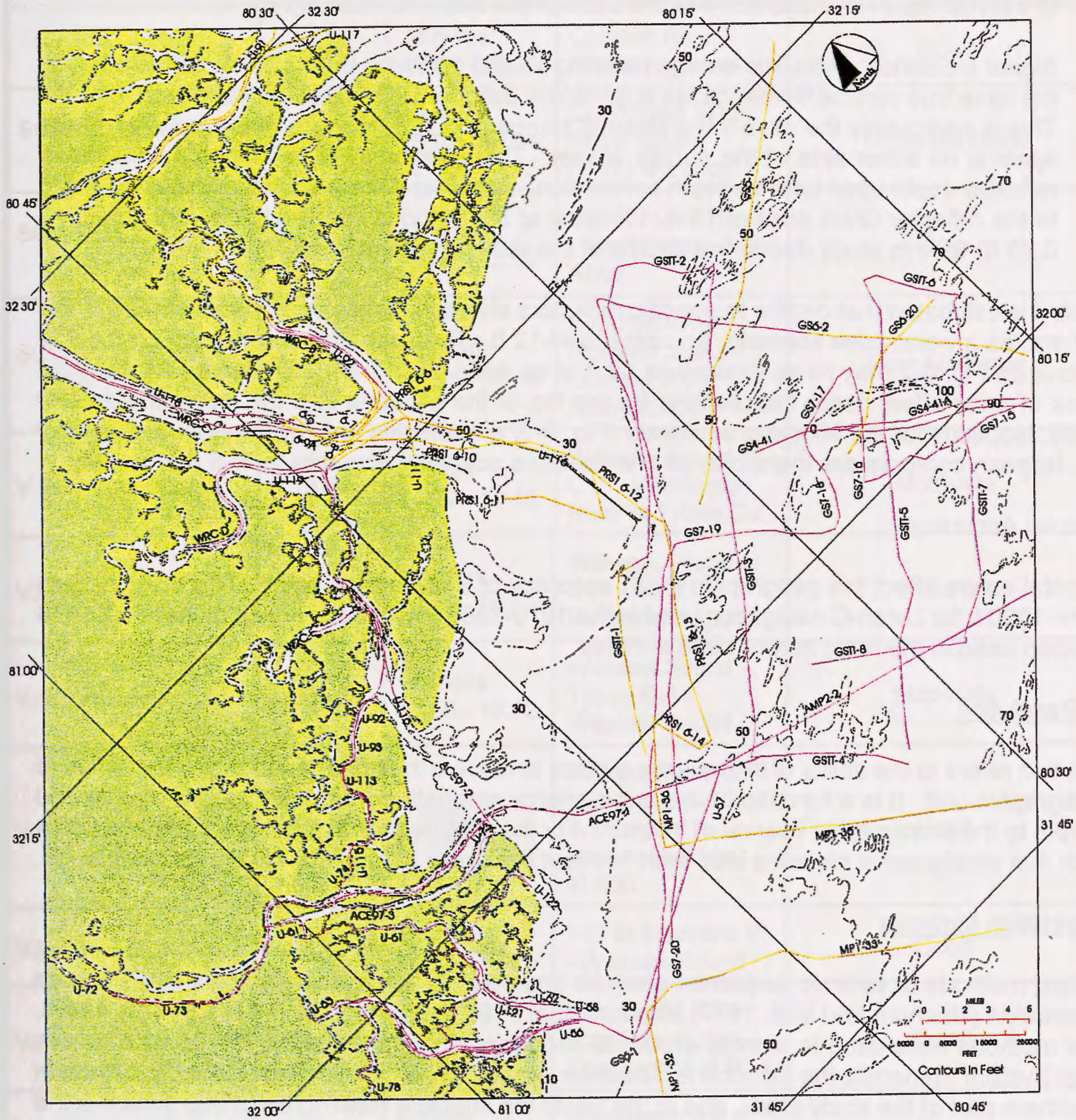

Figure 2-1 Locations of existing seismic-reflection tracklines used in this report.

3. Record Interpretation: Reflectors typically consist of a black-white reflector pair. Most of the archive records used in this report were printed using positive polarity which means that an unconformity on the seismic records is generally marked by the black reflector of the pair. However, due to uncertainty regarding the print polarity for all the records, there may be a vertical error of as much as +/- 2.5 feet when calculating the depth to an unconformity of interest (such as *Reflector 4* at the base of the Miocene section).

4. Signal Incidence: Acoustic energy traveling to and returning from shallow reflectors may not have true vertical incidence, as is generally assumed in the seismic-reflection method. This is particularly the case if the seismic source and streamer are deployed with a wide spacing on either side of the survey vessel. This effect results in an overestimation of reflector depth upon time-to-depth conversion. The error decreases with increasing depth to the reflector (20% error at 10 ft, 1% error at 50 ft) and is inferred to be very small (+/- 0.25 ft) for this study due to the depths of the reflectors of interest.

Overall, it is estimated that depths to specific reflectors shown on cross sections and maps in this report are, as a worst-case scenario, accurate to +/-12 ft. Thus, for example, a point on the 100 ft contour on Fig. 3-2 may lie as shallow as 88 ft or as deep as 112 ft MSL. Because these four sources of error affect depth calculations for the top of the Miocene and the top of the aquifer similarly, isopachs for the Miocene aquiclude (Fig. 3-5) are affected only by the acoustic-velocity error. Isopach contours are therefore, as a worst-case scenario, accurate to +/-5 ft or better.

Horizontal Accuracy

Horizontal errors affect the geographic (X-Y) accuracy of a given data point. This error ranges from +/- 1300 ft for Loran-C navigation used in the 1970-1985 surveys to +/- 30 ft or less for DGPS navigation used in the most recent 1998 surveys.

Data Resolution

Resolution refers to the ability of the seismic system to resolve the upper and lower boundaries to a stratigraphic unit. It is a function of the pulse energy emanating from the acoustic source and the depth to the stratigraphic interval of interest. For the archive data in this report, the resolution is such that stratigraphic horizons less than five feet thick may not be individually resolvable.

Interpretation Methods

Standard methods of seismic sequence analysis and seismic facies analysis were used in data interpretation (Mitchum and Vail, 1977; Mitchum et al., 1977a,b; Vail et al., 1977a,b; Vail, 1987). These methods were used to identify erosional sequence boundaries at the top of the Floridan Aquifer System (generally the Oligocene Suwanee Limestone, or the Eocene Ocala Limestone in the northern part of the study area), and at the top of the Miocene Hawthorne Group (which is the confining unit above the Floridan aquifer). These top-aquifer and top-aquiclude unconformities were picked on the seismic records in areas with good well control (see Published Borehole Data, Maps, and Sections). The generally prominent reflectors associated with these unconformities were cross-tied between intersecting seismic lines and "carried" throughout the study area using patterns of truncation and onlap to facilitate identification. This method allowed stratigraphy to be established in areas away from direct well control.

Table 2-1 Summary information for archive seismic trackline data

Line number / id	Date of survey	Length and time of	Surveyed area	Quality
SCWRC Colleton River (WRC-D)	7.22.70	13 miles 10:28 - 12:25	Colleton River - PRS entrance.	Good
SCWRC Broad River (WRC-C)	7.21.70	16 miles 16:02 - 16:44 12:35 - 14:45	Cole Creek - Port Royal Sound (PRS) entrance.	Moderate-Good
SCWRC Skull Creek (WRC-E)	7.22.70	12 miles 13:30 - 15:52	Chechessee River - Skull Creek - May River.	Good
SCWRC Beaufort River (WRC-B)	7.23.70	14 miles 07:34 - 09:43	Beaufort River (Ballast Creek) - Coosaw River (Buoy #203).	Poor-Moderate
VJH Line U-56	6.13.72	5 miles 14:39 - 16:16	Wassaw Sound at C11 - Wilmington River at Tybee Cut	Moderate
VJH Line U-57	2.12.74	17 miles 14:15 - 16:50	Wassaw Sound at C11 - R2W - Savannah Light	Moderate
VJH Line U-58	4.23.73	10 miles 11:56 - 13:32	Wassaw Sound - Tybee Cut - Wassaw Sound	Moderate
VJH Line U-61	4.26.73	7 miles 07:55 - 09:29	I-80 at Screvens Pt - St Augustine Ck - Wilmington R - Savannah River at R50	Good
VJH Line U-62	4.23.72	10 miles 14:33 - 16:29	I-80 at Screvens Pt - Wassaw Sound	Good
VJH Line U-63	4.28.72	7 miles 10:37 - 12:10	Wilmington River from Priest Ldg - Thunderbolt at R34	Good
VJH Line U-63A	4.28.72	5 miles 12:15 - 13:52	Wilmington Riv @ R34 -> SkIO Dock	Good
VJH Line U-72-73	4.25.73	23 miles 12:26 - 16:11	Savannah River at Onslow Island - Savannah River at G17/R18	Moderate

VJH Line U-74	6.12.72	5 miles time? - time?	St Aug Ck at R10 - Elba Is Cut - Fields Cut - Wright R at R44B	Poor-Moderate
VJH Line U-78	?	10 miles 17:08 - 18:43	Wilm River at R40 - Skidaway River - Burnside River - Vernon River - Possum Pt at G79	Poor-Moderate
VJH Line U-91	3.3.74	29 miles 15:50 - 19:17	S Edisto R at G159 - Coosaw River - Beaufort River - Beaufort at G241A	Poor
VJH U-92-93	3.14.74	33 miles 06:54 - 10:42	Beaufort River at G41 -Fields Cut - Savannah River at R48	Poor-Moderate
VJH U-113	?	6 miles 08:47 - 09:37	Calibogue Sound at R32 - New River at G41 -	Good
VJH U-115	?	6 miles 09:47 - 10:34	New Riv at R42 - Wilmington River at R12	Moderate
VJH U-116	3.25.75	11 miles 07:40 - 09:26	Skull Ck at R6 - Port Royal Sound - G19	Poor-Moderate
VJH U-117	3.26.75	38 miles 11:00 - 16:35	Hilton Hd - Port Royal Sound- Beaufort - Coosaw River - St Helana Sound at R12	Poor-Moderate
VJH U-118	3.27.75	18 miles 09:52 - 13:06	Broad River Bridge - Port Royal Sound	Poor
VJH U-119	3.27.75	23 miles 14:50 - 17:47	Callawassie Ck - Colleton River - Skull Creek - Calibogue Sd R32	Moderate-Good
VJH U-121	7.11.76	11 miles 14:10 - 15:25	Halfmoon River - Wassaw Sound at R14 - Priest Ldg - Sister Island	Good

VJH U-122	7.11.76	17 miles 09:26 - 12:04	Skidaway River at G27 - Wilmington River - Tybee Cut - Lazaretto Creek - Tybee Inlet	Good
VJH U-122A	7.11.76	2 miles 12:56 - 13:16	Bull River - Shad River	Good
VJH U-128	?	2 miles	Skidaway River test at R46	Moderate
VJH U-259 GS-TT Lines 1-8 (Loran converted)	9.3/4.80	106 miles 14:57 - 23:40 07:37 - 14:35	Gaskin Banks - Port Royal Sound - Savannah Light	Good
VJH U-241 GS-7 Lines 14-20	5.8/9.80	53 miles 15:19 - 03:15 (14) (20)	Tybee Trough area - Port Royal Sound Light - offshore Tybee Island	Moderate-Good
VJH U-221 GS-4 Lines 41, 41-rerun	5.9.79	26 miles 06:10 - 08:19 08:24 - 12:10	Tybee Trough area (SE - NW)	Moderate-Good
MP-1 Lines 32 - 36	7.16/17. 1985	63 miles 21:06 - 06:40	Near Savannah Light to offshore Wassaw Island	Poor
PRS-1 Lines 6 - 14	7.16.85	23 miles 11:40 - 21:06	Station Ck - Daws Island - Port Royal Sound - Savannah Light	Poor
GS-6 Lines 1, 2, 20	10.22/23 & 10.25/26 .1979	77 miles 13:56 - 00:45 12:15 - 14:00	Tybee Trough area	Poor
GS-5 Line 1	6.18/22. 1979	34 miles 13:00 - 18:13	Tybee Trough area (SW-NE)	Poor
USACE 1997 Lines 1, 2, 3	10.3/6. 1998	39 miles	Onslow Island - Savannah River - Savannah Light	Good
AMP2-2	8.16.89	25 miles 13:11 - 17:33	Savannah Light - TACTS-A platform	Moderate

Seismic Stratigraphy

From top to base of section, the following five sub-bottom reflectors were identified and correlated with erosional surfaces at or near the tops of the specific stratigraphic intervals listed below:

- *Reflector 1* marks a high-relief (lowstand) erosional surface at the base of the Quaternary section. It is associated with an unconformity that was cut during the most recent lowstand of sea level when fluvial systems such as the Savannah and Broad Rivers incised the continental shelf. Depths to *Reflector 1* are important in areas where it has either removed, or cut down through, subjacent Pliocene deposits. In these situations, *Reflector 1* defines the top of the Miocene aquiclude and may locally define the top of the Floridan aquifer where intervening Miocene sediments have been removed.

- *Reflector 2* marks a moderate- to high-relief (lowstand) erosional surface at the base of the Pliocene section. It is associated with an unconformity that was cut during a late Miocene/early Pliocene lowstand of sea level. *Reflector 2* generally overlies Miocene Unit-A (Upper Miocene Coosawhatchie Formation), but overlies Miocene Unit-B (Middle Miocene Marks Head Formation) where the former has been removed. Locally, *Reflector 2* may define the top of the Oligocene / Eocene aquifer where intervening Miocene sediments have been totally removed.

- *Reflector 3* marks a low-relief erosional surface near the base of Miocene Unit-A and marks the approximate top of the Miocene Unit-B (Middle Miocene Marks Head Formation). *Reflector 3* was picked as the lower reflector of a prominent "rail-track" reflector pair. This reflector pair was a very distinctive key marker horizon. It marks the top of the Upper Floridan aquifer in areas where Miocene Unit-B is absent.

- *Reflector 4* marks a low-relief erosional surface near the base of Miocene Unit-B. It thus marks the approximate top of the Floridan aquifer (the Oligocene Suwanee Limestone, or the Eocene Ocala Limestone where the latter is absent). Topographic highs on *Reflector 4* occur where there is upwarping of the subjacent aquifer limestone. A jagged character to the reflector on these highs suggests karst development.

- *Reflector 5* marks a low-relief erosional surface between the Oligocene Suwanee (or Lazaretto Creek) Limestone and the subjacent Eocene Ocala Limestone. In areas where the Oligocene is absent, *Reflector 5* is truncated by *Reflector 4*.

The stratigraphic positions of *Reflectors 3* and *4* approximate the positions of geophysical gamma-log marker horizons A and C, respectively, as used by Clarke et al. (1990). The gamma-A and gamma-C marker horizons are typically associated with indurated, high-phosphate, carbonate beds that generally lie just above the Miocene-A / Miocene-B and the Miocene-B / top-aquifer unconformities, respectively (Furlow, 1969; Clarke et al., 1990). Colquhoun (1972) noted the presence of a cherty, occasionally phosphatic, resistant horizon (as much as 2 ft thick) at the base of the Miocene section immediately above the aquifer. Hughes et al. (1989) suggested that this "cap rock" is part of the Eocene Ocala limestone, while Duncan (1972) suggested that his top-aquifer reflector was likely associated with this horizon. Consequently, *Reflectors 3* and *4* may, in places, be occurring at the thin carbonate horizon rather than at the subjacent unconformity; hence use of the terms "near" and "approximate" in the above reflector descriptions. *Reflectors 2* through *5* of this study are synonymous with Reflectors 1 through 4, respectively, as used by the U.S. Army

Corps of Engineers (1998).

PUBLISHED BOREHOLE DATA, MAPS, AND SECTIONS

Previously published borehole lithology-log and gamma-log data from coastal Chatham and Beaufort Counties and from offshore were used to ground-truth the seismic stratigraphic interpretations and reflector picks in this study. These borehole data were obtained from Counts and Donsky (1963), Furlow (1969), Colquhoun (1972), Burt and Belval (1987), Hughes et al. (1989), Clarke et al. (1990), Manheim (1992), and Huddlestun (1993). Previously published maps and cross-sections were also used as a check on the seismic data and were obtained from Duncan (1972), Woolsey (1977), Hayes (1979); Kellam (1981), Henry and Rueth (1986), Kellam and Henry (1987), Clarke et al. (1990), and Henry and Idris (1992).

In addition to ground-truthing the seismic data, the borehole and published map data were also used in map generation (Figs. 3-2, 3-5). Along the western parts of the study area, structure and isopach contours derived from limited seismic coverage on the shoreface and from within tidal creeks were merged to fit with on-land contours derived from borehole data. Top-of-aquifer maps presented by Hayes (1979) and Hughes et al. (1989) were used in generation of this study's Fig. 3-2. The thickness of the Hawthorn Formation published in Hughes et al. (1989; their Fig. 8) was used to help define the geometry of isopach contours for the Miocene aquiclude in the intracoastal area (Fig. 3-5).

PART 3: STUDY FINDINGS

SEISMIC-STRATIGRAPHIC RELATIONSHIPS

Structure at the top of the Floridan Aquifer

The uppermost part of the Floridan aquifer in the study area is defined by either the Oligocene Suwanee Limestone or the Eocene Ocala Limestone. In intracoastal areas to the north of Calibogue Sound and landward of Port Royal Sound, the Oligocene pinches out onto the subjacent Eocene so that the overlying Miocene aquiclude generally rests directly on Eocene limestone. The contact between the aquiclude and the aquifer is marked by *Reflector 4*.

Elevations on the top of the Floridan aquifer range from as shallow as -19 ft MSL in the vicinity of Ladies Island north of Beaufort, S.C. (Johnson and Geyer, 1965; Duncan, 1972; Hayes, 1979; Hughes et al., 1989), to as deep as -260 ft MSL in areas just to the south of Savannah, GA (Fig. 3-2). The former area is part of the Burton High identified by Siple (1969). The highest elevations on the aquifer generally occur in intracoastal South Carolina along a broad southwestward-plunging high that extends from beneath Ladies Island, SC, passing beneath Daufuskie Island, SC, to Wassaw Sound, GA (Fig. 3-2). Throughout intracoastal Georgia, the aquifer everywhere lies at depths of at least -100 ft MSL. Offshore, the top of the aquifer generally dips southeastward. However, an isolated topographic high, herein referred to as the Hilton Head High, is centered about 10 miles southeast of central Hilton Head Island and 17 miles east of the Savannah River mouth (Fig. 3-2). Shallowest elevations on this offshore high range from -75 to -80 ft MSL (Fig. 3-2, 3-3). Existing data coverage is insufficient to determine whether this high is attached to the onshore high beneath Hilton Head and Daufuskie Islands.

Gradients on the top-aquifer surface in the intracoastal area are generally low, on the order of 1:400 or less. However, steeper gradients as high as 1:350 occur in southern Jasper County. Offshore gradients are also generally low, on the order of 1:900. The steepest gradients on the aquifer surface, at 1:175 or more, occur about 12 miles SE of northern Hilton Head Island on the east flank of the Hilton Head High (Fig.3-2).

Thickness of the Miocene Aquiclude

Elevations on the top of the Miocene aquiclude generally range from approximately -10 ft MSL beneath Ladies Island, SC (Hughes et al., 1989), to -75 ft MSL beneath Wassaw Sound, GA (Furlow, 1969), to approximately -130 ft MSL offshore and in the Tybee Trough area (Fig. 3-4). The shallowest parts of the aquiclude generally overlie topographically high areas of the subjacent Floridan aquifer, notably along the high that trends southwestward from the Ladies Island - Parris Island, SC, area.

The thickness of the Miocene aquiclude is controlled primarily by: (1) topography on the top-aquifer surface (*Reflector 4*); and (2) incision by present-day channels and Plio-Pleistocene paleochannels (*Reflector 1* and *Reflector 2*). Aquifer highs are generally overlain by a thin Miocene section, while the flanks of highs, and topographic lows, are overlain by a thicker Miocene section (Fig. 3-4).

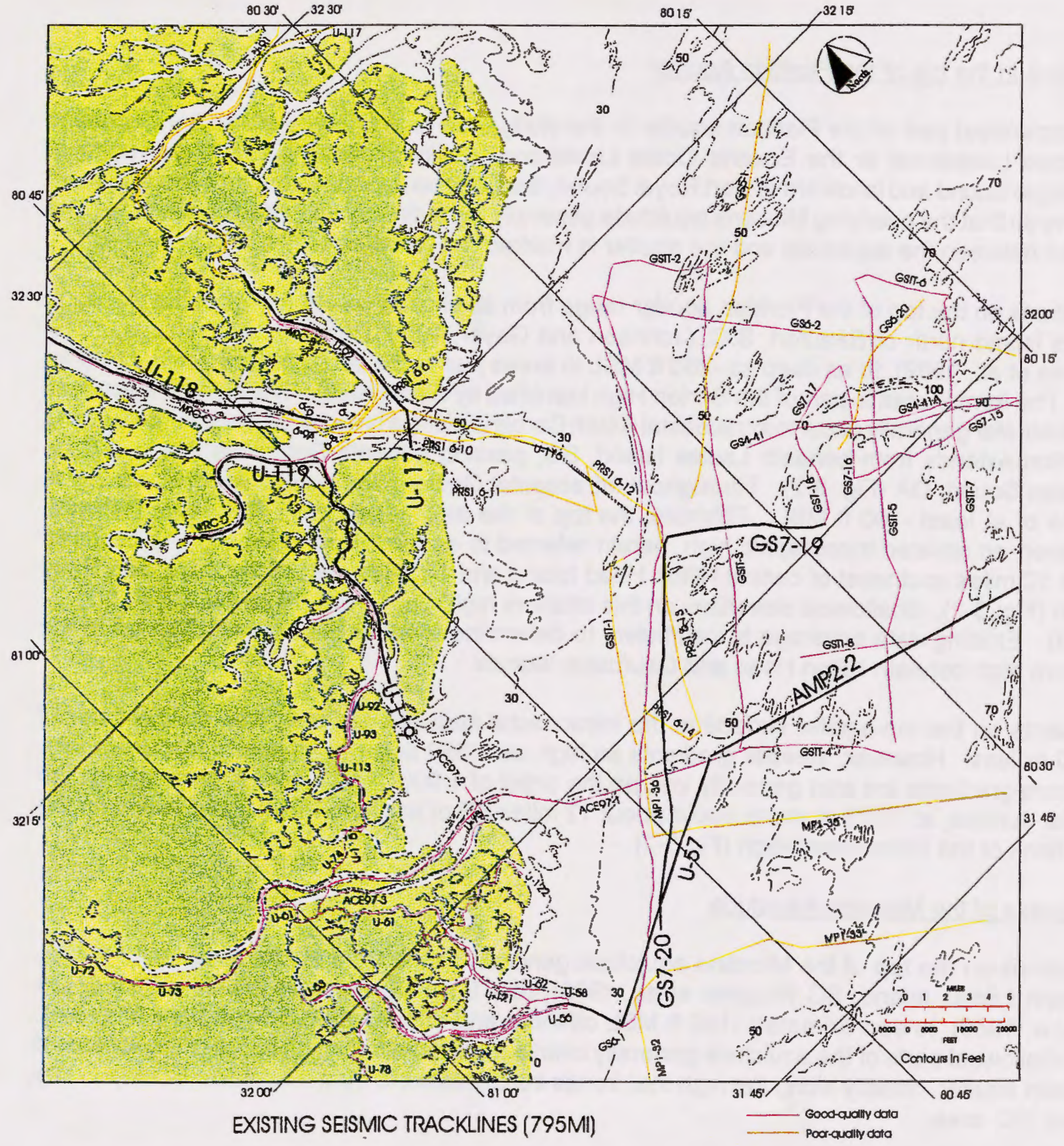

Figure 3-1 Locations of digitized seismic-reflection tracklines shown in Figures 3-3, 3-4, and 3-6 through 3-11.

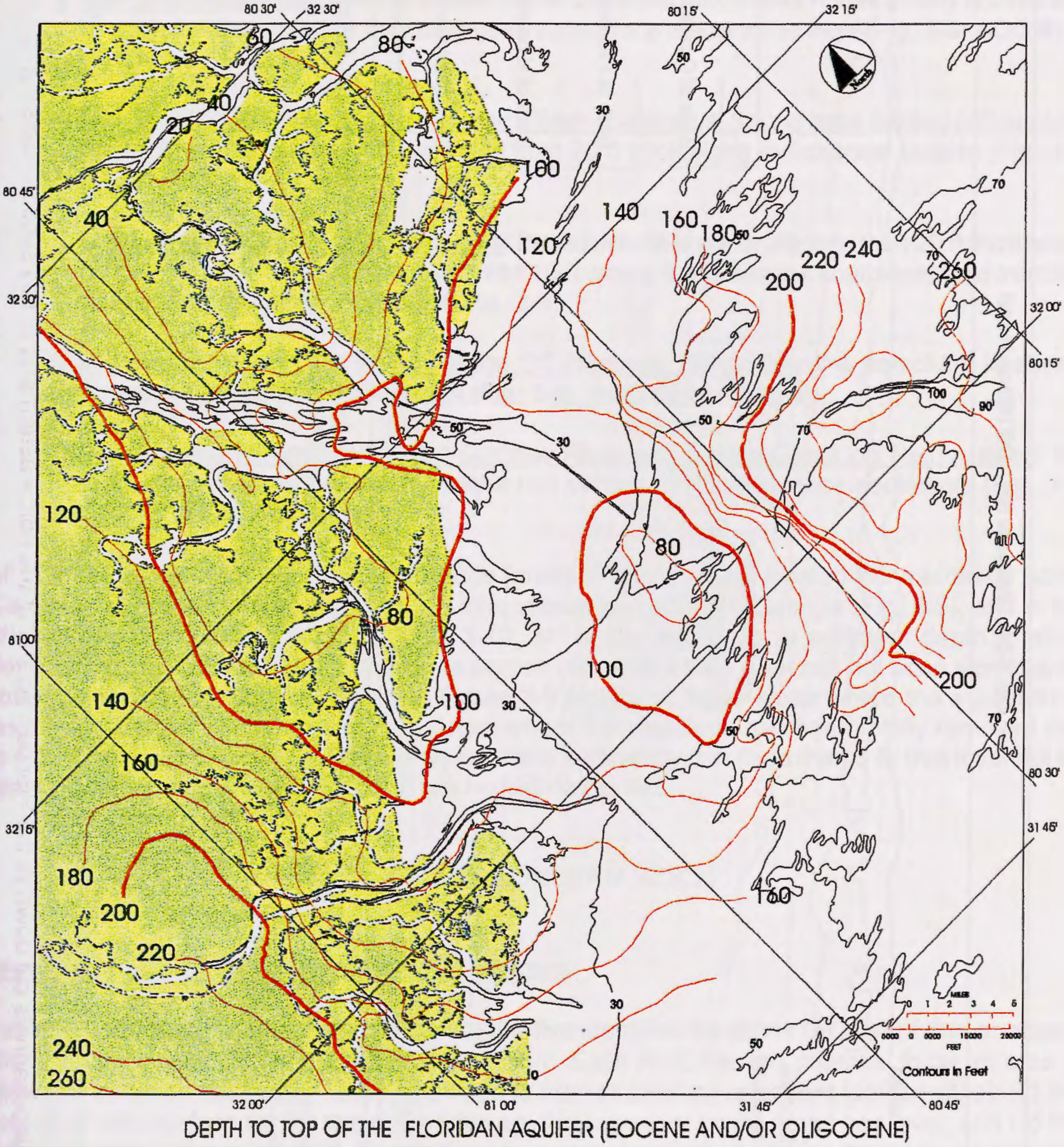

Figure 3-2 Structural contour map showing depths to the top of the Floridan aquifer in northern coastal Georgia and southern coastal South Carolina. This surface equates with seismic Reflector 4.

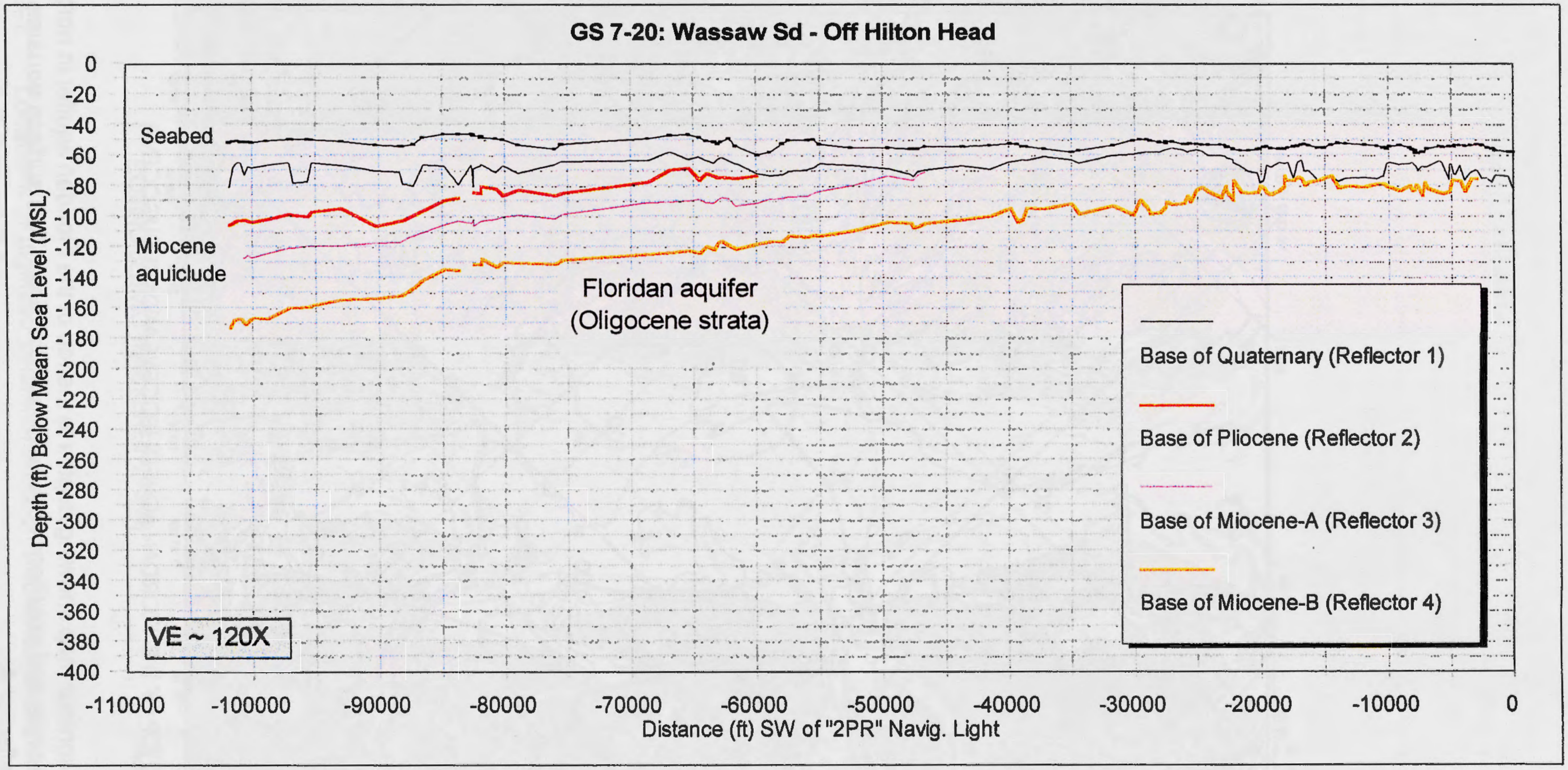

Figure 3-3 Coast-parallel oriented cross section along Seismic Line GS7-20 between offshore Tybee Island and offshore Hilton Head Island. Data-sample points are shown as black dots on the seabed reflector. AOC #1 occurs where Quaternary paleochannels cut down to the Floridan aquifer at the northeastern end of this section. See Fig. 3-1 for location.

Present-day fluvial/tidal channels and Plio-Pleistocene paleochannels incise into or through the Miocene aquiclude in areas where channel thalwegs are of sufficient depth to reach into the Miocene; this is most likely to occur where the aquiclude is perched on aquifer highs. Existing seismic data indicate that the above conditions for a thin or absent aquiclude are met in five specific locations, as shown in Fig. 3-5:

- *The Hilton Head High:* paleochannels of the Savannah and Broad Rivers locally cut into and through the aquiclude as they cross this subsurface topographic high (Fig. 3-3; AOC #1 in Fig. 3-5).
- *The Skull Creek - May River - Cooper River - Calibogue Sound area behind Hilton Head Island:* the aquiclude is generally less than 20 ft thick along the channel bottom (Fig. 3-6; AOC #2 in Fig. 3-5).
- *The Colleton - Chechessee River area:* the aquiclude is generally less than 20 ft thick along the channel axis and is locally as thin as 10 ft where it crosses the southwestward trending aquifer high (Fig. 3-7; AOC #3 in Fig. 3-5).
- *The Broad River in the vicinity of the SC Highway 170 bridge:* the aquiclude is absent across the axis of the aquifer high (Fig. 3-8; AOC #4 in Fig. 3-5).
- *The Beaufort River between the Coosaw River and Ballast Creek on Parris Island:* the aquifer is generally overlain by only a thin veneer of Plio-Holocene sediments (Fig. 3-9; AOC #5 in Fig. 3-5).

All of these areas of thin or absent aquiclude (areas of concern) are located in intracoastal South Carolina or adjacent offshore waters. In intracoastal and offshore Georgia (Fig. 3-5), and in the offshore Tybee Trough area (Figs. 3-5, 3-10, 3-11), the aquifer is at sufficient depth to allow development of a relatively thick aquiclude section (40 - 140 ft thick) that has not been significantly impacted by modern channel incision. Figure 3-5 highlights those areas where the aquiclude is less than 20 ft thick (yellow shading). Areas where the aquiclude has been totally removed due to paleochannel incision, or where the aquiclude is sufficiently thin (less than 5 ft) that it cannot be resolved on the archive seismic data, are highlighted in red.

AREAS OF CONCERN (AOCs)

Weighting Factors Used to Rank Areas of Concern

Table 3-1 summarizes dimensional data for the five identified locations (AOCs) of thin or absent Miocene aquiclude listed in the preceding section. Each AOC has the potential to be an area of saltwater intrusion because: (1) the aquiclude is thin (at all sites) or absent (at four sites); (2) the potentiometric surface for the upper Floridan aquifer is near or below mean sea level; and (3) the overlying water column is saline. Five factors were considered when ranking the relative saltwater-intrusion risk for each AOC. These are:

(1) The length of thinned, and especially absent, aquiclude at each site.

(2) The relative position of each site (with respect to the nearest potentiometric contour) on the upper Floridan aquifer's potentiometric surface.

(3) The proximity of the site to the Savannah cone of depression.

(4) The typical salinities in the overlying water column at each site.

(5) The thickness of the overlying, generally highly-transmissible, Plio-Holocene strata at each site.

The length of the thin - absent aquiclude zone is used as a proxy for the areal dimension of each potential saltwater-intrusion site. It is used as a proxy because calculation of the areal dimension of each site was limited due to the general lack of more than one trackline orientation through each site.

The most recent maps of the potentiometric surface for the Floridan aquifer in coastal Georgia and South Carolina show conditions for 1985 (Hughes et al., 1989) and 1990 (Peck, 1991, 1999). Using the larger scale 1985 potentiometric map as a general approximation for present conditions, the Hilton Head High appears to lie between the -5 and -10 ft potentiometric contours (offshore data are limited), the Skull Creek site lies between the -5 and -15 ft contours, the Colleton River site lies in the vicinity of the -5 ft contour, while the Beaufort River and Broad River sites lie at or above the 0 ft contour. The relative position of an AOC on the potentiometric surface is assigned the second-highest weighting in the ranking scheme shown in Table 3-2.

Table 3-1 Size of potential saltwater-intrusion sites at identified areas of concern. Length values are derived from Fig. 3-5

Site Location	Length of 20-ft isopach polygon in feet (miles)	Length of 10-ft isopach polygon in feet (miles)	Length of 0-ft isopach polygon in feet (miles)
Hilton Head High	35,000 (6.6)	11,000 (2.1)	5,000 (0.9)
Skull Creek - Calibogue Sound	80,000 (15.2)	46,000 (8.7)	6,000 (1.1)
Colleton - Chechessee Rivers	55,000 (10.4)	12,000 (2.3)	0 (0)
Broad River near SC Hwy 170 bridge	27,000 (5.1)	14,000 (2.7)	5,000 (0.9)
Beaufort River	97,000 (18.4)	90,000 (17.0)	85,000 (16.1)

Proximity of each site (AOC) to the center of the Savannah cone of depression is also significant. The closer an AOC is to the center of the cone of depression, the more immediate its impact will be on a large population center if saltwater intrusion occurs at the site.

All sites are characterized by an overlying water column with salinities that range from estuarine through oceanic. Mean annual salinities at the intracoastal AOCs are similar, generally ranging from the high teens to the mid 20s (e.g., 23 to 25 ppt in the Port Royal Sound estuary; Thompson, 1972). Offshore in areas such as the Hilton Head High, mean annual salinities generally range from 30 to 35 ppt (Atkinson, 1985; Menzel et al., 1993). High water-column salinities contribute towards the high rank for the Hilton Head High in Table 3-2.

The thickness of Plio-Holocene sediments overlying the aquiclude (where it is preserved) or the aquifer (where the aquiclude is absent) shows significant spatial variation. The thickest areas likely occur in and adjacent to paleochannels of the Savannah and Broad Rivers beneath the inner shelf. However, the archive data used in this report only partly define the spatial geometry of these fluvial systems. The Plio-Holocene section can also show significant lithologic variation in that fine grained sediments, which generally have lower transmissivities, may be more prevalent in sheltered intracoastal channel areas whereas sandy sediments would likely predominate the section offshore. This variability may affect the transmissivities of the Plio-Holocene section such that it may function as a weak aquiclude: this would be important in areas where the Miocene aquiclude is absent.

Relative Ranking of Areas of Concern

Based on the above considerations and on the existing but incomplete archive data coverages, five areas of concern are ranked in Table 3-2 in order of decreasing saltwater-intrusion risk and potential impact on future freshwater supplies from the upper Floridan aquifer for the coastal area.

Table 3-2 Preliminary saltwater-intrusion relative risk ranking for identified areas of concern. See Fig. 3-5 for site locations.

Site Location	Site Rank	Nearest Potentiometric Contour	Overlying Salinity	Proximity to Cone Apex
Hilton Head High	1	-5 to -10 feet	Oceanic	31 miles
Skull Creek - Calibogue Sound	2	-5 to -15 feet	Estuarine	20 miles
Colleton - Chechessee Rivers	3	-5 feet	Estuarine	24 miles
Broad River near SC Hwy 170 bridge	4	0 feet	Estuarine	27 miles
Beaufort River	5	0 to +5 feet	Estuarine	32 miles

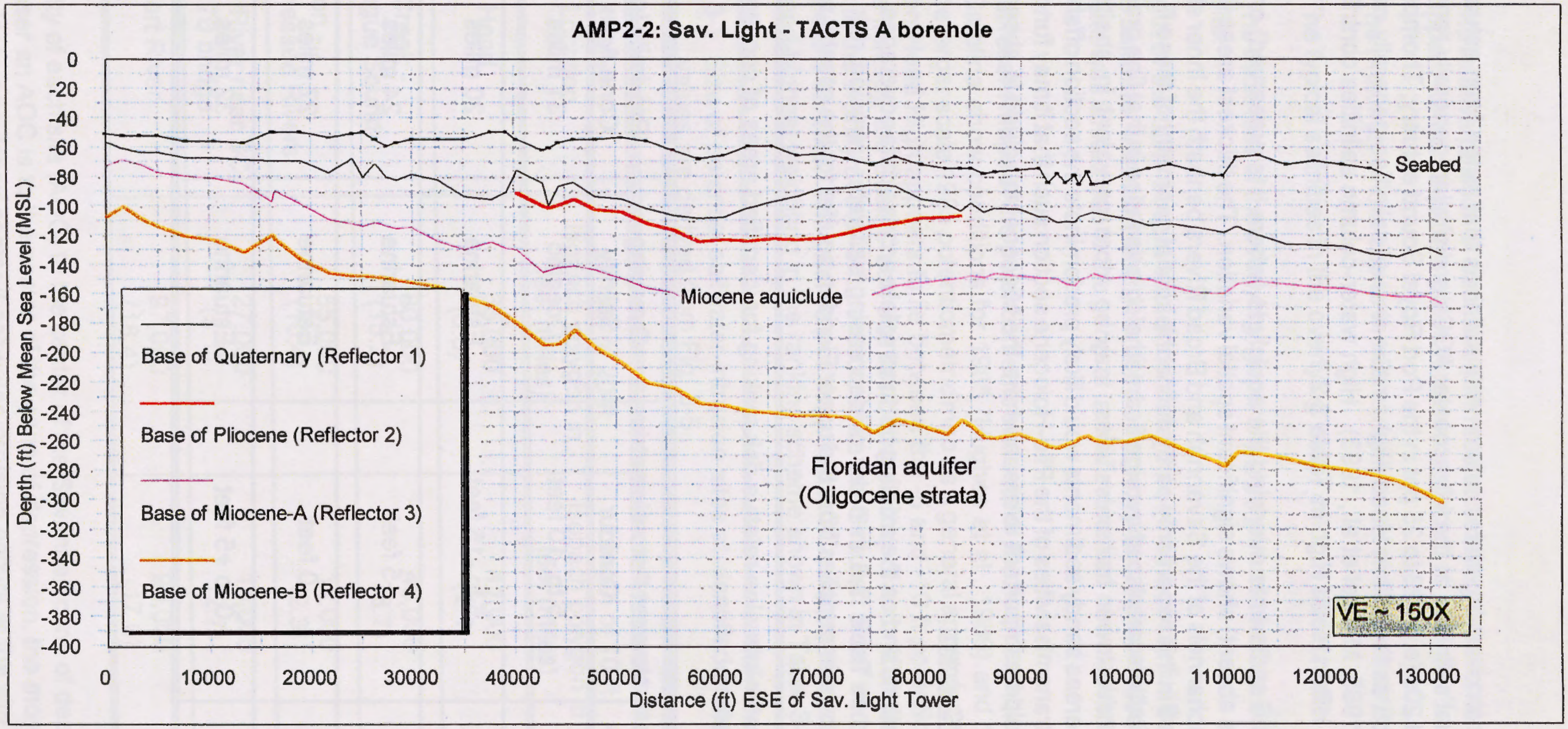

Figure 3-4 Coast-normal oriented cross section along Seismic Line AMP2-2 between Savannah Light Tower and the TACTS A borehole. Data-sample points are shown as black dots on the seabed reflector. See Fig. 3-1 for location.

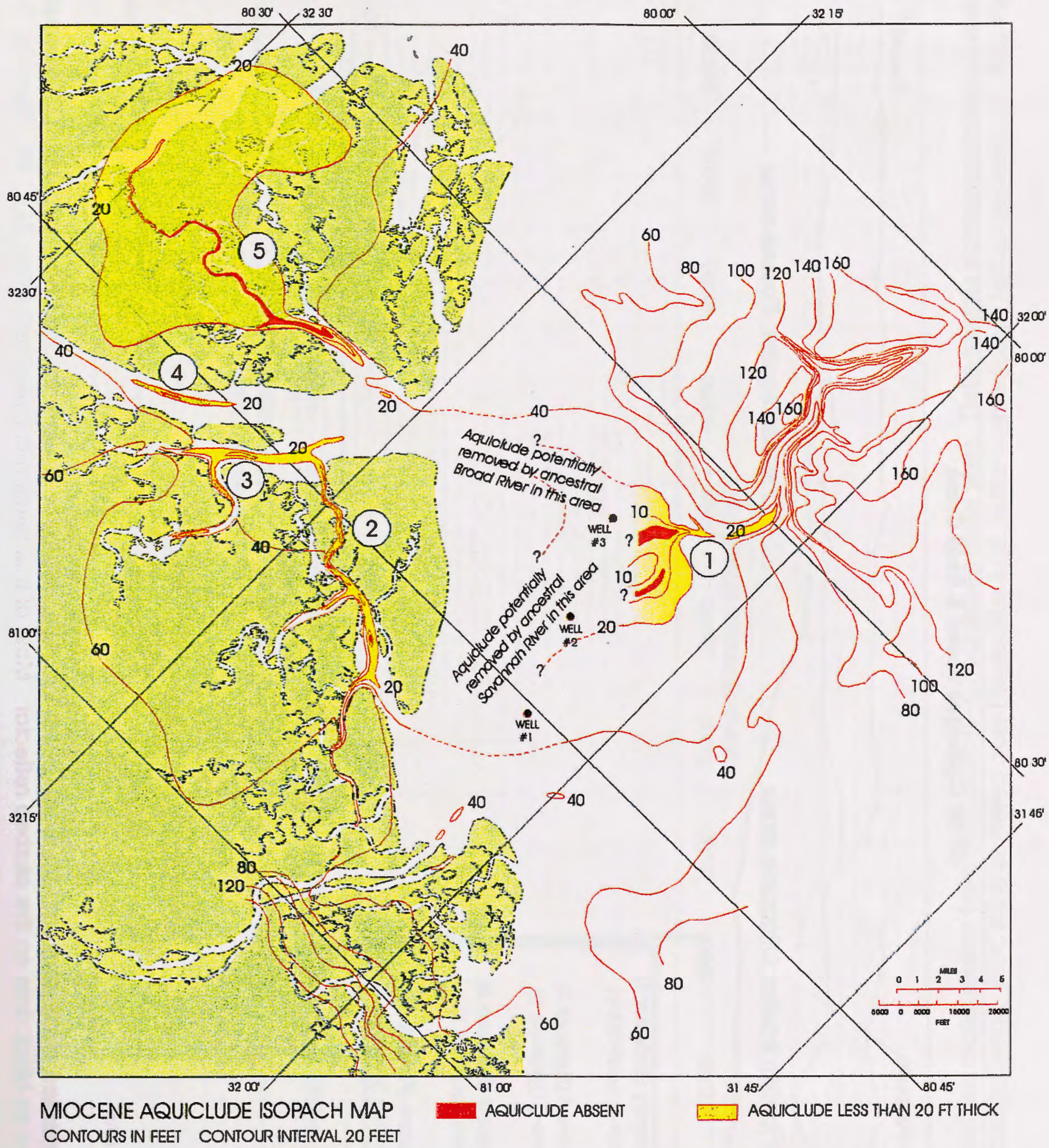

Figure 3-5 Isopach (thickness) map for the Miocene aquiclude in northern coastal Georgia and southern coastal South Carolina. Areas within the 20-ft isopach contour are shaded yellow; areas within the 0-ft isopach contour are shaded red. Areas of Concern (AOCs) are ranked 1 through 5: refer to Table 3-2 for additional details. Proposed USGS well sites 1 through 3 are also shown.

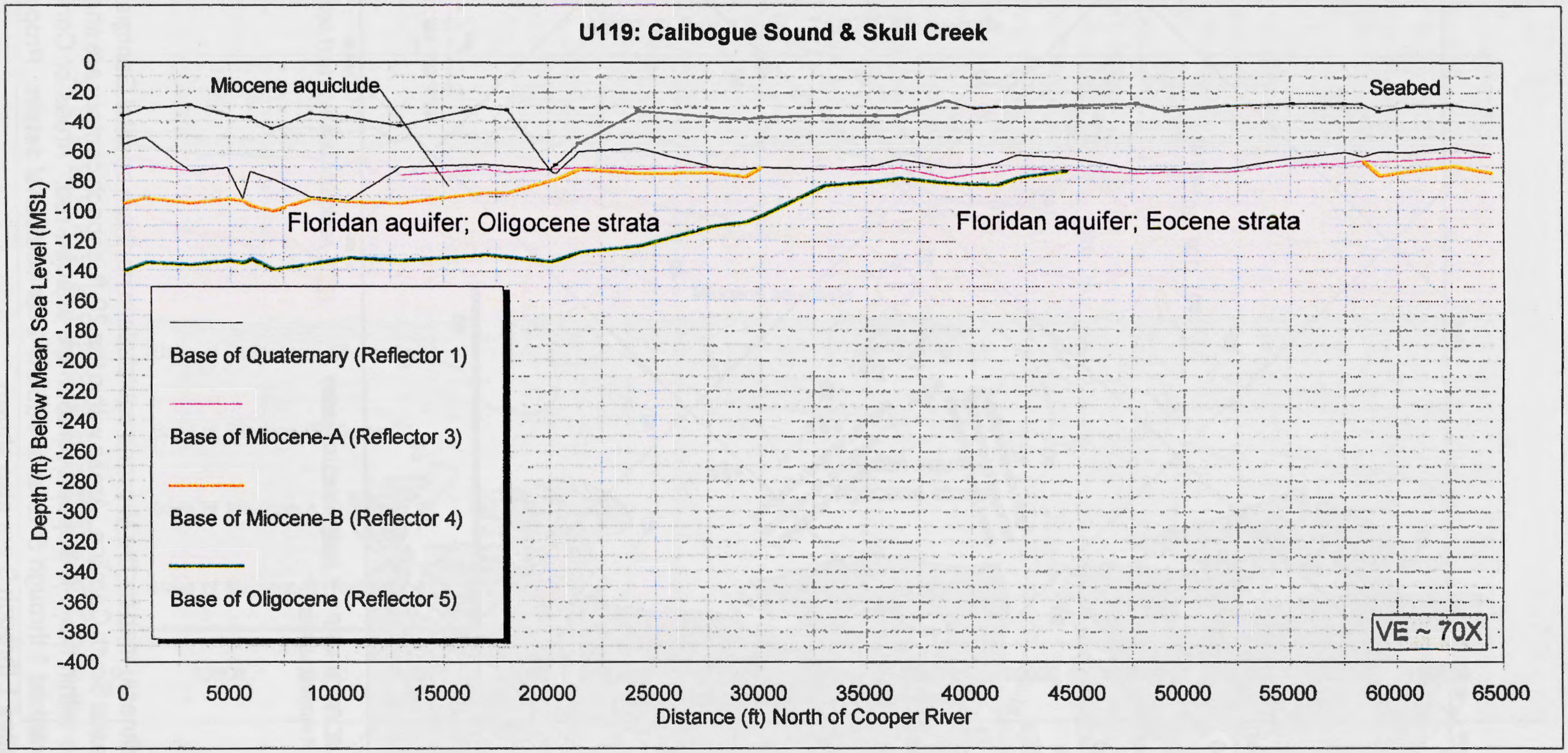

Figure 3-6 Coast-parallel oriented cross section from Skull Creek between Calibogue Sound and Port Royal Sound. Data-sample points are shown as black dots on the seabed reflector. Most of this section is contained within AOC #2. See Fig. 3-1 for location.

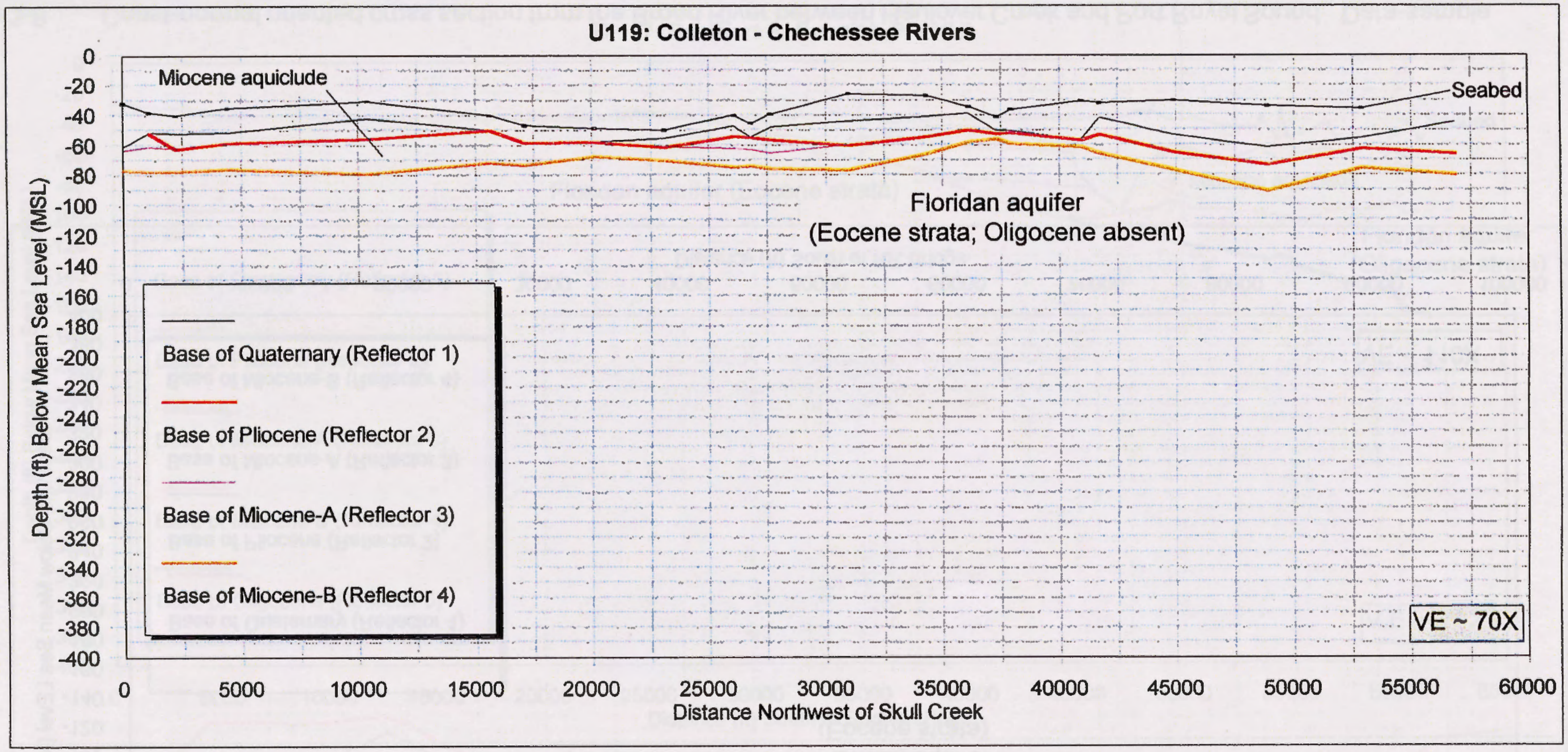

Figure 3-7 Coast-normal oriented cross section from the Colleton - Chechessee River area. Data-sample points are shown as black dots on the seabed reflector. AOC #3 is centered over the aquifer high in the northwestern half of this section. See Fig. 3-1 for location.

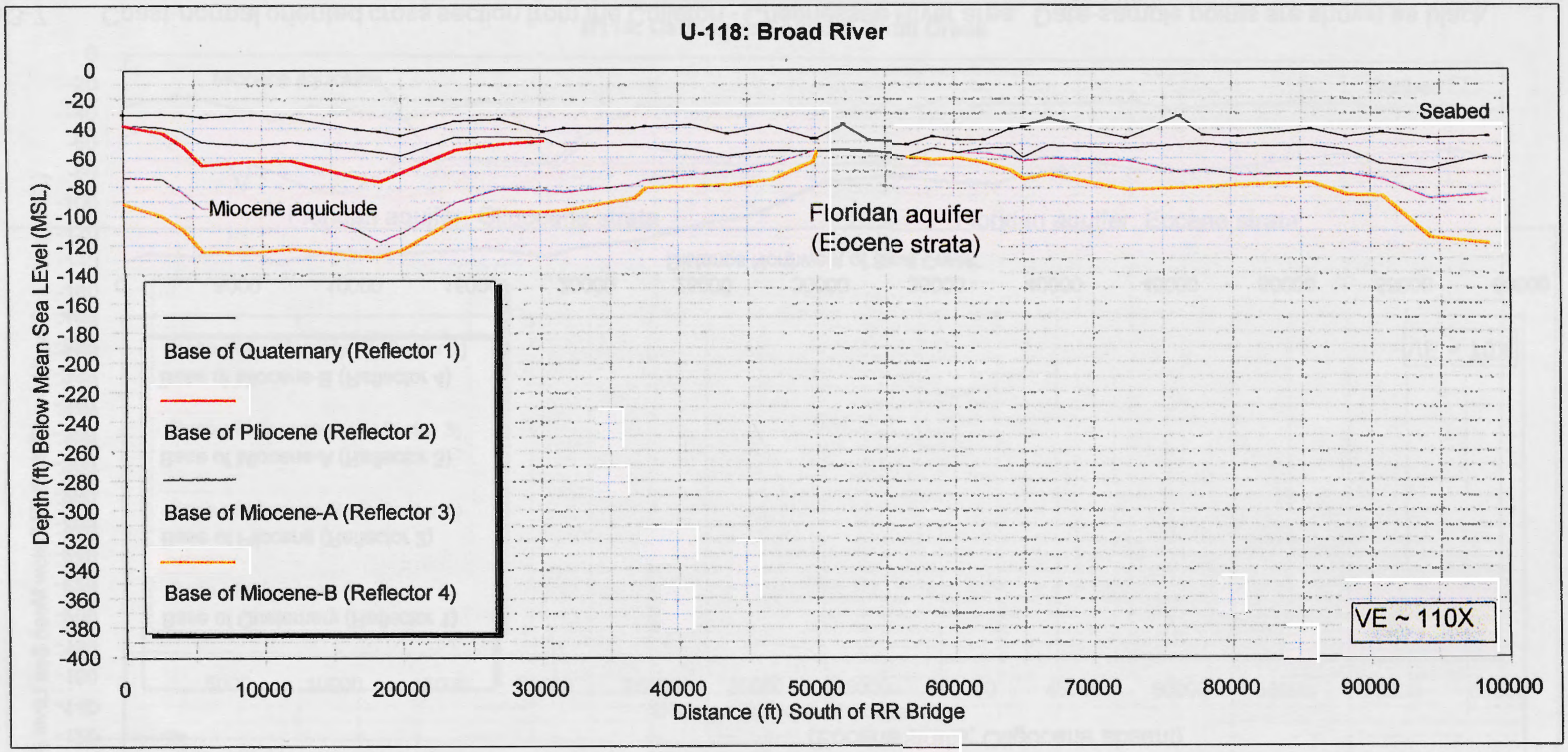

Figure 3-8 Coast-normal oriented cross section from the Broad River between Haulover Creek and Port Royal Sound. Data-sample points are shown as black dots on the seabed reflector. AOC #4 is centered on the aquifer high in the center of this section. See Fig. 3-1 for location.

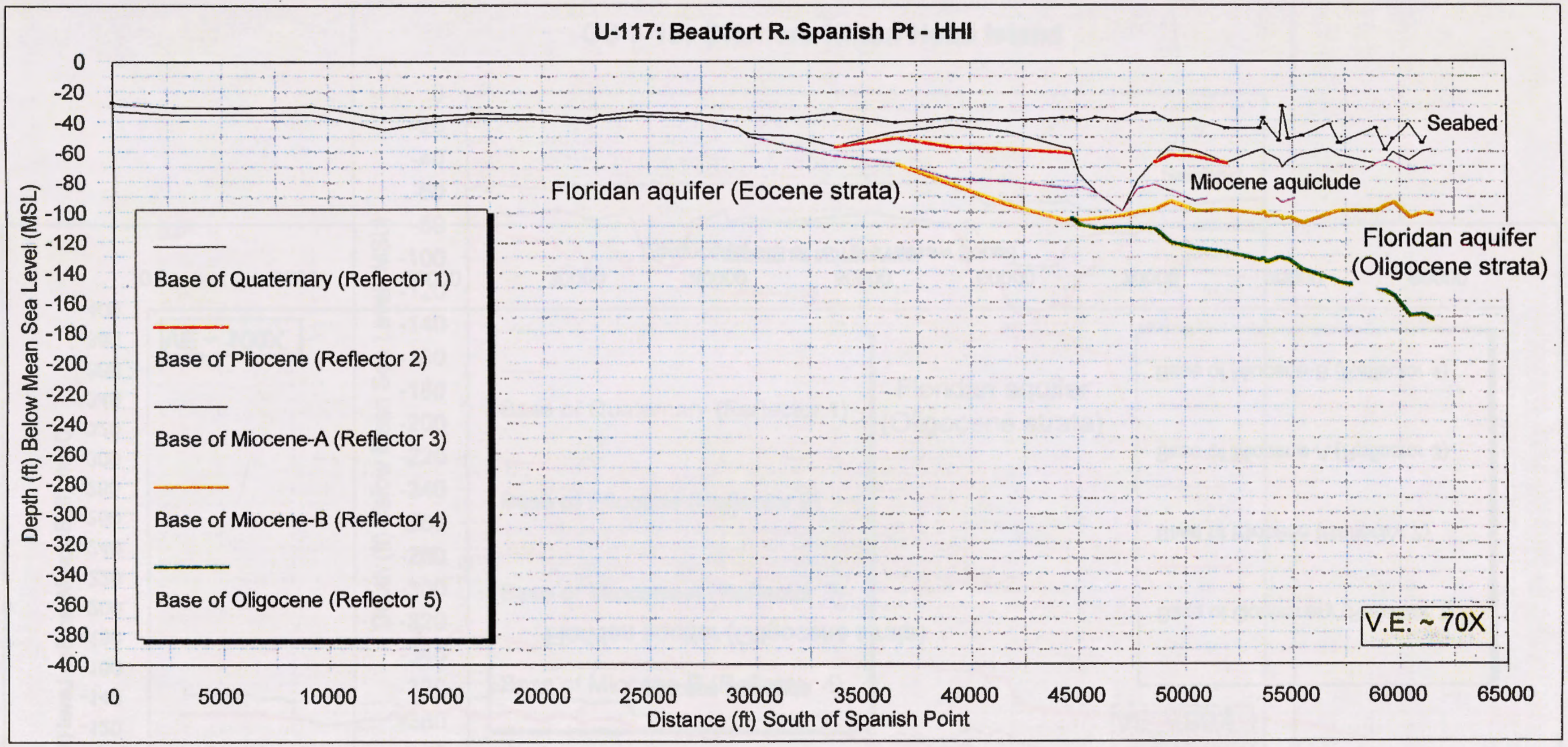

Figure 3-9 Coast-normal oriented cross section from the Beaufort River between Spanish Point and Port Royal Sound. Data-sample points are shown as black dots on the seabed reflector. AOC #5 encompasses the northern half of this section. See Fig. 3-1 for location.

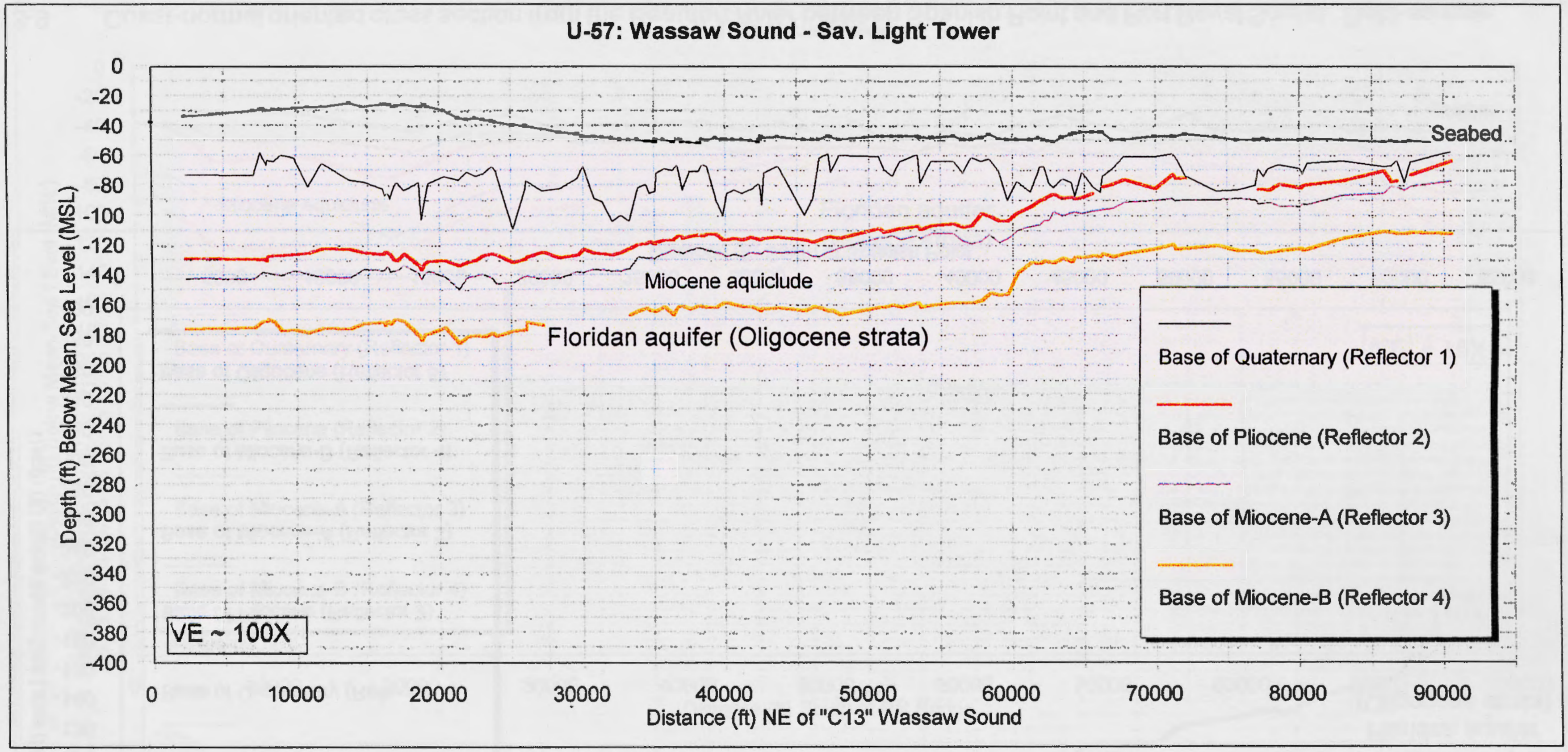

Figure 3-10 Coast-parallel oriented cross section along Seismic Line U-57 between Wassaw Sound and Savannah Light Tower. Data-sample points are shown as black dots on the seabed reflector. See Fig. 3-1 for location.

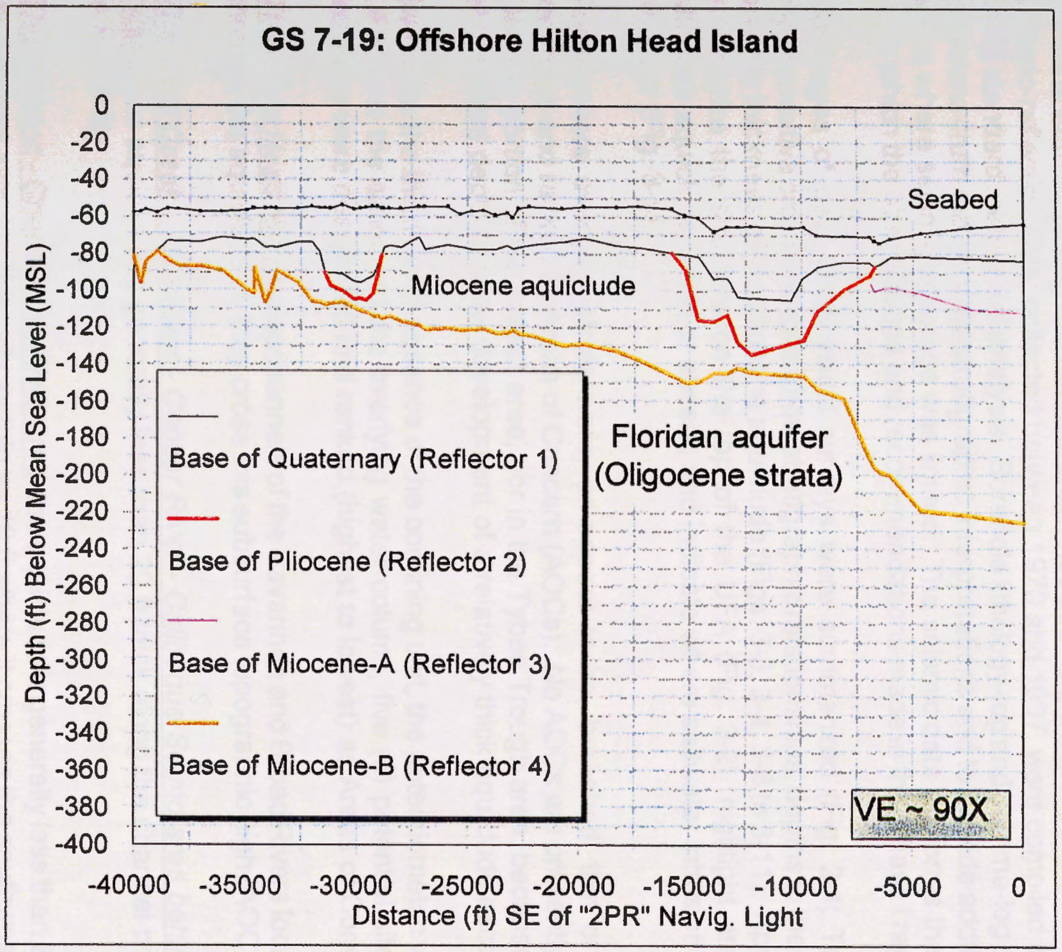

Figure 3-11 Coast-normal oriented cross section along Seismic Line GS7-19 offshore of Hilton Head Island. Data-sample points are shown as black dots on the seabed reflector. See Fig. 3-1 for location.

PART 4: SUMMARY

1. Published and unpublished seismic and geological data in both the public and private domains were reviewed, evaluated and synthesized. Eight hundred miles of high-resolution seismic-reflection data, collected between 1970 and 1997, were compiled and interpreted using standard methods of analysis. Borehole lithology-log and gamma-log data were used to ground-truth the seismic-stratigraphic interpretations and to provide additional control in areas where seismic coverage was limited. The seismic data set forms the primary basis upon which the observations and recommendations made in this Phase I report are based.

2. Coverages of past geophysical surveys were summarized (Fig. 2-1; Table 2-1), and representative cross-sections show stratigraphic relationships, depths to the top of the UFA, and the thickness of the Miocene aquiclude (Figs. 3-3, 3-4, 3-6 to 3-11). Appropriate maps summarize the structure on the top of the UFA (Fig. 3-2), highlight areas where the Miocene aquiclude is thin or absent, and indicate where saltwater intrusion sites are likely to occur (Fig. 3-5).

3. Areas where overlying strata were, or appear to be, breached, thin or missing were identified and ranked as Areas of Concern (AOCs). No AOCs are presently located in the Georgia portion of the project area, nor in the Tybee Trough area, because the aquifer is at sufficient depth to allow development of a relatively thick aquiclude section (Fig. 3-5).

4. Based on the thinness or absence of the confining unit, the potentiometric value within the UFA, and the salinity of the overlying water column, five (5) potential sites of saltwater intrusion were designated and ranked (highest to lowest) as Areas of Concern (AOCs):

   <u>*The Hilton Head High:*</u> paleochannels of the Savannah and Broad Rivers locally cut into and through the aquiclude as they cross this subsurface topographic high (AOC #1 in Fig. 3-5).

   <u>*The Skull Creek - May River - Cooper River - Calibogue Sound area behind Hilton Head Island:*</u> the aquiclude is generally less than 20 ft thick along the channel bottom (AOC #2 in Fig. 3-5).

   <u>*The Colleton - Chechessee River area:*</u> the aquiclude is generally less than 20 ft thick along the channel axis and is locally as thin as 10 ft where it crosses the southwestward trending aquifer high (AOC #3 in Fig. 3-5).

   <u>*The Broad River in the vicinity of the SC Highway 170 bridge:*</u> the aquiclude is absent across the axis of the aquifer high (AOC #4 in Fig. 3-5).

   <u>*The Beaufort River between the Coosaw River and Ballast Creek on Parris Island:*</u> the aquifer is generally overlain by only a thin veneer of Plio-Holocene sediments (AOC #5 in Fig. 3-5).

5. Detailed geophysical surveys will be conducted in the AOCs and adjacent areas as part of Phase II.

ACKNOWLEDGMENTS

The authors would like to recognize Dr. Faisal Idris for his help with data synthesis, Mr. Camille Ransom of the South Carolina Department of Health and Environmental Control for providing both published and unpublished data, Mr. Cardwell Smith of the U.S. Army Corps of Engineers (Savannah) for assisting in field-testing of navigation software and Vicki Patrick of the Skidaway Institute of Oceanography for word processing assistance.

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Cost: $1054
Quantity: 100