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RESULTS OF A SEISMIC REFLECTION INVESTIGATION AND HYDROGEOLOGIC IMPLICATIONS FOR LAKE APOPKA, FLORIDA

By

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FINAL REPORT
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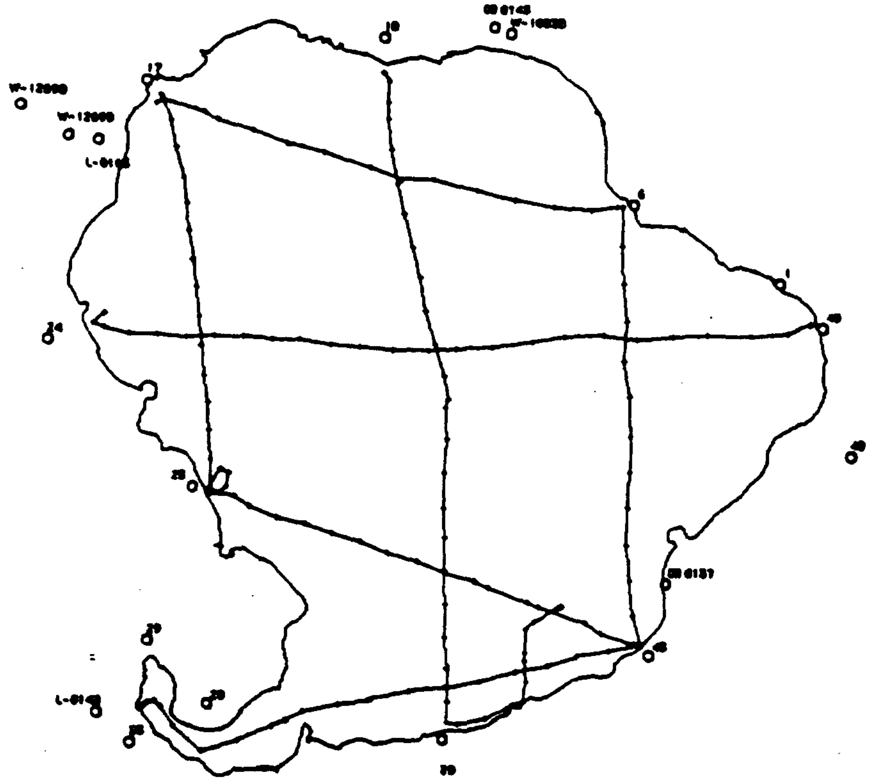

THE CENTER FOR NEARSHORE MARINE SCIENCE
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UNIVERSITY OF SOUTH FLORIDA
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INTRODUCTION

This report presents the results of a seismic reflection survey of Lake Apopka, Florida (Figure 1). The purpose of the study was to correlate subsurface geology across the lake and to assess the nature of the confining units between the lake and the Floridan Aquifer. The contract scope was to shoot and interpret approximately 44 miles of continuous seismic reflection profiles across Lake Apopka. Existing well data available from the St. Johns River Water Management District and the Florida Geological Survey were used to aid in the interpretation.

In February, 1988 seven seismic profile transects were run across the lake to tie among a series of 13 wells identified by the District around the perimeter of the lake (Figures 2 and 3). In addition, data from twelve deep stratigraphic test and production wells were used to correlate deeper strata (Figure 4).

Two deep reflection horizons were mapped which were found to correlate, within reasonable limits, to the top of the Ocala limestone and the top of a dolomite zone in the Avon Park Formation (Figure 4). It was more difficult to derive much valid information on stratal patterns within the upper 15-20 milliseconds on seismic records because the acoustic response of gas-charged lake sediments obscures the shallow portion of the seismic records. Shallow depressions in the bottom were observed but do not appear to reflect recently active sinkhole/solution features.

Results suggest that significant water exchange between the lake and underlying Floridan Aquifer are unlikely. The apparent continuity of muddy lake-bottom sediments probably forms a relatively impermeable confining layer between the lake and underlying strata, and therefore inhibits the transfer of

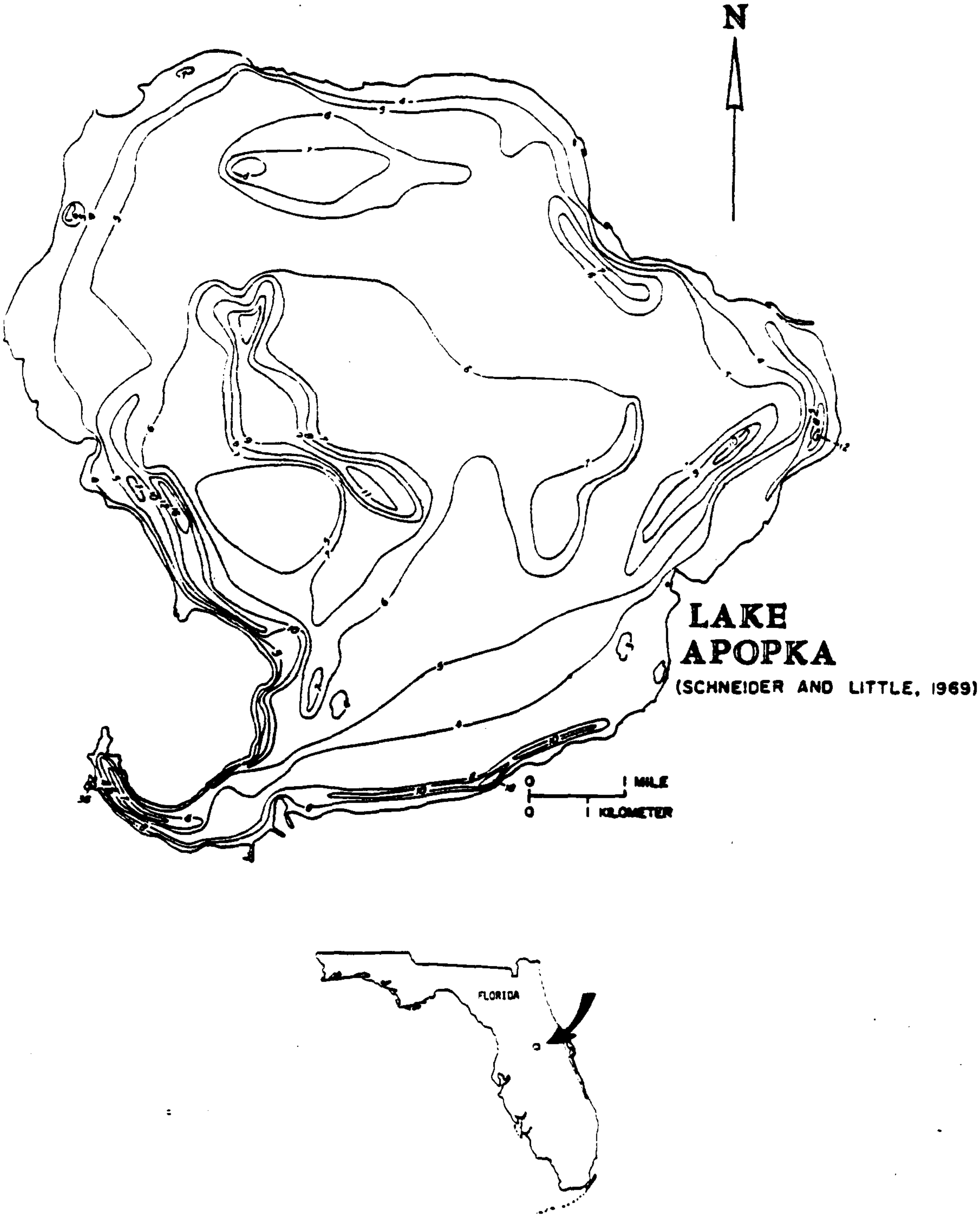

Figure 1. Study location and bathymetry as originally mapped by Schneider and Little (1969). Water depth in feet.

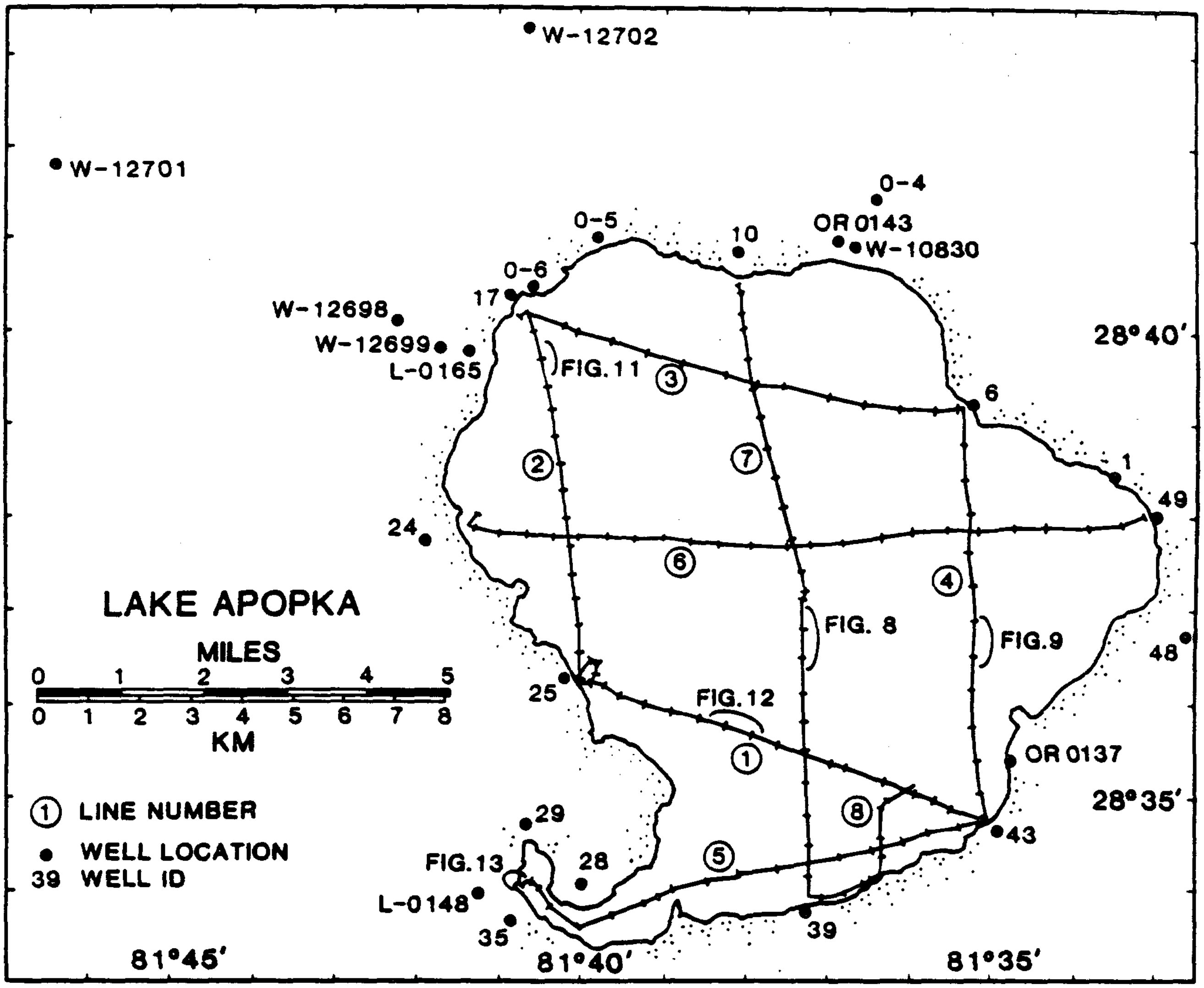

Figure 2. Seismic profile tracklines and selected well locations close to Lake Apopka. All wells plotted here are shown in Figure 4. Also shown by Figure # are the locations of seismic Figures in text.

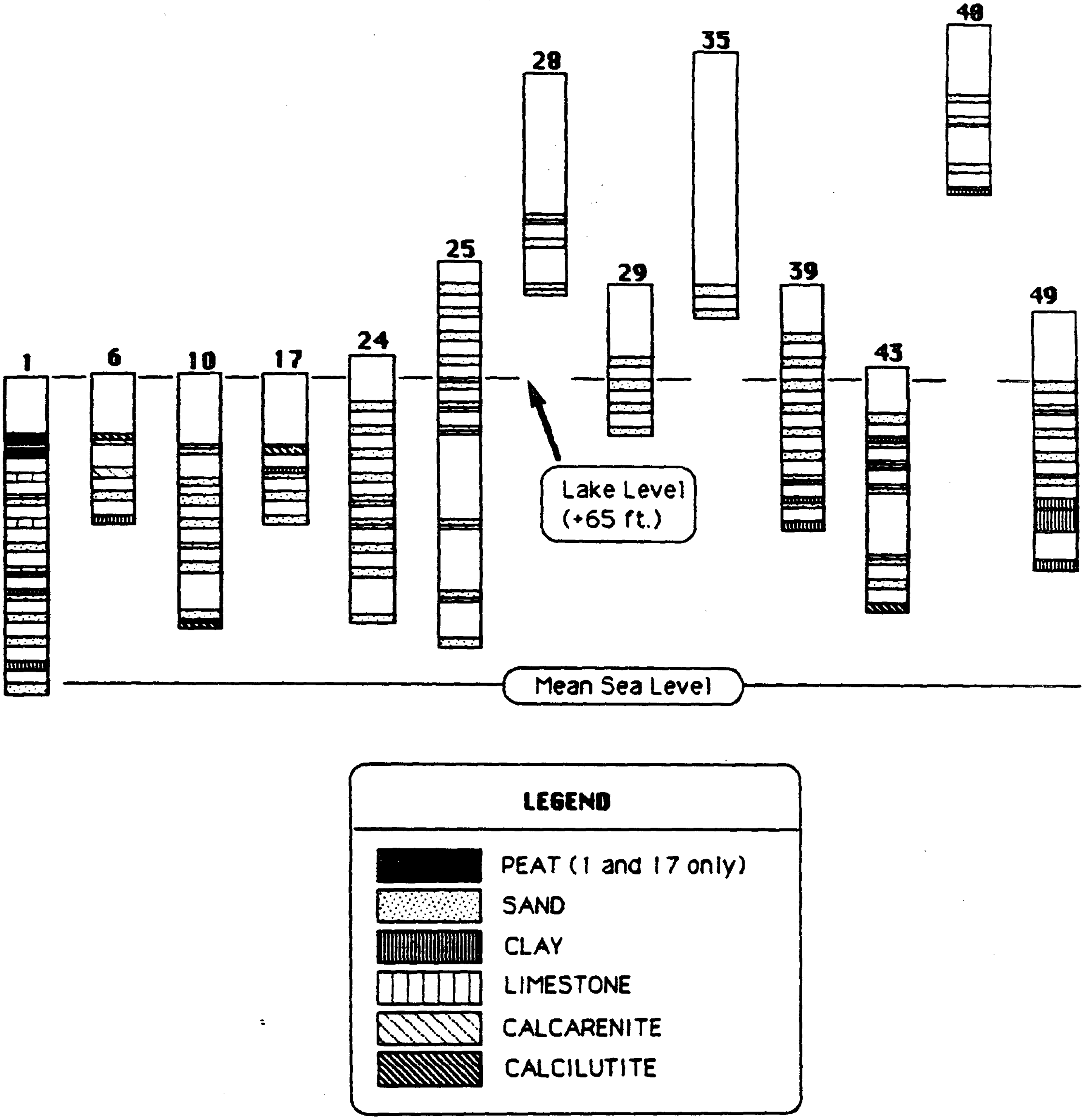

Figure 3. Shallow well data from sites around the perimeter of lake. These wells primarily sampled the upper zone of undifferentiated clastics and possibly the Hawthorn Formation.

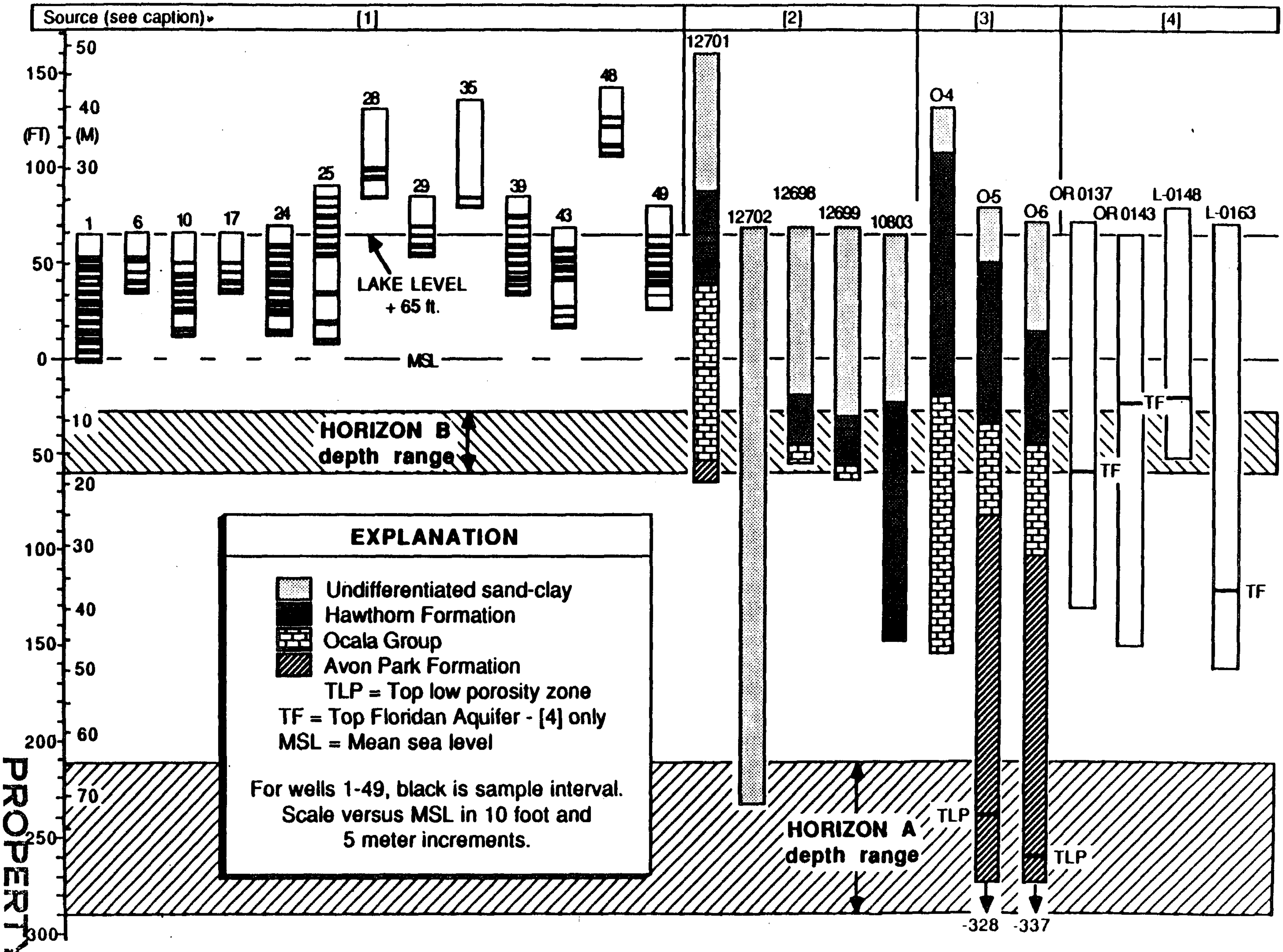

Figure 4. Summary of all well data used in this study. The range in depths to horizons A and B below Lake Apopka in Figures 15 and 16 are also shown for comparison. Conversion of travel time to depth used a constant velocity/depth function of 1900 m/s and 2400 m/s for B and A, respectively. Sources of well data are: [1] well logs from St. Johns River Water Management District (SJRWMD);

water below the lake bottom. Also, a strong (high-amplitude) reflection horizon at the base of the sediments, suggests a well-lithified or compact surface, which would further inhibit exchange between the lake and a 20-25m thick section of clastics and carbonates that is thought to overlie the Floridan Aquifer.

GEOLOGIC SETTING

The area of investigation lies at the southern end of the Central Valley lowland province proposed by Puri and Vernon (1964) (Figure 5). Lake Apopka is bounded along its west, south, and east sides by the highland areas of the Lake Wales Ridge and Mount Dora Ridge. These highland ridge areas, consisting of clayey sand deposits, are believed to represent fossil beach ridges of marine origin (Lichtler, et al. 1968) and to be underlain by remnant Miocene fluvial deposits termed the Hawthorn Delta by White (1958). White (1970) suggested that the Central Valley may represent an unprotected soluble area reduced to its low elevation by dissolution. However, the low relief may be more a reflection of accretion of the ridges around the Central Valley area. The Lake Apopka valley area has been mapped as bare or thinly covered limestone with a few broad and shallow solution type sinkholes (Sinclair and Stewart, 1985; Lane, 1986).

The subsurface geology for this area has been described by Pride, et al. (1966), Lichtler, et al. (1968), Knochenmus (1971), Scott (1978), Johnson (1979), and Scott and Hajishafie (1980). The focus of most of this literature has been on the hydrogeologic aspects of the subsurface stratigraphy. A summary of the local stratigraphic nomenclature, lithologies, and aquifer relationships is shown in Figure 6.

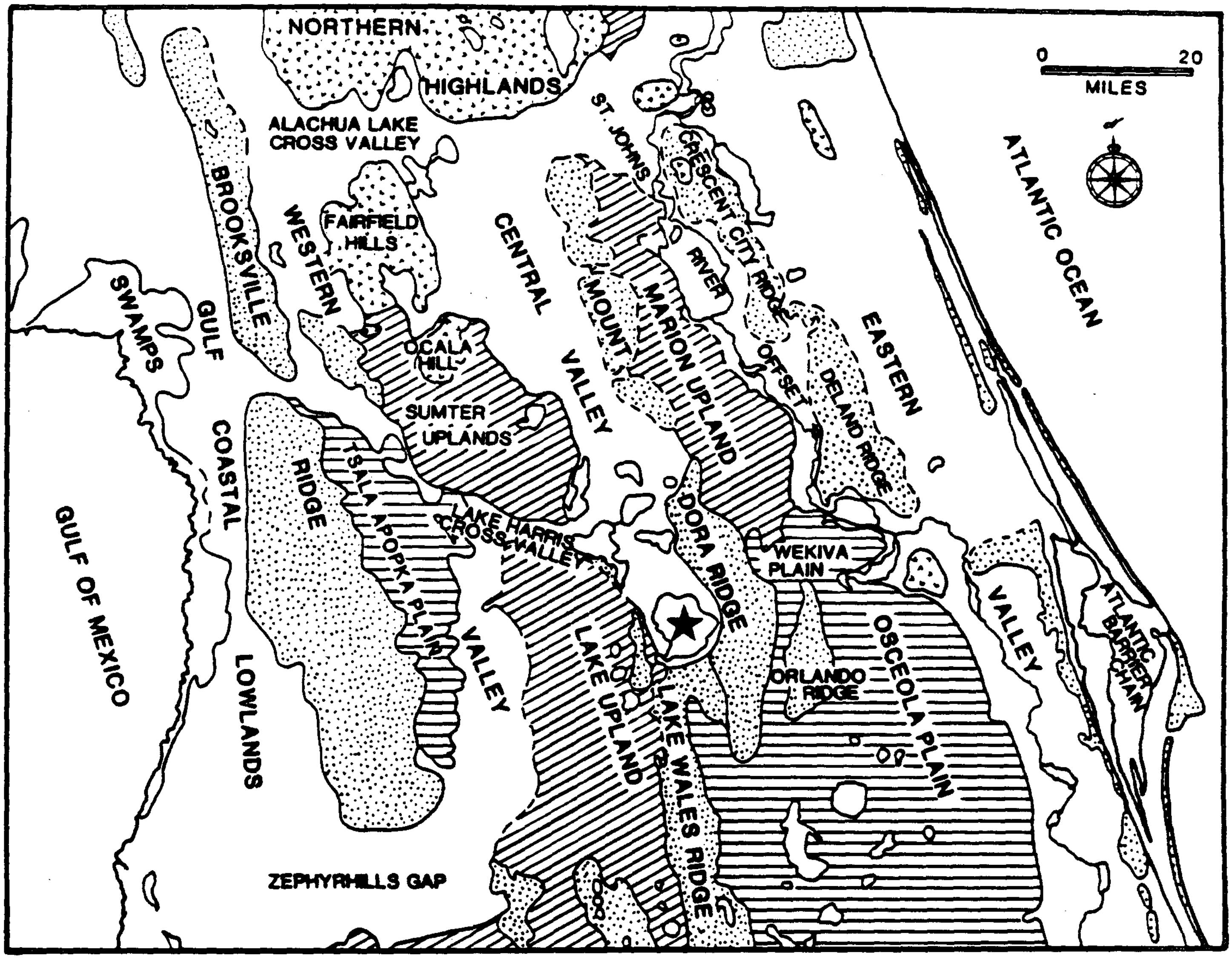

Figure 5. Physiographic provinces of central Florida simplified from Puri and Vernon (1964). Lake Apopka (see star) is located at the southern end of the Central Valley province.

STRATIGRAPHIC RELATIONSHIPS AND HYDROGEOLOGIC UNITS - LAKE APOPKA REGION -

AGE	FORMATION	LITHOLOGY	HYDROLOGIC UNITS	SEISMIC CORRELATION
LATE MIOCENE TO PRESENT	Undifferentiated sands and clays		Water table aquifer	
MIOCENE	HAWTHORN	UPPER: Clay with sandy clay, locally phosphatic LOWER: Interbedded clay, limestone, and dolomite	Mixed: Aquifers and confining units	
EOCENE	OCALA LIMESTONE	Relatively pure limestone	Floridan Aquifer	—?— HORIZON B
	AVON PARK LIMESTONE	Interbedded limestone and dolomite		—?— HORIZON A

Figure 6. Summary of local stratigraphy, hydrogeologic units, and inferred seismic horizon correlation.

Four principle stratigraphic units characterize the Lake Apopka area. The uppermost section, including the ridge features, consists of undifferentiated clastics (sands and clays) of the late Miocene to present. Below are late to middle Miocene clays underlain by limestones that comprise the Hawthorn Formation. The Hawthorn Formation may support shallow artesian aquifers, partially confine the Floridan Aquifer, or be in hydrologic contact with the Floridan Aquifer (ibid.). Below the Hawthorn lie the Upper Eocene Ocala Group limestones. The Ocala and underlying Avon Park Formations comprise the upper levels of the Floridan Aquifer. Within the middle Eocene Avon Park Formation a low porosity zone described by Johnson (1979) and mapped as a dolomite zone by Lichtler, et al. (1968) is significant since we find a seismic reflection interface at that approximate depth. The seismic reflection profiles collected in this study penetrate approximately to the middle Eocene Avon Park Formation.

Based upon data collected in this investigation, we mapped acoustic reflection horizons that may correspond to the change from clastics to carbonate, and to the top of dolomite.

METHODS

Seventy-five line kilometers (47 miles) of single channel high-resolution seismic reflection data were collected using a Geopulse high-resolution profiling system, which consisted of an ORE power supply, towed acoustic source, 20 element hydrophone array, a filter/amplifier unit, and an EPC 1650 graphic recorder. The seismic profiles were recorded using a 100 millisecond (ms) sweep with band pass filters typically set for 500-2000 Hz. The raw unfiltered signal was also recorded on analog tape.

Navigation was by LORAN C, with positions taken every 5 minutes and features marked as necessary (Figure 7). The LORAN C readings of degrees and decimal minutes (hundredths of minutes) were converted to degrees/minutes/seconds for real-time plotting. A positioning offset was apparent during the field work and was later determined to be a constant calibration offset for all the positions based on the close fit of the corrected navigation to shoreline configuration. Original LORAN C readings and corrected positions are listed in Appendix I. A boat, LORAN C receiver, and operator were provided by the District.

Interpretation procedures involved identification of prominent subbottom reflection horizons and classification of shallow reflection character. Since the shallow portion of the seismic records was often obscured by the acoustic interference discussed below, it was not possible to construct a sediment thickness map. However, two subbottom horizons were mapped with some confidence based on our ability to correlate the same horizon at tie points on crossing lines.

In general, seismic reflections are produced from interfaces of different acoustic impedance (density X sound velocity). Thus, we might expect to see

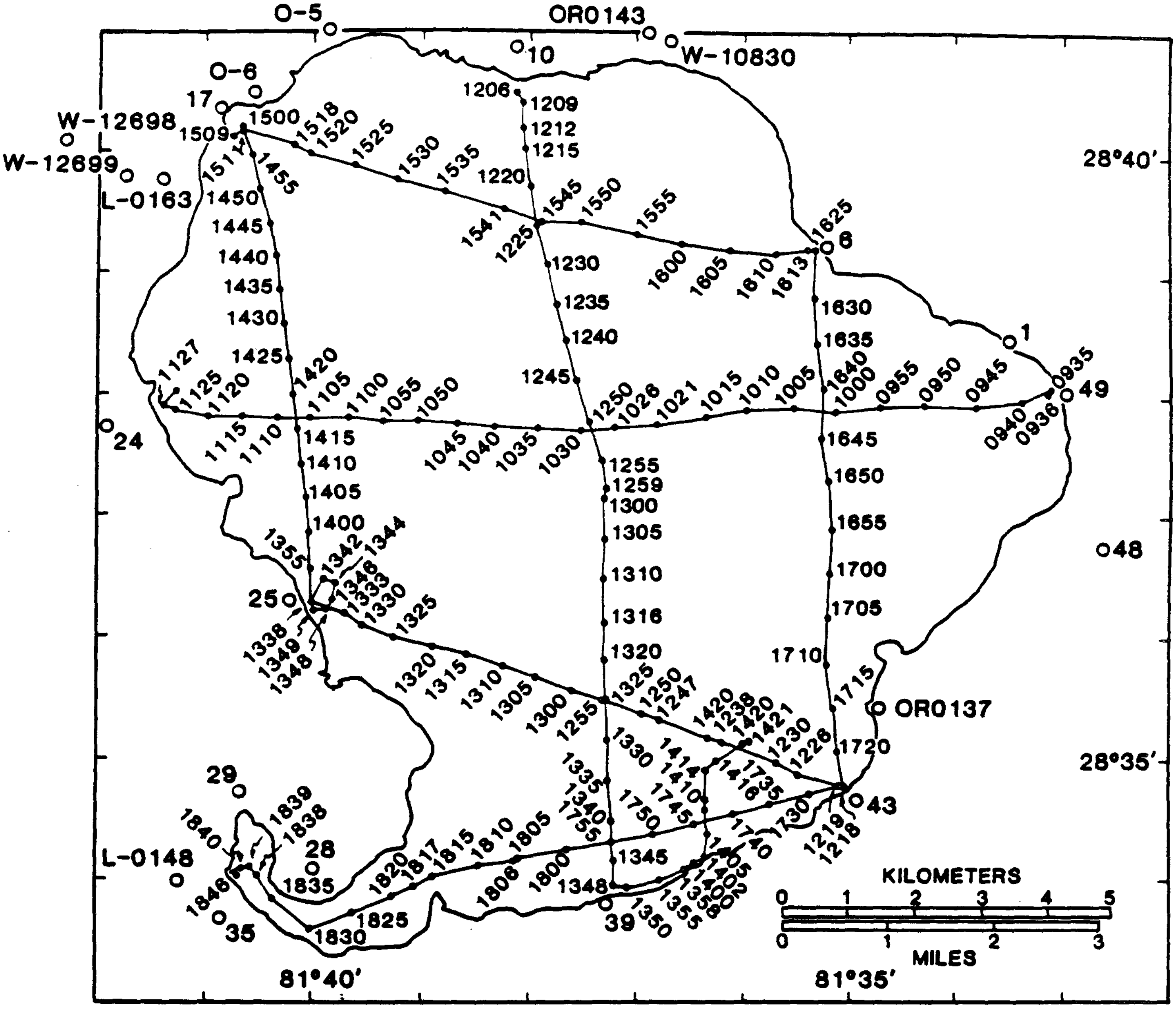

Figure 7. Plot of corrected navigation by time. The raw data is listed in Appendix I. Refer to Figure 2 for line numbers.

reflections from bedding planes, unconformities, and abrupt lithologic changes. However data quality in Lake Apopka was restricted due to acoustic interference resulting in masking of normal reflection patterns. This limitation was not due to acquisition technology or methods, but due to 3 principal sources of interference caused by the physical properties of the lake sediments and the character of the limestone strata beneath the lake.

Two common interference problems encountered were, 1) multiples caused by the echo of strong (high-amplitude) bottom or subbottom reflections within the water column, and 2) chaotic or disturbed reflection patterns caused by karstified limestone (Figure 8). While the solution-riddled nature of the subsurface limestone sequences is known to support high flow within the Floridan Aquifer, it also represents a difficult medium in which to apply seismic reflection techniques because of the disruptive scattering of acoustic energy by the irregular rock fabric.

A third more uncommon problem, was the effect of appreciable amounts of biogenic gas contained in the lake sediments. We believe this to be the cause of the high-amplitude broad-band reflection response that is present in most of the seismic data, and that prevents resolution within the lake sediments (Figure 8). A highly unusual "fuzzy" reflection character observed in some areas may have been caused by a high gas concentration, possibly in combination with a change in sediment texture (Figure 9). Evidence for gas is also indicated by a phase shift of the seismic signal observed at 2 locations on lines 4 and 7 where abrupt gaps in interference indicated gas was absent (Figures 8 and 9). A distinct phase-shift of the seismic wavelet is observed as we traversed the lake in and out of these areas (Figure 9). A phase shift is caused when a seismic pulse is reflected from an interface of higher acoustic impedance over lower acoustic impedance. Since acoustic impedance is

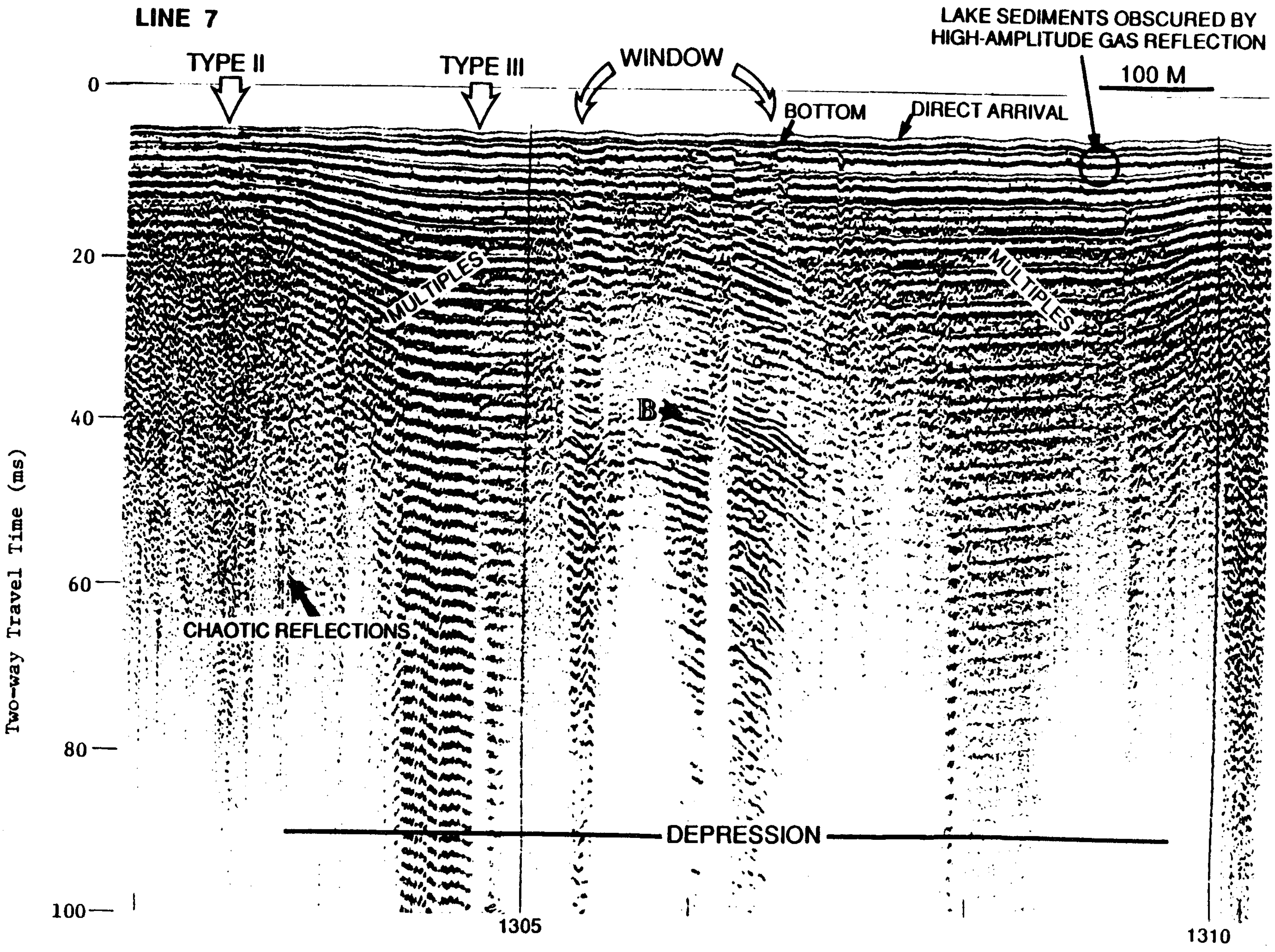

Figure 8. Section of seismic line 7 illustrating reflection character and shallow depression. See Figure 2 for location.

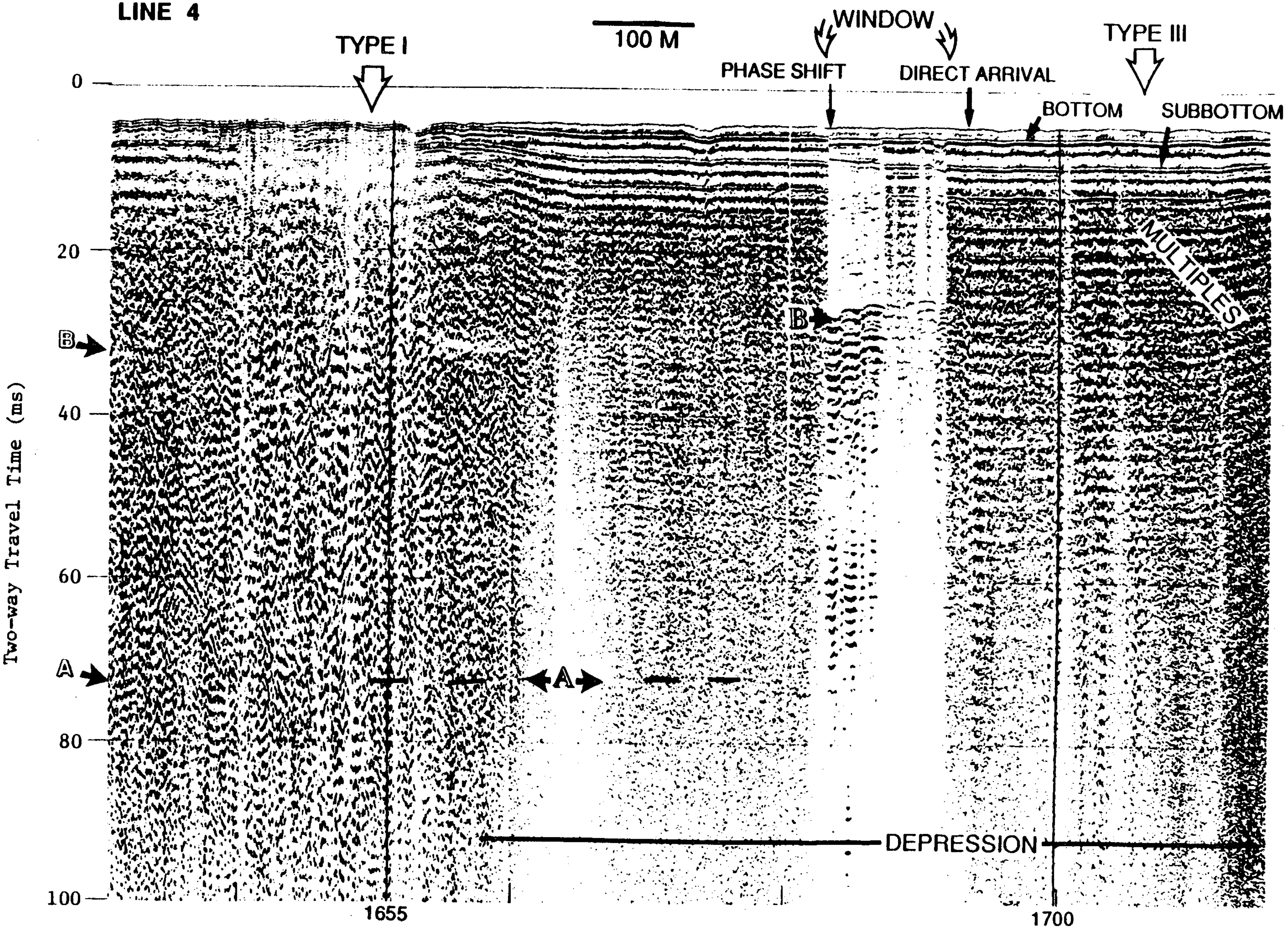

Figure 9. Section of seismic line 4 showing examples of reflection character types, a "window", and deep seismic horizons A and B. A clear phase shift in the reflected pulse is observed at the edge of the window. See Figure 2 for location.

the product of density X velocity, the presence of interstitial gas can cause a drop in impedance contrast. Locations where a more normal subbottom seismic record is observed are called "windows" in this paper.

RESULTS

Reflection Character

Three principle reflection character types generated by the lake bottom and shallow subbottom were identified and plotted along track in Figure 10. This classification is arbitrary with some overlap of types, but it provides a qualitative analysis of bottom types in Lake Apopka. Calibration of this classification will require a sediment coring program to ground truth bottom types.

Type I is a fuzzy or washed-out surface reflection followed by low-frequency reverberations (Figures 9 and 11). We interpret this to be highly gas-charged sediments that appear to absorb or attenuate most of the high frequencies and return a pulsing low-frequency reverberation. This is not a typical seismic response to sediments containing gas that usually causes a scattering of energy and wipe-out zone below. Figure 12 shows an example (and the only one in Lake Apopka) of what is normally expected from gas rich sediments. Perhaps an unusual combination of organic-rich sediment with high concentrations of biogenic gas created unique physical properties yielding this anomalous seismic response. The low frequency reverberations that follow below the surface return are of variable amplitude and sometimes sag significantly, suggesting a depression below the bottom (Figure 11). Alternatively, depressions associated with the fuzzy/low frequency reverberations may be a velocity pull-down effect caused by gaseous sediments

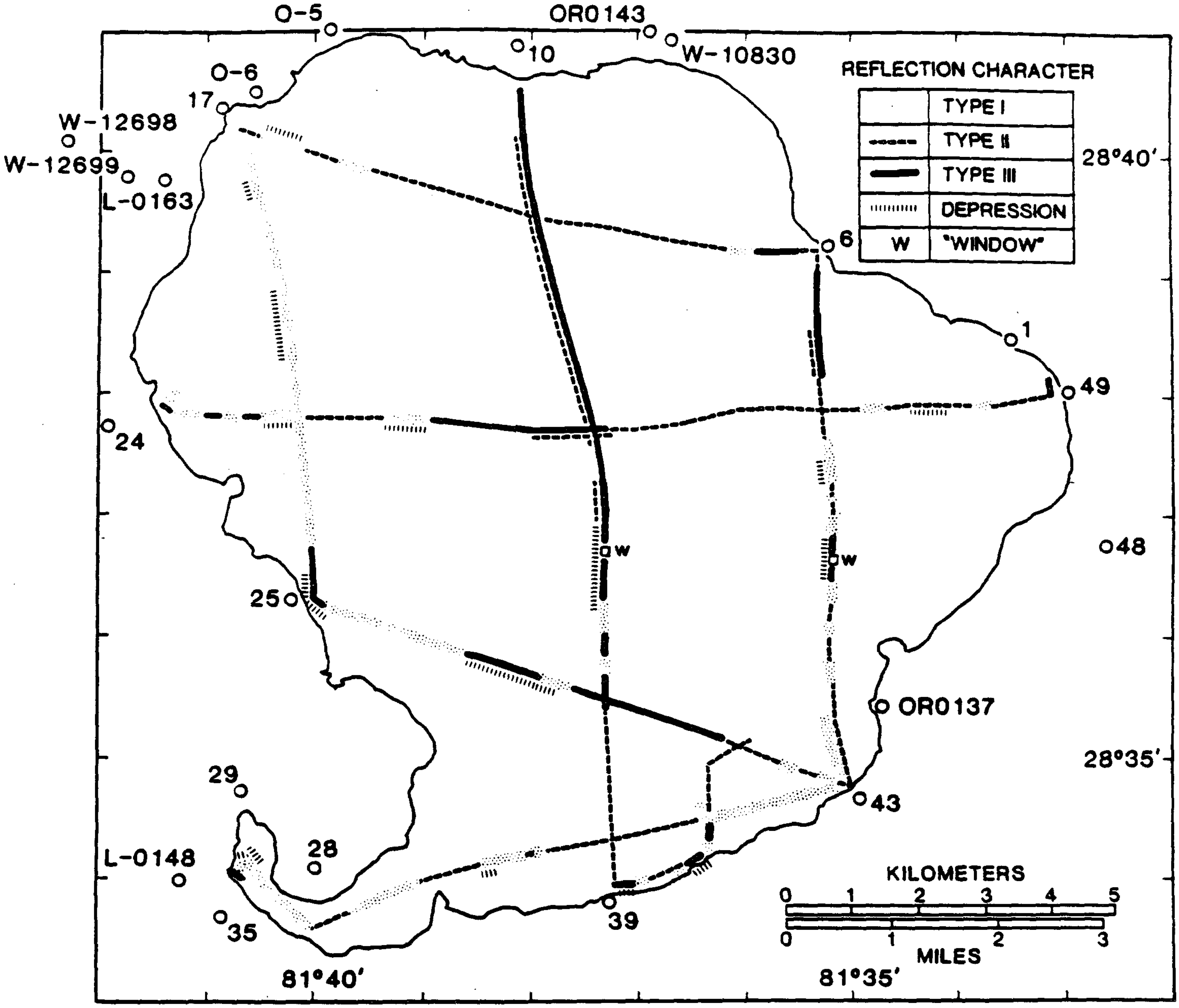

Figure 10. Reflection character. Type I is fuzzy with low frequency reverberations. Type II is normal without strong multiples. Type III is high-amplitude shallow subbottom with strong multiples.

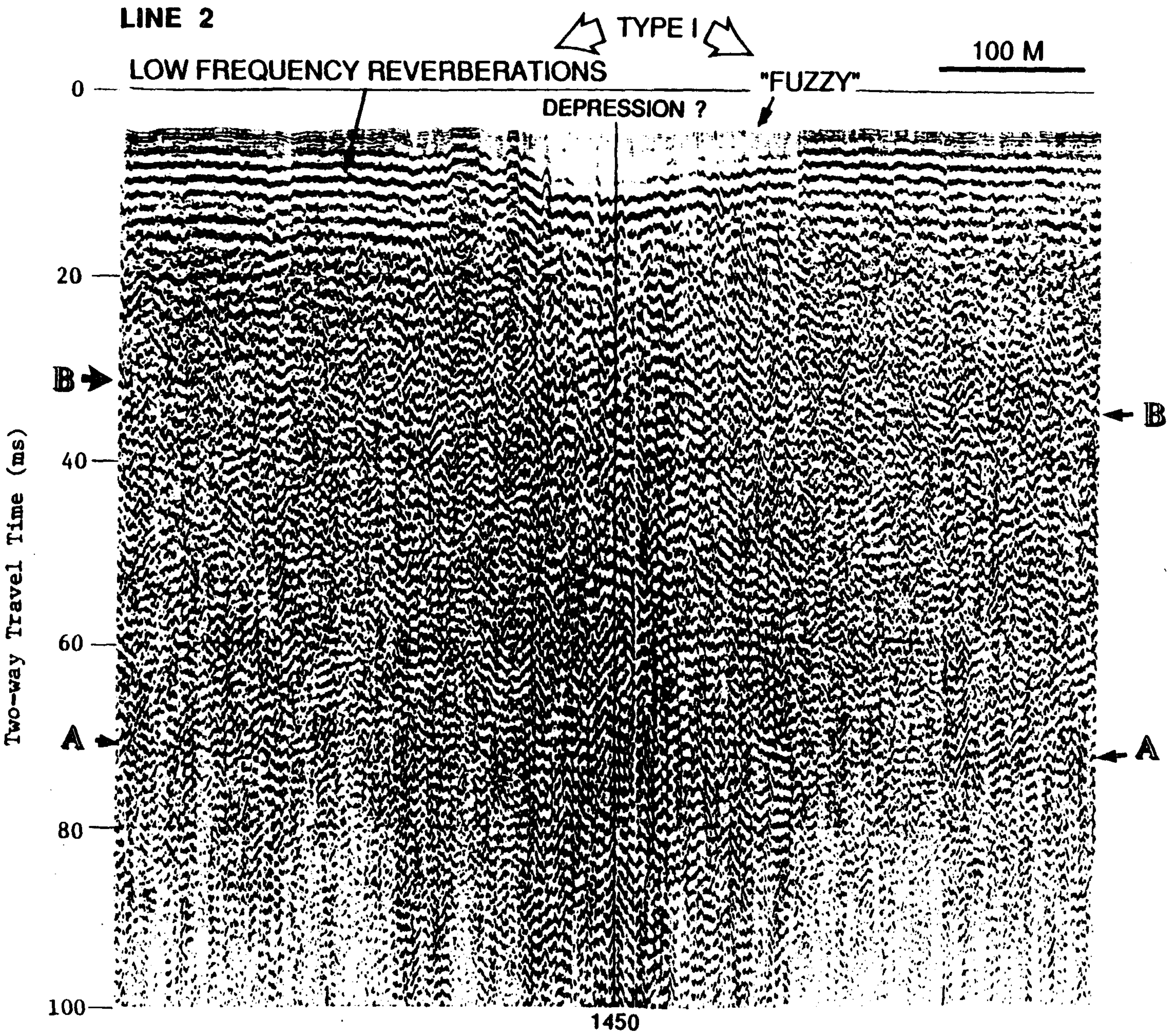

Figure 11. Section of seismic line 2. Reflection horizons A and B, and a shallow depression associated with the fuzzy (Type I) acoustic facies are shown. See figure 2 for location.

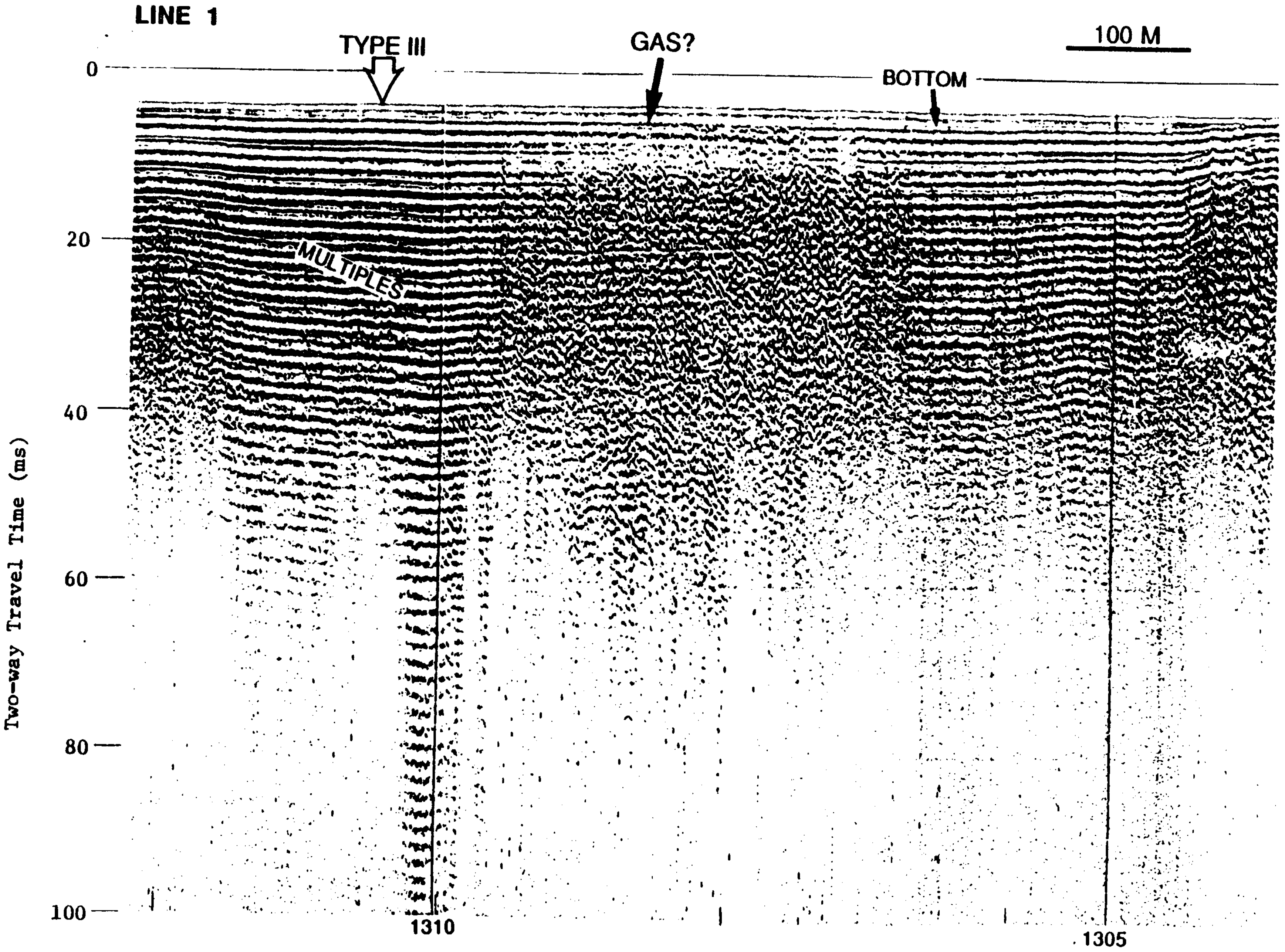

Figure 12. Section of seismic line 1 showing possible example of gas exhibiting a reflection character characterized by a "wipe-out" zone below. See Figure 2 for location.

along with the sharp attenuation of high frequency energy. Whether or not these features are real depressions or are acoustic artifacts requires field verification by probing.

Type II is a more normal seismic record without excessive multiples or problems caused by the seismic response of the near surface (Figures 8 and 13). Usually, the deeper portion of the seismic records are best in these areas.

Type III is characterized by strong ringing multiples that appear to follow a high-amplitude subbottom reflection horizon (Figures 8, 9, 12, and 13). This reflection type is often associated with shallow depressions and is commonly found in near-shore regions of the lake. The intensity of this type of reflector is indicative of a relatively flat, well lithified or compacted horizon that returns most of the seismic energy. However, it is sometimes difficult to distinguish between lake bottom multiples and a real subbottom base-of-sediment horizon. This is partly due to complicated geometries in reflection ray paths in the shallow water, as well as to the interference from gas in the sediments. For example, the direct arrival of the seismic signal arriving at the hydrophone through the water is often indistinguishable from the bottom return (Figures 8 and 9). Also, water depths which might be used to predict and distinguish a bottom multiple from a subbottom reflector are distorted in the seismic lines due to the non-vertical ray paths for the bottom arrival in shallow water. Verification of seismic interpretations and sediment thickness could be accomplished by a probe rod transect along tracklines.

Some patterns are evident in the spatial distribution of reflection types in Lake Apopka (Figure 10). The distinction between Types II and III is subtle, so in general there are two basic types; fuzzy/with restricted

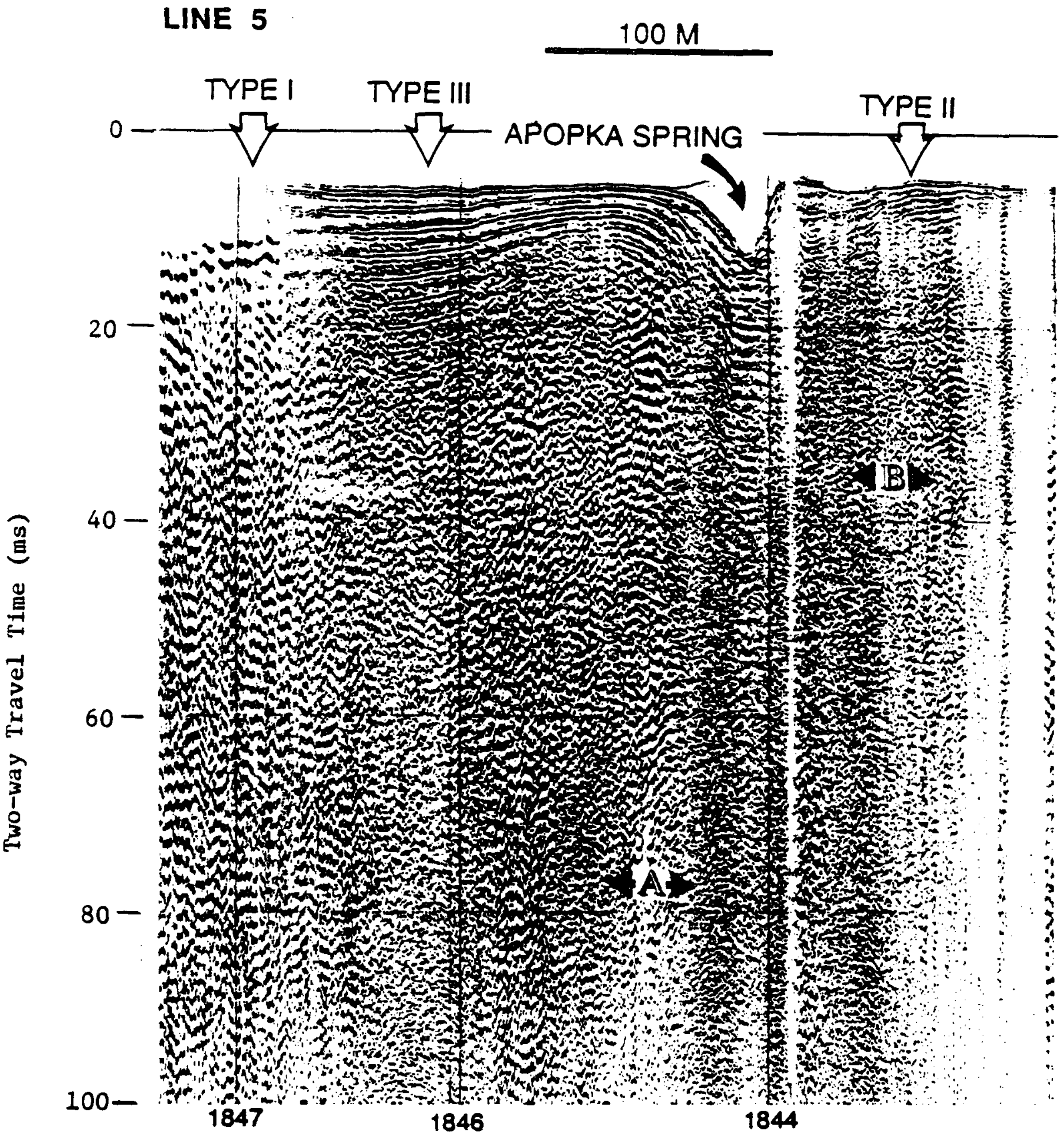

Figure 13. Section of seismic line 5 over Apopka Spring. Water depth over spring is approximately 9 meters (29.5 feet).

penetration (Type I), or strong bottom or subbottom returns (Type II and III). The Type I (fuzzy) reflection occurred over approximately 35% of trackline coverage, while 65% of the tracklines were of type II/III. Fuzzy reflections are found along the western and southeastern areas of the lake, while the other types are characteristic of the central, north and northeast areas of the lake.

Shallow depressions, which can occur independent of reflection type, underlie approximately 13% of the area surveyed, and appear to be absent at least from the NE quadrant of the lake. Some are clearly shallow structural features, exhibiting thicker sediment fill, and are probably depressions related to underlying limestone units. Because the sediment fill appears to be undisturbed, these depressions appear to be relict features. We found no evidence of recent collapse structures.

Deep Reflection Horizons

Line drawing interpretations of the seismic lines are shown in Figures 14A and 14B. They were normalized to a vertical exaggeration of 50X based on the average speed over each line. Below 20 milliseconds, numerous discontinuous reflectors were identified and two major subbottom horizons mapped. The major horizons, A and B, are highlighted by bolder line weights in Figure 14, which are only for emphasis and do not imply higher amplitudes. Our confidence in interpreting these horizons is based on two facts. The first is that we see corresponding horizons on intersecting lines, suggesting that a genuine acoustic discontinuity exists. The other is that we see a clear, indisputable reflection for horizon B that appears to be an unconformity in the "windows" on lines 4 and 7 (Figures 8 and 9).

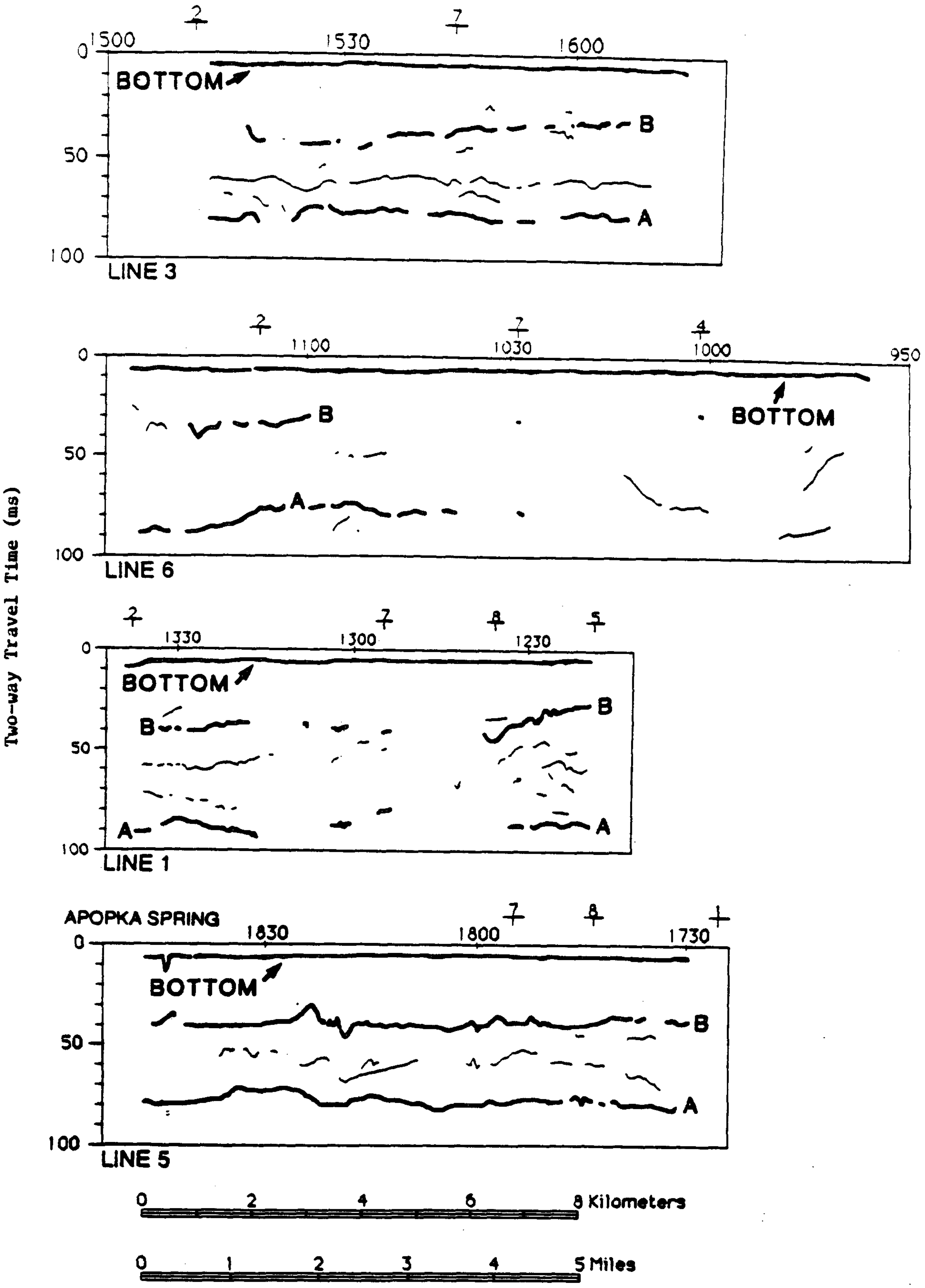

Figure 14A. Line drawing interpretations of east-west oriented seismic lines. Bold lines are used to highlight the lake bottom and horizons A and B. All lines are normalized to a vertical exaggeration of 50X. Location of crossing tie-lines and time are along top of section. Location of lines in Figure 2.

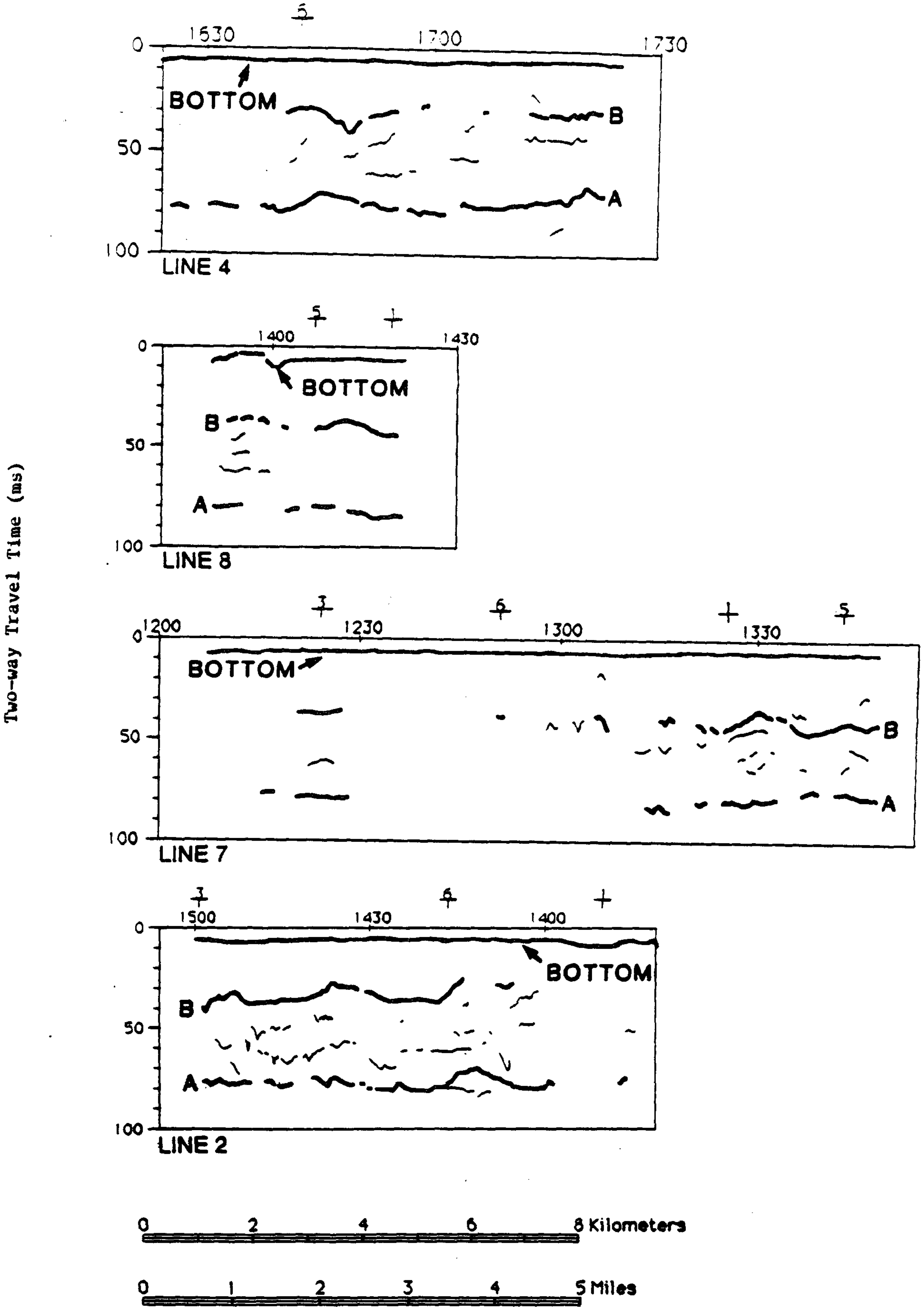

Figure 14B. Line drawing interpretation of north-south orientated seismic lines. See Figure 14A caption for additional description.

Our correlation between these horizons and local stratigraphy is shown in Figures 4 and 6. For an overall comparison, the range in depth to these horizons below Lake Apopka is overlaid with all well information in Figure 4. The velocities used to convert travel time to depths are estimates that resulted in reasonable correlations between the seismic horizons and wells close to the seismic lines in the northwest areas of the lake. The major assumption that is made is that seismic horizons correspond to lithologic boundaries in nearby wells. Verification of these calls would necessitate drilling on the lines. Typical velocities that might be expected for clastics in this setting might be on the order of 1600-2000 meters/second. Velocities for limestone can be highly variable, on the order of 2500-5000 meters/second. Constant velocity/depth values of 1900 and 2400 meters/second down to horizons B and A, respectively, gave reasonable correlations to well data.

In general, horizons A and B are irregular and discontinuous horizons that bound relatively flat-lying sections. Evidence of paleokarst features exist at depth, but are only expressed by subtle depressions in the lake bottom (Figures 14A and B). Structural contour maps on these horizons in milliseconds of two way travel time below the lake level are presented in Figures 15 and 16.

Reflection Horizon A

Analysis of stratigraphic information from well data and published maps indicates that horizon A is below the top of the Avon Park Formation as shown by Lichtler, et al. (1968) and may correspond to the top of the low porosity zone of Johnson (1979), also known as the dolomite zone of Lichtler, et al. (1968). Johnson (1979) identified the top of the low porosity zone at

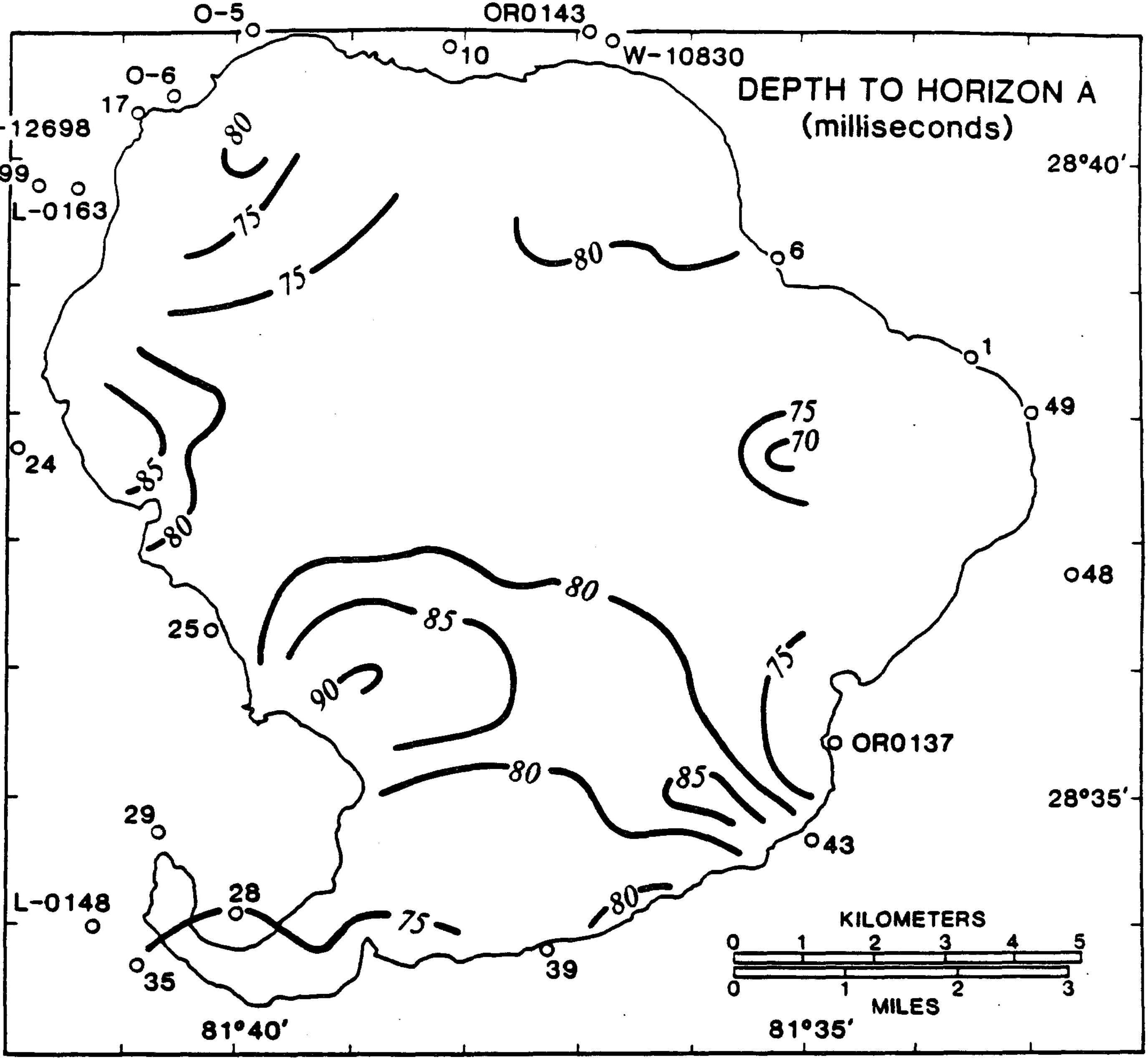

Figure 15. Depth to horizon A in milliseconds of two-way travel time below the lake level.

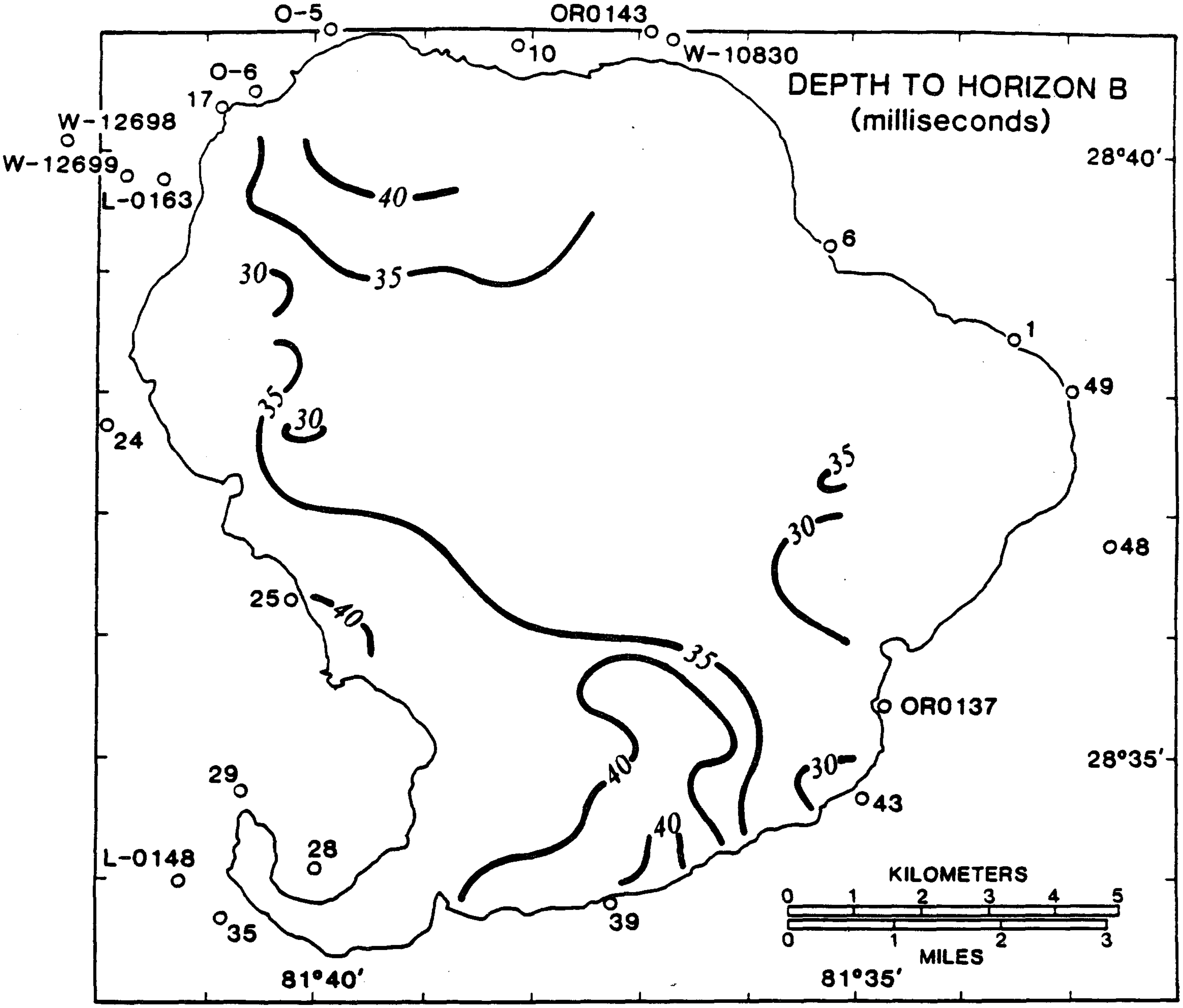

Figure 16. Depth to horizon B in milliseconds of two-way travel time below the lake level.

-241 ft_{MSL} and -262 ft_{MSL} in wells 0-5 and 0-6, respectively (Figure 4). The depth to our nearby horizon A at 80 milliseconds (Figure 15) equates to -250 ft_{MSL} using a constant velocity factor of 2400 meters/second (7874 ft/sec.). This velocity factor is estimated assuming a velocity component of less than 2000 meters/second for the section above the Ocala Group limestone and approximately 3000 meters/second for the limestone.

Horizon A spans a depth range of 70-90 milliseconds on the seismic records (211-289 feet below mean sea level using a velocity of 2400 meters/second) (Figures 4, 9 and 11). A low trough is indicated trending NW-SE across the southern half of the lake (Figure 15).

Reflection Horizon B

Horizon B occurs at a depth range of 30-40 ms below lake level (Figure 16). Assuming a velocity factor of 1900 meters/second (6234 ft/sec.), 30-40 milliseconds equates to 28-60 feet below mean sea level (Figure 4). Analyses of the available stratigraphic data suggest that horizon B corresponds most closely to the top of the Ocala Group limestone (Figure 6). Johnson (1979) places the top of the Ocala at -34 ft_{MSL} and -44 ft_{MSL} at wells 0-5 and 0-6. Assuming a velocity factor of 1900 m/s (6234 ft/sec), our 35 millisecond contour interval near well 0-6 equates to -44 ft_{MSL}, a good match. There is also reasonable correspondence between horizon B and the top of the Floridan Aquifer which is projected to be approximately -25 ft_{MSL} across the western side of Lake Apopka (Knochenmus, 1971; Scott and Hajishafie, 1980), and which has been recorded in deep wells around the lake (Figure 4).

Horizon B is an irregular surface suggestive of paleokarst features. On lines 4 and 7 (Figures 8 and 9), strong high-amplitude reflections are observed in the "windows" that correspond to horizon B. Also, a depression in the lake bottom on line 7 appears to correspond with dipping reflectors at depth. In this case the deeper structures, probably related to subsidence due to dissolution, are reflected as near surface depressions.

DISCUSSION

Significance

A primary objective of this study is the extrapolation of seismic reflection data to hydrogeology of Lake Apopka. Overall, we found no dramatic stratigraphic discontinuities below the lake or evidence of active sinkhole development. Shallow depressions are present and may be related to solution features in underlying limestone formations, but these depressions are apparently flat floored, containing undisturbed lake sediments. The only area of dramatic lake bottom relief is Apopka Spring in the southwestern extremity of the lake (Figure 13).

If horizon B is an accurate estimate of the top of the Ocala Limestone, which is the top of the Floridan Aquifer, then a rather consistent thickness of 20-25 meters of clastics and carbonates lies between the Floridan Aquifer and the lake bottom. The stratigraphic sequences overlying the Ocala Limestone could not be determined by seismic profiling. That will require vibracoring or drilling.

However in terms of water exchange through the lake bottom, the seismic reflection characteristics indicate that a blanket of organic-rich mud overlies a high-amplitude reflection surface which might confine the strata directly beneath the lake. Ground truthing is required to confirm this hypothesis and to test the accuracy of the seismic interpretations which are tentative and should be considered with caution.

Recommendations

Lack of ground truth in the lake leaves us uncertain about several aspects of the seismic data. A follow-up program that includes probing of sediment thickness and coring would help to calibrate the seismic data and provide essential lithofacies information. This would have direct relevance for interpretation and correlation of shallow stratigraphy and defining confining characteristics beneath Lake Apopka. Probe measurements to determine sediment thickness would verify the depth of subbottom and determine if the depressions associated with some fuzzy/low-frequency reverberation zones are acoustic artifacts or real features.

The issue of gas in the sediments and resulting affects on the seismic records needs to be addressed. Are the "fuzzy" zones really areas most highly charged with gas? Select sediment cores would shed some light on this problem.

A sediment coring program could also help assess the relationship between lake sediments and underlying material. Do limestones or clastics underlie lake sediments? Do the undifferentiated sands and clays of the surrounding shoreline ridges extend beneath the lake? This cannot be determined from the seismic data alone, but might be determined from cores.

A coring program would also provide a data base for studying the lake history and for the assessment of anthropogenic impacts. This could involve measurements of sedimentation rates and lithologic changes over time. Important parameters to measure are grain size, organic carbon content, and contaminants (metals, PCB's, pesticides, etc.).

CONCLUSIONS

Seismic reflection profiling in Lake Apopka provides insight to the nature of strata associated with the Floridan Aquifer, shallow solution features, and the character of near surface sediments. Interference from suspected gaseous sediments and intense reflections with multiples from a shallow horizon beneath lake sediments obscured much of the shallow portion of the seismic profiles. Additional field work involving sediment probing and coring is recommended to ground truth seismic interpretations and to provide a basis for more in-depth analyses of the seismic profiles. A sampling program, guided by the seismic reflection survey, would be fundamental to further assessment of stratigraphy and hydrogeology beneath Lake Apopka.

The principal findings are:

1. Two primary reflection horizons (A and B) were mapped and appear to correlate to the top of the Ocala Group limestone and top of a low porosity zone (dolomite zone) in the Avon Park Formation, respectively. These horizons are irregular and discontinuous, suggestive of paleokarst environments.
2. Major structural discontinuities, such as large sinkholes, were not found on the lines surveyed. The primary sequences below the lake appear to be relatively flat lying, but modified by solution processes. However, there is no evidence of active subsidence.
3. The structural contour map on horizon B indicates variations in the strata that closely correspond to the top of the Floridan Aquifer.
4. Shallow near-surface depressions are found in all areas of the lake (13% of tracklines) except in the central-northeast quadrant. These appear to be inherited from underlying Miocene to Eocene age limestone sequences.

5. Lake sediments appear to contain various amounts of gas (probably biogenically derived) that probably causes a fuzzy wipe-out zone in areas of high concentrations.
6. From the seismic reflection data we cannot be unequivocal about the hydrologic conditions related to exchange of water with the Floridan Aquifer. However, muddy sediments and an underlying lithified or compact surface suggests that little exchange between lake water and the deeper strata (aquifer) occurs.
7. A sediment probing and coring program is recommended to ground truth the seismic interpretations presented herein and to construct accurate stratigraphic sections for a more direct assessment of hydrogeology beneath Lake Apopka.

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APPENDIX I

Lake Apopka Navigation
Feb. 23-24, 1988

BOL = beginning of line
EOL = end of line

Corrected navigation:
Latitude shifted south 3 sec.
Longitude shifted west 8 sec.

	LORAN C POSITIONS (degree and decimal minutes)		CORRECTED POSITIONS (decimal degrees)		
TIME	Latitude	Longitude	Latitude	Longitude	
Date: 2/23/88					
1218	28 34.80	-81 34.93	28.57917	-81.58444	
1219	28 34.82	-81 34.98	28.57944	-81.58528	BOL 1
1226	28 34.92	-81 35.37	28.58111	-81.59167	
1230	28 35.02	-81 35.57	28.58278	-81.59500	
1238	28 35.18	-81 36.08	28.58556	-81.60361	
1240	28 35.22	-81 36.20	28.58611	-81.60556	
1247	28 35.37	-81 36.67	28.58861	-81.61333	
1250	28 35.42	-81 36.83	28.58944	-81.61611	
1255	28 35.52	-81 37.17	28.59117	-81.62172	
1300	28 35.61	-81 37.49	28.59267	-81.62706	
1305	28 35.71	-81 37.82	28.59433	-81.63256	
1310	28 35.81	-81 38.13	28.59600	-81.63772	
1315	28 35.90	-81 38.47	28.59750	-81.64333	
1320	28 35.97	-81 38.78	28.59867	-81.64856	
1325	28 36.04	-81 39.12	28.59983	-81.65422	
1330	28 36.15	-81 39.42	28.60167	-81.65922	
1333	28 36.24	-81 39.59	28.60317	-81.66206	
1338	28 36.32	-81 39.89	28.60450	-81.66706	EOL 1
1342	28 36.52	-81 39.77	28.60783	-81.66506	
1344	28 36.48	-81 39.67	28.60717	-81.66339	
1346	28 36.36	-81 39.70	28.60517	-81.66389	
1347:50	28 36.26	-81 39.76	28.60350	-81.66489	
1349:20	28 36.26	-81 39.87	28.60350	-81.66672	BOL 2
1355	28 36.60	-81 39.89	28.60917	-81.66706	
1400	28 36.90	-81 39.91	28.61417	-81.66739	
1405	28 37.18	-81 39.94	28.61883	-81.66789	
1410	28 37.45	-81 39.99	28.62333	-81.66872	
1415	28 37.75	-81 40.02	28.62833	-81.66922	
1420	28 38.04	-81 40.06	28.63317	-81.66989	
1425	28 38.33	-81 40.10	28.63800	-81.67056	
1430	28 38.62	-81 40.14	28.64283	-81.67122	
1435	28 38.90	-81 40.19	28.64750	-81.67206	
1440	28 39.18	-81 40.22	28.65222	-81.67250	
1445	28 39.43	-81 40.28	28.65639	-81.67361	
1450	28 39.74	-81 40.37	28.66150	-81.67506	
1455	28 40.02	-81 40.45	28.66611	-81.67639	
1500	28 40.27	-81 40.55	28.67028	-81.67806	EOL 2
1509	28 40.18	-81 40.62	28.66889	-81.67917	
1511	28 40.24	-81 40.54	28.66983	-81.67789	BOL 3
1518	28 40.11	-81 40.06	28.66767	-81.66989	
1520	28 40.05	-81 39.92	28.66667	-81.66756	
1525	28 39.93	-81 39.50	28.66472	-81.66056	
1530	28 39.82	-81 39.10	28.66283	-81.65389	
1535	28 39.72	-81 38.66	28.66117	-81.64656	
1541	28 39.57	-81 38.13	28.65867	-81.63772	
1545	28 39.47	-81 37.78	28.65700	-81.63189	

TIME	Latitude	Longitude	Latitude	Longitude	
1550	28 39.47	-81 37.42	28.65700	-81.62589	
1555	28 39.36	-81 36.90	28.65517	-81.61722	
1605	28 39.23	-81 36.01	28.65300	-81.60239	
1610	28 39.21	-81 35.58	28.65267	-81.59522	
1613	28 39.25	-81 35.30	28.65333	-81.59056	EOL 3
1625	28 39.25	-81 35.22	28.65333	-81.58917	BOL 4
1630	28 38.83	-81 35.23	28.64639	-81.58944	
1635	28 38.46	-81 35.20	28.64017	-81.58889	
1640	28 38.09	-81 35.14	28.63400	-81.58789	
1645	28 37.68	-81 35.17	28.62722	-81.58833	
1650	28 37.33	-81 35.10	28.62133	-81.58722	
1655	28 36.93	-81 35.07	28.61472	-81.58667	
1700	28 36.57	-81 35.08	28.60867	-81.58689	
1705	28 36.20	-81 35.10	28.60250	-81.58722	
1710	28 35.82	-81 35.11	28.59617	-81.58739	
1715	28 35.46	-81 35.05	28.59017	-81.58639	
1720	28 35.11	-81 35.01	28.58433	-81.58572	
1724:40	28 34.82	-81 34.91	28.57950	-81.58406	EOL4/BOL5
1730	28 34.75	-81 35.27	28.57833	-81.59006	
1735	28 34.68	-81 35.63	28.57717	-81.59606	
1740	28 34.59	-81 35.97	28.57567	-81.60172	
1745	28 34.51	-81 36.33	28.57433	-81.60772	
1750	28 34.42	-81 36.73	28.57283	-81.61439	
1755	28 34.35	-81 37.11	28.57167	-81.62072	
1800	28 34.30	-81 37.52	28.57083	-81.62756	
1805	28 34.23	-81 37.97	28.56967	-81.63506	
1806	28 34.20	-81 38.02	28.56917	-81.63589	
1810	28 34.16	-81 38.34	28.56850	-81.64122	
1815	28 34.08	-81 38.76	28.56717	-81.64822	
1817	28 34.00	-81 38.94	28.56583	-81.65122	
1820	28 33.92	-81 39.12	28.56450	-81.65422	
1825	28 33.78	-81 39.50	28.56217	-81.66056	
1830	28 33.65	-81 39.90	28.56000	-81.66722	
1835	28 33.90	-81 40.25	28.56417	-81.67306	
1838	28 34.09	-81 40.39	28.56733	-81.67539	
1839	28 34.16	-81 40.46	28.56850	-81.67656	
1840	28 34.15	-81 40.53	28.56833	-81.67772	
1842:30	28 34.09	-81 40.64	28.56733	-81.67956	
1846	28 34.09	-81 40.58	28.56733	-81.67856	EOL 5

Date: 2/24/88

0935	28 38.08	-81 33.01	28.63383	-81.55239	
0936	28 38.10	-81 33.00	28.63417	-81.55222	BOL 6
0940	28 37.99	-81 33.28	28.63233	-81.55689	
0945	28 37.96	-81 33.70	28.63183	-81.56389	
0950	28 37.95	-81 34.20	28.63167	-81.57222	
0955	28 37.94	-81 34.61	28.63150	-81.57906	
1000	28 37.90	-81 35.03	28.63083	-81.58606	
1005	28 37.93	-81 35.41	28.63133	-81.59239	
1010	28 37.91	-81 35.86	28.63100	-81.59989	
1015	28 37.85	-81 36.23	28.63000	-81.60606	
1021	28 37.79	-81 36.70	28.62900	-81.61389	
1026	28 37.76	-81 37.10	28.62850	-81.62056	
1030	28 37.74	-81 37.40	28.62817	-81.62556	
1035	28 37.75	-81 37.81	28.62833	-81.63239	
1040	28 37.77	-81 38.20	28.62867	-81.63889	

TIME	Latitude	Longitude	Latitude	Longitude	
1045	28 37.79	-81 38.55	28.62900	-81.64472	
1050	28 37.82	-81 38.89	28.62950	-81.65039	
1055	28 37.82	-81 39.22	28.62950	-81.65589	
1100	28 37.85	-81 39.55	28.63000	-81.66139	
1105	28 37.85	-81 39.89	28.63000	-81.66706	
1110	28 37.84	-81 40.21	28.62983	-81.67239	
1115	28 37.86	-81 40.53	28.63017	-81.67772	
1120	28 37.86	-81 40.84	28.63017	-81.68289	
1125	28 37.92	-81 41.14	28.63117	-81.68789	
1126:30	28 37.95	-81 41.25	28.63167	-81.68972	EOL 6
1130	28 38.07	-81 41.13	28.63367	-81.68772	
1206	28 40.54	-81 38.01	28.67483	-81.63572	
1209	28 40.46	-81 37.95	28.67350	-81.63472	BOL 7
1212	28 40.25	-81 37.95	28.67000	-81.63472	
1215	28 40.08	-81 37.93	28.66717	-81.63439	
1220	28 39.76	-81 37.88	28.66183	-81.63356	
1225	28 39.43	-81 37.82	28.65639	-81.63250	
1230	28 39.12	-81 37.73	28.65117	-81.63106	
1235	28 38.78	-81 37.63	28.64556	-81.62944	
1240	28 38.48	-81 37.54	28.64050	-81.62789	
1245	28 38.15	-81 37.45	28.63500	-81.62639	
1250	28 37.80	-81 37.33	28.62917	-81.62444	
1255	28 37.49	-81 37.21	28.62400	-81.62239	
1259	28 37.26	-81 37.17	28.62017	-81.62172	
1300	28 37.18	-81 37.19	28.61883	-81.62206	
1305	28 36.85	-81 37.18	28.61333	-81.62189	
1310	28 36.52	-81 37.20	28.60783	-81.62222	
1316	28 36.16	-81 37.19	28.60183	-81.62206	
1320	28 35.86	-81 37.18	28.59683	-81.62189	
1325	28 35.53	-81 37.17	28.59133	-81.62172	
1330	28 35.20	-81 37.15	28.58583	-81.62139	
1335	28 34.86	-81 37.15	28.58017	-81.62139	
1340	28 34.53	-81 37.11	28.57467	-81.62072	
1345	28 34.20	-81 37.10	28.56917	-81.62056	
1348	28 34.00	-81 37.10	28.56583	-81.62056	EOL7/BOL8
1350	28 33.97	-81 36.97	28.56533	-81.61839	
1355	28 34.03	-81 36.67	28.56639	-81.61333	
1358	28 34.13	-81 36.42	28.56800	-81.60922	
1400	28 34.18	-81 36.34	28.56883	-81.60789	
1402	28 34.23	-81 36.23	28.56967	-81.60606	
1405	28 34.42	-81 36.21	28.57283	-81.60572	
1408:30	28 34.62	-81 36.24	28.57617	-81.60622	
1410	28 34.70	-81 36.23	28.57750	-81.60606	
1414	28 34.94	-81 36.24	28.58150	-81.60622	
1416	28 35.02	-81 36.14	28.58283	-81.60456	
1420	28 35.17	-81 35.88	28.58533	-81.60022	EOL 8
1421	28 35.19	-81 35.82	28.58567	-81.59922	

APPENDIX IIA

WELL LOCATIONS

Well ID	Latitude			Longitude			TD (ft) (versus land surface)
Source: SJRWMD*							
1	28°	38'	27"	-81°	33'	35"	67
6	28°	39'	13"	-81°	35'	18"	32
10	28°	40'	52"	-81°	38'	08"	54
17	28°	40'	22"	-81°	40'	52"	32
24	28°	37'	44"	-81°	41'	54"	57
25	28°	36'	17"	-81°	40'	13"	82
28	28°	34'	03"	-81°	40'	00"	47
29	28°	34'	43"	-81°	40'	41"	32
35	28°	33'	41"	-81°	40'	52"	57
39	28°	33'	47"	-81°	37'	17"	52
43	28°	34'	39"	-81°	34'	57"	52
48	28°	36'	44"	-81°	32'	38"	37
49	28°	38'	01"	-81°	33'	00"	55
Source: SJRWMD*							
OR 0137	28°	35'	24"	-81°	34'	47"	202
OR 0143	28°	40'	59"	-81°	36'	54"	215
L-0148	28°	33'	59"	-81°	41'	15"	132
L-0163	28°	39'	46"	-81°	41'	23"	233
Source: Johnson (1986) Florida Geological Survey (CIRCULAR 103)							
W-12698	28°	40'	06"	-81°	42'	16"	123
W-12699	28°	39'	48"	-81°	41'	43"	132
W-12701	28°	41'	48"	-81°	46'	25"	225
W-12702	28"	43'	17"	-81°	40'	39"	302
W-10830	28°	40'	55"	-81°	36'	42"	213
Source: Johnson (1979) well locations estimated from his figure 2.							
0-4	28°	41.5'		-81°	36.40'		154
0-5	28°	40.56'		-81°	39.49'		406
0-6	28°	40.26'		-81°	40.30'		408

*St. Johns River Water Management District

APPENDIX IIB

WELL INTERVAL DATA

Formation depths (in feet) and sample interval information for deep wells.

A. Johnson, 1986; Florida Geological Survey, Information Circular 103
[Well I.D., Elevation, TD below surface]

W-12701	Elev. = 160 ft.	TD = 225 ft.	
Depth	160 — 87	Undifferentiated	
	87 — 66	Coosawhatchie FM	Hawthorn Group
	66 — 60	Marks Head FM	
	60 — 39	Penny Farms FM	
	39 — -5	Crystal River FM	Ocala Group
	-5 — -53	Williston FM	
	-53 — -65	Avon Park FM	

W-12702	Elev. = 68 ft.	TD = 302 ft.
	68 — -234	Quartz sand and clay

W-12698	Elev. = 68 ft.	TD = 123 ft.	
	68 — -19	Undifferentiated	
	-19 — -45	Penny Farms FM	Hawthorn Group
	-45 — -55	Williston FM	Ocala Group

W-12699	Elev. = 68 ft.	TD = 132 ft.	
	68 — -31	Undifferentiated	
	-31 — -37	Marks Head FM	Hawthorn Group
	-37 — -56	Penny Farms FM	
	-56 — -64	Crystal River FM	Ocala Group

W-10803	Elev. = 65 ft.	TD = 213 ft.	
	65 — -23	Undifferentiated	
	-23 — -73	Hawthorn Undiff.	Hawthorn Group
	-73 — -148	Penny Farms FM	

B. Well data from Johnson, 1979

0-4	Elev. = 131 ft.	TD = 154 ft.
131	surface	
108	TOP HAWTHORN	
-19	TOP OCALA	
-23	TD vs MSL	

0-5	Elev. = 78 ft.	TD = 406 ft.
78	surface	
51	TOP HAWTHORN	
-34	TOP OCALA	
-83	TOP AVON PARK	
-241	LOW POROS. ZONE	
-328	TD vs MSL	

0-6	Elev. = 71 ft.	TD = 408 ft.
71	surface	
14	TOP HAWTHORN	
-44	TOP OCALA	
-104	TOP AVON PARK	
-262	LOW POROS. ZONE	
-337	TD vs MSL	

C. U. S. Geological Survey well data.

OR 0137	Elev. = 71 ft.	TD = 202 ft.
71	surface	
-59	TOP FLORIDAN	
-131	TD vs MSL	

OR 0143	Elev. = 64 ft.	TD = 215 ft.
64	surface	
-24	TOP FLORIDAN	
-151	TD vs MSL	

L-0148	Elev. = 79.51 ft.	TD = 132 ft.
79.51	surface	
-21.49	TOP FLORIDAN	
-52.49	TD vs MSL	

L-0163	Elev. = 70.4 ft.	TD = 233 ft.
70.4	surface	
-119.6	TOP FLORIDAN	
-162.6	TD vs MSL	