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DEPARTMENT OF COMMERCE · UNITED STATES OF AMERICA

DEEP-SEA TIDE OBSERVATIONS OFF THE SOUTHEASTERN UNITED STATES

Carl A. Pearson

Rockville, Md.
December 1975

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DEEP-SEA TIDE OBSERVATIONS OFF THE SOUTHEASTERN UNITED STATES

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ABSTRACT. A deep-sea tide gage was placed on the ocean bottom 425 km east of Jacksonville, Fla., for a period of 6 months. The tide range was observed to be about half of that found at adjacent coastal locations and was in agreement with the range estimated by Redfield (1958).

INTRODUCTION

Until recently knowledge of the tides in the open ocean has been based almost entirely on coastal observations. Unfortunately, coastal tides are greatly influenced by local topography and prevalent weather. A need for offshore measurements has long existed, but logistic and technological problems have prevented extensive observational programs. With the present interest in the continental shelves as a source of energy and food and as an avenue of commerce, it is increasingly important that we know something of how tidal characteristics change as the tide wave progresses from the deep ocean, across the continental shelf, and into the coastal zone.

One of the applications of offshore tidal data is their use as corrections to ensure accurate bathymetric mapping of the continental shelves. To this end, a deep-sea tide gage was deployed as part of the Southern Coastal Plains Expedition (SCOPE), a combined hydrographic/oceanographic project of the National Ocean Survey. The deep-sea tide data will be used to aid in the reduction of soundings, as well as to develop a further understanding of tidal processes across the continental shelf.

The deep-sea tide gage was located about 425 km east of Jacksonville, Fla., just seaward of the Blake Plateau in a position determined by Loran A at 30°26'N, 76°25'W, at a depth of 3,766 m as shown in figure 1. The gage was emplaced on September 18, 1973, and recovered March 20, 1974. The 180-day record obtained with this gage is one of the longest tide series obtained so far in the deep Atlantic Ocean.

Preliminary analysis of these data indicates reasonable agreement with Redfield's (1958) theory of tides along the east coast of the United States. Further efforts will focus on relating additional tidal observations to this theory and on applications to bathymetric mapping. As part of this continuing effort to provide better spatial definition of the tidal characteristics, additional deep-sea and related coastal tide gages have since been installed in the SCOPE project area. The results of this effort will be available at a later date. This paper presents a preliminary analysis of the data currently available.

INSTRUMENTATION

The tide gage used during this project is equipped with a Bourdon tube pressure transducer with a frictionless optical readout (Filloux 1970, 1971). Relative pressure was recorded twice per hour on a Rustrak strip-chart recorder controlled by an Accutron timer.

Figure 2 shows the mooring configuration used. The tide gage is housed in a 66-cm internal diameter aluminum sphere mounted on an aluminum instrument base. Flanking the tide gage are two AMF acoustic release transponders. They are connected to the anchor base tripod by a chain in such a way that the instrument base will be freed from the tripod when either release mechanism fires. Floatation is provided by a syntactic foam buoy connected to the instrument base by 37 m of cable.

DATA REDUCTION

The Accutron timer in the tide gage showed a drift of 100 minutes over the 6-month period. The time was checked prior to deployment and immediately after recovery and, since the gage was in a relatively constant environment while on the bottom, it was assumed that the clock drift rate was constant. This assumption has since been confirmed by laboratory tests. Data were tabulated at (approximately) one-hour intervals and a time correction factor was applied during analysis.

The Bourdon tube is subject to creep resulting from the intense abyssal pressure at operating depth. The creep, which has been found empirically to approximate a logarithmic curve, results in an apparent gradual monotonic increase in sea-level pressure. The rate of creep, usually about 50 to 100 mb during the first month of deployment, decreases with time. Creep was corrected by least squares fitting the data to the curve

$$Y = A + B \ln (\Delta T),$$

where Y is the creep curve in mb, and ΔT is the time elapsed in hours since the gage was emplaced on the ocean bottom. This curve was then subtracted from the data. A 15-day portion of the series beginning January 1, 1974, is plotted in figure 3.

TIDE ANALYSIS

The data were analyzed for tidal components by the response method (Munk and Cartwright, 1966). For the analysis of deep-sea tides, the response method gives results which are slightly better than those obtained by traditional harmonic methods (B. Zetler, personal communication). It also has a certain physical advantage in that it measures the ocean's response to the gravitational potential itself, rather than analyzing the data for a set of predetermined frequencies. In the response method, a set of complex response weights is computed, and from these the system's admittance (ratio of output to input and phase shift) is computed at each desired frequency.

The procedure for analysis was based on that suggested by Cartwright et al. (1969). Since deep-sea tide records are remarkably noise-free and this was a relatively long series, the gravitational potential was used as the reference series. The predicted deep-sea series can then be used as a reference in the analysis of nearby shore station data.

Table 1 gives the admittances and associated harmonic constants for the major diurnal and semidiurnal tide lines. An estimate of standard error per lunar month, defined by Cartwright et al. (1969) as

$$\text{S.E.} = \left(\frac{1}{2} \cdot \frac{\text{residual variance}}{\text{recorded variance}} \cdot \frac{27.3}{\text{days of series}} \right)^{\frac{1}{2}},$$

is given for each species.

The tide is predominantly semidiurnal, which is characteristic of east coast tides, and admittance amplitudes for the diurnal tides are relatively constant. However, for the semidiurnal species, the admittance amplitudes decrease rapidly with increasing frequency and have correspondingly large phase shifts. A similar situation exists in the tides of Bermuda and the Azores, a condition that Wunsch (1972) attributes to a weak natural resonance (with a period of 14.8 hours) in the North Atlantic basin. Both diurnal and semidiurnal amplitudes are approximately 25% larger at the SCOPE deep-sea site than those observed during the Mid-Ocean Dynamics Experiment (MODE) with gages located about 700 km to the ESE (Zetler et al. 1975). The phases of both species are slightly earlier at the SCOPE location than at the MODE sites.

The gravitational tide was removed from the record to leave the residual long-period tides and nontidal pressure fluctuations. This series was then low-passed with a cutoff of 30 hours using a Lanczos filter and decimated to one point every

4 hours. This series, starting September 25, 1973, has been plotted in figure 4. The fluctuations are similar to those observed by the MODE pressure sensors. Significant coherence was found among the MODE bottom pressures and the calculated Bermuda bottom pressure, while little coherence was observed between atmospheric and bottom pressure fluctuations (Brown et al. 1975).

The power spectrum of the residual series over the frequency range of 0 to 10 cycles per lunar month is shown in figure 5. The energy within each frequency band increases with decreasing frequency. Peaks are found at periods of about 30 days, 14 days, and at higher harmonics of those periods. Most likely, these are due to the monthly and fortnightly tides, although weather factors undoubtedly contribute.

TIDES ACROSS THE CONTINENTAL SHELF

A tidal data series from the gage at Savannah Beach for the 3-month period, October through December 1973, was analyzed using the response method, and a reference series computed from the weights of the deep-sea record (table 2). For the diurnal species, the admittance amplitudes are approximately equal to unity, and the phase at Savannah Beach lags the deep-sea station by slightly less than an hour. On the other hand, amplitudes for the semidiurnal species at Savannah Beach are approximately twice those of the deep-sea station.

Redfield (1958) hypothesized that the tides along the east coast of the United States may be approximated by a co-oscillating tide analogous to tides in embayments. He used the method of Defant (cf. Proudman, 1953) to estimate the range of the M_2 tide across the continental shelf. Figure 6 shows a profile of depth and of the M_2 amplitude, computed by the Defant method, on a line between the deep-sea location and Savannah Beach. The computed range of the M_2 at the deep-sea site is 45 percent of that at Savannah Beach, which is quite close to the observed range of M_2, considering that the Defant method neglects friction and assumes a pure standing wave. The observed M_2 phase difference between the two gages, 0.6 hour, is also in agreement with that estimated for this area by Redfield (1958).

Similar computations were carried out for the K_1 tide (not shown). The Defant method predicted little amplification for the diurnal tide across the continental shelf. This appears to be verified by the observed data, although the lower signal-to-noise ratio of the diurnal band introduces greater uncertainty.

ACKNOWLEDGMENTS

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Table 1.—Deep-sea tide response analysis. Station units are millibars, reference is gravitational potential in centimeters.

Station: SCOPE Deep Sea Tide Gage

Reference: gravitational potential

$C_2^{1,2}$ (0, ±48, ±96)

September 18, 1973 to March 20, 1973
(180 days)

Lat. 30°26N
Long. 76°25W
Depth 3766 meters

Frequency (CPD)	Admittance, station to reference REAL	IMAG	Amplitude (R)	Phase lead (°)	Harmonic constants: Harmonic constituents	H (mb)*	G (°)	K (°)
0.8929	0.2787	-0.0179	0.2793	-3.7	Q_1	1.4	183.8	107.4
0.8932	0.2787	-0.0187	0.2793	-3.8	O_1	7.4	194.3	117.9
0.9295	0.2737	-0.0697	0.2824	-14.3	M_1	0.6	192.4	116.0
0.9661	0.2630	-0.0577	0.2692	-12.4	P_1	3.2	189.8	113.4
0.9973	0.2575	-0.0443	0.2613	-9.8	K_1	9.7	189.8	113.4
1.0027	0.2590	-0.0448	0.2629	-9.8	J_1	0.7	194.6	118.2
1.0393	0.3085	-0.0802	0.3188	-14.6				
	Predicted variance 84.0 mb2		SE = 1.4%	0.8°				
1.8591	0.8343	0.5296	0.9883	32.4	μ_2	1.9	-32.4	174.7
1.8960	0.8156	0.3687	0.8950	24.3	N_2	10.8	-24.3	182.9
1.9323	0.6970	0.0292	0.6976	2.4	M_2	44.1	-2.4	204.8
1.9689	0.4902	-0.2089	0.5329	-23.1	L_2	1.0	23.1	230.3
2.0000	0.2606	-0.1109	0.2833	-23.1	S_2	8.3	23.1	230.3
2.0055	0.2168	-0.0585	0.2246	-15.1	K_2	1.8	15.1	222.3
	Predicted variance 1089 mb2		SE = 0.9%	0.5°				

*1.00 mb ≈ 1.01 cm sea water

Total recorded variance	1183.38 mb^2	= 99.15%
Total predicted variance	1173.34 mb^2	
Residual variance	10.04 mb^2	

Table 2.— Savannah Beach response analysis. Stations units in centimeters, reference is deep-sea prediction in millibars.

Station: Savannah Beach

Reference: "Predicted" SCOPE deep-sea tide gage

$X_2^{1,2}$ (0,±48)

October 1, 1973 to December 31, 1973 (92 days)

Lat. 31°57.0N
Long. 80°40.8W

Frequency (CPD)	Admittance, station to reference REAL	IMAG	Amplitude (R)	Phase lead (°)	Harmonic constants	H (cm)	G (°)	K (°)
0.8932	1.1726	-0.1358	1.1805	-6.6	Q_1	1.7	190.4	109.7
0.9295	1.0393	-0.1804	1.0548	-9.8	O_1	7.8	204.1	123.4
0.9661	0.9513	-0.2115	0.9746	-12.5	M_1	0.6	204.9	124.2
0.9973	0.9273	-0.2221	0.9536	-13.5	P_1	3.1	203.3	122.6
1.0027	0.9284	-0.2227	0.9546	-13.5	K_1	9.3	203.3	122.6
1.0393	0.9752	-0.2103	0.9976	-12.2	J_1	0.7	206.8	126.1
	Predicted variance 91.2 cm^2							
1.8591	1.3144	-0.4767	1.3982	-19.9	μ_2	2.7	-12.5	186.1
1.8960	1.6732	-0.5383	1.7577	-17.8	N_2	19.0	-6.5	192.1
1.9323	1.9009	-0.5792	1.9871	-16.9	M_2	87.6	14.5	213.1
1.9689	1.9571	-0.5921	2.0447	-16.8	L_2	2.0	39.9	238.5
2.0000	1.8582	-0.5785	1.9461	-17.3	S_2	16.2	40.4	239.0
2.0055	1.8276	-0.5739	1.9156	-17.4	K_2	3.4	32.5	231.1
	Predicted variance 4002. cm^2							

Total recorded variance 4453.18 cm^2
Total predicted variance 4093.59 cm^2 = 91.93%
Residual variance 359.58 cm^2

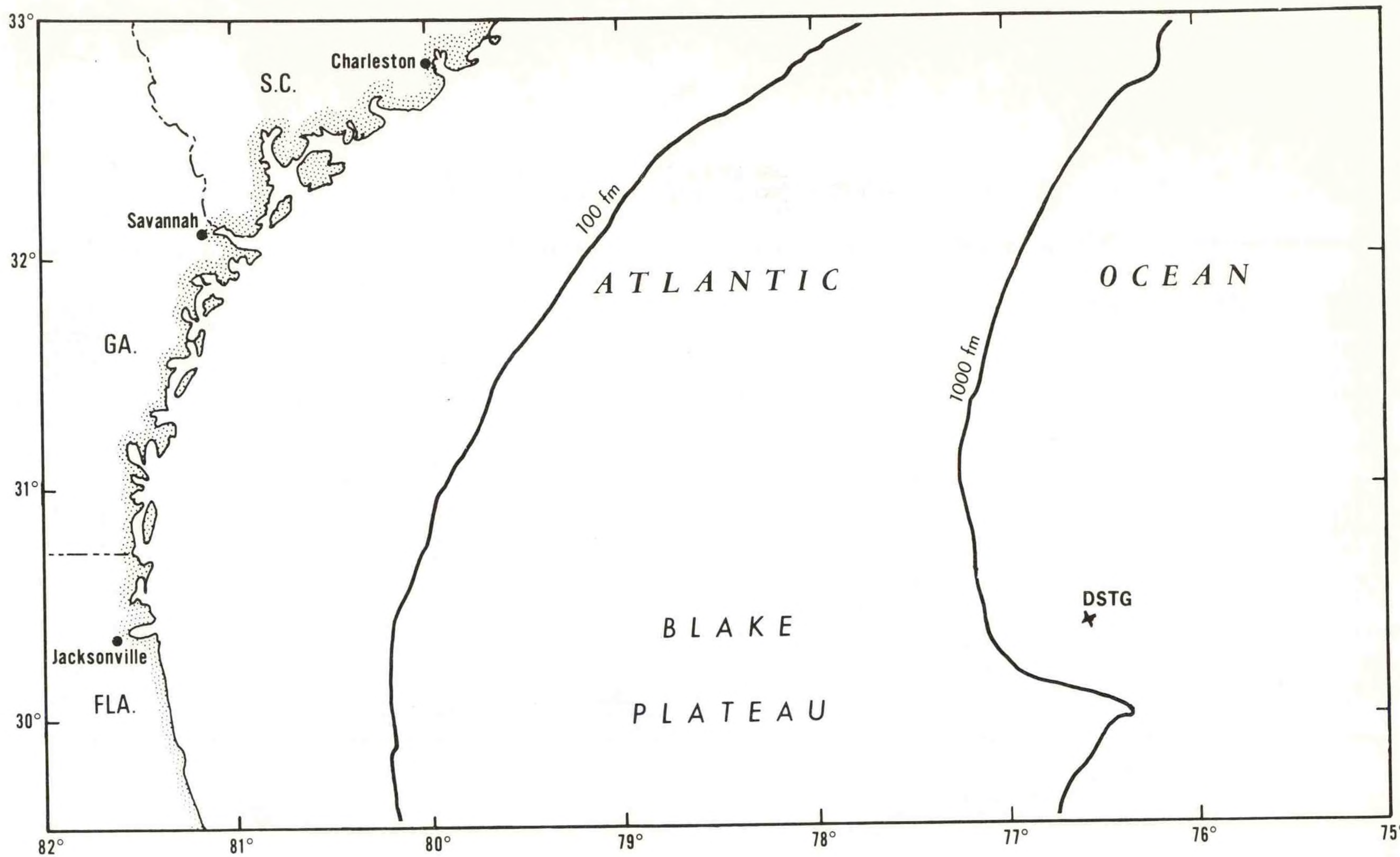

Figure 1--Location of the deep-sea tide gage (DSTG).

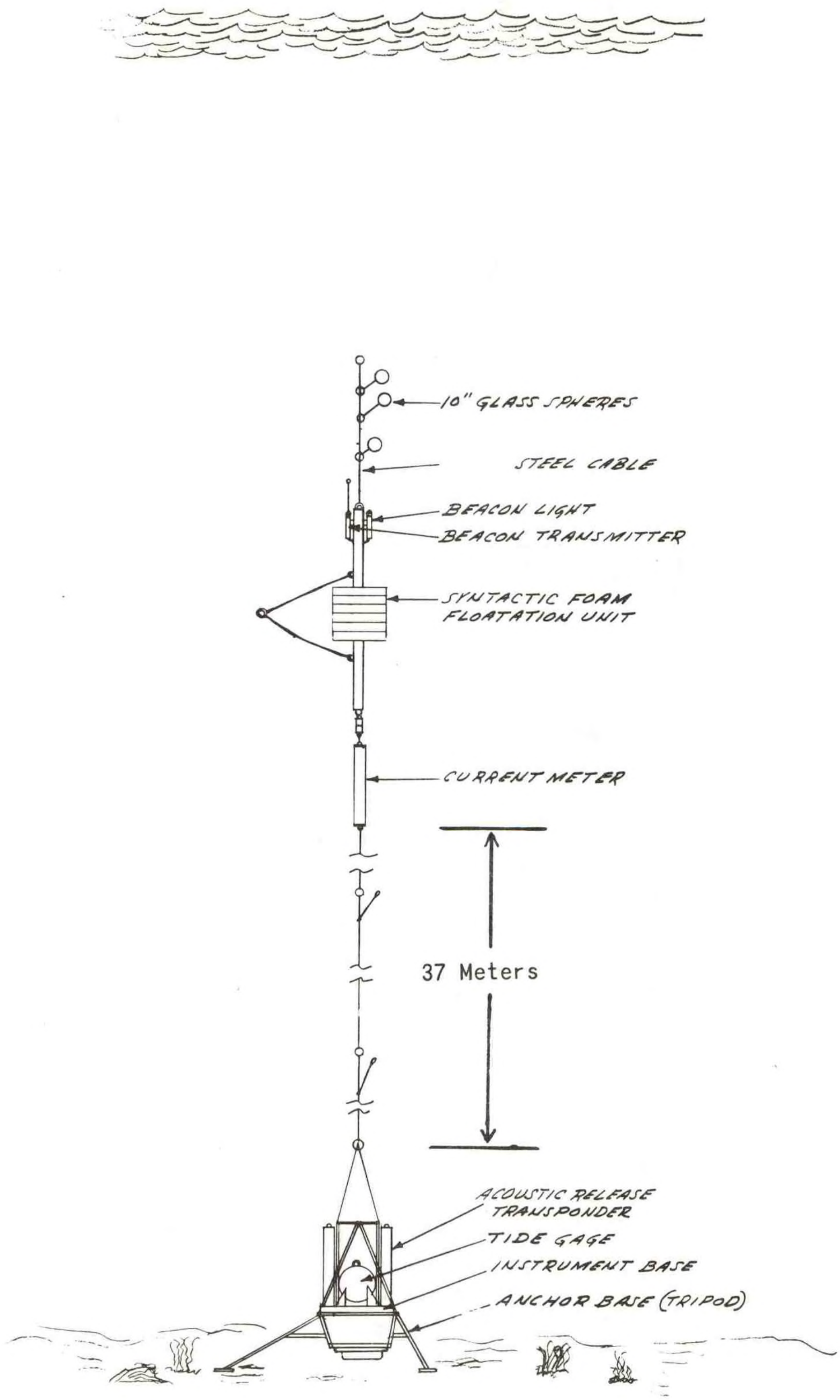

Figure 2--Mooring configuration of the deep-sea tide gage system.

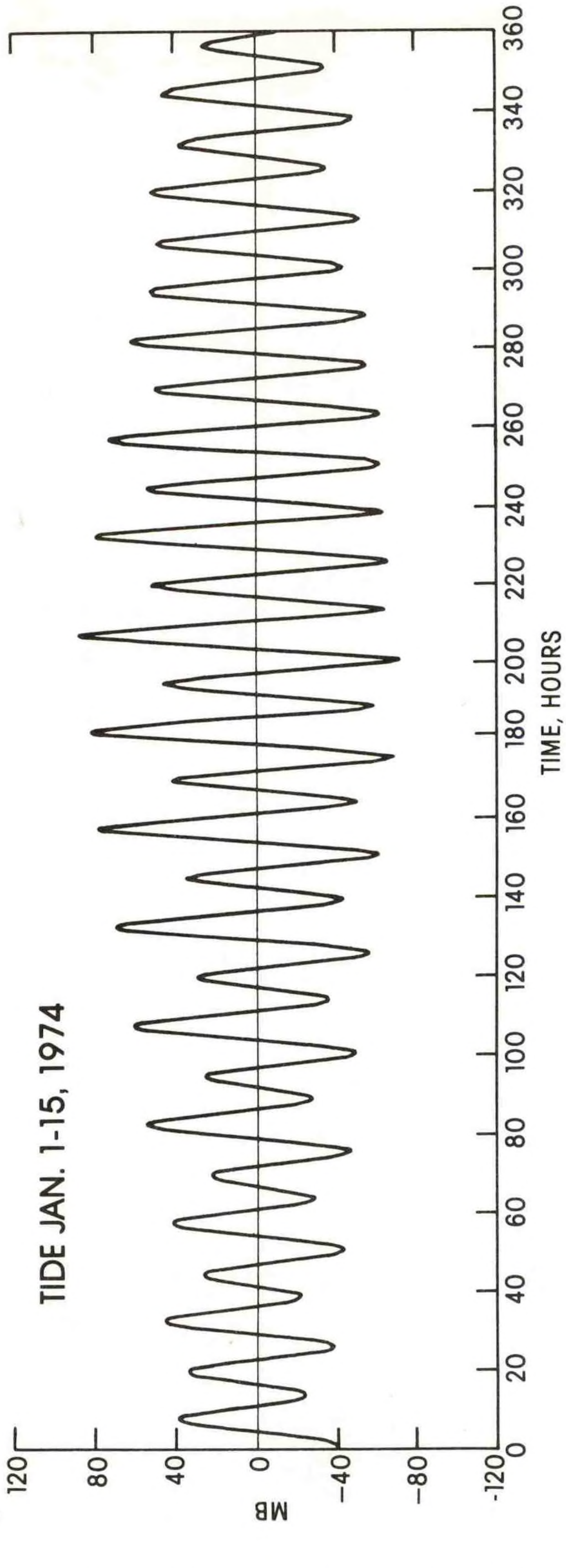

Figure 3--Plot of a 15-day sample of the deep-sea tide record, January 1-15, 1974.

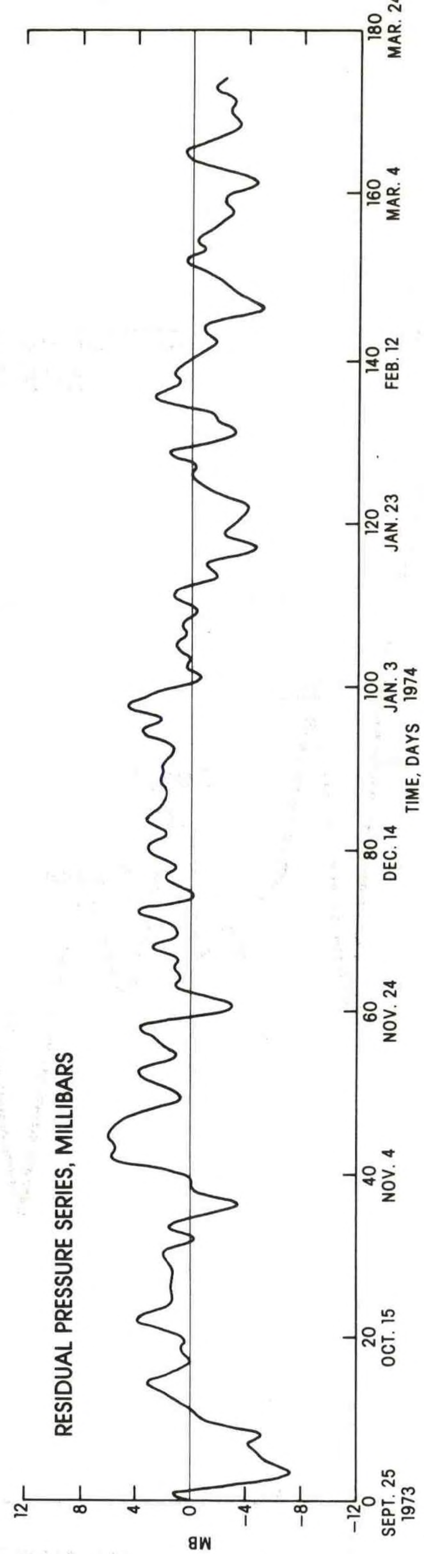

Figure 4--Plot of the residual pressure series, September 25, 1973, to March 24, 1974.

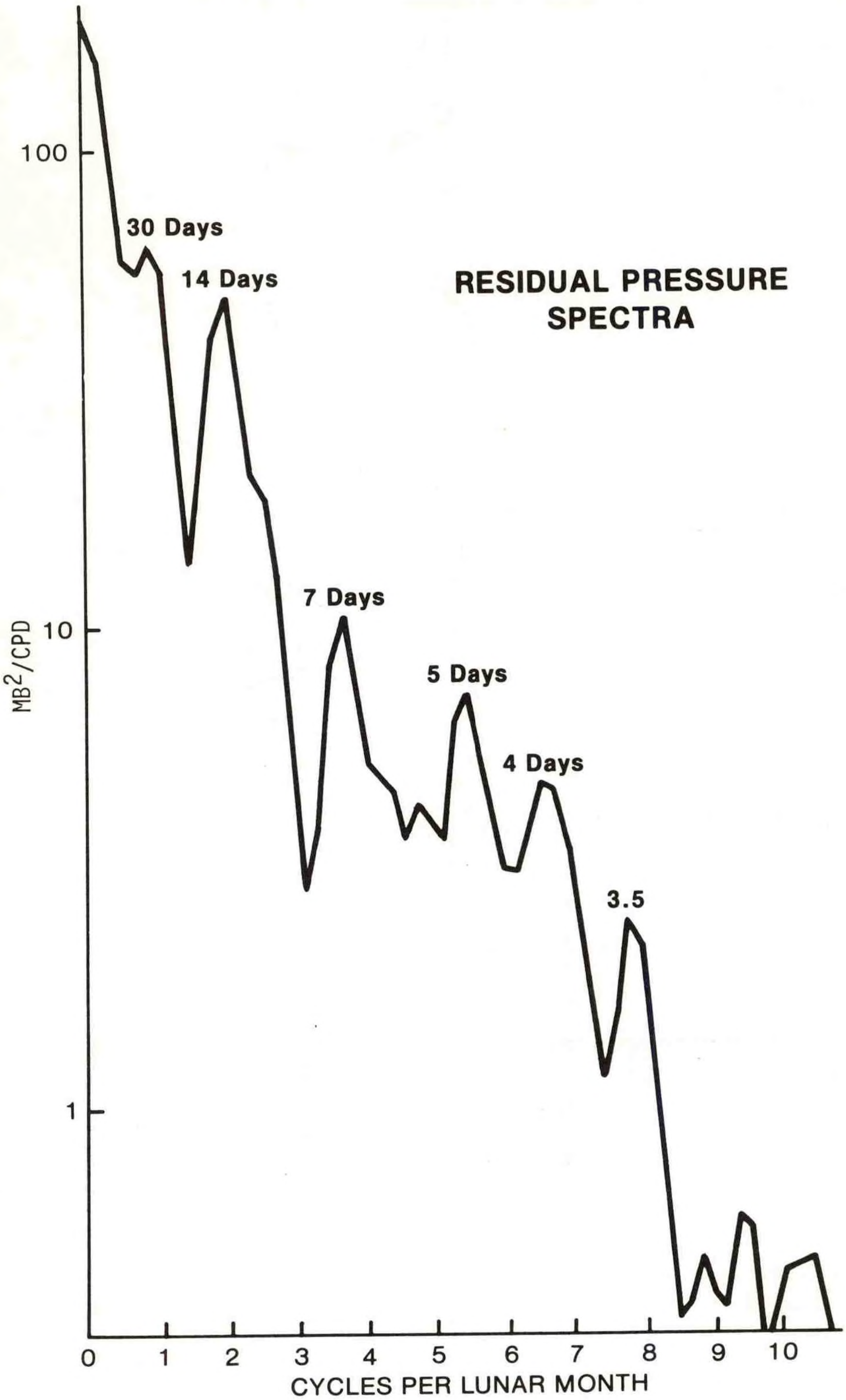

Figure 5--Residual pressure spectra.

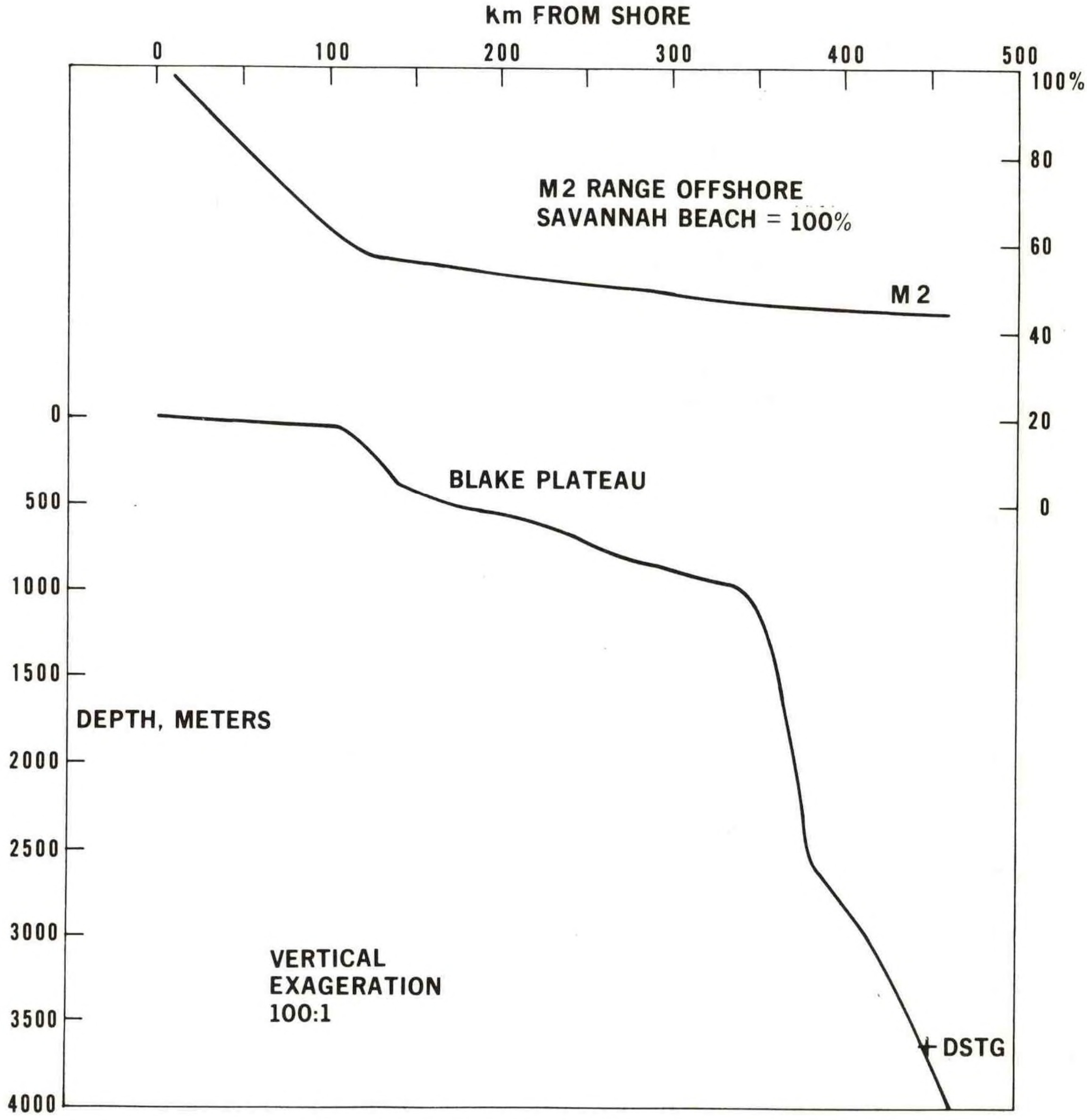

Figure 6--Profile of depth and M_2 amplitude on a line from Savannah Beach to the deep sea tide gage position.