responding to a constant α/f^2 value and the high-frequency step, respectively. The low-frequency step — the anomaly—is similarly characterized by the third term.

The experimental points and 1 standard error are shown for the data from Lake Superior. The results show that the low-frequency anomaly persists in freshwater, thus eliminating the effect of electrolytes at seawater concentrations as being responsible for the absorption. That the $MgSO_4$ absorption is absent in freshwater can be inferred from the approximately equal displacements of the horizontal lines in both curves in Fig. 1.

The acoustic absorption spectra for seawater and Lake Superior water are compared quantitatively in Fig. 2. A maximum in $\alpha\lambda$ (wavelength in meters) corresponds to a relaxation process described by a particular relaxation frequency. A relaxation frequency of 1 khz is indicated by the third term in Eq. 1 and is corroborated by the nearly coincident maximums for salt- and freshwater (*4*). From the variation in temperature of the $MgSO_4$ relaxation frequency established in laboratory experiments (*3*) a value is predicted in good agreement with the 64-khz relaxation frequency observed for seawater at 4°C. Since the depth of the minimum velocity of sound is usually about 1250 m for the ocean and only 61 m for Lake Superior, a pressure effect on the relaxation is suspected. Fisher (*5*) has shown with $MgSO_4$ solution that the magnitude of absorption decreases with increasing pressure, but we note that the relaxation frequency is expected to vary only a few percent for the change in pressure determined by differences in the two experimental depths.

A particularly interesting aspect of the study of attenuation in freshwater is the application of low-frequency acoustics to elucidating the structure of water, suggesting that in our investigation, pure liquid water relaxes structurally at 1 khz. This possibility should be of interest to those concerned with the water structure and, more specifically, with the slow kinetic process (relaxation time of 1.6×10^{-4} seconds) which our results indicate. The "flicker-cluster" model (*6*) for water is associated with a lifetime of about 10^{-10} seconds, which would seem to have no bearing on our findings. Other experimental conditons affecting attenuation must be changed in order to gather more information on the 1-khz absorption. Increasing the temperature of the medium has the effect of shifting a relaxation frequency toward higher frequencies. An experiment is planned for Lake Tanganyika, a tropical lake in central Africa, which has a water temperature of 23°C where its sound velocity is minimum.

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Sea Levels during the Past 35,000 Years

Abstract. *A sea-level curve of the past 35,000 years for the Atlantic continental shelf of the United States is based on more than 80 radiocarbon dates, 15 of which are older than 15,000 years. Materials include shallow-water mollusks, oolites, coralline algae, beachrock, and salt-marsh peat. Sea level 30,000 to 35,000 years ago was near the present one. Subsequent glacier growth lowered sea level to about −130 meters 16,000 years ago. Holocene transgression probably began about 14,000 years ago, and continued rapidly to about 7000 years ago. Dates from most shelves of the world agree with this curve, suggesting that it is approximately the eustatic curve for the period.*

Many attempts have been made to establish the eustatic positions of sea level during the Wisconsin regression and the Holocene transgression. Two major difficulties are the dearth of radiocarbon dates greater than 15,000 years, and the identification of stable shelves. The most commonly used sea-level indicators are shallow-water mollusks, particularly the oyster *Crassos-*

Table 1. Radiocarbon dates for indicators of ancient sea levels off eastern United States (*10*).

Sample number	Material	Location N	Location W	Depth (m)	Age (yr)	Reference source
L 1380	Oolite	29°53′	80°35′	35	16,920 ± 200	(*2*)
L 1386	Oolite	29°53′	80°25′	45	20,730 $^{+2670}_{-4030}$	(*2*)
L 1434	Oolite	28°54′	80°06′	70	13,500 ± 170	(*2*)
L 40	Oolite	34°12′	76°42′	28	29,100 $^{+1440}_{-1750}$	(*2*)
L 127	Oolite	33°30′	76°57′	65	22,420 $^{+380}_{-400}$	(*2*)
Gos 1847	Oolite	34°09′	76°44′	33	25,420 ± 850	(*3*)
Gos 1847*	Oolite	34°09′	76°44′	33	27,650 $^{\pm 1050}_{-950}$	(*3*)
Gos 1806	Oolite	33°20′	77°30′	25	24,200 ± 700	(*3*)
L 1388	Oolitic rock	29°53′	80°21′	48	12,630 ± 230	(*2*)
E 8851	Oolitic rock	28°38′	80°03′	74–81	13,730 ± 180	(*8*)
E 8999	Oolitic rock	29°14′	80°09′	79–86	9,620 ± 160	(*8*)
1087	Algal rock	33°43′	76°40′	90	19,200 ± 650	(*7*)
E 8200	Algal rock	33°58′	76°22′	99–108	12,270 ± 190	(*8*)
E 8851	Algal rock	28°38′	80°03′	79–86	11,170 ± 160	(*8*)
E 7845	Beachrock	34°06′	76°15′	74	13,500 ± 230	(*8*)
E 8200	Beachrock	33°58′	76°22′	99–108	15,180 ± 280	(*8*)
S-185	*Crassostrea virginica*	46°00′	62°37′	37	6,850 ± 100	(*22*)
Scarrett	Oyster	46°49′	64°40′	22	7,335 ± 105	(*22*)
Pil 36	Oyster	31°20′	80°50′	19	21,000 ± 800	(*23*)
Gos 1508	*Ostrea equestris*	30°00′	81°15′	19	7,170 ± 300	(*24*)
Gos 1790	*C. virginica*	33°11′	78°15′	33	17,290 ± 500	(*24*)
BB 10a	*Mercenaria campechiensis*	23°21′	80°13′	4	33,750 ± 3200	(*25*)
I 749	*C. virginica*	38°32′	75°15′	(+10)	34,000 ± 2000	(*26*)
I 1745	Salt-marsh peat	33°55′	78°09′	0	36,000 $^{+3700}_{-2600}$	(*26*)

* Inner 40 percent.

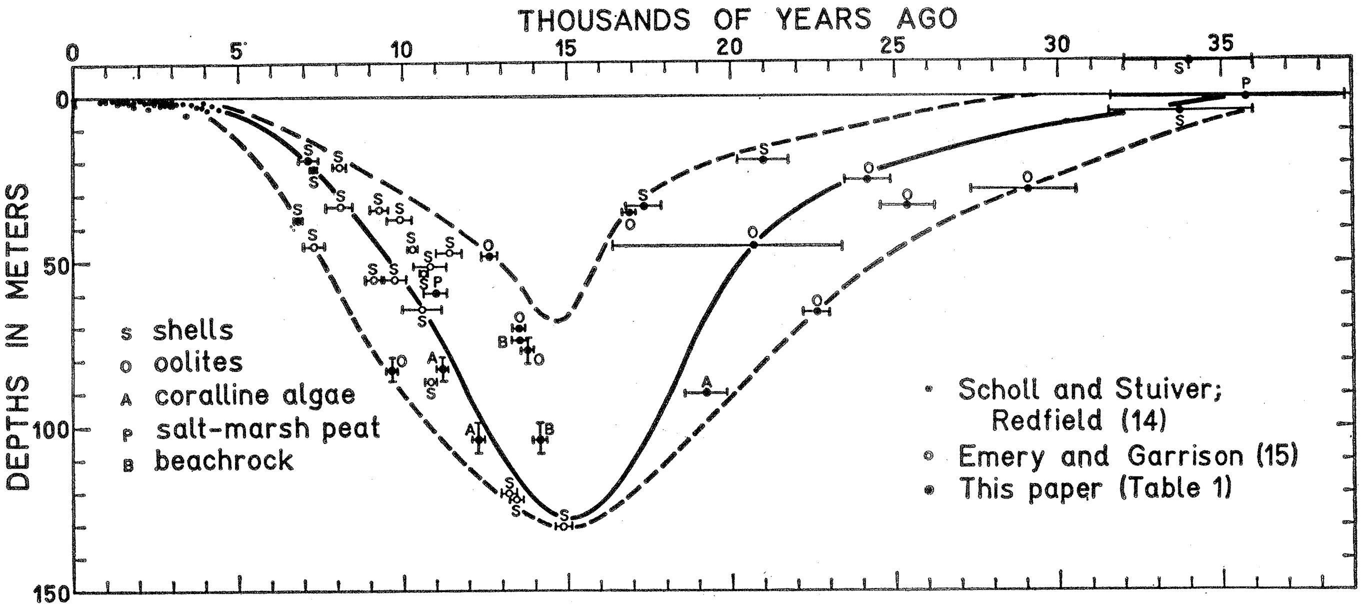

Fig. 1. Depths and ages of sea-level indicators from the Atlantic continental shelf of the United States. The solid line is the inferred sea-level curve for the past 35,000 years; the dashed line, envelope of values.

trea virginica (Gmelin), and salt-marsh peat. Several workers have used fresh-water peat, but, because such peats can form well above sea level, they are unreliable indicators of past sea levels. Our studies for the continental shelf off the Atlantic coast of the United States have used several additional sea-level indicators that permit an extension of the sea-level curve to the outer limits of the radiocarbon method.

Oolite deposits occur on the continental shelf off North Carolina, South Carolina, Georgia, and Florida (*1–3*). At present, oolite forms only in agitated shallow warm waters (*4, 5*). Mineralogical and chemical studies show that the North Carolina and Florida oolites are unaltered, and suggest that they were deposited in shallow saline lagoons (*2, 3*). Because oolites accrete slowly, their nuclei may be considerably older than their outer laminae (*6*; Table 1). However, ages for whole modern oolites average about 700 years (*5, 6*), suggesting that the oolites of the continental shelf may be somewhat older than other sea-level indicators. The oolites off North Carolina yielded dates of 17,000 to 29,000 years, indicative of the regressive stage of sea level. Although some oolites off Florida are regressive, most are younger than 14,000 years

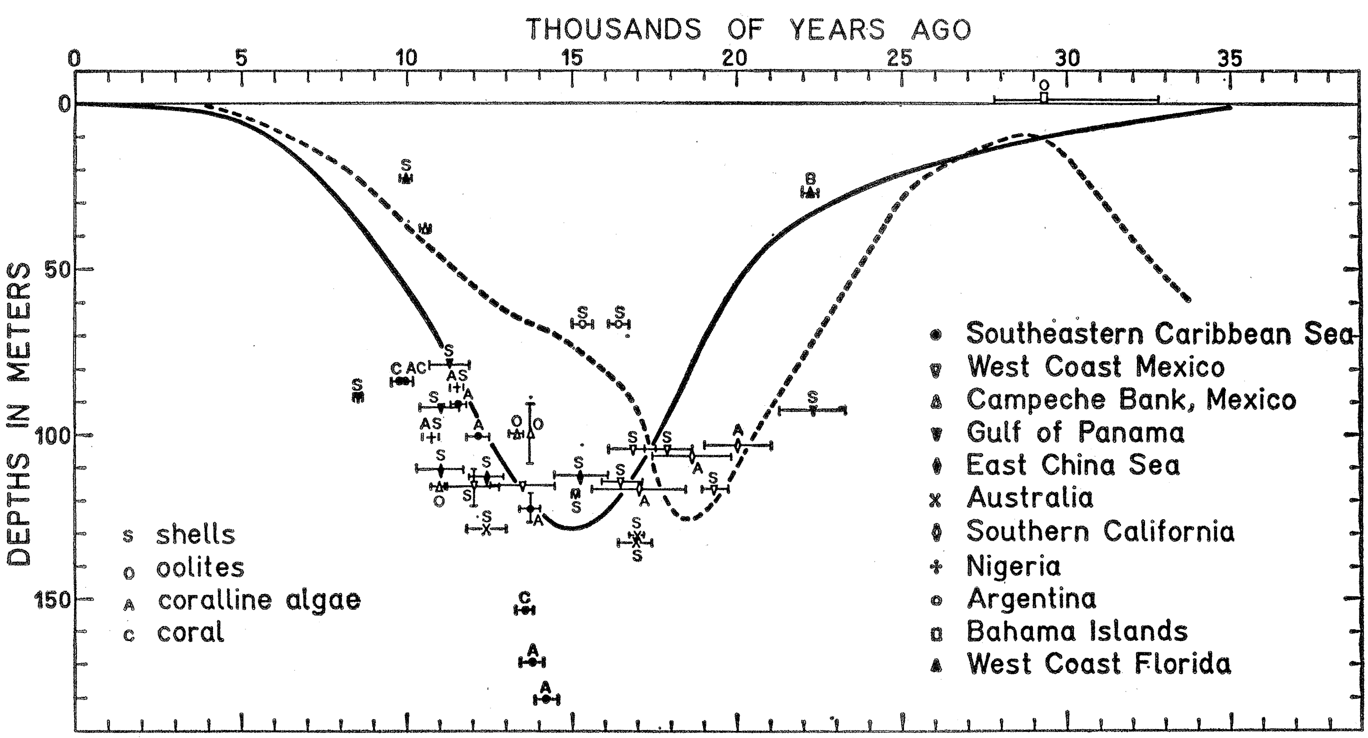

Fig. 2. Depths and ages of sea-level indicators throughout the world. The solid line is the sea-level curve for the Atlantic continental shelf, as defined in Fig. 1. The dotted line is the sea-level curve for the Texas shelf (*12*).

and belong to the transgressive stage.

Coralline algae and hermatypic corals can be used as sea-level indicators, but only with care, because certain species can live in depths greater than 20 m. Several samples of unrecrystallized algal rock were obtained from an algal ridge system that lies off the coast of North Carolina and Florida (*7, 8*). Dates for these algae range from 11,000 to 19,000 years.

Beachrock, which forms in the intertidal zone, can be recognized by its fragmented shallow-water components and by its bedded nature. Submerged beachrock appears to be rather common on the shelf off the southeastern United States. We dated two samples of beachrock dredged off the coast of North Carolina (*8*).

In addition to dates for these samples, Table 1 includes eight samples of shallow-water mollusks and salt-marsh peat. The new dates, plus those reported (*9, 10*) are plotted in Fig. 1. The values lie within an envelope that widens with age, perhaps reflecting both greater contamination with greater age, and the effects of regional uplift or subsidence. For example, many samples south of Cape Hatteras are shallower for given times than are samples farther north; thus the southern area may have participated in the uplift now evident for the continental shelf off Texas.

Several significant trends are indicated. The last interglacial high stand of sea level was near the present level about 30,000 to 35,000 years ago. Sea level then fell slowly until about 21,000 years ago. Between 21,000 and 16,000 ago it fell rapidly, reaching a maximum depth of about −130 m. By 14,000 the Holocene transgression had begun, and sea level rose rapidly until about 7000 years ago, after which the rise was more gradual. This date for the transgression coincides with the sharp increase of surface temperature about 15,000 years ago, indicated in Caribbean deep-sea cores (*11*). We find no evidence that transgression began 19,000 years ago. This date, the usual one given for transgression (*12*), is based on the time of glacial retreat in North America, and it may not coincide with the worldwide retreat of glaciers. Neither do we find any indication of a sharp climatic change at 11,000 years ago (*13*).

Emery and Garrison (*10*) noted the difference in ancient sea-level curves for the shelves off the Atlantic and Texas coasts. They suggested either a subsidence of the Atlantic shelf or an uplift of part of the Gulf of Mexico. Lacking sufficient data, they were unable to identify the eustatic curve. On the basis of deviations from a "eustatic" curve, Newman and March (*14*) concluded that the Atlantic shelf had downwarped as much as 80 m. However, their eustatic curve was based only on a few freshwater peats, which are poor sea-level indicators.

Thirty-eight radiocarbon ages greater than 8000 years have been reported from 11 areas throughout the world. These areas include Campeche Bank, Mexico (*15*), the southeastern Caribbean Sea (*16*), Australia (*17*), western Mexico and Panama (*17, 18*), western Florida (*19*), the East China Sea (*20*), and others (*10*). Dates from the elevated Hawaiian terraces were omitted because of their probably very great (Sangamon) age (*21*). Nearly all the dates cluster near the Atlantic shelf sea-level curve, whereas only five of them coincide with data for the Texas shelf (*12*) (Fig. 2). Three values from the southeastern Caribbean Sea are significantly below the curve of the Atlantic shelf, but these are for coralline algae and corals which may have lived in deep water. The fact that so many of the world dates coincide with those for the Atlantic shelf of the United States suggests that the latter defines a eustatic curve. It further suggests that the Texas shelf probably has undergone uplift during the Holocene.

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Manganese Nodules in Lake Michigan

Abstract. *Manganese nodules containing up to 22 percent manganese oxide were found in Green Bay and the western and northern parts of Lake Michigan. The chemical composition of these nodules resembles that of shallow-water lacustrine and marine nodules. The manganese content of interstitial water is in some places enriched as much as 4000 times over that of lake water.*

Manganese nodules were discovered at several localities in Lake Michigan: in the western and northern portions of the basin and Green Bay (Fig. 1). Before the first nodule was discovered (June 1967), the only known manganese deposits in the Great Lakes occurred as crusts on a buoy in Lake Erie and in the sediment of Lake Superior (*1*). Nodules from stations 1, 2, and 4 are brown, spherical concretions with an internal structure of alternating brown and black layers. Those from the other stations, except station 12, consist of black ferromanganese aggre-