or by some combined effect, a diminution in long-range signal amplitude would be expected as the source passes through the upper sound channel; a resulting separation of the signal into two groups would occur. The reversal of the two groups in time, and probably of the waves within each group, caused by the rocket outrunning its own sound, would not alter this argument.

We hope to resolve many of the questions raised by this study through a more detailed plan of observation of coming launchings.

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12. We wish to acknowledge NASA support in providing data on the Saturn V trajectory and to thank A. Nowroozi for his Fourier analysis program. Work was supported by NSF grant GA 1333 and Army Research Office, Durham, contract DAH CO4 0037.
13. This report is Lamont Geological Observatory (Columbia University) contribution No. 1265.

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Attenuation of Low-Frequency Sound in Freshwater

Abstract. *Lake Superior was chosen as an experimental site to compare sound absorption of freshwater with the results of absorption measurements in seawater. The relaxation-like absorption at 1 kilohertz occurring in seawater is also present in freshwater. A relaxation related to the structural characteristics rather than to the salt content of water may be responsible for the anomalous absorption.*

Acoustic waves have been used to investigate the properties of liquids and solutions. Sound absorption is the result of both viscous forces, common to all liquids, and relaxations between different chemical or structural forms. Investigations in seawater (*1*) revealed two attenuation anomalies which cannot be explained in terms of known structural relaxations or viscous absorption.

The well-known chemical relaxation of $MgSO_4$ is one of these anomalies (*2*) accounting for the excess attenuation in seawater observed below 100 khz. However, the cause of the low-frequency absorption below 10 khz is still unknown. Comparative measurements in freshwater were desired in order to determine if the salt content of seawater was also responsible for the second anomaly. Since losses of acoustic energy are so small below 10 khz, laboratory-scale experiments measuring attenuation are limited to relatively high frequencies. A large body of freshwater was required for the experiment. Lake Superior, with a viable acoustic path length of several hundred kilometers, was chosen as an appropriate site (see *3*).

The design of the Lake Superior experiment was the same as that used in measurements of salt water. Acoustic signals were generated by fused trinitrotoluene (TNT) charges detonated at selected ranges from the receiving vessel. Both the source and the hydrophone were located where the velocity of sound was minimum, which corresponded to the sound-channel axis. The broad-band signals received were filtered to obtain the appropriate frequencies, and the resulting attenuation coefficients were computed.

Figure 1 shows the results of the measurements in Lake Superior and those obtained from a large number of attenuation experiments conducted in seawater. Analytically the attenuation coefficient α at 4°C for seawater is described by

$$\frac{\alpha}{f^2} = 3.46 \times 10^{-8} + \frac{1.23 \times 10^{-6}}{1 + (f/64)^2} + \frac{1.26 \times 10^{-5}}{1 + (f/1)^2} \quad (1)$$

where α is in nepers per meter and the frequency f is in kilohertz. The first and second terms in Eq. 1 are the viscous and $MgSO_4$ relaxation components cor-

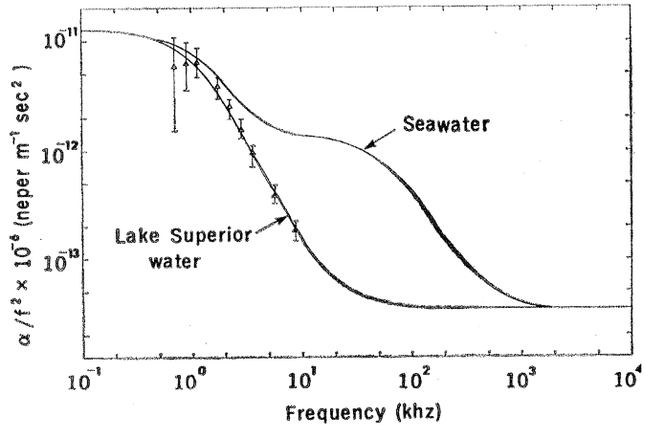

Fig. 1 (left). Values of α/f^2 for Lake Superior and seawater measurements plotted as a function of frequency.

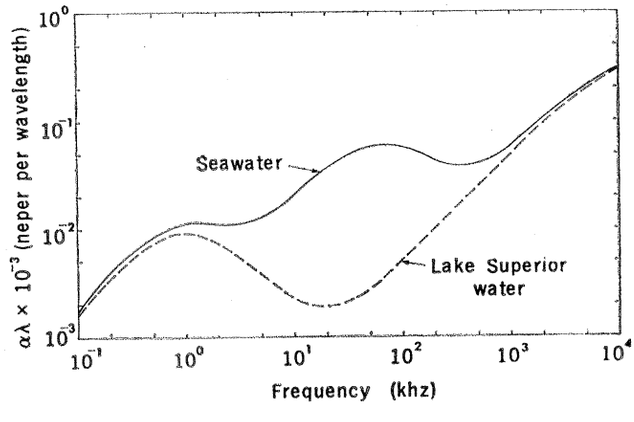

Fig. 2 (right). Absorption-wavelength product variation with frequency for seawater and Lake Superior water at 4°C. The two relaxation processes for salt water mutually affect each other, leading to a slight shift in both relaxation frequencies. The minimum velocities of sound for salt water and freshwater were 1480 m/sec and 1426 m/sec, respectively.

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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7 August 1968; revised 7 October 1968

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		Depth (m)	Age (yr)	Reference source
		N	W			
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	$27{,}650^{\pm1050}_{-950}$	(*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.