Sound attenuation as a function of depth in the sea floor*

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Recently published data on the attenuation of compressional (sound) waves in marine sediments and sedimentary rocks as a function of frequency and sediment porosity have been added to previously published figures. The revised figure illustrating attenuation as a function of frequency (5 Hz–1 MHz), and attendant discussion, continue to support the conclusion that attenuation is approximately related to the first power of frequency in sands, muds, and sedimentary rocks. The revised figure illustrating sediment porosity versus attenuation affirms that sediment porosity is an important index property which can be used to predict sound attenuation in surficial sediments. Data were collected and illustrated on sound attenuation as a function of depth in the sea floor. It is concluded that attenuation decreases with about the $-1/6$ power of depth in sands. As a silt–clay sediment (mud), or turbidite, is placed under increasing overburden pressure, there may be a progressive increase in attenuation due to reduction in sediment porosity, and a progressive decrease in attenuation due to increasing pressure on the sediment mineral frame. At about 200-m depth a null point may be reached. Thereafter, pressure is the dominant effect, and attenuation decreases smoothly with depth and overburden pressure. The figure can be used to aid prediction of sound attenuation in sediment and rock layers in the sea floor.

Subject Classification: [43]30.20.

INTRODUCTION

In 1972 the writer published the results of *in situ* measurements of the attenuation of compressional (sound) waves in marine sediments off San Diego.[1] Additional published data on attenuation in sediments were collected in diagrams which related attenuation with frequency and with sediment mean grain size and porosity. The first two sections of this report can be considered a supplement, or revision, to these data in the 1972 report, and a brief section in a later paper.[2] The main purpose of this report, however, is to discuss the variations of attenuation with depth in the sea floor.

Figures 1 and 2 have been revised from Hamilton[1] with additional data from various published sources (listed in Table I). Data on attenuation versus depth in the sea floor are listed in Table I and in the 1972 report, and illustrated in Fig. 3.

This report concerns only water-saturated sediments, without gas, in the sea floor, and some of the common rocks which might be present below the upper, unlithified sediment layer.

Measurements of attenuation *in situ* are difficult at best, and the results of even the most careful measurements will show scatter. When a large collection of *in situ* data is assembled, there will be much scatter. This is because the experimenter cannot usually know exactly what he has measured. Over a short distance (e.g., one meter), just below the sea floor, the sediment may be relatively homogeneous and isotropic, and the intrinsic absorption of the material may be measured after accounting for spreading losses. When measurements of "attenuation" are made through thick sections, however, energy can be lost in several ways: by spherical spreading, by reflection, refraction, and scattering phenomena, as well as through intrinsic attenuation in the material (e.g., Anderson[3]). For example, Schoenberger and Levin,[4] and O'Doherty and Anstey[5] have recently reviewed the energy losses which might be due to transmission through multiple layers and the generation of intrabed multiple reflections. Schoenberger and Levin, in examining synthetic seismograms for two wells, indicated that attenuation due to layering accounted for $\frac{1}{3}$–$\frac{1}{2}$ of the total frequency dependent attenuation estimated from field seismograms at the well locations.

It should be understood that some of the data shown in Figs. 1 and 3, which involved measurements through thick layers (at the lower frequencies) is not intrinsic attenuation of the sediment and rock materials, but is energy lost from multiple causes. This "attenuation" is called "the effective attenuation coefficient" by Soviet authors who have published most of the data for thick layers in the sea floor. In this report, when "attenuation" is used, it refers to the energy lost upon transmission of a compressional wave from all causes and is thus "effective attenuation" in most cases below the top few meters of sediments. Fortunately, for many purposes of underwater acoustics and marine geophysics, it is effective attenuation which is desired for computations.

I. ATTENUATION VERSUS FREQUENCY

The relationships between wave energy losses and frequency are critically important in determining an appropriate anelastic model for earth materials. Additionally, the relationship is critical in predicting energy losses by extrapolating to various frequencies from measurements. These subjects have been previously reviewed,[1,2] and it was concluded that the experimental evidence indicates that most of the data are consistent with an approximate first-power dependency of attenuation on frequency and that velocity dispersion is negligible, from a few hertz to the megahertz range in most sediments. An appropriate viscoelastic model

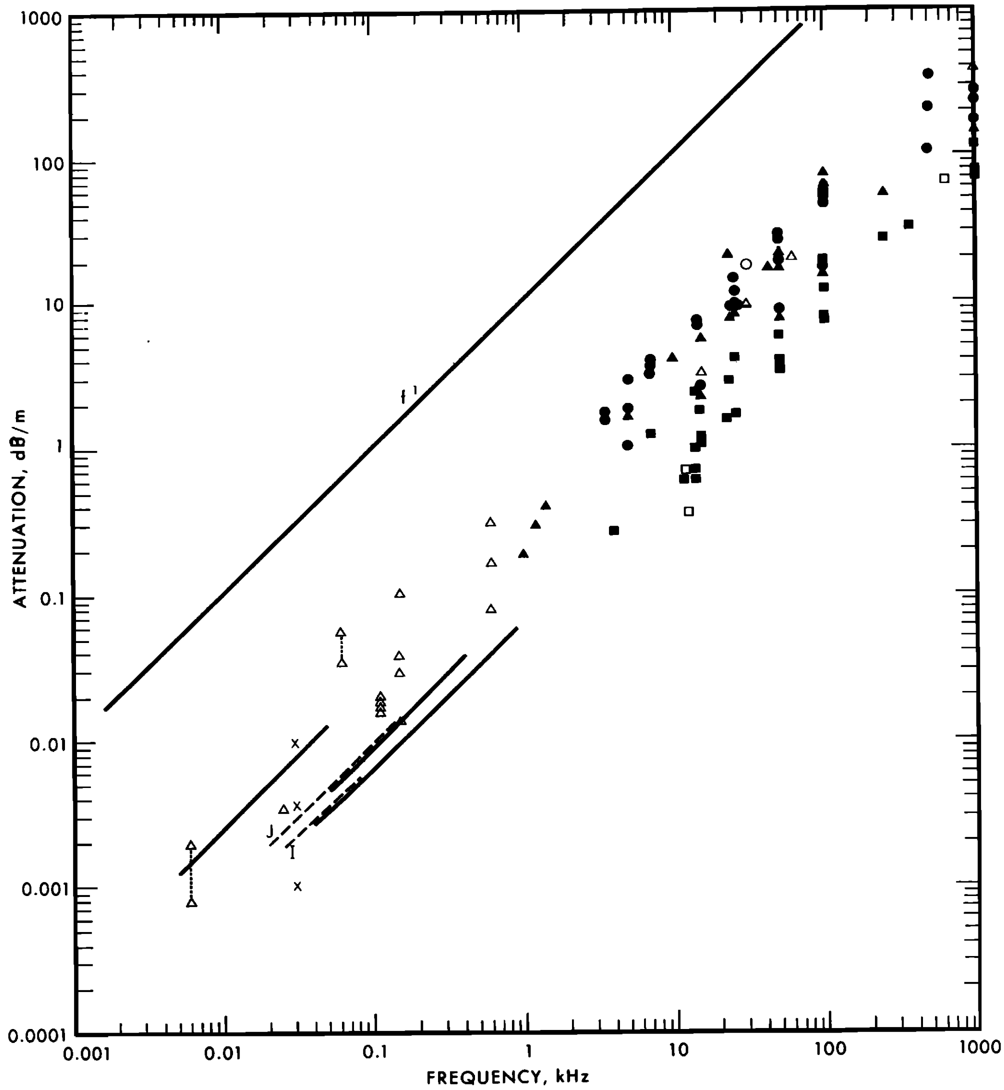

FIG. 1. Attenuation of compressional waves vs frequency in natural, saturated sediments and sedimentary strata. Symbols: circles-sand (all sizes); squares-clay-silt (mud); triangles-mixed sizes (e.g., silty sand, sandy silt). The solid lines and symbols are from Hamilton (Ref. 2) (Fig. 2); the open symbols and dashed lines are the newly-added data listed in Table I. The lines marked "J" and "I" represent the general equations for the Japan Sea and Indian Ocean Central Basin, North (Tables I, Footnotes d and e), The vertical, dashed lines indicate a range of attenuation values at a single frequency. The line labelled "f^1" indicates the slope of any line having a dependence of attenuation on the first power of frequency.

was recommended and discussed.

Figure 1 illustrates the relations between attenuation of compressional waves in dB/m and frequency in kHz in unlithified marine sediments. The new data in this revised figure, listed in Table I, include 25 measurements made in field experiments, and one from laboratory experiments. These newly added data are given different symbols from the original figure so that the reader can readily see the impact of the additional data. Data in the figure range in frequency from 5 Hz to 1 MHz. It can be seen that the new data complement and supplement the original data and strongly support an approximate first-power dependence of attenuation on frequency.

In Fig. 1, at frequencies above 1 kHz, the sands (round dots) lie in a narrow band along the top of the data plot, and the muds (silt-clays), represented by squares, lie along the bottom of the plot. The mixed sands-silts (triangles) lie in between, and with and above the sands.

Important new data have been added to Fig. 1 below 1 kHz. Measurements of energy losses by Li and Smith[6] and Meissner[7] in sand and boulder clay, and diluvial sand and clay, have extended the mixed sand-silt-clay data to 60 Hz. Data from the Soviet literature have added important information down to 5 Hz in turbidites (alternating thicker layers of silt-clay with thinner layers of silt and sand).

Neprochnov[8] has summarized Soviet measurements of the effective absorption coefficient in the main sediment and rock layers of the Black Sea, Japan Sea, Arabian Sea, Bay of Bengal, and in other areas of the Indian Ocean (Table I). The first layers in these areas are largely formed by turbidites. The reported values of the effective absorption coefficient were determined by studies of the amplitudes of compressional waves

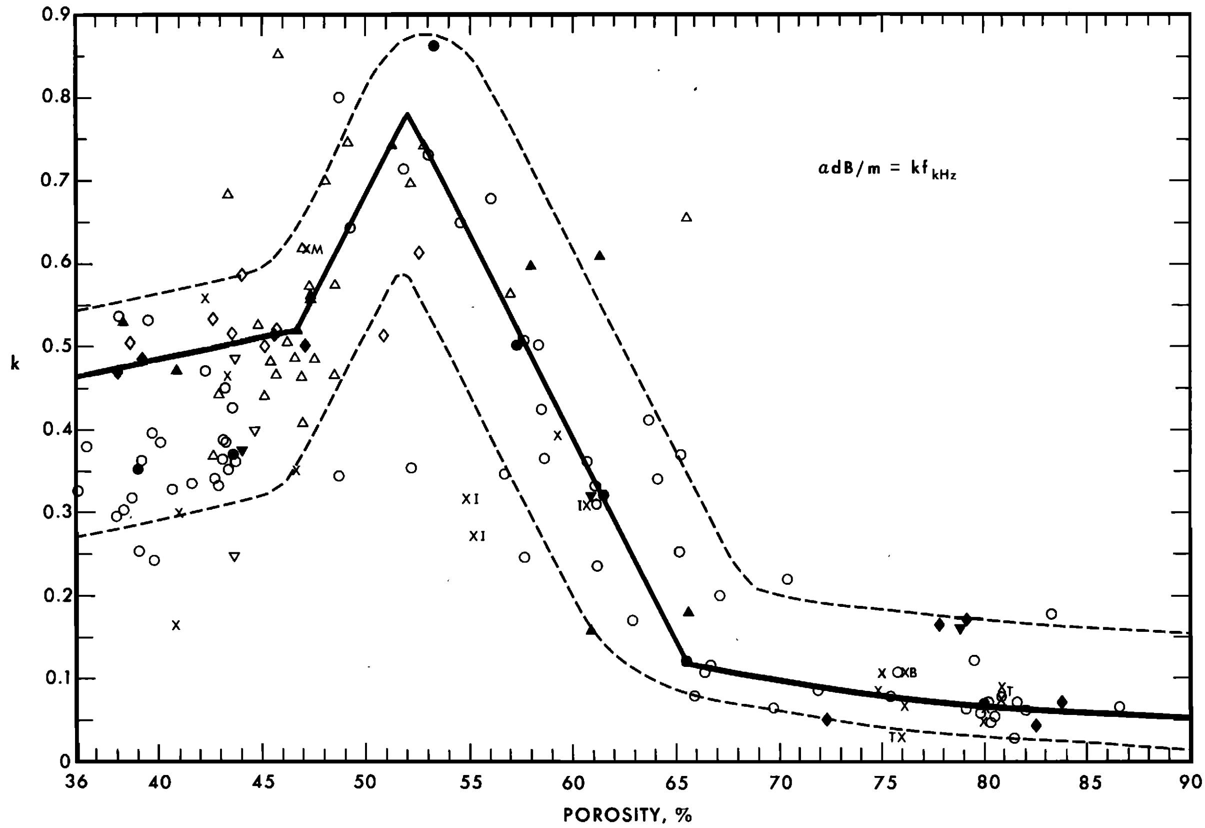

FIG. 2. Attenuation of compressional waves (expressed as k in $\alpha_{dB/m}=kf_{kHz}$) versus sediment porosity in natural, saturated, surface sediments. Solid symbols are averages and open symbols are the averaged data from measurements off San Diego; solid lines are regressions on the best data [from Hamilton (Ref. 1), Fig. 5]; $\times$ indicates a value from the literature. The dashed lines represent areas into which it is predicted most data will fall. Regression equations are included in the caption to the original (1972) figure for the solid lines. Newly-added data are from Tyce (Ref. 10) (marked "T"), Muir and Adair (Ref. 11) (marked "M"), Igarashi (Ref. 12) (marked "I"), and Buchan *et al.* (Ref. 13) (marked "B").

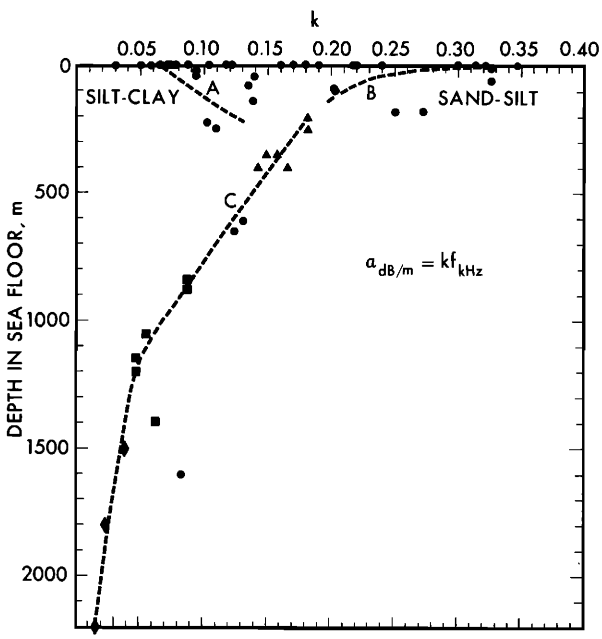

FIG. 3. Attenuation of compressional waves (expressed as k in $\alpha_{dB/m}=kf_{kHz}$) vs depth in the sea floor, or in sedimentary strata. Values are listed in Table I. Symbols: circles, measurements from the literature; triangles, squares, and diamonds represent the first, second, and third layers, respectively, in the sea floor in seven areas [from Neprochnov (Ref. 8)]. See text for discussion of the labelled curves.

reflected from the main boundaries, or reflectors (sea floor, sedimentary rock layers, the basaltic basement). Values were reported for frequencies from 20 to 200 Hz (average of 110 Hz). Neprochnov[8] (p. 711) stated that, as a rule, a linear relationship was found between the effective absorption coefficient and frequency in the frequency range from 20 to 400 Hz.

Figure 1 includes only unlithified sediments, therefore only the first layers are plotted from Neprochnov's report. Most of the data are plotted at 110 Hz, the average for the frequency range: 20–200 Hz, but in two cases where an equation was given, the data are indicated by dashed lines. These equations were for the Japan Sea and the northern part of the central basin in the Indian Ocean.

In a following section, the subject of the variations of attenuation with depth in the sea floor will be discussed. It is appropriate to note here that there is a depth-pressure effect on attenuation which indicates caution in comparing attenuation measurements made at the sediment surface and those at depth in the sediments. Attenuation may increase or decrease with depth depending on the sediment type and depth (discussed in the last section). The important question in this section is the dependence of attenuation on frequency, and in the cases noted by Neprochnov,[8] and others noted by Hamilton[1,2] for thick sections and sedimentary

TABLE I. Attenuation, frequency, and depth in sedimentary materials used in the figures (in addition to that in Hamilton (Ref. 1).

Area Material	f	α (dB/m)[a]	k[b]	Depth (m)	Reference	Figures[c]
Wales, Cardigan Bay:						
Sand and clay,	150 Hz	0.030	0.200	86	6	1,3
		0.014	0.093	47		1,3
		0.038	0.253	181		1,3
		0.104	0.693	152		1
	600 Hz	0.081	0.135	86		1,3
		0.083	0.138	48		1,3
		0.163	0.272	181		1,3
		0.321	0.535	175		1
Texas, Corpus Christi:						
Fine sand, shell	30 kHz	18.7	0.623	Sfc	11	1,2
	100 kHz	61.4	0.614	Sfc		1,2
Baltic Sea:						
Mud (clay-silt)	1.2 kHz	0.29	0.242	Sfc	33	1,3
	1 MHz	383	0.383	Sfc		1,3
Mediterranean, Atlantic:						
Abyssal plains (av)	12 kHz	0.70	0.058	Sfc	34	1,3
Non-aby. plain (av)	12 kHz	0.36	0.030	Sfc		1,3
California, off Santa Barbara:						
Silty sand (av)	15 kHz	3.3	0.220	Sfc	12	1,2,3
	30 kHz	9.4	0.313	Sfc		1,2,3
	60 kHz	20.8	0.347	Sfc		1,2,3
West Germany:						
Sand and Clay,	60 Hz	0.035– 0.057	0.583– 0.950	45	7	1
Clay, Russia	25 Hz	0.0035	0.139	0–280	35	1,3
Black Sea:						
First layer	20–200-Hz (110 Hz)	0.0165	0.150	0–700	8	1,3
Second layer		0.0061	0.055	700–1400		3
Third layer		0.0026	0.024	1400–2200		3
Japan Sea[d]:						
First layer		0.0200	0.182	0–500	8	1,3
Second layer		0.0096	0.087	500–1200		3
Third layer		0.0043	0.039	1200–1800		3
Arabian Sea:						
First layer		0.0156	0.142	0–800	8	1,3
Second layer		0.0052	0.047	800–1600		3
Indian Ocean, Bay of Bengal:						
First layer		0.0165	0.150	0–700	8	1,3
Second layer		0.0052	0.047	700–1600		3
Third layer		0.0017	0.016	1600–2800		3
Indian Ocean, Central Basin:						
North[e]:						
First layer		0.0182	0.166	0–800	8	1,3
Second layer		0.0069	0.063	800–2000		3
South: First layer		0.0200	0.182	0–400	8	1,3
Ob' Trench		0.0174	0.158	0–700	8	1,3
North Atlantic:						
Deep-sea clay[f]:	604 kHz	65	0.108	Sfc	13	1,2
Russia:						
Clays	(100 Hz) assumed	0.0326	0.326	0–20	16	1,3
Clays		0.0326	0.326	20–100		3
Sands and Clays		0.0109	0.109	100–400		3
Clays, ss, mudstone		0.0124	0.124	400–900		3
Texas Gulf Coast:						
Clay sand	50–400 Hz (200 Hz)	0.0187	0.093	2–34	32	1,3

TABLE I (*Continued*)

Area Material	f	α (dB/m)[a]	k[b]	Depth (m)	Reference	Figures[c]
Texas Gulf Coast:						
Sandy clay		0.0407	0.203	34–152		3
Clay sand		0.0204	0.102	152–305		3
Philippine Trench:						
Turbidites	25 Hz	0.0022	0.088	870	36	3
Texas, Dallas County:						
Sandy shale	12.5 Hz	0.001	0.080	680–2532	37	3
Colorado:						
Pierre shale	50 Hz	0.0066	0.132	0–1219	15	3

[a]Attenuation in dB/m computed (if necessary) using $1/Q = aV/\pi f = \Delta/\pi$; $\alpha = 8.686a$ where $1/Q$ is the specific attenuation factor, a is the attenuation coefficient, V is compressional wave velocity, f is frequency, Δ is the logarithmic decrement, α is attenuation/linear measure, V/f is wavelength [see Hamilton (Ref. 1, p. 634) for discussion of the complete viscoelastic equation].

[b]k in: attenuation, dB/m$=kf$; where f is in kHz; values rounded.

[c]Numbers indicate figure numbers in which data appears.

[d]Japan Sea general equation (20–100 Hz): $\alpha_{\mathrm{dB/m}} = 0.096 f_{\mathrm{kHz}}$.

[e]Indian Ocean, Central Basin, North; general equation (30–80 Hz): $\alpha_{\mathrm{dB/m}} = 0.069 f_{\mathrm{kHz}}$.

[f]North Atlantic; average of 11 cores with less than 5% $CaCO_3$.

strata, the dependence was reported as linear. It is remarkable that both intrinsic attenuation of the material[1,9] and the "effective attenuation" in thick layers, which includes other causes of energy losses, are related to an approximate first power of frequency, as clearly indicated in Fig. 1, and by most of the investigators who made the measurements.

II. ATTENUATION VERSUS SEDIMENT POROSITY

In the 1972 report, the attenuation data were presented in the form

$$\alpha = kf^n \ , \tag{1}$$

where α is attenuation in dB/m, k is a constant, f is the frequency in kHz, n is the exponent of frequency.

The case has been made (and in Sec. I), that attenuation was related, approximately, to the first power of frequency in saturated marine sediments. The data added to Fig. 1 continue to support this point of view. If the exponent of frequency, Eq. (1), is taken as one, then the only variable in the relation is the constant k. This allows k (or attenuation) to be studied in relation to common sediment properties which might be useful in prediction of attenuation. The constant k in this and earlier reports was derived for any set of measurements by dividing attenuation in dB/m by frequency in kHz. For many of the reports listed in Table I, the data were recomputed into dB/m, using the relationships discussed by Hamilton[1] and listed under Table I.

Figure 2 (revised from Fig. 5 of Hamilton), illustrates the variations of the constant k with sediment porosity. Four new data sets have been added to Fig. 2. These are measurements *in situ* by Tyce[10] in silty clay in the San Diego Trough and calcareous sediments on the Carnegie Ridge, by Muir and Adair[11] in fine sand and shell in the Texas Gulf Coast, by Igarashi[12] in silty sand off Santa Barbara, California, and by Buchan *et al.*[13]: average of 11 cores from the North Atlantic with less than 5% $CaCO_3$.

The causes of the variations of k (or attenuation) with porosity, as in Fig. 2, and with mean grain size, were discussed at length in the original report[1] (pp. 635–643) and will not be repeated here. In general, it was concluded that internal friction between mineral particles was by far the dominant cause of energy losses, and that internal friction varied with the size of grains, the number and kind of grain contacts, and with surface areas of grains in sands, and with cohesion and friction between fine silt and clay particles.

The relations between sediment porosity and the constant k (Fig. 2) furnish a simple method for predicting attenuation in surficial sediments. The diagram or regression equations (in Hamilton,[1] Fig. 5) can be entered with measured or predicted porosity, and a value of k can be obtained which, when placed in Eq. (1), yields an equation useable at any frequency. A similar figure relating mean grain size and k is in the original report.

III. ATTENUATION VERSUS DEPTH IN SEA FLOOR

A. Introduction

For various computations in underwater acoustics and marine geophysics it is necessary to know, or approximate, the average value of attenuation for an interval or layer, or to approximate the gradient of attenuation with depth in the sea floor. Consequently, a collection has been made of available published data on attenuation at the surface and at depth in marine sediments and rocks.

B. Results

As briefly discussed in the preceding section, the relations between the constant k in Eq. (1) and sediment physical properties have furnished a useful means of extrapolation of measurements and of predicting attenuation. The constant k will be used in this section to study the variations of attenuation with depth in the sea floor.

Figure 3 illustrates the available published data (listed by Hamilton,[1,2] and in this report) on the variations of attenuation (expressed as k) at the surface and at depth in silt-clays, turbidites, sedimentary rocks, and basalt in the sea floor. Not shown in Fig. 3 are values of k for sands and mixed sands and silts; values of k in these materials usually range from about 0.3 to about 0.9 (see Fig. 2). Sand bodies in the sea floor are usually relatively thin compared to thick silt-clay and turbidite sections, and gradients of attenuation in sands are better known than in silt-clays, as discussed below. The data shown in Fig. 3 were previously published, or are listed in Table I. All of the referenced, basic data were recomputed (if necessary) in the form of Eq. (1), and then k was computed. Where attenuation was given for an interval or layer, the value is plotted at $\frac{1}{2}$ the interval thickness for the first layer, or to the midpoint of a lower layer. As a result, the data in Fig. 3 form curves of "instantaneous attenuation" versus depth in the sea floor.

Neprochnov (p. 711) presented attenuation data for 7 areas (listed in Table I) in three forms: (i) as layer or interval values of the effective absorption coefficient, km^{-1}, (ii) as values of the effective absorption coefficient as a function of frequency for the Japan Sea and a basin in the central Indian Ocean (recomputed and listed in Table I), and (iii) the effective absorption coefficient as a function of layer thickness. For four of the areas (Black Sea, Japan Sea, Arabian Sea, and the Bay of Bengal), the following equation was presented for the two or three layers (sediments, sedimentary rock, and in some cases, basalt) for the frequency range of 20–200 Hz:

$$a_p = 3.1 e^{-0.7h} , \tag{2}$$

where a_p is the attenuation coefficient in km^{-1} for an interval or layer having a thickness h in km, e is the base of natural logarithms.

Equation (2) can be reduced to values of k, as in Eq. (1), by inserting various values of layer thickness h and deriving a_p/km. Dividing by 1000 results in a_p/m, and multiplying by 8.686 yields attenuation in dB/m, which, when divided by 0.110 kHz yields the constant k in Eq. (1). If these values of k are plotted at $\frac{1}{2}h$, they form a curve of instantaneous attenuation versus depth which is close to curve "C" in Fig. 3.

In Fig. 3, the Soviet data are given special symbols: the first layers are designated by triangles, the second layers by squares, and the third layers by diamonds. Curve C, drawn by hand, has two parts: first-to-second-layer data, and second-to-third-layer data. The first layer, only, is plotted in Fig. 1 (attenuation versus frequency).

In the subsequent discussions, Curve C is slightly favored over a curve which could be drawn, as noted, using Eq. (2). This is because Eq. (2) is based on the data in three layers, and as a mathematical artifact, is on the low side of attenuation, or k, values between 300 and 900 m; whereas the first layer of unlithified sediments is the main interest in this paper.

Several comments should be made in relation to Curve C. The Deep Sea Drilling Project has drilled in most of those areas represented by Neprochnov's data. All of the first layers should be unlithified turbidites. The depths of lithification vary, but the second layers are dominantly sedimentary rock (probably mudstone). In the Arabian Sea at Deep Sea Drilling Site 222, mudstone occurs at about 600 m depth below the sea floor.[14] The third layers are sedimentary rock and basalt. Two values of k between 600 and 700 m are from measurements on land. A value of k (0.13) for the Pierre shale (McDonal *et al.*[15]) is plotted at 610 m (0–1219 m), and a value (0.12) at 650 m (400–900 m) for "clays, sandstone, and aleurolites (mudstone)" from Zhadin (in Vassil'ev and Gurevich,[16]).

For those interested in values of the constant k in Eq. (1) for basalts, various laboratory studies of basalts (e.g., Balakrishna and Ramana,[17] and Levykin[18]), and measurements in the field (e.g., Neprochnov *et al.*[19,8]) where the nature of the material is identified by geographic locations, stratigraphic position, and velocity (6.6–7.0 km/sec), indicate that k in basalts under the sea floor should usually vary between 0.02 and 0.05.

IV. DISCUSSIONS AND CONCLUSIONS

As a result of laboratory experiments in rocks, it has been known for some time that attenuation decreases with increasing pressure (e.g., Birch and Bancroft,[20] Levykin,[18] Volarovich,[21] Balakrishna and Ramana,[17] and Merkulova *et al.*[22]).

Experimental work on attenuation of shear and compressional waves versus pressure in sediments has been largely confined to sands.[23–28] This is because, after initial adjustments, there is very little decrease in porosity with pressure in laboratory samples under low pressures, and in the upper few tens of meters in sands *in situ*. Therefore, the effects of pressure, alone, can be studied. In the studies of sand, referenced above, both shear and compressional wave attenuation decreased with increasing pressures. All of these experiments were in dry or partially saturated sands.

Anderson[3] (p. 150) noted that energy losses in earth materials in both shear and longitudinal vibrations can be attributed to losses in shear. Therefore, it is expectable that attenuation of shear and compressional waves should decrease about the same under increasing pressures. This effect has been noted in studies of attenuation in rocks[18] and in partially saturated sands and granular materials.[24,27]

Pilbeam and Vaisnys[27] and Hardin[25] noted that attenuation decreased with about the $-\frac{1}{2}$ power of confining pressure in sand and in some granular materials. Gardner *et al.*[24] reported that attenuation decreased with the $-\frac{1}{6}$ power of effective overburden pressure in Ottawa sand and glass beads. The data of Hunter *et al.*[23] in natural sands appears to be near the $-\frac{1}{6}$ power of pressure. Curve "B," shown in part in Fig. 3, was computed for a fine sand using an average value of k (0.45, off the figure to the right) for four stations in fine sands off San Diego[1] at one meter depth, and assuming a decrease in k with the $-\frac{1}{6}$ power of depth. As seen in Fig. 3, Curve B, and in Gardner *et al.*,[24] there is a very rapid decrease in attenuation with increasing depth to about 10 m, and a less rapid decrease to 150 m (where the computations stopped).

In silt-clays there is probably a distinctly different reaction of attenuations with depth (or overburden pressure) in the sea floor. The data indicate a probability that attenuation *increases* with depth from the sediment surface to some depth where the pressure effect becomes dominant over reduction in porosity. If so, this is a previously unreported finding.

High porosity silt-clays at or near the sediment surface, or sea floor, usually have porosities ranging from about 70% to 90%.[29,30] The values of the constant k in these surficial materials, and at these porosities usually range from about 0.05 to about 0.10 (Fig. 2). A number of *in situ* measurements at the sediment surface, between these values of k and porosity, are shown in Fig. 3. Silt-clays of this range in porosities form the dominant part of surficial turbidites in deep-sea fans and in abyssal plains, and in deep-sea pelagic clays.

When a high-porosity silt-clay sediment is placed under overburden pressure, porosity decreases with pressure (or depth). A study of Fig. 2 indicates that in the high-porosity silt-clays (70–90% porosity), the value of k increases with decreasing porosity. A recent study of the decrease of porosity with depth in the sea floor[31] indicates that if a deep-sea pelagic clay had a porosity of about 80% at the sea floor, it would have a porosity of about 65% at 200 m depth. If there were no other factors involved than porosity, there would be an *increase* in k from about 0.07 to about 0.12 to a depth of 200 m. This is indicated by Curve A in Fig. 3. For terrigenous (land-derived) sediments, there is even a more rapid reduction of porosity with depth; for example, 75%–55% reduction in the upper 200 m.

Factors other than porosity are, of course, involved in changes in attenuation as depth in the sea floor increases. Porosity reduction is the dominant effect, another is pressure on the mineral frame of the sediments as the mineral grains are forced closer together. It is known from the studies of attenuation in sands (previously noted) that pressure on the grain structure causes attenuation to decrease as internal friction between grains decreases. Thus, as a silt-clay sediment is placed under increasing overburden pressure, there should be a progressive increase in attenuation due to reduction in porosity, and a progressive decrease in attenuation due to increase in pressure on the mineral frame. From the appearance of the data plot (Fig. 3) it is predicted that the balance of effects is such that attenuation increases with depth in high-porosity silt-clays until a null point is reached. Thereafter, pressure is the dominant effect, and attenuation decreases smoothly with depth and overburden pressure.

The approximate depth and k values where the above null point is reached should vary according to the rate of reduction in porosity with depth and overburden pressure. This porosity reduction varies with sediment type and is greatest in terrigenous sediments which form the turbidites of deep-sea fans and abyssal plains. The first layers of Neprochnov[8] are dominantly turbidites; the average k in these layers is 0.16 at an average depth of 330 m for layers in seven areas. From this average value of k, there is a regular decrease in k to deeper depths (Curve C in Fig. 3). For this average value, and decrease with further depth, to be valid for thick layers, the null point where k starts to decrease would have to be around 100–200 m. In other words: starting at the sediment surface with values of k between 0.05 and 0.10, k increases for the first 100 m or so, until values around 0.2 are reached (this increase due to reduction in porosity); somewhere around 100–200 m, the pressure effect becomes dominant and attenuation (k values) starts to decrease.

There is little substantiating data (in single experiments) for the above increase-decrease in attenuation. There is , however, an increase in attenuation to about 100 m in the first two layers of water-saturated clay and sand of Tullos and Reid,[32] followed by a decrease in the third layer (data in Table I). The marked decrease in attenuation between the second and third layer (from the top) could, of course, be due, in part at least, to other factors, including the marked layering evident in the velocity profile of the section (Tullos and Reid,[32] Fig. 2). Schoenberger and Levin[4] have discussed the appreciable energy losses which may occur in such multilayered sections. The data of Li and Smith[6] show that attenuation increases with depth in the first 100 m at about the same rate as in the data of Tullos and Reid, but in the Li and Smith sections there is no decrease in attenuation to about 180 m.

In summary, the variations of attenuation of compressional waves with depth in the sea floor, for the first 100–200 m, should depend on the sediment type. If the material is dominantly sand, the reduction in attenuation is predicted to be with the $-\frac{1}{2}$ to $-\frac{1}{6}$ power of depth; the $-\frac{1}{6}$ power is favored pending further experiments. If the material is dominantly silt-clay, or turbidites, attenuation should increase from a value at the sediment surface to about 100–200 m in depth, and thereafter decrease gradually with increasing overburden pressure, or depth. Below about 200 m depth, attenuation should decrease in silt-clays, turbidites, and sedimentary rock, along, or parallel to, curve C in Fig. 3. In basalt layers below the sea floor, values of k in Eq. (1), usually vary between 0.02 and 0.05. The value of the effective absorption coefficient, km^{-1}, favored for basalts by Neprochnov,[8] and Neprochnov *et al.*[19] converts into a k value of about 0.03.

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