

USE OF REGIONAL CONSTANT CORRECTION FACTORS FOR REDUCTION OF ECHO SOUNDINGS

by

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At the third meeting of the Pan-Pacific Science Congress held in Tokyo, October 30 to November 11, 1926, a paper, entitled "Correct values of the velocity of sound for echo soundings in the Pacific Ocean", was presented by Commander N. H. HECK and Lieutenant Jerry H. SERVICE, both of the United States Coast and Geodetic Survey (1).

In that very interesting paper there was discussed a method for simplifying the calculation of echo soundings by using constant correction factors applicable to certain areas in the Pacific Ocean — in this case for areas along or between designated parallels of latitude, the resulting depths having errors not exceeding one per cent.

The table of HECK and SERVICE, applicable only to the Pacific Ocean, is reproduced here in table 1, the tabular values being in percentages and based on an assumed velocity of sound of 4,800 feet (1,463 metres) per second.

TABLE 1. — Table for reducing acoustic soundings to correct values

<i>Latitude</i>	<i>Fathoms</i>								
	600	1,200	1,800	2,400	3,000	3,600	4,200	4,800	5,400
	<i>Metres</i>								
	1,097	2,194	3,292	4,389	5,486	6,584	7,681	8,778	9,875
60° N.....	0.0	0.5	1.1	1.9	2.5	3.2	3.9	4.5	5.1
55.....	0.3	0.8	1.3	2.0	2.6	3.2	4.0	4.6	5.2
50 - 40.....	0.6	1.0	1.5	2.0	2.6	3.3	4.0	4.6	5.2
35.....	1.3	1.4	1.7	2.2	2.8	3.4	4.1	4.8	5.3
30° N. - 40° S.....	2.0	1.7	2.0	2.5	3.0	3.6	4.2	4.9	5.4
45 S.....	1.3	1.4	1.7	2.2	2.8	3.4	4.1	4.8	5.3
50.....	0.6	1.0	1.5	2.0	2.6	3.3	4.0	4.6	5.2
55.....	0.3	0.5	1.1	1.7	2.3	3.0	3.7	4.3	4.9
60.....	0.0	0.1	0.7	1.5	2.1	2.7	3.5	4.1	4.7

Since the presentation and publication of that paper, the *Carnegie* has traversed a considerable portion of the Pacific within the latitudes 50° N. to 40° S. in her memorable cruise of 1928-9, which was fatefully terminated at Apia, Samoa, in November, 1929.

Inasmuch as about 1,200 echo soundings were obtained during this cruise, it was deemed worth while to examine some of the results of that cruise and to ascertain what contribution they might make in answer to the question whether or not it might be feasible and practicable to devise a method for simplifying sounding reductions by the use of factors constant for certain areas, by which a great amount of computational work might be eliminated from the usual methods, and especially in view of the fact that so many soundings are made at stations at which there are no accompanying observations of temperature and salinity of the sea water.

As noted by HECK and SERVICE, "the problem was to find the extent of the areas over which the same velocity may be used for any given depth". This is indeed the crux of the situation, assuming adequate knowledge of temperature and salinity conditions, as well as of sound velocity characteristics.

(1) *Proc. Third Pan-Pacific Sci. Congr. Tokyo, 1926, Vol. 1, pp. 202-4, 1928.*

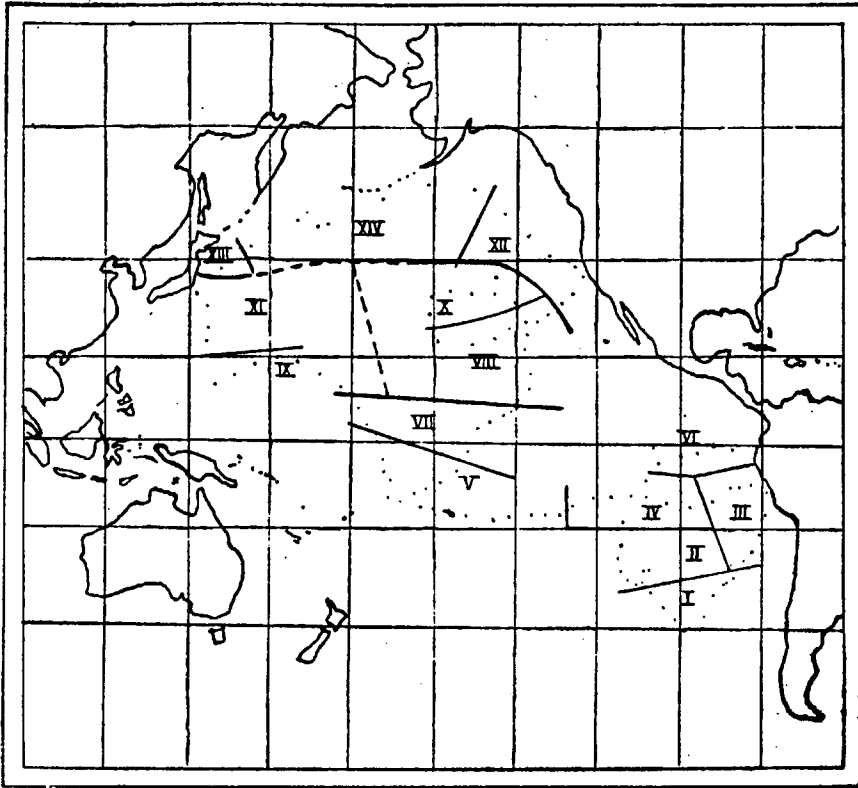


FIG. 1

Regions showing nearly uniform sounding velocity correction factors, Pacific Ocean, Carnegie results, 1928-29

The arbitrary selection of areas between or along certain parallels of latitude seems open to some criticism for the reason that the correction factors vary with longitude as with latitude. Taking as an example the area between the parallels of latitude 50° and 40° N., the regions adjacent to the American and Asiatic coasts within the said limits have on the average almost identical characteristics of the velocity of sound, both regions apparently differing in this respect from the more central part of the area in question. Similar conditions obtain within other regions of the Pacific.

In order, if possible, to override these objections, as well as to attain a higher degree of accuracy in the results, a compilation of all correction factors was made for selected levels at each *Carnegie* oceanographic station, which factors were determined in connection with the *Carnegie* reductions.

This compilation was then classified according to the values of the factors with a view to establishing regions having similar characteristics within themselves. While such a selection must necessarily be of a more or less arbitrary nature, the variations from region to region are sufficiently marked to warrant the regional selections.

In this manner 14 regions were classified and designated I to XIV, as shown in Fig. 1.

The correction factors used in the *Carnegie* reductions were based on the velocity of sound of 1,450 metres per second. This value was arbitrarily selected (1) simply for the reason that "it is an approximate round number, is somewhere near the true velocity, and in nearly all cases gave additive values".

The factors represent the ratios, average velocity of sound in metres per second down to the applicable depth divided by the basic velocity, 1,450 metres per second. These average velocities were determined for each *Carnegie* oceanographic station from

(1) Soule, F. M. and Ennis, C. C. *Trans. Am. Geophys. Union*, 11th Annual Meeting, pp. 264-74, 1930.

the British Admiralty velocity tables (1), being corrected for the observed temperatures and salinities and for pressure by means of tables 2 and 3 of the publication referred to. In this paper the correction factors are expressed in percentages for the sake of simplicity, thus 2.35 signifies factor 1.0235.

As previously stated, the *Carnegie* factors were classified and arranged in groups of stations where the values were in close agreement at corresponding levels. Group means were formed and the resulting values were considered as applicable to the regions embracing the groups of stations, 14 in number, and designated "Region I", etc., as shown on the map (Fig. 1).

Table 2 gives the mean values of the *Carnegie* correction factors for the respective regions at every 500-metre interval of depth from 1,000 metres down to the greatest depths. The table also gives the oceanographic stations included within each region. Depths less than 1,000 metres were not considered because of the more or less unstable conditions as compared with those at greater depths. Furthermore, about 95 per cent of the depths determined from the *Carnegie* observations exceeded 2,000 metres.

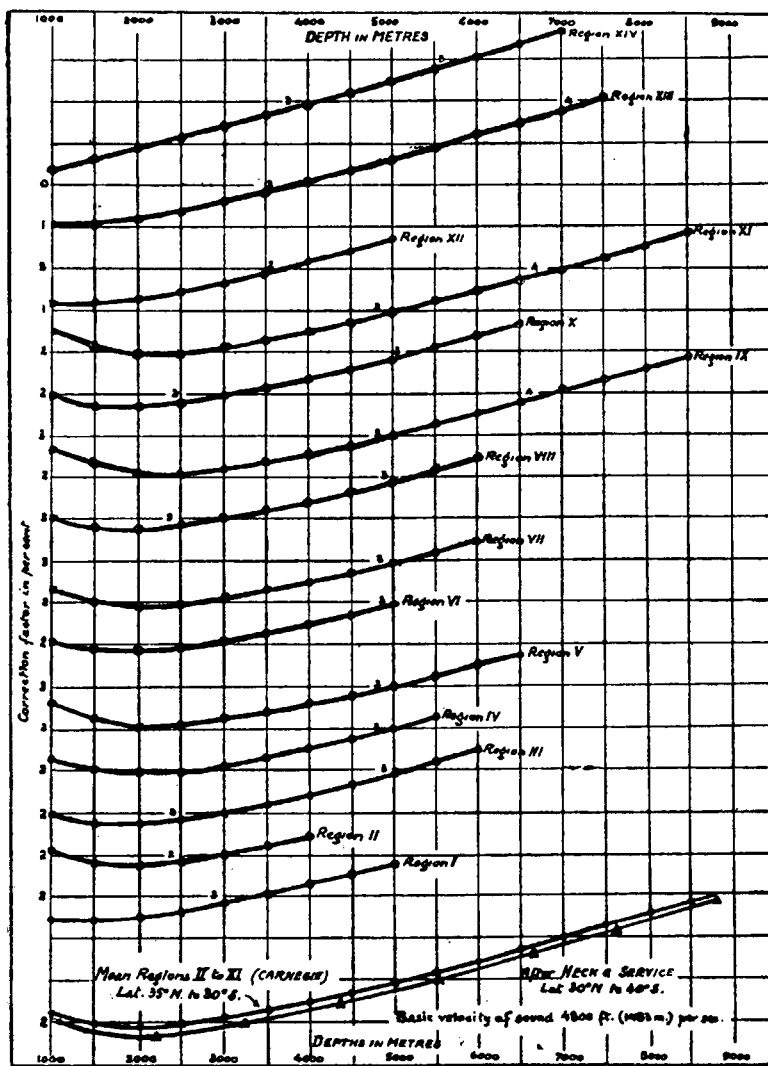


FIG. 2

Correction factors, echo soundings, Regions I to XIV, Pacific Ocean, Carnegie results, 1928-9.

(1) Admiralty Hydrogr. Dep. Pub. No. 282, London, 1927.

TABLE 2.—Regional mean values correction factors in per cent. determined for sonic depth reductions basis sound velocity 1,450 metres per second, Carnegie results, 1928-9.

Depth in metres	Region and stations														Mean II-XI (35°N.-30°S.)	Max. dep. from mean
	I 57-65	II 49-56	III 66-75	IV 76-82	V 83-98 158-162	VI 35-45	VII 99-100 153-157	VIII 133-140 147-152	IX 101-108	X 141-146	XI 109-113	XII 126-132	XIII 114-117	XIV 118-125		
1,000	2.42	3.00	2.87	3.21	3.50	2.96	3.20	2.91	3.54	2.85	2.06	2.02	1.26	3.14	0.40	
1,500	2.36	2.75	2.69	2.93	3.10	2.78	2.91	2.68	3.14	2.62	2.06	2.02	1.48	2.86	0.28	
2,000	2.43	2.70	2.65	2.84	3.00	2.76	2.84	2.66	2.98	2.62	2.19	2.12	1.75	2.79	0.19	
2,500	2.57	2.78	2.75	2.89	3.00	2.82	2.90	2.75	2.99	2.67	2.36	2.30	1.99	2.84	0.17	
3,000	2.74	2.94	2.92	3.00	3.10	3.00	3.01	2.88	3.10	2.85	2.57	2.52	2.25	2.98	0.13	
3,500	2.97	3.12	3.13	3.20	3.28	3.16	3.20	3.08	3.26	3.03	2.80	2.78	2.54	3.16	0.13	
4,000	3.18	3.34	3.34	3.40	3.47	3.40	3.40	3.31	3.46	3.25	3.04	3.02	2.82	3.37	0.12	
4,500	3.43	3.57	3.57	3.60	3.62	3.60	3.60	3.54	3.68	3.48	3.31	3.28	3.11	3.60	0.12	
5,000	3.63	3.83	3.83	3.90	3.90	3.86	3.89	3.79	3.91	3.75	3.60	3.55	3.41	3.85	0.10	
5,500		4.10	4.10	4.20	4.16	4.10	4.10	4.08	4.17	4.02	4.08	3.85	3.71	4.11	0.09	
6,000			4.40		4.40	4.40	4.40	4.34	4.40	4.30	4.15	4.15	4.00	4.37	0.07	
6,500				4.65		4.65	4.65		4.70	4.57	4.40	4.40	4.30	4.64	0.07	
7,000						4.90	4.90	5.00	5.00	4.90	4.70	4.70	4.60	4.95	0.05	
7,500						5.20	5.20	5.20	5.20	5.20	5.00	5.00	5.00	5.20	0.00	
8,000						5.50	5.50	5.50	5.50	5.50	5.30	5.30	5.30	5.50	0.00	
8,500						5.75	5.75	5.75	5.75	5.75	5.50	5.50	5.50	5.75	0.00	

TABLEAU 2

Valeurs moyennes des facteurs de correction régionaux en pour cent pour réduire les sondages par le son, basées sur une vitesse du son de 1,450 mètres par seconde; Résultats obtenus à bord du Carnegie en 1928-1929

TABLE 3.—Regional mean values Carnegie correction factors in per cent. reduced from basic sound velocity 1,450 metres per second to basis 4,800 feet per second.

Depth in metres	Region and stations														Mean II-XI (35°N.-30°S.)	Max. dep. from mean
	I 57-65	II 49-56	III 66-75	IV 76-82	V 83-98 158-162	VI 35-45	VII 99-100 153-157	VIII 133-140 147-152	IX 101-108	X 141-146	XI 109-113	XII 126-132	XIII 114-117	XIV 118-125		
1,000	1.51	2.08	1.95	2.29	2.58	2.04	2.28	1.99	2.62	1.93	1.15	1.11	0.36	2.22	0.41	
1,500	1.45	1.84	1.78	2.01	2.18	1.87	1.99	1.77	2.22	1.71	1.28	1.21	0.58	1.94	0.28	
2,000	1.52	1.79	1.74	1.92	2.08	1.85	1.92	1.75	2.06	1.71	1.28	1.21	0.84	1.87	0.19	
2,500	1.66	1.87	1.84	1.97	2.08	1.90	1.98	1.84	2.07	1.76	1.45	1.39	1.08	1.93	0.17	
3,000	1.83	2.02	2.01	2.08	2.18	2.08	2.08	1.96	2.18	1.93	1.66	1.61	1.34	2.06	0.13	
3,500	2.05	2.20	2.21	2.28	2.36	2.24	2.28	2.16	2.34	2.11	2.24	2.12	1.63	2.24	0.12	
4,000	2.26	2.42	2.42	2.48	2.55	2.48	2.48	2.39	2.54	2.33	2.44	2.36	1.91	2.45	0.12	
4,500	2.51	2.65	2.65	2.68	2.78	2.70	2.68	2.62	2.76	2.56	2.68	2.63	2.19	2.68	0.12	
5,000	2.71	2.91	2.91	2.98	2.98	2.94	2.97	2.87	2.99	2.83	2.94	2.68	2.49	2.94	0.11	
5,500		3.17	3.17	3.27	3.23	3.17	3.15	3.24	3.09	3.15	3.15	2.93	2.79	3.18	0.09	
6,000		3.47	3.47	3.47	3.47	3.47	3.41	3.47	3.42	3.42	3.42	3.22	3.07	3.44	0.07	
6,500				3.72		3.72	3.77	3.77	3.69	3.69	3.69	3.47	3.37	3.70	0.07	
7,000						4.07	4.07	4.07	3.97	3.97	3.97	3.77	3.67	4.02	0.05	
7,500						4.26	4.26	4.26	4.26	4.26	4.26	4.07	4.07	4.26	0.00	
8,000						4.56	4.56	4.56	4.56	4.56	4.56	4.37	4.37	4.56	0.00	
8,500						4.81	4.81	4.81	4.81	4.81	4.81	4.67	4.67	4.81	0.00	

TABLEAU 3

Valeurs moyennes des facteurs de correction régionaux du Carnegie exprimées en pour cent et réduites de la vitesse de base de 1,450 mètres par seconde à une vitesse de base de 4,800 feet par seconde

It will be noted that the tabular values for Regions I, XII, XIII and XIV vary considerably from those for the remaining regions, and that those for Regions XII and XIII are in very close agreement with each other. The ten regions, II to XI, exhibit characteristics sufficiently similar to justify their being grouped into one series. Over the route traversed by the *Carnegie*, this series comprises the area approximately between latitudes 35° N. and 30° S. The means of the factors for this series and the maximum departures of the factors for any region from the means are given in the last two columns of the table. It is significant that these departures are of the order of only one tenth of one per cent at 3,000 metres, decreasing to about zero at the greater depths.

For the purpose of comparison with the results of HECK and SERVICE, the values in table 2, based on the velocity of sound of 1,450 metres per second, have been reduced to the basic velocity of 4,800 feet (1,463 metres) per second by applying the ratio $1450/1463 = 0.991$. These reduced values, given in table 3, may be of interest to institutions, such as those of the United States, viz. Navy, Coast Guard, and Coast and Geodetic Survey, which use the assumed velocity of 4,800 feet per second.

In order to show the consistency and uniformity of the correction factors, the values in table 3 have been plotted, the results being shown in Figure 2. The two curves at the bottom of the graph afford a comparison of the *Carnegie* results for latitudes 35° N. to 30° S. with those of HECK and SERVICE for latitudes 30° N. to 40° S. It is interesting to note the striking similarity of these two curves, although the *Carnegie* values are about 0.1 to 0.2 per cent. greater than those of HECK and SERVICE.

TABLE 4.—Comparison depths determined from constant correction factors with those computed for each station in *Carnegie* reductions.

Sound. sta.	Near oc. sta.	Region	Approx. depth metres	Corr. fact. per cent.			Diff. metres		Prob. error ^b metres
				Sta.	Reg.	Area ^a	Reg.	Area ^a	
334	35	VI	3,671	3.30	3.30	3.29	0	0	±50
360	38	VI	2,437	2.93	2.83	2.84	2	0	±25
366 ^c	44	VI	4,210	3.50	3.56	3.53	3	1	
389 ^c	50	II	2,800	2.96	2.90	2.95	2	0	
409 ^c	55	II	2,685	2.78	2.86	2.91	2	3	
429 ^c	60	I	3,880	3.12	3.18	....	2	..	
452 ^c	65	I	3,490	3.03	3.01	....	1	..	
473 ^c	70	III	4,785	3.80	3.81	3.83	0	1	
506	75	III	3,776	3.30	3.30	3.33	0	1	
559	80	IV	3,477	3.26	3.24	3.20	1	2	
622	85	V	3,766	3.43	3.43	3.33	0	4	
637	85	V	1,014	3.49	3.45	3.12	0	4	
707	90	V	4,589	3.82	3.81	3.74	0	4	
770	95	V	4,290	3.67	3.68	3.58	0	4	±25
819	100	VII	5,754	4.38	4.41	4.38	2	0	±30
887	105	IX	5,534	4.32	4.30	4.26	1	3	
934 ^d	109	XI	8,169	5.86	5.85	5.86	1	0	
943	110	XI	3,066	3.11	3.06	3.03	2	2	
980	115	XIII	5,410	3.98	3.93	....	3	..	
1023	120	XIV	5,754	3.96	4.00	....	3	..	
1072	125	XIV	4,546	3.26	3.23	....	1	..	±30
1131	130	XII	3,208	2.73	2.71	....	1	..	
1179	135	VIII	4,648	3.65	3.70	3.76	2	5	±25
1225	140	VIII	1,398	2.98	2.70	2.89	4	1	±10
1227	140	VIII	4,770	3.84	3.77	3.83	3	0	
1231	141	VIII	2,557	2.93	2.79	2.88	4	1	
1258	143	X	5,800	4.28	4.33	4.40	3	7	±30
1280	145	X	5,492	4.10	4.14	4.23	2	7	
1332	150	VIII	4,131	3.43	3.44	3.50	0	3	
1385	155	VII	4,966	3.95	3.96	3.94	0	0	
1442	159	V	1,868	3.00	2.99	2.80	0	4	±10
1463	160	V	1,179	3.37	3.32	3.01	1	3	
1470	160	V	2,608	3.06	3.04	2.90	1	4	±15

(a) Mean of factors for Regions II-XI. (lat. 35° N.-30° S.), designated "area" to differentiate from "region".

(b) Probable error assigned to final depths in *Carnegie* reductions.

(c) Depths by "shotgun" method:

(d) Fleming Deep.

In order to test out the results obtained by the use of constant factors as compared with those determined for each oceanographic station in the *Carnegie* reductions, table 4 was prepared. Comparisons were made at or near every fifth oceanographic station

along the whole cruise in the Pacific. In some cases, in order to include some of the smaller depths, selections were more frequent.

The depths determined in the *Carnegie* reductions being accepted as the true depths, comparison was made with them, both on the basis of the regional factors and of those for the area, latitude 35° N. to 30° S., as given in table 2. The columns headed "differences" in table 4 show the differences between the "true" depths and those determined by the use of constant factors. It will be seen that those differences vary from zero to about one-tenth per cent. Differences of this order seem almost negligible when we consider the several sources of errors, instrumental and observational, in the determination of echo soundings. The probable errors estimated for the *Carnegie* depths range from about 0.5 to 1.5 per cent.

It is hoped that the seeming possibilities indicated herein, necessarily limited in scope, may serve to emphasize and stress the need of more thorough and comprehensive surveys, not only for a fuller knowledge of the characteristics of the "waters that cover the deep" and of their great systems of circulation, but also of the configuration of the ocean bottoms.

