ON THE RECENT SEA-LEVEL VARIATION AT THE ITALIAN AND AUSTRIAN MAREOGRAPH STATIONS, AND ON THE CAUSE OF THE MESSINA-REGGIO EARTHQUAKE OF 1908.

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With Plates XXIII—XXIX.

1. *Introduction.* The present paper is a note on the variation in height of the mean yearly sea-level at the mareograph stations of Italy, between 1897 and 1908, and those of Austria-Hungary, between 1897 and 1910, with a reference to the cause of the Messina-Reggio earthquake of Dec. 28th, 1908. High credit is due to Prof. G. Grablovitz, who published in a recent number of the Bollettino della Società Sismologica Italiana the result of discussion on the variation in height of the mean sea-level at Ischia during the 21 years, 1890–1910.* He found that during this period the sea-level at Ischia was on the whole rising, the total increase of height being about 90 mm, with the yearly average of about 3 mm.

* G. Grablovitz ;—Il mareografo d'Ischia in relazione ai bradisismi. *Boll. d. Società. Sism. Italiana*, Vol. XV, 1911.

It is, however, to be remarked that the comparison of the height of the mean sea-level at the different mareograph stations indicates the course of the sea-level variation at Ischia to be quite exceptional, and in some respect opposite to those at the other places. For seismologists, the chief interest in the phenomena of the sea-level variation is in the capacity of the latter as one of the secondary causes which leads to the occurrence of the final underground disturbances producing a great earthquake.

2. *Annual variation in sea-level height, barometric pressure, and surface sea-water temperatures, at Pola.* Table I, which has been compiled from the lists of the observations made at the Hydrographic Office of Pola,* during the 11 years, 1900 to 1910, gives for the different months, the height of the mean sea-level, the mean barometric pressure, and the air and surface sea-water temperatures.

TABLE I. MONTHLY MEAN BAROMETRIC PRESSURE, AIR TEMPERATURE, SEA-WATER TEMPERATURE, AND HEIGHT OF SEA-LEVEL, AT POLA.

(Deduced from the observations between 1900 and 1910.)

Month.	Air Temperature.	Temperature of the Sea (surface) Water.	Barometric Pressure.**	Height of Sea-level.***	Height of Sea-level with barometric correction.
			mm	cm	cm
I	4.51° C	9.6° C	762.32	161.1	158.0
II	5.78	8.7	57.87	155.5	158.3
III	8.16	9.4	57.56	156.7	159.9
IV	11.49	11.5	56.75	156.2	160.5
V	16.11	15.6	57.78	156.6	159.5

* The *Jahrbuch d. met., erdmagn. u. seism. Beobachtungen,* Pola.

** Reduction to standard gravity and sea-level = +0.034 mm.

*** Greater figures correspond to the lower water levels and the smaller figures to the higher levels. See also the note to Table II.

Fig. 1. Map showing the positions of the Italian and Austrian Mareograph Stations, and the Average Change Rate of Height of the Sea-level, between 1900 and 1908.

Figures marked beside each mareograph station give its average yearly amount of the level change. The curves are the lines of equal decrease rate, respectively of 10, 7, and 4 mm per year.

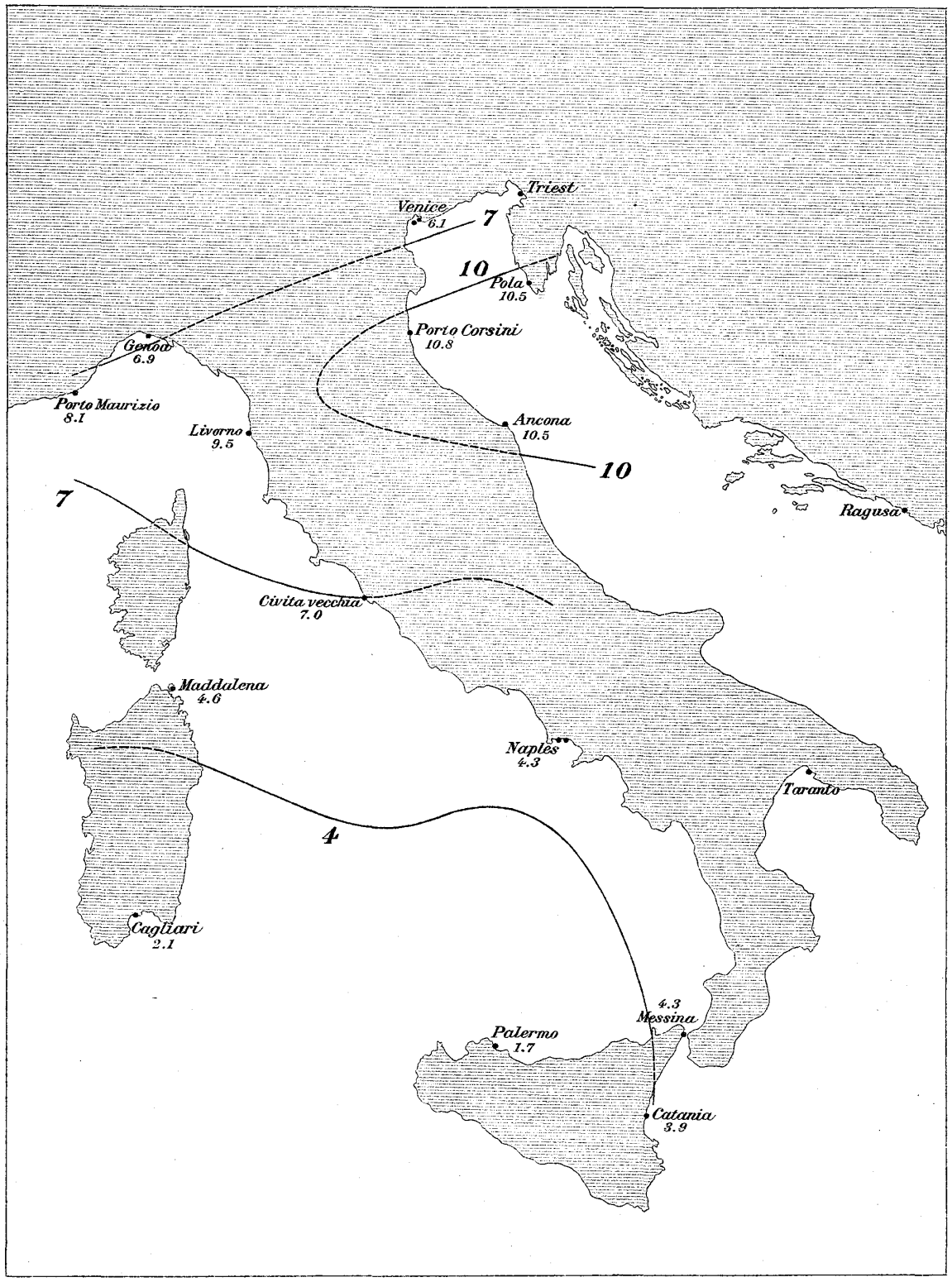


Fig. 2. Annual Variation in Height of the Sea-level compared with those of the Barometric Pressure and the Water and Air Temperatures. Pola, 1897-1910.

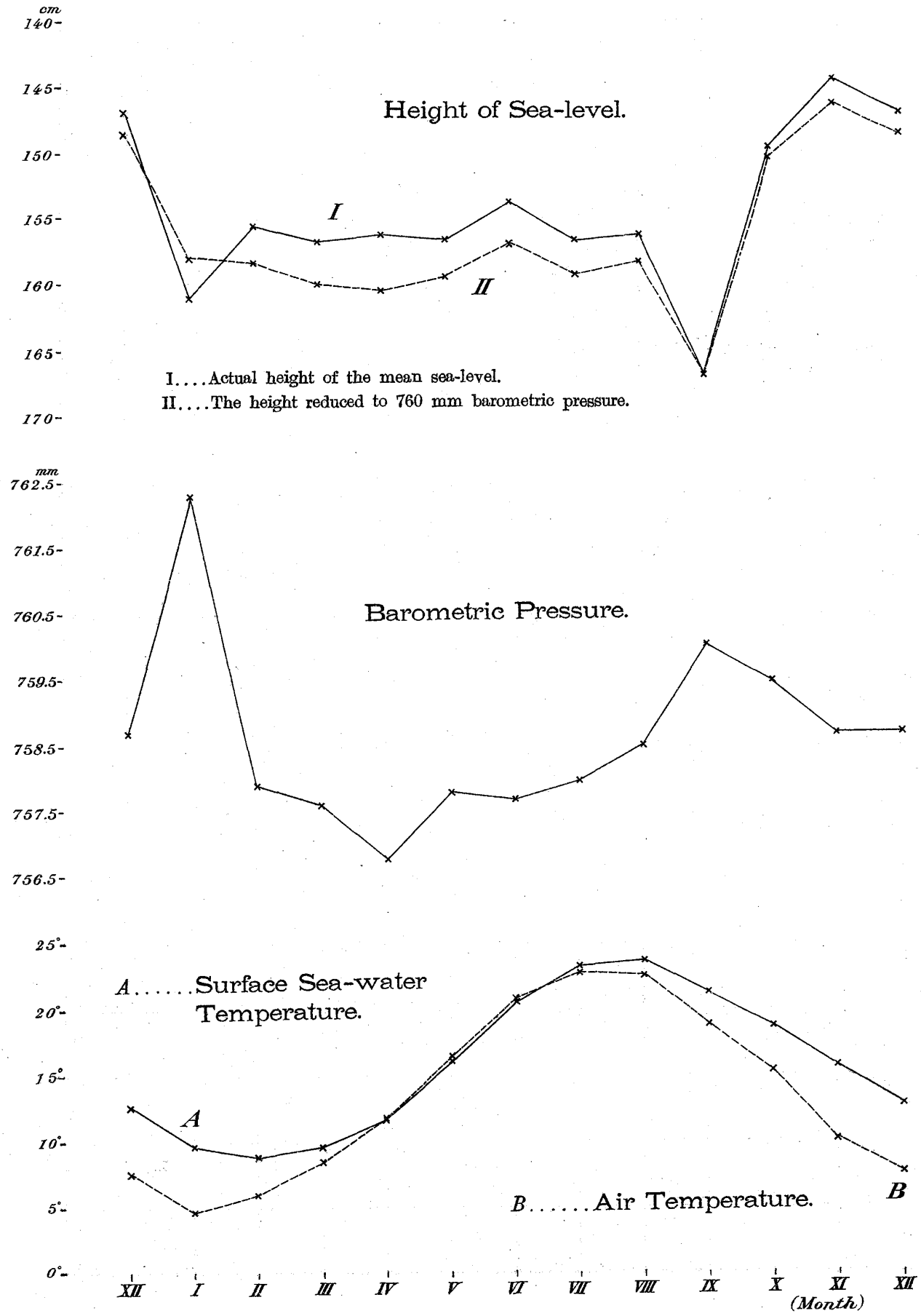
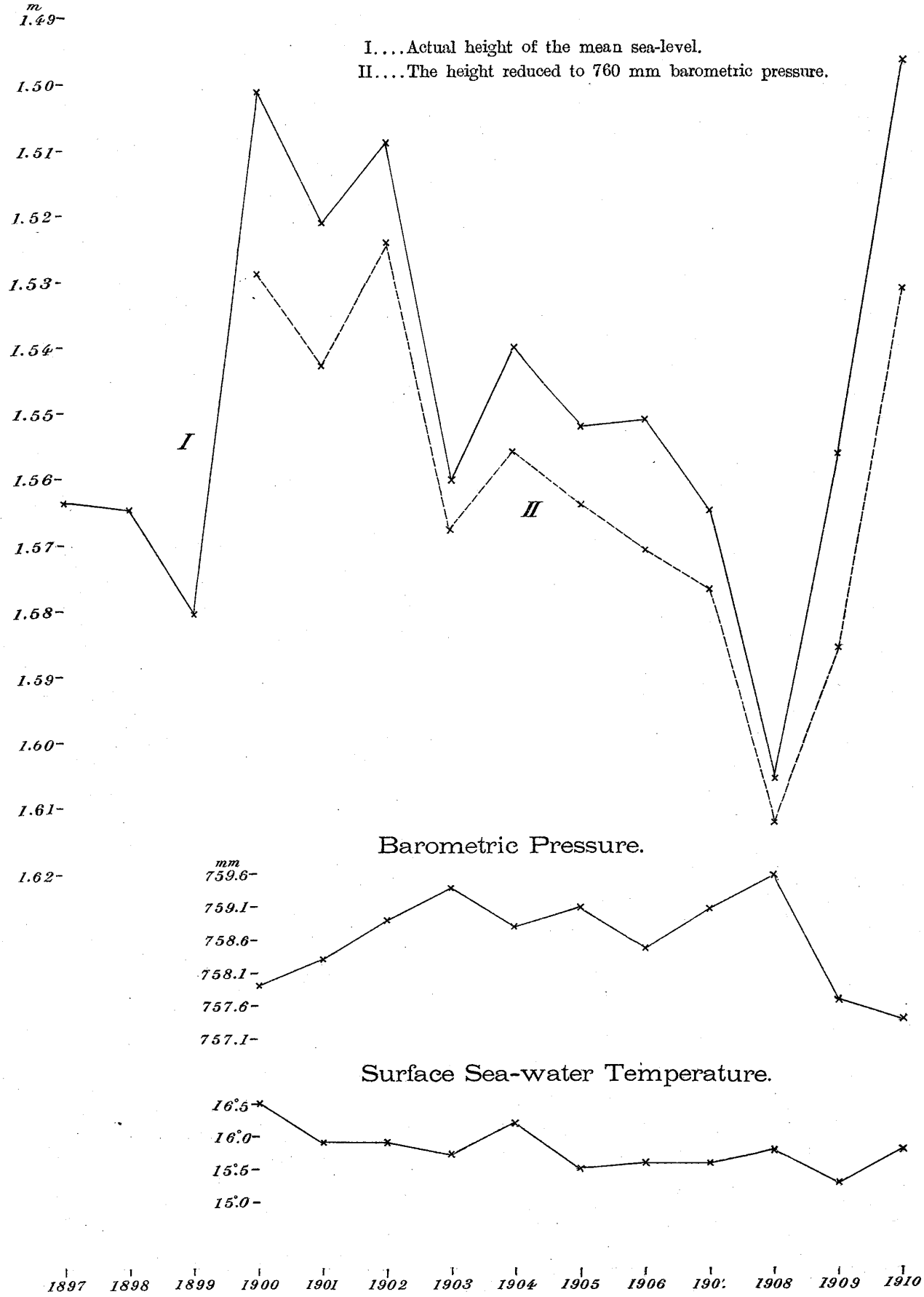


Fig. 3. Variation in Height of the Mean Sea-level.
Pola, 1897-1910.



Month.	Air Temperature.	Temperature of the Sea (surface) Water.	Barometric Pressure.	Height of Sea-level.	Height of Sea-level with barometric correction.
	°	°	mm	cm	cm
VI	20.19	20.3	57.65	153.8	156.9
VII	22.46	23.1	57.96	156.6	159.3
VIII	22.37	23.4	58.47	156.3	158.3
IX	18.61	21.0	60.02	167.0	167.0
X	15.03	18.4	59.47	149.7	150.4
XI	9.83	15.4	58.67	144.4	146.2
XII	7.38	12.4	58.68	146.9	148.6

As will be noted from Fig. 2, the annual variation in height of the mean sea-level is in a measure symmetrically opposite to that of the barometric height, which peculiarity does not entirely disappear even after the reduction to the 760 mm atmospheric pressure. (See also the last column of Table I.) The height of the mean sea-level, with the barometric correction, is almost constant during the 8 months, January to August, being lowest in September, and highest in November, with the extreme difference of 208 mm.

The mean monthly temperature of the water of the sea surface was lowest in February and highest in August, with the extreme difference of 14°.7 C. It was on the average 2°.2 C higher than that of the air temperature, the course of the annual variation being, however, similar in the two cases. It may be added that the mean yearly temperature of the surface sea water was, in the course of the 11 years from 1900 to 1910, was 2°.0 to 2°.7 C higher than that of the air, giving the average difference of 2°.3 C, which is practically identical with the value above obtained. There is no marked apparent similarity between the annual varia-

tion in height of the mean sea-level, corrected for the barometric pressure, and that of the sea water temperature.

3. *Variation in height of mean sea-level at Pola.* Table II gives the yearly height of the mean sea-level at the three Austrian mareograph stations of Triest, Ragusa,* and Pola, together with the yearly mean values of the barometric pressure, and the air and the surface sea-water temperatures at the last named place, from 1900 to 1910.

TABLE II. YEARLY HEIGHT OF THE MEAN SEA-LEVEL AT POLA, TRIEST, AND RAGUSA; AND THE MEAN YEARLY BAROMETRIC PRESSURE, AIR TEMPERATURE, AND SEA-WATER TEMPERATURE, AT POLA. 1897—1910.

Year.	Height of Sea-level.**			Barometric Pressure.*** (Pola).	Air Temperature. (Pola).	Temperature of Surface Sea Water. (Pola).	Height of Sea-level at Pola with barometric correction.
	Pola.	Triest.	Ragusa.				
	cm	cm	cm	700 mm+	C°	C°	cm
1897	156.4	——	——				
1898	156.5	——	——				
1899	158.1	——	——				
1900	150.1	——	——	57.88	14°.10	16°.5	152.9
1901	152.1	100.8	——	58.32	13.29	15.9	154.3
1902	150.9	99.9	——	58.87	13.33	15.9	152.4
1903	156.0	103.2	31.2	59.41	13.69	15.7	156.8
1904	154.0	103.5	32.3	58.81	14.23	16.2	155.6
1905	155.2	——	32.9	59.07	13.09	15.5	156.4

* The height of the mean sea-level at Triest and Ragusa is taken from Mitteilungen des K. u. K. Militärgeographischen Institutes.

** For Pola and Triest, the greater figures correspond to the lower water levels aud the smaller to the higher. In the original publications, the height of the sea-level at Pola is given, since 1905, with reference to a fixed point which is 4 m below the "zero point" of the old mareograph. In the present table I have converted the height of the sea-level since 1905 also to the reference point used in the previous years.

*** Reduction to the standard gravity and the sea-level = +0.034 mm.

Year.	Height of Sea-level.			Barometric Pressure. (Pola).	Air Temperature. (Pola).	Temperature of Surface Sea Water. (Pola).	Height of Sea-level at Pola with barometric correction.
	Pola.	Triest.	Ragusa.				
	cm	cm	cm	700mm+	°	°	cm
1906	155.1	——	32.9	58.48	13.28	15.6	157.1
1907	156.5	——	31.4	59.10	13.36	15.6	157.7
1908	160.6	——	27.2	59.58	13.05	15.8	161.2
1909	155.6	——	32.9	57.73	13.22	15.3	158.6
1910	149.6	——	——	57.36	13.71	15.8	153.1

In the course of the 14 years, 1897 to 1910, the height of the actual sea-level was maximum in 1900 and in 1902, thence gradually decreased, reaching the minimum in 1908, with the extreme difference of 105 mm. Since 1908 the level again rapidly increased; the height difference between 1908 and 1910 being 110 mm. During the same time interval, the mean barometric height varied between 757.4 and 759.6 mm; the correction for deducing the actual mean sea-level in the different years to the case of the 760 mm pressure being 8 to 35 mm, according to the assumption adopted before. The difference between the highest and lowest positions of the mean sea-level becomes 88 mm, but as may be seen from Fig. 3, the introduction of the barometric correction does not change the general character of the variation in height of the sea-level. The mean temperature of the surface sea water varied to the amount of 1°.2 C, between 16°.5 and 15°.3 C, being highest and lowest respectively in 1900 and 1909. It may be remarked that the variation of the barometric pressure was in a measure opposite to that in height of the mean sea-level. The latter, corrected for the barometric pressure, was, however, highest in 1902 and lowest in 1908; the sea-water temperature in these two years being respectively not maximum and minimum.

4. *Mean height of sea-level at Italian mareograph stations.* Table III, which is taken from the "Processo Verbale della Sedute della R. Commissione Geodetica Italiana," gives for the 12 years, 1897 to 1908, the mean height of the sea-level at the 15 Italian mareograph stations of Venice (R. Marina), Venice (San Stefano), Porto Corsini, and Ancona, on the Adriatic coast; Porto Maurizio and Genoa (R. Marina), on the Galf of Genoa; Livorno, Civita vecchia, Naples (Arsenale), Naples (Mandracchio), and Palermo, on the Tyrrhenean coasts; Messina and Catania, on the estern coast of Sicily; and Maddalena and Cagliari, in Sardinia. The height of the sea-level is referred for the mareographs at the different places, as follows: at Livorno and Venice (S. Stefano) to the local hydrographical zero immersed under water; at Genoa, Venice (Arsenale), Maddalena, and Naples (Arsenale), to the top level of the Thomson mareograph; and, at Ancona, Cagliari, Catania, Civita vecchia, Messina, Naples (Mandracchio), Palermo, Porto Corsini, and Porto Maurizio, to the bench mark. It will thus be seen that, except at the two first-named stations, the larger figures correspond to the lower levels and the smaller figures to the higher levels.

TABLE III. YEARLY HEIGHT OF THE MEAN SEA-LEVEL AT ANCONA, CAGLIARI, CATANIA, CIVITA VECCHIA, GENOA (R. MARINA), LIVORNO, MADDALENA (R. MARINA), MESSINA, NAPLES (ARSENALE), NAPLES (MANDRACCHIO), PALERMO, PORTO CORSINI, PORTO MAURIZIO, VENICE (ARSENALE), AND VENICE (SAN STEFANO). 1897—1908.

Station.	1897	1898	1899	1900	1901	1902	1903	1904	1905	1906	1907	1908	Mean.
Ancona	2.346	2.372	2.384	2.312	2.329	2.324	2.360	2.327	2.344	2.352	2.404	2.403	2.355
Cagliari	2.178	2.137	2.123	2.113	2.098	2.105	2.122	2.091	2.116	2.099	2.132	2.123	2.120

Station.	1897	1898	1899	1900	1901	1902	1903	1904	1905	1906	1907	1908	Mean.
Catania	1.924	1.945	1.941	1.922	1.920	1.904	1.929	1.896	1.941	1.924	1.945	1.949	1.928
Civita vecchia	2.957	2.974	2.966	2.919	2.939	2.935	2.956	2.941	2.963	2.953	2.968	2.992	2.955
Genoa (R. Marina)	2.987	2.983	2.997	2.955	2.970	2.955	2.973	2.974	2.993	2.987	2.997	3.017	2.982
Livorno	0.485	0.465	0.480	0.536	0.525	0.544	0.514	0.524	0.497	0.495	0.470	0.464	0.500
Maddalena (R. Marina)	2.740	2.728	—	2.679	2.683	2.687	2.711	2.687	2.709	2.697	2.707	2.726	2.705
Messina*	1.119	1.110	1.123	1.084	1.082	1.075	1.096	1.082	1.095	1.089	1.097	1.130	1.099
Naples (Arsenale)	—	—	2.890	2.841	2.838	2.841	2.853	2.833	2.872	2.844	2.861	2.887	2.856
Naples (Mandracchio)	2.317	2.313	2.323	2.276	2.283	2.281	2.302	2.284	2.299	2.288	2.302	2.319	2.299
Palermo	3.593	3.588	3.617	3.587	3.590	3.579	3.593	3.574	3.579	3.573	3.603	3.609	3.590
Porto Corsini	3.236	3.255	3.261	3.190	3.222	3.209	3.255	3.231	3.236	3.240	3.263	3.310	3.242
Porto Maurizio	3.565	3.562	3.563	3.531	3.543	3.534	3.566	3.557	3.573	3.569	3.567	3.585	3.560
Venice (Arsenale)	3.881	3.911	3.932	3.880	3.873	3.859	3.917	3.899	3.897	3.896	3.875	3.964	3.899
Venice (S. Stefano)	1.297	1.281	1.247	1.323	1.307	1.310	1.284	1.296	1.308	1.307	1.284	1.251	1.291

5. *Relative height of mean sea-level between* 1897 *and* 1908. In Table IV, the height of the yearly sea-level at each of the different Italian and Austrian mareograph stations is referred to the lowest mean position as zero. From the graphical illustrations in Figs. 4 and 5, which relate respectively to the Adriatic coasts and to the Tyrrhenian and the Ligurian coasts, will be seen that the course of variation in height of the mean sea-level between 1897 and 1908 was more or less alike for all the different places, the similarity being particularly striking in the cases of Pola, Venice (San Stefano), Venice (Arsenale), Porto Corsini, Ancona, Livorno, Civita vecchia, Genoa, Porto Maurizio, and also probably of Triest and Ragusa. The special points in the height fluctuations common to almost all the stations are a minimum in 1899, 1903, and 1908, and a maximum in 1900 and 1902. The difference between the heighest and lowest positions of the mean

* Mean from the maximum and minimum values.

yearly sea-level was, within the time limit in question, from 44 to 120 mm, as follows:—

Pola	105 mm	Livorno	80 mm
Ancona	92 „	Ischia	61 „
Porto Corsini	120 „	Naples (Mandracchio)	47 „
Venice (Arsenale)	105 „	Messina	55 „
Venice (San Stefano)	76 „	Catania	53 „
Geona	62 „	Palermo	44 „
Porto Maurizio	84 „	Cagliari	87 „
Civita vecchia	73 „	Maddalena	61 „

I give below the yearly values deduced by taking the average of the mean height at the different places:—

1897	24 mm	1903	33 mm
1898	21 „	1904	48 „
1899	13 „	1805	35 „
1900	59 „	1906	41 „
1901	52 „	1907	24 „
1902	58 „	1908	0 „

These relative heights for the different years, whose maximum amount was 59 mm, represent in a rough way the general course of the variation in the height of the mean sea-level for the whole of Italy. According to the above figures the average sea-level was lowest in 1899 and in 1908. That the height of the sea-level reached a mimimum in the latter year as well as in the former is shown clearly by the variation in the mean height at Pola and Ragusa.

TABLE IV. RELATIVE HEIGHT OF THE MEAN YEARLY SEA-LEVEL AT THE AUSTRIAN AND ITALIAN MAREOGRAPH STATIONS. 1897—1908.

(Without the barometric and temperature corrections.)

Station. \ Year.	1897	1898	1899	1900	1901	1902	1903	1904	1905	1906	1907	1908
Pola	42	41	25	105	85	97	46	66	54	55	41	0
Ragusa	—	—	—	—	—	—	40	51	57	57	42	0
Ancona	58	32	20	92	75	80	44	77	60	52	0	1
Cagliari	0	41	55	65	80	73	56	87	62	79	46	55
Catania	25	4	8	27	29	45	20	53	8	25	4	0
Civita vecchia.	35	18	26	73	53	57	36	51	29	39	24	0
Genoa (R. Marina)	30	34	20	62	47	62	44	43	24	30	20	0
Livorno.	21	1	16	72	61	80	50	60	33	31	6	0
Maddalena (R. Marina)	0	12	—	61	57	53	29	53	31	43	33	14
Messina	11	20	7	46	48	55	34	48	35	41	33	0
Naples (Mandracchio)	6	10	0	47	40	42	21	39	24	35	21	4
Naples (Arsenale)	—	—	0	49	52	49	37	57	18	46	29	3
Palermo	24	29	0	30	27	38	24	43	38	44	14	8
Porto Corsini	74	55	49	120	88	101	55	79	74	70	47	0
Porto Maurizio	20	23	22	54	42	51	19	28	12	16	18	0
Venice (Arsenale)	83	53	32	84	91	105	47	65	67	68	89	0
Venice (S. Stefano)	50	34	0	76	60	63	37	49	61	60	37	4
Ischia.	0	29	24	47	49	37	61	16	50	59	30	22
Mean	30	27	19	65	58	64	39	54	41	47	30	6

6. *Variation in height of the mean sea-level between* 1900 *and* 1908. Confining our attention to the nine years, 1900 to 1908, we see that the height of the mean (actual) sea-level decreased steadily, on the whole, at the different Italian and Austrian stations. Assuming, for this time interval, a linear relation of the form $y=c+ax$, in which y is the height of the mean sea-level in the year denoted by x, whose time origin is 1900, and in which a and c are constants, we obtain the following results:—

(For the interval of 1900 to 1908)

		mm	mm
Porto Corsini	$y=$	113.5	$-10.8x$
Pola	$y=$	102.9	$-10.5x$
Ancona	$y=$	95.4	$-10.5x$
Livorno	$y=$	81.7	$-9.47x$
Porto Maurizio	$y=$	62.3	$-8.1x$
Civita vecchia	$y=$	68.4	$-7.03x$
Genoa	$y=$	64.4	$-6.88x$
Venice (Arsenale)	$y=$	94.8	$-6.6x$
Venice (San Stefano)	$y=$	72.3	$-5.65x$
Maddalena	$y=$	60.1	$-4.63x$
Naples (Arsenale)	$y=$	56.3	$-4.62x$
Naples (Mandracchio)	$y=$	46.3	$-4.00x$
Messina	$y=$	54.8	$-4.27x$
Catania	$y=$	39.1	$-3.92x$
Ischia	$y=$	59.5	$-2.09x$
Cagliari	$y=$	75.3	$-2.07x$
Palermo	$y=$	36.3	$-1.68x$

In the above series of the equations, the coefficient of x denotes for the different places the average rate, for the interval of 1900 to 1908, of decrease in height of the actual mean sea-level, in mm

Fig. 4. Variation in Height of the Mean Sea-level at the Mareograph Stations on the Adriatic Coast: Venice (San Stefano), Venice (Arsenale), Porto Corsini, Ancona, Pola, Triest, and Ragusa. 1897-1908, 1909.

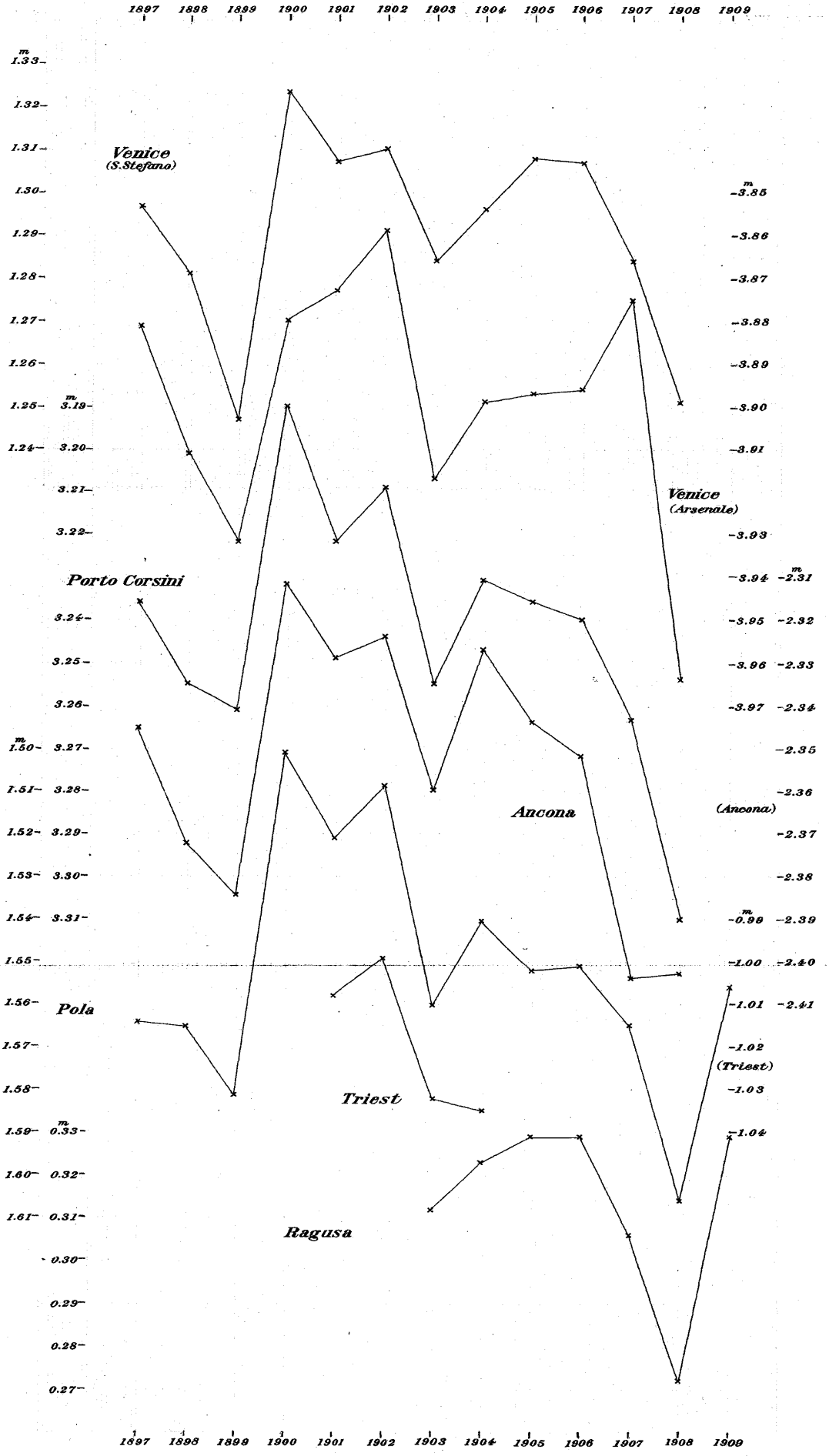


Fig. 5. Variation in Height of the Mean Sea-level at the Mareograph Stations on the Tyrrhenian and Ligurian Coasts: Genoa, Porto Maurizio, Civita vecchia, Livorno, Naples (Mandracchio), Naples (Arsenale), Messina, Palermo, Catania, Cagliari, Maddalena, and Ischia. 1897-1908.

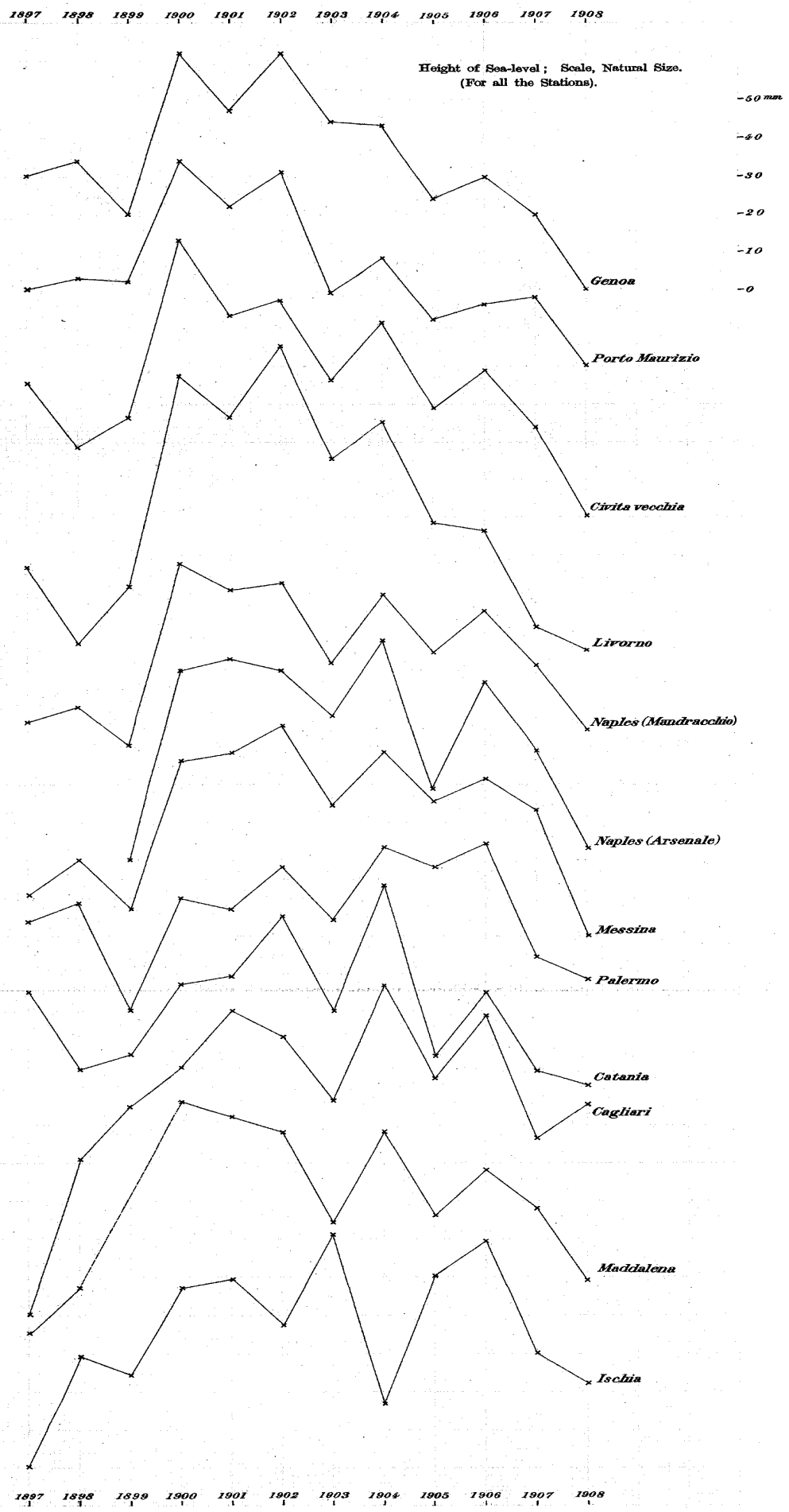
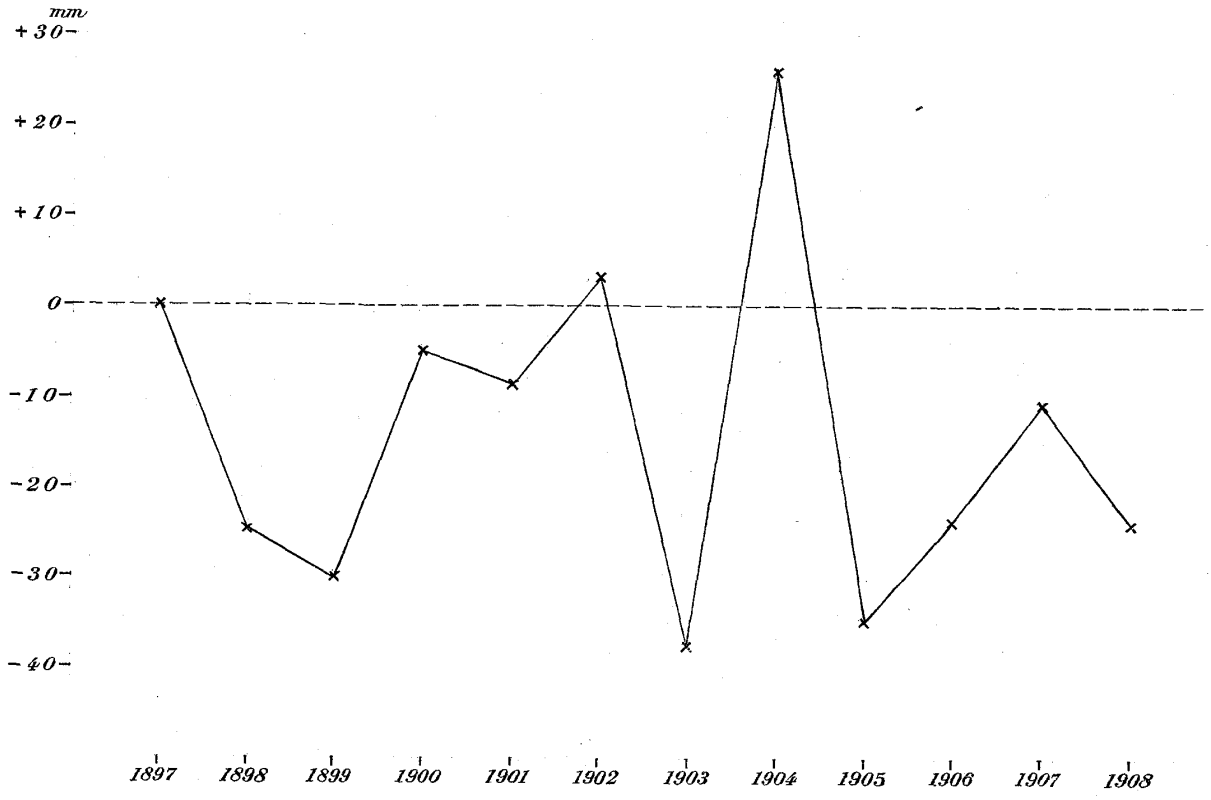


Fig. 6. Variation in Height of the Datum Plane at Ischia referred to that at Naples.

y = Height of sea-level at Naples *minus* the height of sea-level at Ischia.



per year; varying from about 11 mm per year at Porto Corsini, Pola, Ancona, and Livorno, to about 2 mm per year at Cagliari, Palermo, and Ischia. The sea-level change at the last named place, situated on a small volcanic island recently convulsed by violent local seismic disturbances, may have the special character of its own. (See § 7.)

In Fig. 1, I have drawn, by interpolating the results for the 10 mm, 7 mm, and 4 mm average decrease rates of the height of the mean actual sea-level, extended alike across the seas and the land. This is equivalent to the assumption that the variation of the sea-level along the Italian and Austrian coasts extends over the Adriatic and the Tyrrhenean in the same way as if these two bodies of water were not separated by the peninsula of Italy. From the figure, we see that the decrease in height of the mean sea-level was greatest, 8.1 to 10.8 mm, in a zone nearly East-West in direction, which extends from Pola, Port Corsini, and Ancona, on the one hand, to Livorno and Port Maurizio on the other. The rate lessened bothways from this zone, namely, to 6.1 and 6.9 mm at Venice and Genoa northwards, and to 7 mm at Civita vecchia southwards, being least, 1.7 to 4.6 mm, at Naples and the Sardinian and the Sicilian stations. If the depression of the sea-level be interpreted, as in the case of the Japanese stations, to denote the rise of the land, then the above results lead us to the supposition that, during the interval of 1900 to 1908, both continental and insular parts of Italy were subjected on the whole to an elevation, whose amount was greatest and about 10 mm per year in the neighbourhood of Ancona, Port Corsini, and Livorno, and was least and about 2 to 4 mm per year in Sicily, Sardinia, and the south-western part of the peninsula.

7. *Variation in height of mean sea-level at Ischia*, 1897-

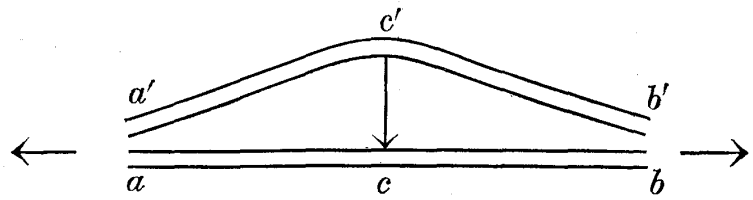
1908. As the island of Ischia lies close to the coast of Naples, the relative variation in height of the mean sea-level at the mareograph stations of these places must give the results practically independent of the barometric and the temperature influences. Thus, subtracting from the mean height at Ischia the average of those at the two Neapolitan stations of Mandracchio and the Arsenale, we obtain the following differential yearly values :—

Year.	Mean Height of Sea-level at Ischia referred to that at Naples.	Year.	Mean Height of Sea-level at Ischia referred to that at Naples.
1897	0 mm	1903	+38 mm
1898	+25	1904	−26
1899	+30	1905	+35
1900	+ 5	1906	+24
1901	+ 9	1907	+11
1902	− 3	1908	+24

As the height of the mean sea-level must be identical for the limited sea area between the places under consideration, the apparent general superiority of the level at Ischia over that at Naples indicated in the above table must denote the actual sinking of the land at the former station relative to the mean position of the sea-level at the latter. (See Fig 6.) Thus, in the time interval of 1897 to 1908, the land at the mareograph station of Ischia suffered, relative to the Neapolitan coast, a depression whose average amount was 14.3 mm, the maximum being 38 mm.

8. *On the cause of Messina-Reggio earthquake of* 1908. In the preliminary report on the Messina-Reggio earthquake of 1908,* the present author pointed out the fact that the very initial direction of the earthquake motion was, according to the instrumental records obtained at the different seismological observatories, divergent, or directed away from the centre; this being a characteristic feature of a seismic disturbance of non-volcanic (i. e., non-explosive) origin. There I put forward a supposition that the earthquake might have been due to the formation of a vertical crack in the upper layer of the earth's crust. Now, according to the preceding §§, the height of the mean sea-level was in the interval of 1897–1908 lowest at Messina as well as for the whole of Italy in 1899 and 1908, after which latter the level rose distinctly as may be judged from the cases of Pola and Ragusa. Thus the height of the mean sea-level attained a well defined minimum in 1908. In the same year, therefore, the elevation of the *land* reached a maximum, giving an upward strain to the surface layer (*ab*, Fig. 9) of the earth's crust in the region under consideration. This resulted probably in a sort of the vertical elastic rebound, bringing down the surface layer from the strained position, *a′ c′ b′*, to the original level, *a c b* accompanied by some sudden rupture, such as the formation of a vertical crack at *c*, the origin of the earthquake. Under

Fig. 9.



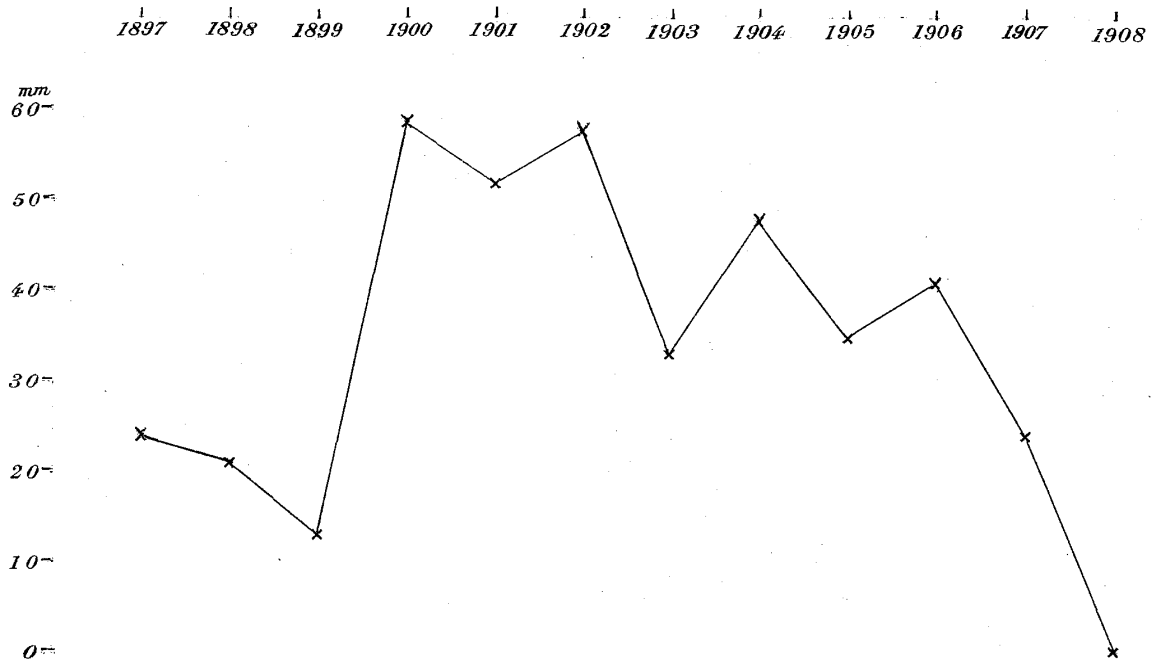
ab.....Surface layer of earth's crust in its normal state.
a′b′....Strained position of *ab*.

* The *Bulletin*, Vol. III, No. 1.

these circumstances, the direction of motion of the initial displacement of the seismic motion at the surrounding places would be divergent. The necessary subsidence of the ground at the epifocal region, which was submarine, may be taken as having given rise to the "tsunami" (maremoto), which devastated the two sides of the Messina Strait.

In conclusion it must be stated that, in §§ 3–7, no consideration has been taken of the effects on the mean yearly sea-level of the sea water temperature and of the barometric pressure. According to the results obtained in the preceeding Article, however, the corrections due to those influences appear to be not so great as to materially modify the general course of the variation in the yearly height of the mean sea-level.

Fig. 7. Variation in the Average Height of the Mean Sea-level along the Italian and Austrian Coasts, 1897-1908.



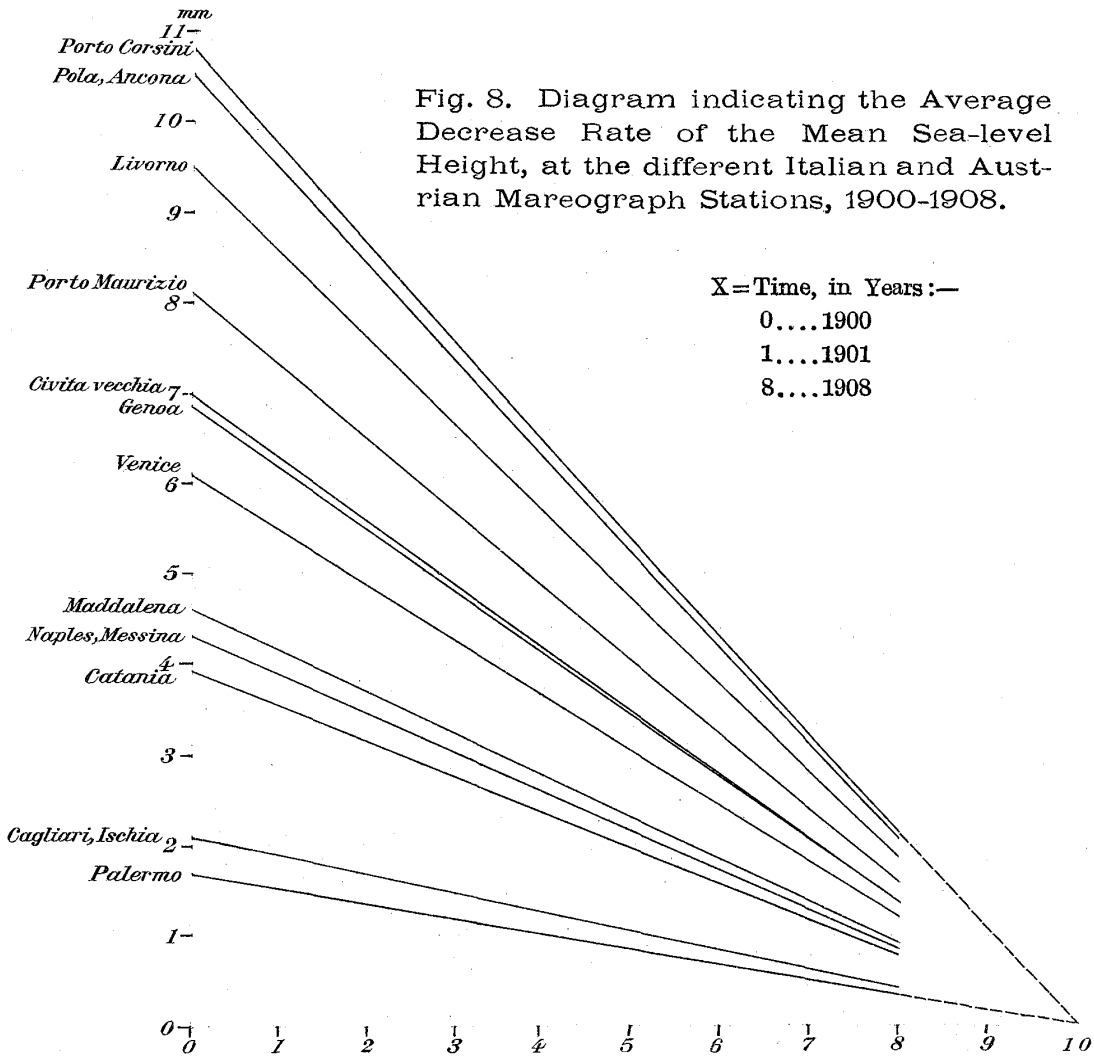


Fig. 8. Diagram indicating the Average Decrease Rate of the Mean Sea-level Height, at the different Italian and Austrian Mareograph Stations, 1900-1908.

X = Time, in Years :—
0....1900
1....1901
8....1908