THE SAKURA-JIMA ERUPTIONS AND EARTHQUAKES. IV.

Results of the Leveling Surveys and the Kagoshima Bay Soundings made after the Sakura-jima Eruption of 1914.

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With Plates LXXI–LXXVI.

CHAPTER I. DEPRESSION AND ELEVATION OF THE GROUND ABOUT THE KAGOSHIMA BAY.

1. ***Precise leveling.*** By the liberality of the Imperial Academy and the good-will of the authorities of the Military Survey, a precise leveling survey along the northern coast of the Kagoshima bay was repeated in Nov. 1918–Feb. 1919, the heights of the bench marks being newly determined and compared with those measured in 1914 and 1915. The surveys in these latter years extended over the distance of 366 km. and reached from Sashiki (B.M. No. 2865) in the province of Higo to the city of Kagoshima (B.M. No. 2468), thence along the coast down to the most southerly leveling station of Hanaoka (B.M. No. 2512) in the province of Osumi, and from the town of Shikine (B.M. No. 2797) at the N.E. corner of the Kagoshima bay up to the tide gauge station of Hososhima (B.M. No. 2715) in the province of Hyuga. In the

new survey, the measurement was limited to the distance of 130 km. between the neighbourhood of Ijuin (B.M. No. 2456) near the west coast of the Satsuma peninsula to the town of Hanaoka (B.M. No. 2512), and from Shikine (B.M. No. 2797) eastwards to Sueyoshi (B.M. No. 2789). According to the previous surveys the effect of the eruptive activity of Sakura-jima on the level change of the ground rapidly decreased eastwards with the distance from the coast of the Kagoshima bay, and the last-named place may in the present instance be taken as the starting point in the consideration of the depression and upheaval of the region around the Sakura-jima subsequent to the eruption of 1914.

2. *Course of the level change between* 1914 *and* 1919. The level measurement along the distance of 40 km. about the W. and N. coast of the bay between the city of Kagoshima (B.M. No. 2468) and the town of Shikine (B.M. No. 2488), and the distance of 10 km. from the latter eastwards to Fukuyama (B.M. No. 2793), was first carried on in June to Aug. 1914, then repeated in Feb. 1915, and again recently in Nov.–Dec., 1918. From Table I, which gives a comparison of the heights of the different bench marks in the three different surveys, it will be seen that, compared to the level in 1914, there was in Feb. 1915 a general depression (with the exception of the B.M. No. 2468, newly set after the eruption); while, compared to the level in the latter epoch, there was a general elevation in 1918. Thus, referred to the B.M. No. 2793 as a fixed point, which supposition certainly entails no very gross error, the relative depression in Feb. 1915 was quite marked and nearly constant at the bench marks Nos. 2481 to 2486 along the western and northern coast of the bay, amounting to 0.040 m. on the average. The elevation in 1918 relative to the level in 1915 was most distinctly shown also along the same sea coast, the

TABLE I. HEIGHT VARIATION OF THE DIFFERENT BENCH MARKS BETWEEN 1914, 1915, AND 1918.

Year. / Bench Mark.	1914	1915	1918	Difference.*			
				1914–1915		1915–1918	
No.	(August). m	(February). m	(December). m	m		m	
2793	380.744	380.744	380.744	0.000		0.000	
2794	337.010	337.008	337.011	−0.002		+0.003	
2795	254.205	254.195	254.202	−0.010		+0.007	
2796	164.267	164 249	164 266	−0.018		+0.017	
2797	88.223	88 205	88.228	−0.018		+0.023	
2488	56.847	56.826	56.850	−0.021		+0.024	
2187	3.002	2.974	3.007	−0.028		+0.033	
2186	2 624	2.585	2.644	−0.039		+0.059	
2185	4.862	4.813	4.895	−0.049		+0.082	
2184	2 939	2 890	2.986	−0.049		+0.096	
2183	(July). 11 610	11,561	11.669	−0.049		+0.108	
2482	15.434	15.386	15.495	−0.048		+0.109	
2481	46.258	46.220	46.313	−0.038		+0 093	
2480	2.644	2.612	2.698	−0.032		+0.086	
2179	9.361	9.329	9.415	−0.032	Mean:	+0.086	Mean:
2478	9.694	9.661	9.748	−0.033	−0.040	+0.087	+0.106
2177	4.586	4.549	4.653	−0.037		+0.104	
2476	11.141	11.401	11.525	−0.040		+0 124	
2175	5 244	5 201	5.339	−0.043		+0.138	
2474	6.198	6.143	6 311	−0.055		+0.168	
2473	5.180	5.135	5.278	−0.045		+0.143	
2472	(June). 11 027	10.984	(November). 11.113	−0.043		+0.129	
2471	9.807	9 780	9.870	−0.027		+0.090	
2470	7.525	7.512	7.579	−0.013		+0.067	
2469	2.340	2.336	2.376	−0.004		+0.040	
2468	4.360	4.370	4.396	−0.010		+0.026	

* Positive, when the height increased, and negative when it decreased.

average value being 0.106 m. Amongst the others, the bench mark No. 2474 situated at the promontory of Osaki-hana, about 10 km. to the north of the city of Kagoshima, exhibited the

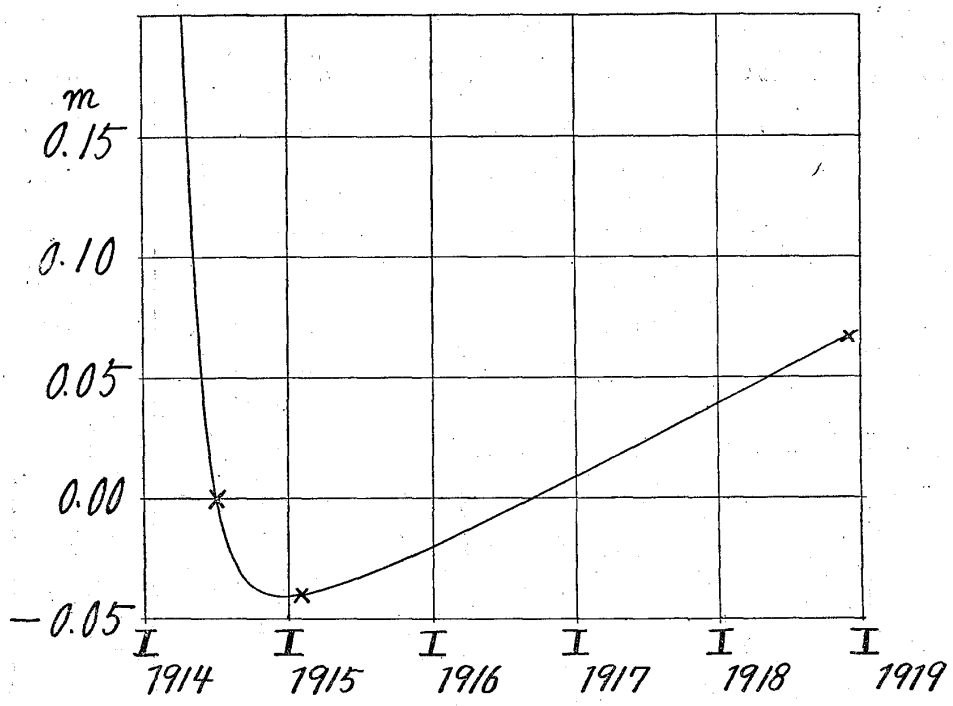


Fig. 1. Average Height Change of the Bench Marks Nos. 2471 to 2486.

maximum depression of 0.055 m. and the maximum elevation of 0.168 m. in the time intervals under consideration. The mean rate of the depression was about double that of the elevation, as follows :—

Change Rate.	Depression of the Ground. July 1914—Feb. 1915.	Elevation of the Ground, Feb. 1915—Dec. 1918.
Average.	69 mm. per year	28 mm. per year.
Maximum.	94 „ „	44 „ „

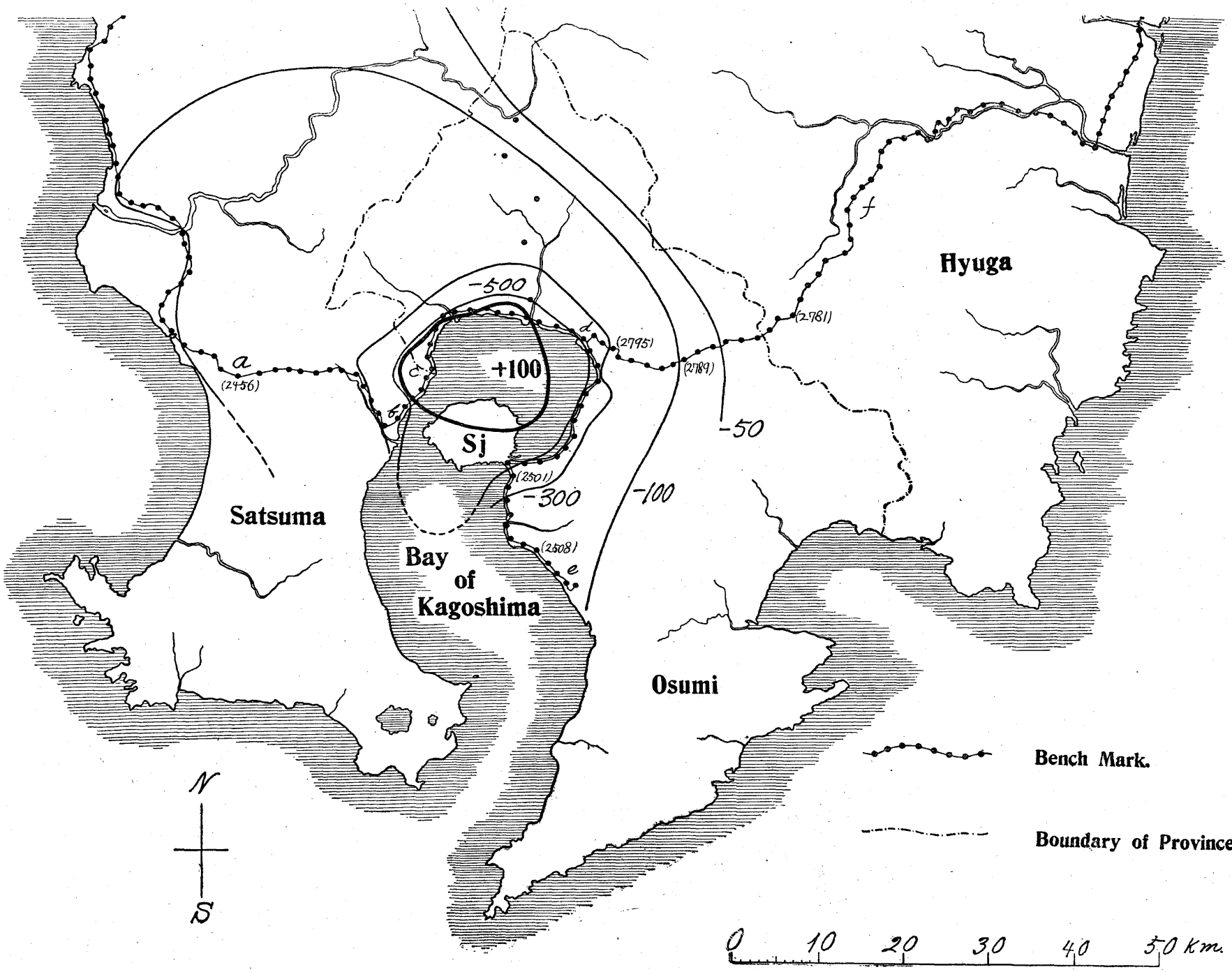
In fig. 1 is illustrated the course of variation of the average level change between 1914 and 1918. The maximum ground depression seems to have taken place in or about October 1915.

3. *Elevation of the depressed region.* In Table IV are compared the results of the leveling in 1914–1915 with those in 1918–1919. In the older surveys, the heights of the different bench marks are referred to the B.M. No. 4 in the tide gauge room at Hososhima, measured in January 1915; it being implied that the height variation remained slight in the time interval during which the surveys were executed. This causes no very great inconvenience, as the leveling along the bay coast between the B.M. Nos. 2468 and 2488, where the height change was most marked, was finished in Feb. of the same year. In the newer survey, started from the vicinity of the town of Ijuin the heights are referred in Table IV to the B.M. No. 2456 assumed to have undergone no vertical change. This latter supposition may be inaccurate to a certain extent, as the region about Ijuin has been shaken by several strong earthquakes previous to the eruption. In Table II the total amount of the height variation of the different bench marks during the 4 years 1914–5 to 1918–9 is given with reference to the B.M. No. 2789 at the eastern extremity as a fixed point. According to Table II the elevation was slight and nearly constant, with the average amount of 53 mm., across the Satsuma peninsula from the B.M. No. 2469 at Kagoshima to the B.M. No. 2456 at Ijuin. It was also small at the N.E. corner of the bay coast, with the amount of 27.5 mm. at B.M. No. 2796, thence quickly decreasing toward the east. Along the whole N.E. coast of the Kagoshima bay, for the distance of 50 km. between B.M. No. 2512 on the south, the elevation was slight and, with a few exceptions, nearly constant, the mean amount being 35 mm. On the other hand, the elevation was considerable for the distance of about 30 km. along the coast from a little to the north of Kagoshima to the vicinity of Kokbu, between the bench marks

TABLE II. HEIGHT CHANGES OF THE DIFFERENT BENCH MARKS AROUND THE KAGOSHIMA BAY AFTER THE GREAT SAKURA-JIMA ERUPTION OF 1914: AMOUNT OF RECOVERY OF THE DEPRESSED REGION IN THE COURSE OF ABOUT 4 YEARS BETWEEN JUNE 1914—SEPT. 1915 AND NOV. 1918—FEB. 1919.

No. of Bench Mark.	Amount of Elevation.	Remark.	No. of Bench Mark.	Amount of Elevation.	Remark.
	mm			mm	
2456	55.4		2487	42.7	
2457	55.0		2488	34.6	
2458	56.1		2797	33 0	
2459	56.8		2489	13.3	
2460	61 9		2490	12.9	
2461	53.9	Amount of Elevation	2492	37.2	
2462	56.5	nearly constant: mean	2493	46.1	
2463	57.5	value = 53 mm.	2495	40.3	
2464	53.0		2496	37 4	
2465	51.8		2497	8.6	
2466	52.1		2498	40.0	With the exception of
2467	39.8		2499	−1.5	a few points, the amo-
2468	37 3		2500	39 0	unt of elevation nearly
2469	50.9		2501	48.7	constant: mean value =
			2502	38 6	35 mm.
2470	77.3		2503	31.6	
2471	100.9		2504	25.7	
2472	139 1		2505	28.7	
2473	152 9		2506	32.1	
2474	178.4		2507	37.0	
2475	148.1		2508	38.4	
2476	134.0		2509	39.6	
2477	113.4		2510	42.6	
2478	96.7	The elevation very	2511	49.4	
2479	96.7	conspicuous.	2512	49.3	
2480	96.2				
2481	103.2		2796	27.5	
2482	119.3		2795	16.7	Amount of elevation
2483	118 1		2794	13.4	rapidly decreased with
2484	106.9		2793	9.5	the distance from the
2185	92 8		2792	3.1	N.E. coast of the Kago-
2486	68.6		2791	0.6	shima bay.
			2790	−0.5	
			2789	0.0	

Fig. 2. Map of Sakura-jima and the Vicinity, showing the Depression of the Ground after the Eruption of 1914 and the Subsequent Upheaval. (−50), (−100), (−300), and (−500) curves indicate the boundaries of the areas whose depressions after the Eruption were, relative to 1894, respectively 50, 100, 300, and 500 mm.



The thick (+100) curve indicates the area within which the restitution process resulted in the upheaval of over 100 mm. in the course of the 4 years 1914-5 to 1918-9. a b c d e f....Line of Precise Leveling.

a... B. M. No. 2456, at Ijuin. b....B. M. No. 2469, in the city of Kagoshima
c... B. M. No. 2474, at Osaki-hana, where the height changes were most marked

Nos. 2470 and 2486, with the mean amount of 114 mm. This region must, therefore, be much nearer to the origin of the upheaval than the remaining part of the coast; the Osaki-hana promontory, with the maximum elevation of 178.4 mm. being evidently at the shortest radial distance. The *iso-elevation* curve of 100 mm. drawn by interpolations from the results of the observations, is, as shown in fig. 2, an irregular circle about 17 km. in diameter, whose centre is situated under the sea, about 5 km. to the east

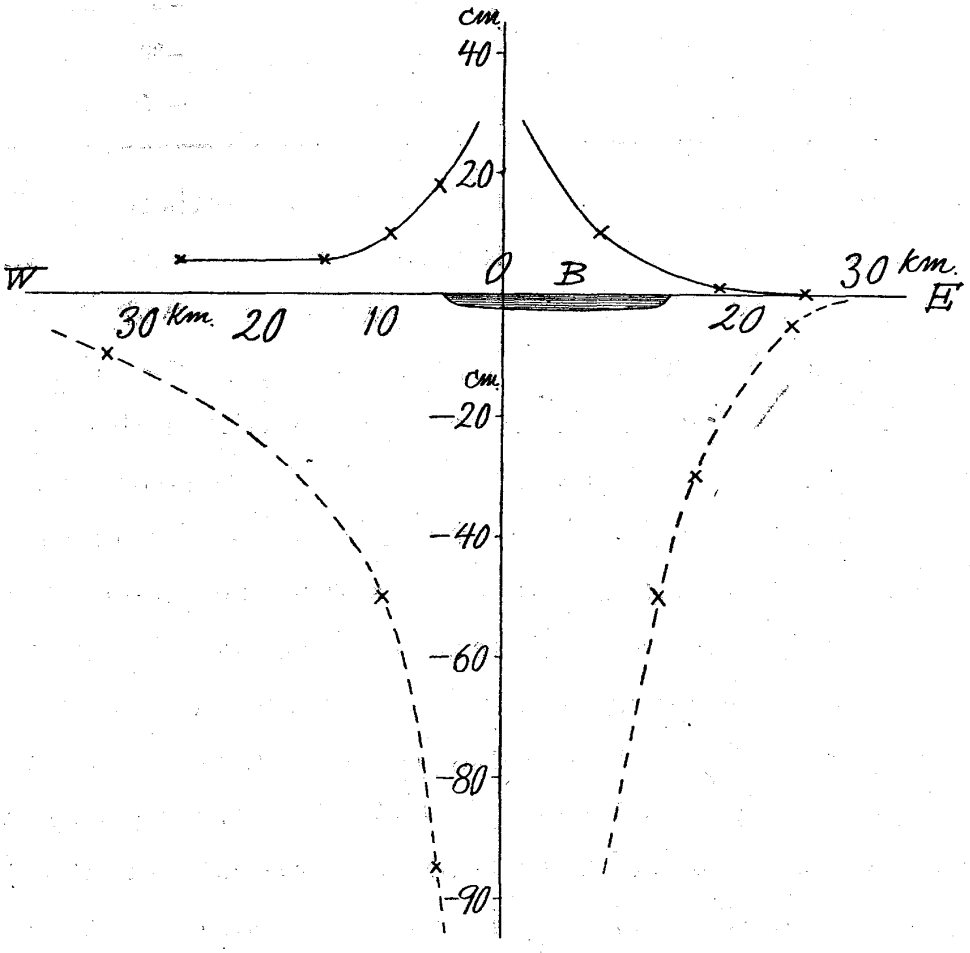


Fig. 3. Sectional Diagram representing the amount of the Depression caused by the Sakura-jima Eruption and of the subsequent Upheaval in an E.W. direction at varying radial distances from the Centre (0) of the Level Changes. The depression is measured downwards, and the elevation upwards, along the vertical axis drawn through 0.

B..... Inner Kagoshima Bay.

TABLE III. LEVEL CHANGES ALONG THE E.W. LINE THROUGH THE UPHEAVAL CENTRE.

Distance.	Elevation in 1918–1919.	Distance.	Depression in 1914–1915.
To the West of the Centre of Elevation.			
5.4 km.	+178.4 mm.	5.4 km.	−949 mm.
9.5	+100	10	−550
15–27	+ 55	33	−100
To the East of the Centre of Elevation.			
8 km.	+100 mm.	13 km.	−500 mm.
18	+ 10	16	−300
25	+ 0	24	− 50

of the Osaki-hana and 4 km. from the northern coast of Sakura-jima. It will be noticed that this area of marked elevation is nearly concentric with, and of an extension not widely inferior to, the *iso-depression* curve of 500 mm. relating to the time interval of June 1914—Feb. 1915, given in Pl. XXIX of this Volume and reproduced in fig. 2. Further the two curves nearly coincide with, or are not very much distant from, the coast line of the bay to the north of Sakura-jima. In other words, the present area of maximum elevation is the same as that of the previous maximum depression; both approximately coinciding with the bay coast, which is consequently to be regarded as the boundary of the region specially susceptible to the depression and elevation caused by eruption of the neighbouring volcano of Sakura-jima, or the joint activity of Sakura-jima and Kirishima. The amount of the depression in 1914–1915 was some 5 times greater than that of the subsequent recovery, or elevation. Fig. 2 and fig. 3, which latter gives a diagrammatic representation of the level variations along the E.W. line drawn through the centre of the upheaval, seem to

indicate that, towards the east, both the depression and the elevation were reduced to a comparatively slight degree already at the distance of 30 km. Towards the west, however, these changes continued to be distinct to a much greater distance.

TABLE IV. HEIGHT OF THE DIFFERENT BENCH MARKS AROUND THE KAGOSHIMA BAY IN 1914—1915 AND IN 1918—1919.

Bench Mark.			Leveling, 1914-15.		Leveling, 1918-19.		Difference.
Locality.		No.	Month, Year.	Height.	Date.	Height.	
[Province of Satsuma.]				metre.	1918.	metre.	metre.
Shimo-Ijuin.	日置郡下伊集院村	2456	VI, 1914.	55.8702	XI, 16	55.8702	0.0
,,	,, ,,	2457	,,	64.3488	18	61.3484	−0.0004
,,	,, ,,	2458	,,	81.8929	,,	81 8936	+0.0007
,,	,, ,,	2459	,,	104.6832	19	104.6846	+0.0014
,,	,, ,,	2460	,,	101.1277	,,	101.1342	+0.0065
Ishiki.	鹿兒島郡 伊敷村	2461	,,	143.3369	17	143.3354	−0.0015
,,	,, ,,	2462	,,	105.4131	21	105.4142	+0.0011
,,	,, ,,	2463	,,	65.8109	22	65.8130	+0.0021
,,	,, ,,	2464	,,	26.5141	23	26.5117	−0.0024
,,	,, ,,	2465	,,	17.5973	,,	17.5937	−0.0036
,,	,, ,,	2466	,,	13 9173	28	13.9140	−0.0033
Kagoshima.	鹿兒島市 草牟田町	2467	,,	7.3953	30	7.3797	−0.0156
,,	,, 平野町	2468	II, 1915.	4.3695	27	4.3514	−0.0181
,,	,, 小川町	2469	,,	2.3351	30	2.3310	−0.0045
Yoshino.	鹿兒島郡 吉野村	2470	,,	7.5119	29	7.5338	+0.0219
,,	,, ,,	2471	,,	9.7798	,,	9.8253	+0.0455
,,	,, ,,	2472	,,	10.9840	28	11.0677	+0.0837
,,	,, ,,	2473	,,	5.1354	XII, 6	5.2329	+0.0975
,,	,, ,,	2474	,,	6.1434	7	6.2664	+0.1230
,,	,, ,,	2475	,,	5.2009	6	5.2939	+0.0930
[Province of Osumi.]							
Shigetomi.	姶良郡 重富村	2476	,,	11.4009	7	11.4795	+0.0786

Bench Mark. Locality.			No.	Leveling, 1914-15. Month, Year.	Height.	Leveling, 1918-19. Date.	Height.	Difference.
[Province of Osumi.]								
					metre.	1918.	metre.	metre.
Shigetomi.	姶良郡	重富村	2477	II, 1915.	4.5496	XII, 5	4.6076	+0.0580
Chosa.	〃	帖佐村	2478	〃	9.6614	5	9.7027	+0.0413
Kajiki.	〃	加治木町	2479	〃	9.3290	10	9.3703	+0.0413
〃	〃	〃	2480	〃	2.6123	10	2.6531	+0.0408
〃	〃	〃	2481	〃	46.2198	10	46.2676	+0.0478
Nishi-Kokbu.	〃	西國分村	2482	〃	15.3861	14	15.4500	+0.0639
〃	〃	〃	2483	〃	11 5611	14	11.6238	+0.0627
〃	〃	〃	2484	〃	2.8899	13	2.9414	+0.0515
Higashi-Kokbu.	〃	東國分村	2485	〃	4.8130	13	4.8504	+0.0374
〃	〃	〃	2486	〃	2.5855	16	2.5987	+0.0132
Shikine.	〃	敷根村	2487	〃	2.9744	16	2.9617	−0.0127
〃	〃	〃	2488	〃	56.8259	16	56.8051	−0.0208
						1919.		
Fkuyama.	〃	福山村	2489	VIII, 1914.	2.2544	I, 4	2.2123	−0.0421
〃	〃	〃	2490	〃	5.7590	4	5.7165	−0.0425
Ushine.	肝屬郡	牛根村	2491	〃	2 6216	5	5.6171	newly set.
〃	〃	〃	2492	〃	9.3017	5	9.2835	−0.0182
〃	〃	〃	2493	〃	6.2465	13	6.2372	−0.0093
〃	〃	〃	2494	〃	14.2079	8	5.8552	newly set.
〃	〃	〃	2495	〃	2.1600	10	2.1449	−0.0151
〃	〃	〃	2496	〃	8.4140	11	8.3960	−0.0180
〃	〃	〃	2497	VII, 1914.	5.4574	11	5.4106	−0.0468
	〃	〃	2498	〃	4.0482	19	4 0328	−0.0154
	〃	〃	2499	〃	8.2395	22	8.1826	−0.0569
Tarumizu.	〃	垂水村	(A)	〃	12.2759	22	12.2595	−0.0164
〃	〃	〃	2501	〃	6.0637	23	6.0570	−0.0067
〃	〃	〃	2502	〃	3.0201	25	3.0033	−0.0168
〃	〃	〃	2503	〃	2,9455	26	2.9217	−0.0238
〃	〃	〃	2504	〃	4.1481	28	4.1184	−0.0297

Bench Mark.			Leveling, 1914–15.		Leveling, 1918–19.		Difference.
Locality.		No.	Month, Year.	Height.	Date.	Height.	
[Province of Osumi.]				metre.	1919.	metre.	metre.
Tarumizu.	肝屬郡 垂水村	2505	VII, 1914.	3.0159	I. 28	2.9892	−0.0267
„	„ „	2506	IX, 1914.	5.4960	27	5.4727	−0.0233
„	„ „	2507	„	3.7853	27	3.7669	−0.0184
Shinzyo.	„ 新城村	2508	„	3.6367	29	3.6197	−0.0170
„	„ „	2509	„	4.1233	II. 1	4.1075	−0.0158
„	„ „	2510	„	7.6411	1	7.6283	−0.0128
Hanaoka.	„ 花岡村	2511	„	17.4511	1	17.4451	−0.0060
„	„ „	2512	„	128.2957	1	128.2896	−0.0061
					1918.		
Shikine.	姶良郡 數根村	2797	II, 1915.	88.2051	XII. 20	88.1827	−0.0224
Fkuyama.	„ 福山村	2796	„	164.2492	19	164.2213	−0.0279
„	„ „	2795	„	254.1953	18	254.1566	−0.0387
„	„ „	2794	„	337.0075	27	336.9655	−0.0420
„	„ „	2793	„	380.7444	26	380.6985	−0.0459
„	„ „	2792	XII, 1914.	367.3154	26	367.2631	−0.0523
„	„ „	2791	„	307.8617	25	307.8069	−0.0548
„	„ „	2790	„	297.7945	25	297.7386	−0.0559
Sueyoshi.	噌唹郡 末吉村	2789	„	292.1460	29	292.0906	−0.0554

CHAPTER II. SEA-LEVEL CHANGE AT KAGOSHIMA.

4. *Sea-level change after* 1914. The great Sakura-jima eruption of 1914 was followed by abnormal changes in the height of the mean sea-level of the Kagoshima bay; the course of the variation during the first two years having already been considered in Part 2 of the present Volume. In the following §§ I give a few remarks on the results of the tide gauge observations carried

on by the Civil Engineering Department of the Kagoshima Prefecture at the Kogoshima harbour during the 6 years 1914 to 1919.

5. *Maximum daily tide range.* According to Table V, the maximum daily tide range in the different months after the eruption varied, in the yearly mean, between 9.86 *shaku** (=2.99 m.) and 10.01 *shaku* (=3.03 m.) with the general average value of 9.93 *shaku* (=3.01 m.). These values are almost exactly identical

TABLE V. DAILY MAXIMUM TIDE RANGE AT THE KAGOSHIMA HARBOUR BEFORE END AFTER THE GREAT SAKURA-JIMA ERUPTION OF 1914. (In *shaku.*)

Year. / Month.	Before the Eruption.		After the Eruption.					
	1903	1904	1914	1915	1916	1917	1918	1919
I	10.7	10.4	—	—	10.5	10.7	9.9	9.35
II	10.1	10.9	8.3	9.7	10.4	10.25	10.5	9.8
III	9.2	10.2	10.6	8.9	9.7	9.55	10.0	9.8
IV	9.7	9.6	10.4	10.6	9.8	9.65	10.3	10.7
V	10.2	9.8	—	10.2	10.2	9.45	10.3	11.15
VI	10.1	10.0	—	10.0	10.0	9.45	9.4	10.25
VII	10.6	10.1	—	9.8	10.4	10.2	9.75	9.6
VIII	10.1	10.4	—	10.7	10.1	10.2	9.75	9.3
IX	9.2	10.1	—	8.6	9.5	10.0	9.7	9.35
X	9.1	9.9	—	9.6	8.5	9.95	10.4	10.3
XI	9.0	9.6	—	10.0	9.7	9.9	10.1	10.6
XII	9.9	9.6	—	10.3	10.4	9.5	10.05	10.3
Mean.	9.83	10.05	9.77	9.86	9.93	9.90	10.01	10.04
General Mean.	9.94		9.95					

* 1 *shaku* = 0.994 foot = $\frac{1}{3.3}$ × 1 metre.

with those for the years previous to the eruption, the average range in question during 1903 and 1904 being 9.94 *shaku* (=3.01 m.).

6. *Annual variation of mean sea-level.* The Kagoshima bay mean sea-level relative to the coast attained its maximum elevation at the latter part of the year of the great eruption, 1914, after which it began to be lowered somewhat. As

TABLE VI. MEAN MONTHLY SEA-LEVEL HEIGHT AT THE HARBOUR OF KAGOSHIMA BEFORE AND AFTER THE SAKURA-JIMA ERUPTION OF 1914.

Month.	Before the Eruption. 1903-1905.		After the Eruption.						
	Mean.	Mean (Relative).	1915	1916	1917	1918	1919	Mean.	Mean (Relative).
	shaku.	*shaku.* mm.	*shaku.*	*shaku.*	*shaku.*	*shaku.*	*shaku.*	*shaku.*	*shaku.* mm.
I	5.29	0.28 = 84.8	—	6.65	6.81	6.35	6.82	6.66	0.00 = 0.0
II	5.01	0.00 = 0.0	7.26*	6.80	6.46	6.67	6.99	6.73	0.07 = 21.2
III	5.28	0.27 = 81.8	7.26*	6.77	6.35	6.62	7.06	6.70	0.04 = 12.1
IV	5.24	0.23 = 69.7	7.07	6.94	6.55	6.55	6.88	6.80	0.14 = 42.4
V	5.23	0.22 = 66.7	7.04	7.10	6.75	6.75	6.83	6.89	0.23 = 69.7
VI	5.60	0.59 = 178.8	7.39	7.16	7.10	6.79	7.33	7.15	0.49 = 148.5
VII	5.95	0.94 = 284.8	7.49	7.40	7.22	7.40	7.35	7.37	0.71 = 215.1
VIII	6.04	1.03 = 312.1	7.76	8.01	7.61	7.58	7.74	7.74	1.08 = 327.2
IX	6.11	1.10 = 333.3	7.69	7.49	7.55	7.93	7.47	7.63	0.97 = 293.9
X	5.94	0.93 = 281.8	7.54	7.48	7.48	7.63	7.36	7.50	0.84 = 254.5
XI	5.35	0.34 = 103.0	7.34	7.39	6.85	7.13	7.05	7.15	0.49 = 148.5
XII	5.13	0.12 = 36.4	6.82	7.05	6.46	6.85	6.64	6.76	0.10 = 30.3
Mean Level.	5.51	—	*shaku.* 7.33	*shaku.* 7.19	*shaku.* 6.93	*shaku.* 7.02	*shaku.* 7.13	*shaku.* 7.13	—
Mean Barometric Pressure.			mm. 761.87	mm. 762.29	mm. 762.28	mm. 762.65	mm. 761.08	—	—
Mean Level With Bar. Correction.			*shaku.* 7.41	*shaku.* 7.28	*shaku.* 7.02	*shaku.* 7.13	*shaku.* 7.22	—	—

* Excluded in the deduction of the mean monthly value in the annual variation, as the sea-level elevation was then markedly much greater than in the other years.

will be seen, however, from Table VI, the sea-level decrease ceased to be distinctly marked since February 1915. Consequently the average height for the different months of the year deduced from the tide gauge observations during nearly the five years

Annual Variation of the Mean Sea-level at Kagoshima and Hososhima.
(Averaged from the observations during the 5 years after the Eruption, 1915–1919.)

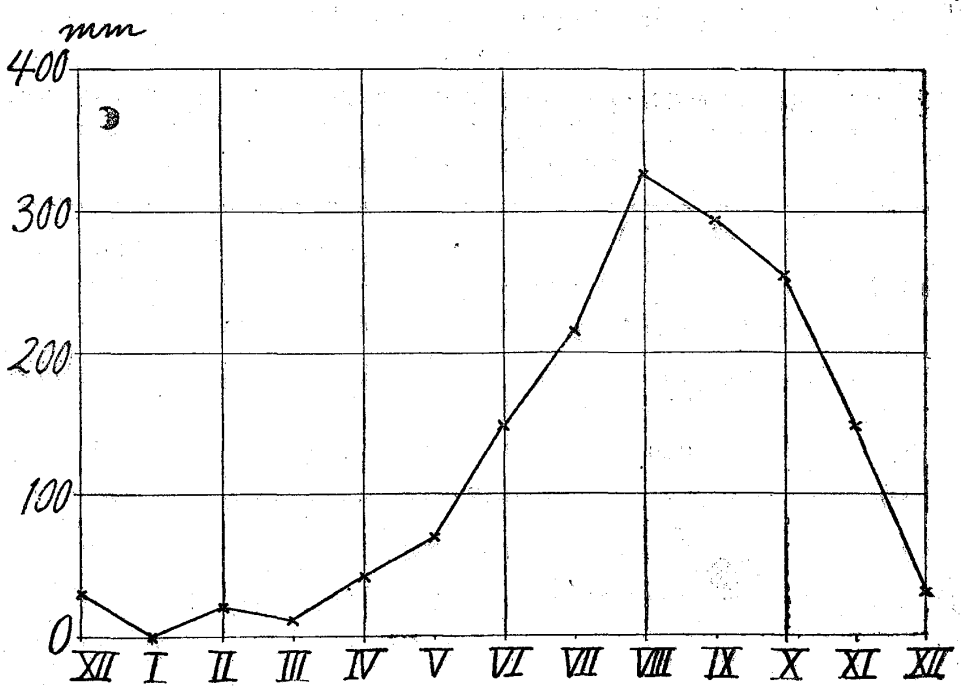


Fig. 4. Kagoshima.

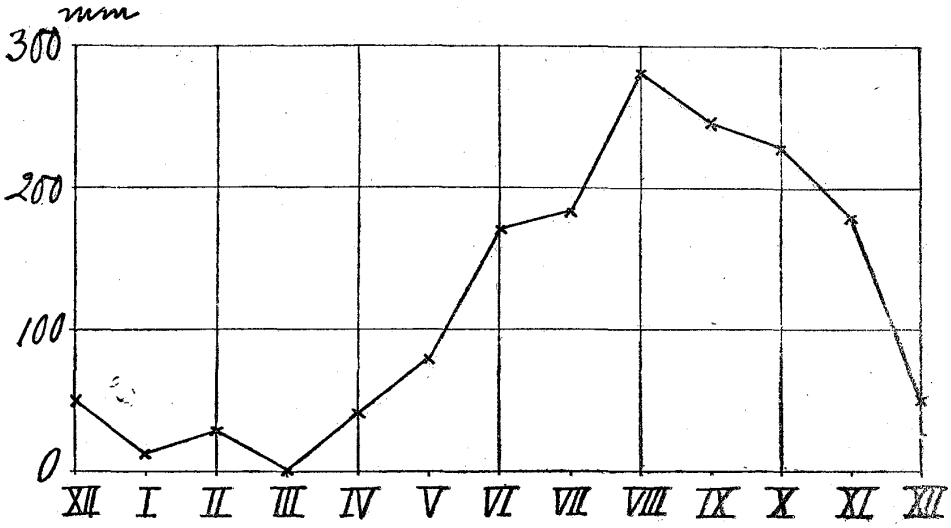


Fig. 5. Hososhima.

from April 1915 to Dec. 1919 will not be affected by the secular sea-level lowering to any considerable extent. Thus according to Table VI and fig. 4, the mean monthly sea-level in the time interval under consideration subsequent to the eruption was lowest in December, January, February, March, and April, and highest in August and September; the maximum amount of the fluctuation or the extent of the annual variation in the mean height of the sea surface being 1.08 *shaku*=0.33 m.

It will be noted that the general course and the amount of the annual variation subsequent to the eruption as above mentioned is very much similar to those for the years previous to the latter. Thus, in 1903 and 1905, the mean monthly sea-level was also highest in August and September, the range of the annual variation being 1.1 *shaku*=0.33 m.

The annual variation of the sea-level height at the tide gauge station of Hososhima during the corresponding time interval was almost perfectly identical with that at Kagoshima here considered. (See fig. 5 and Table X.)

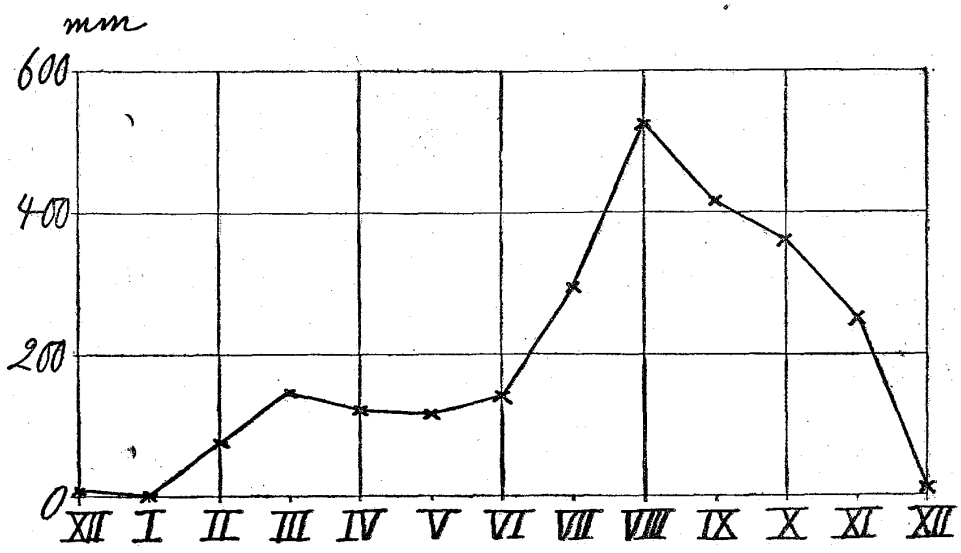


Fig. 6. Annual Variation of the Mean High-Water Level at Kagoshima.
(Averaged from the observations during the 6 years after the Eruption, 1914–1919.)

TABLE VII. MAXIMUM MONTHLY SEA-LEVEL HEIGHT AT THE HARBOUR OF KAGOSHIMA, BEFORE AND AFTER THE SAKURA-JIMA ERUPTION OF 1914.

Year. / Month.	Before the Erupt. 1903–5.	After the Eruption.							
		1914	1915	1916	1917	1918	1619	Mean.	Mean (relative)
	shaku.	*shaku.*	*shaku.*	*shaku.*	*shaku.*	*shaku.*	*shaku.*	*shaku.*	*shaku.* mm.
I	10.5	—	11.3	11.4	11.6	11.2	11.40	11.38	0.00 = 0.0
II	10.5	10.8	12.1	11.8	11.5	11.7	11.85	11.63	0.25 = 75.8
III	10.4	12.2	11.8	11.8	11.5	11.7	12.15	11.86	0.48 = 145.5
IV	10.3	11.8	12.0	11.6	11.5	11.5	12.25	11.78	0.40 = 121.2
V	9.9	11.5	11.8	11.9	11.6	11.8	11.95	11.76	0.38 = 115.1
VI	10.6	11.7	12.2	12.2	11.5	11.3	12.20	11.85	0.47 = 142.4
VII	10.8	12.1	12.1	12.3	12.3	13.25	12.05	12.35	0.97 = 293.9
VIII	10.8	13.5	12.7	13.0	12.8	12.8	13.85	13.11	1.73 = 524.2
IX	11.2	12.7	13.1	12.3	12.9	12.9	12.55	12.74	1.36 = 412.1
X	11.0	12.9	12.5	12.5	12.6	12.65	12.35	12.58	1.20 = 363.6
XI	10.3	12.2	12.5	12.3	12.1	11.8	12.30	12.20	0.82 = 248.5
XII	9.8	11.3	11.6	11.7	10.9	11.3	11.65	11.41	0.03 = 9.1
Mean.	10.51	12.06	12.14	12.07	11.90	11.99	12.21	12.05	—

7. Annual variation of maximum high water level. According to Table VII, the greatest spring tide in the Kagoshima harbour during the first 5 years was 13.5 *shaku* and occurred in August of the year of the eruption. In 1919, six years after the latter event, a still higher level of 13.85 *shaku* was reached in August. Taking the averages from the six years, 1914 to 1919, the high water was lowest in December, January, and February, and highest in August and September; the amount of the annual fluctuation of the monthly value being 1.73 *shaku* = 0.52 m. Although the high tide level is naturally much affected by the barometric pressure existing at the time of the springs, the course

of its annual variation is on the whole much similar to that of the mean monthly sea-level. (See fig. 6.)

8. *Tide range and the subsidence of ground.* The remarkable subsidence of the ground in Sakura-jima and about and under the northern portion of the Kagoshima bay, which set in after recent great eruption, is doubtless to be attributed to the great amount of the lava outflow and of the pumice and ash ejection, whose volume aggregates to 2.2 c. km., or 1/12th of that of the whole mountain. It is likely that after the eruption of 1914 a partial void, or a state more or less equivalent to a void, existed under the volcano on the region neighbouring it, and it might be supposed that such a condition would favour an increase in the range of the daily tide motion and of the annual variation of the mean monthly sea-level. This was, however, not the case; there being, according to the two preceding §§, no apparent difference of the sort under consideration before and after the great outburst. The conclusion is that the earth's crust, or rather the surface ground, about the Sakura-jima was, even immediately after the eruption, rigid enough to be thrown into daily or annual vertical oscillation by the tidal water, at least not to such an extent as would be revealed by the ordinary tide gauge observations.

9. *Average height of Kagoshima sea-level.* In Table VIII are compared the average heights of the sea-level at Kagoshima (referred to the bench-mark No. 2469 at Ogawa-machi, in Kagoshima) for the different years before and after the eruption. (ii) and (iv) give the annual means respectively of the monthly mean and of the monthly high tide level; while (i) gives the mean sea-level during the three months of February, March, and April, during which the sea-level is lowest and nearly constant. (iii) is

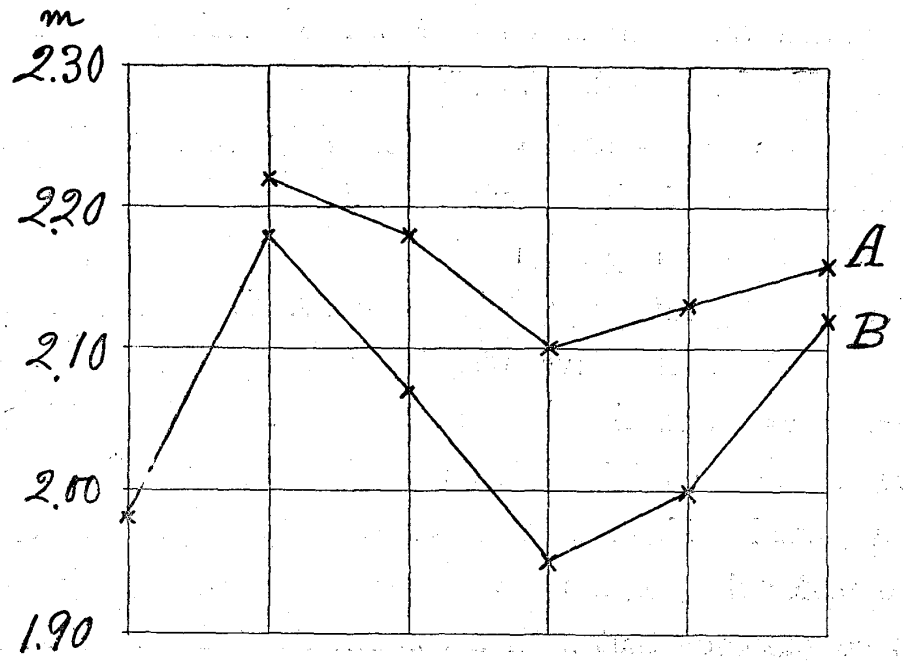


Fig. 7. Kagoshima.

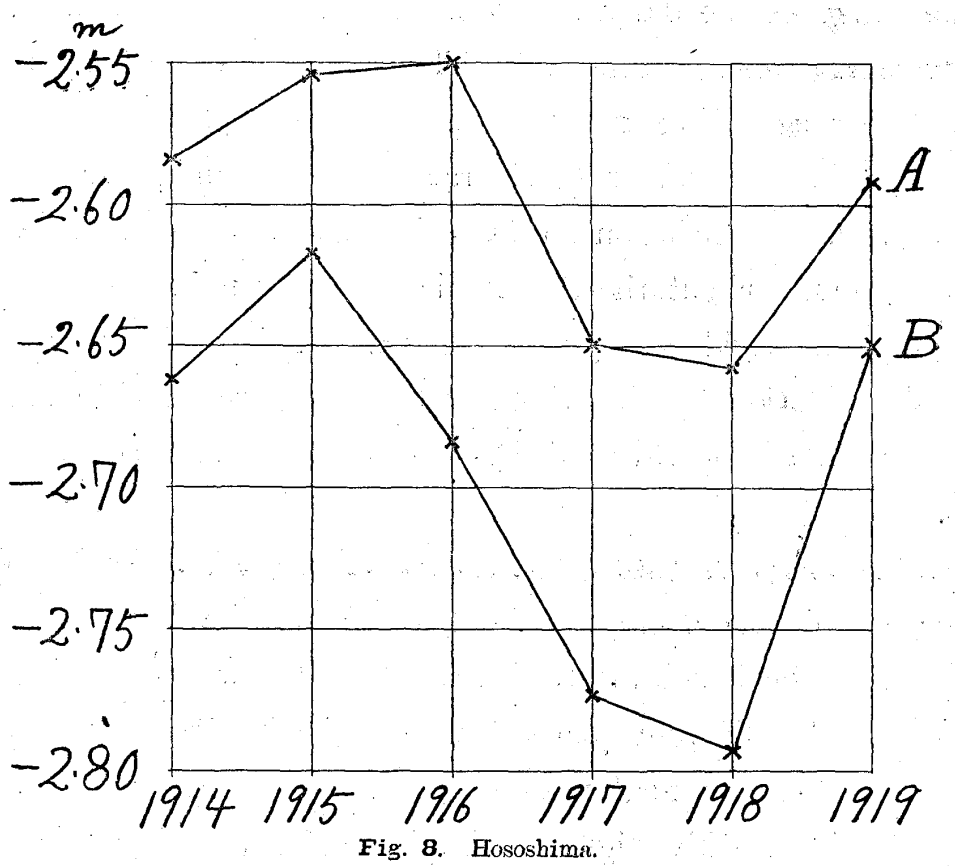


Fig. 8. Hososhima.

Yearly Variation of the Mean Sea-level, 1914–1919.

(A) Annual mean height. (B) Mean height in Feb., March, and April.

TABLE VIII. AVERAGE SEA-LEVEL BEFORE AND AFTER THE ERUPTION.

Deduction of the Mean.	Before the Eruption.	After the Eruption.							Water Level Elevation. (II)-(I)
	(I) 1903-1905.	1914.	1915.	1916.	1917.	1918.	1919.	(II) Mean.	
Monthly mean sea-level:—	*shaku.*	*shaku.*	*shaku.*	*shaku.*	*shaku.*	*shaku.*	*shaku.*	*shaku.*	*shaku.*
(i). Feb., March, April.	5.18	6.55	7.20	6.84	6.45	6.61	6.98	6.77	1.59
(ii). Whole Year.	5.51	—	7.33	7.19	6.93	7.02	7.18	7.13	1.62
(iii). *Do.* with barometric correction.	5.63	—	7.41	7.28	7.02	7.13	7.22	7.21	1.59
Monthly highest sea-level:— (iv). Whole Year.	10.51	11.98	12.14	12.07	11.90	11.99	12.26	12.06	1.55

TABLE IX. MEAN MONTHLY BAROMETRIC HEIGHT AT KAGOSHIMA, REDUCED TO SEA-LEVEL, IN MM.

Year. \ Month.	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Mean.
1915	767.91	763.96	764.84	762.63	759.80	758.90	757.89	753.81	757.88	761.59	766.90	766.27	761.87
1916	768.24	763.38	765.11	763.47	760.40	757.96	758.01	754.69	760.61	763.77	765.44	766.45	762.29
1917	767.69	764.99	765.33	760.70	759.99	757.75	758.87	757.54	760.53	761.86	766.58	765.47	762.28
1918	767.32	767.90	764.91	762.76	760.20	758.67	755.1	758.8	758.3	763.8	766.87	766.72	762.65
1919	766.29	765.49	763.69	762.17	760.88	755.82	757.6	761.2	758.20	762.03	764.15	766.27	761.98
Mean.	767.49	765.14	764.78	762.35	760.25	757.82	757.49	757.21	759.10	762.61	765.99	766.24	762.21

the same as (ii) with a barometric correction, i.e., reduced to the case of the pressure of 760 mm., supposing 1 mm. barometric decrease to be compensated by the sea water rise of 13.3 mm. (See figs. 7 and 8.) The general average water level during the 6 years following the eruption was about 1.6 *shaku* (=0.49 m.) higher than in 1903–1905.

10. *Comparison with the mean sea-level at Hososhima.* For the sake of reference let us here examine the contemporaneous

changes in the mean sea-level at the tide gauge station of Hososhima, which is situated along the Pacific coast of the neighbouring province of Hyuga to the N. E. of the Sakura-jima. The average height in question was —2.541 m. in the years (i) 1903 to 1905, and —2.603 m. in the interval (ii) of 1915 to 1919, as shown in Table X. Thus the average sea-level in the period

TABLE X. MEAN SEA-LEVEL AT HOSOSHIMA.

Year.	Mean sea level.
	(−) m.
1903	2.531
1904	2.551
1905	2.540
1906	2.557
1907	2.571
1908	2.556
1909	2.575
1910	2.598
1911	2.614
1912	2.597
19.3	2.583
1914	2.584

Year. / Month.	1915	1916	1917	1918	1919	Mean.	Mean (relative).
	(−) m.	(−) m.	(−) m.	(−) m.	(−) m.	(−) m.	(+) mm.
I	2.606	2.702	2.648	2.852	2.702	2.714	12
II	2.620	2.675	2.748	2.786	2.662	2.698	28
III	2.635	2.723	2.813	2.815	2.616	2.726	0
IV	2.597	2.654	2.758	2.777	2.641	2.685	41
V	2.604	2.572	2.706	2.713	2.642	2.647	79
VI	2.489	2.508	2.580	2.684	2.517	2.556	170
VII	2.532	2.492	2.590	2.579	2.524	2.543	183
VIII	2.403	2.325	2.474	2.539	2.483	2.445	281
IX	2.413	2.490	2.529	2.420	2.555	2.481	245
X	2.459	2.455	2.524	2.507	2.543	2.498	228
XI	2.539	2.430	2.662	2.560		2.548	178
XII	2.689	2.577	2.767	2.669		2.676	50
Mean.	2.554	2.550	2.650	2.658	2.592		

(ii) was 2.603–2.541=0.062 m. lower than in the period (i). If this depression ought to exist independently of the Sakura-jima eruption also for the Kagoshima bay, the sea-level at the coast of the latter may be assumed to have experienced in reality an elevation of 0.49 m.+0.06 m.=0.55 m. nearly between the two time intervals under consideration.

11. ***Variation of the yearly mean sea-level.*** As illustrated in fig. 7, the mean sea-level at Kagoshima for February, March, and April, which was only 6.55 *shaku* in 1914, reached the maximum height of 7.20 *shaku* in 1915, thence being reduced to a minimum of 6.45 *shaku* in 1917. Thereafter the mean level was again elevated, reaching the height of nearly 7.0 *shaku* in 1919. The height of the mean yearly sea-level also indicated a similar course of variation with a minimum in 1917. The reduction to the standard barometric pressure of 760 mm., which gives only a slight modification to the mean sea-level, does not much alter the relative heights of the latter for the different years.

CHAPTER III. CHANGE IN THE DEPTH OF THE KAGOSHIMA BAY BEFORE AND AFTER THE ERUPTION OF 1914.

12. ***Hydrographic surveys of Kagoshima bay.*** According to the precise leveling carried on in 1914–1915 around the northern or inner portion of the Kagoshima bay, the centre of the disturbance, where the depression might amount to 1 or 2 fathoms, was unmistakably located in the latter. I asked, therefore, Rear-Admiral Kamimra, hydrographer of the Navy, to make new soundings for the purpose of ascertaining the changes in the water depth due to the eruption of Sakura-jima. Although the depression of the sea bottom formed no cause of inconvenience to the navigation, the work of completely resounding the bay, which was a task of highest scientific importance to be solved adequately nowhere else, was taken up by the Navy and very minutely carried into execution in 1917, a preliminary survey having been made off the S. W. coasts of Sakura-jima already in the latter part of 1914. The number

of the soundings taken in the first hydrographic survey of the Kagoshima bay, executed in 1906, was far smaller than that on the recent occasions. Hence the comparison of the old and new depths of the water at different points of the bay is to be regarded as being only approximately correct. At those portions of the bay, however, where the sea bottom is flat and the depth does not much vary from place to place, the amount of the relative depression or elevation can be ascertained with a fair degree of accuracy. It is hereby to be remarked that the water depth given on a chart is expressed in fathoms, the amount below one fathom being altogether not taken into account. Thus the comparison in the present instance, based on the examination of the old printed charts and the new detail manuscript charts of the Kagoshima bay may be subject to some error, ranging between 0 and 5 feet.

13. *Depth of Inner Kagoshima Bay in* 1917. All along the coast of Sakura-jima, except at the N.W. portion, there are promontories of various dimensions formed by lava streams; these latter having caused a certain modification in the contour in the immediate vicinity and sometimes leading to the formation of small lava islets off the coast. Marked elevations and depressions of the sea bottom were, however, confined almost entirely to the northern portion of the bay, these changes having accompanied a great volcanic outburst on more than one occasions previous to 1914. Fig. 9, which has been drawn from the new Navy charts of the Kagoshima bay and of the Kagoshima harbour, gives a general representation of the present depth of the sea around Sakura-jima. It will be noted that in the northern portion of the bay which is deep and in which the 50-and 70-fathom isobath lines run quite close to the coast, there exist three depth centres A, B, and C, respectively of the maximum depths of 85, 113, and 79

Fig. 9.

Chart of the Inner Kagoshima Bay, showing Changes in the Depth before and after the Sakura-jima Eruption of 1914. (Based on the comparison of the sounding in 1896 and those in 1916)

D_1, D_2, D_3,....Portions of the bay where the bottom was depressed more than 1 fathom.

E_1, E_2,.....Elevated portions of the bay bottom.

The figures indicate the amount of change of the water depth, in fathoms, plus (+) when augmented, and minus (−) when lessened.

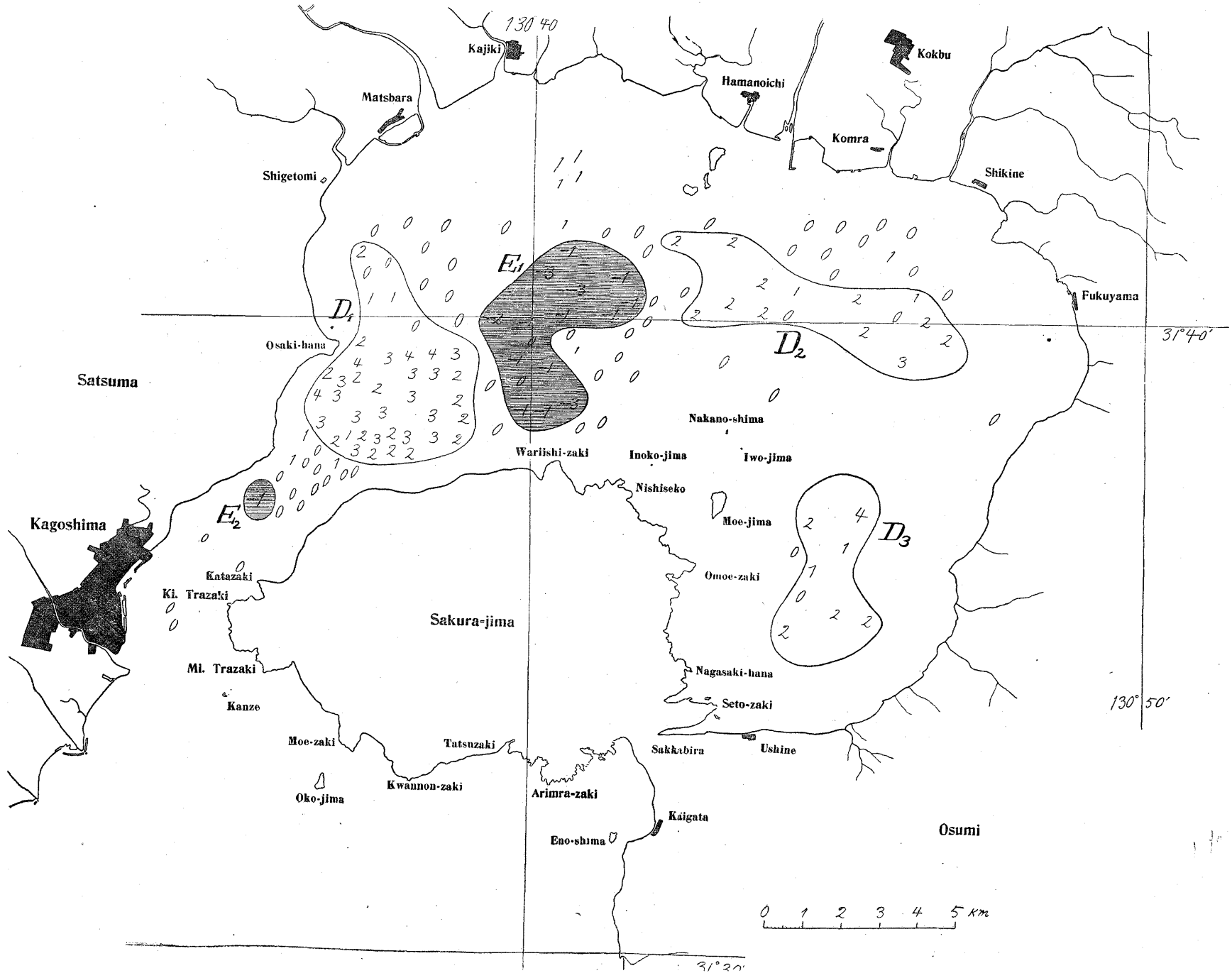
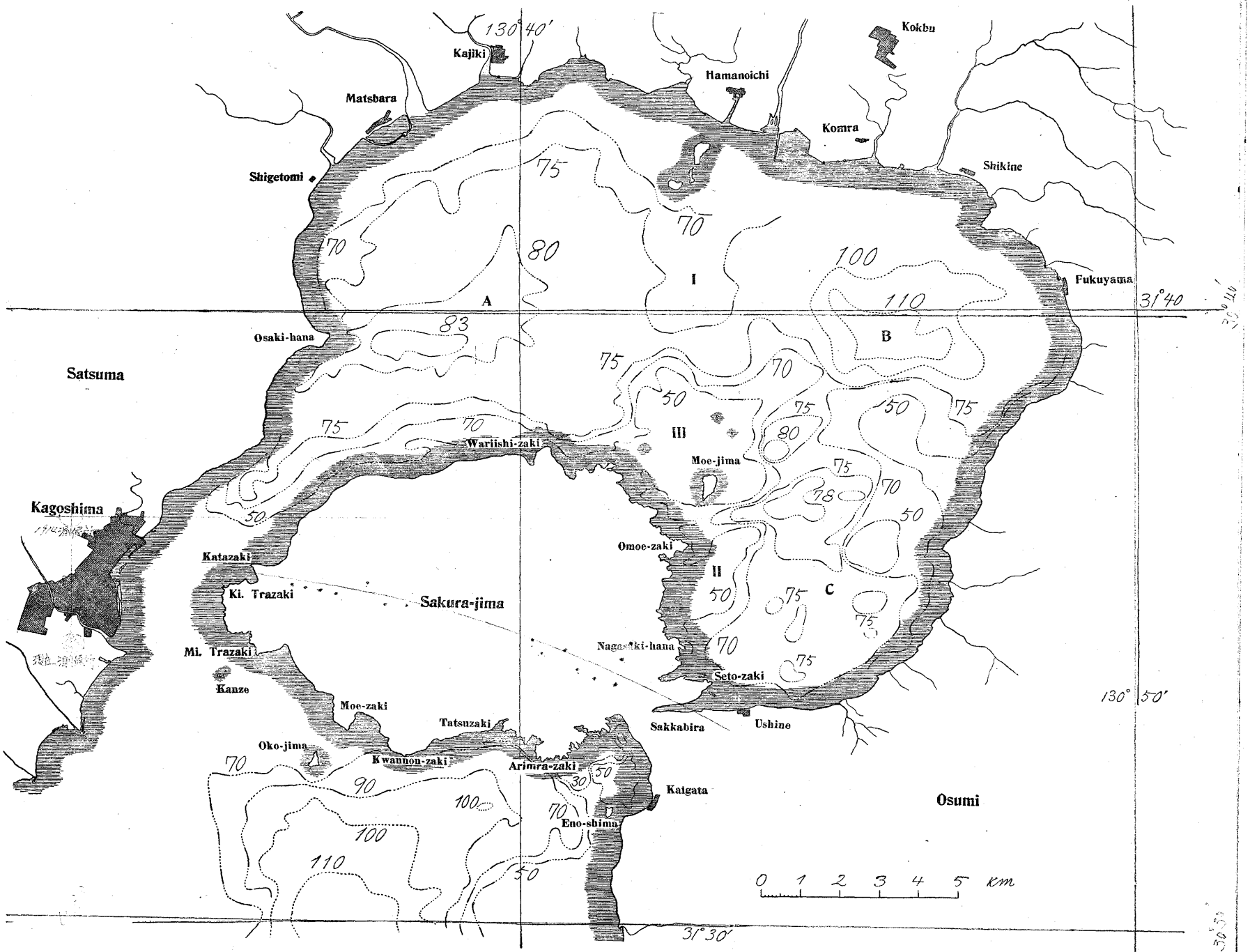


Fig. 10. Isobathymetric Chart of the Inner Kagoshima Bay after the Sakura-jima Eruption of 1914.

(Based on the hydrographic survey of the Imperial Navy in 1916.)



The depth is indicated in fathoms.

A, B, C.....Deepest Portions of the Inner Bay.
I, II, III....Shallow Portions " " "

fathoms; the first being situated at the west and the other two at the eastern parts of the sea under question. (B) and (C) form evidently a continuous trough, which is separated from (A) on the west by a sort of a N.-S. submarine ridge formed by the three areas I, II, and III, which are shallower than the adjacent parts, and which are bounded by the isobaths of 70; 50; and 50 fathoms respectively. From the figure, it will be observed that these areas form protuberances, the first from the northern shore of the bay and the two latter from the N.E. part of Sakura-jima, close along which the 50-fathom isobath runs otherwise continuous and parallel to the coast. In fact the formation of the area III is due to the great Sakura-jima eruption of 1779, when the sea bottom, previously 80 or 90 fathoms in depth, was raised up, forming amongst the others new islet of Moe-jima, whose present hight is 43.2 m. above the sea surface. It is probable that the area II was raised at the time of the eruption of the Bummei period, 1468–1476, when the lava promontory of Omoe-zaki was formed in the vicinity; also that the area I was raised in the Tempyo-Hoji period, 764 A.D., when the submarine eruption off the north coast of the bay resulted in the formation of three new islets, the Heta-kojima and the Oko-jima group of the present day. The ridge I-III-II thus seems to be mainly the effects of the elevation due to the eruptions during the historical times, and is to be regarded as the result of the powerful upward tension, or expansive force existing along the chain connecting the two active volcanoes of Sakura-jima and Kirishima-yama. It is conceivable that with the formation of a new elevation area, the three depth centres A, B, and C, were affected and more or less deepened on the occasions of the different great eruptions of Sakura-jima, as was actually the case with the changes caused by the recent outburst.

14. *Difference in depth of Inner Kagoshima Bay before and after the eruption.* Pl. X in No. 2 of the Bulletin, Vol. VIII, gives a general sketch of the the contour of the bay bottom previous to the eruption of 1914, based on the hydrographic survey in 1896. In that year the maximum water depths in the northern inner bay were 83, 110, and 78 fathoms respectively at the areas A, B, and C (fig. 9), while the corresponding depths after the eruption have become 85, 113, and 84 fathoms. Hence we may say that the greatest depth of the bay was increased by 3 fathoms.

The amount of change in the water depth at different points of the bay before and after the great Sakura-jima outburst was from −3 fathoms (decrease) to +4 fathoms (increase); the pronounced variation being, as shown in fig. 10, principally localized at the three depression areas D_1, D_2, D_3, and the two elevation areas E_1 and E_2. The integral extension of the two latter is much smaller than that of the three former.

Change. (Ground level)	Water Depth.	Area.	Approximate Extension. (sq. km.)	Amount of Change. (fathoms.)	
				Average.	Maximum.
Depression.	Increase.	D_1	17.6	+2.4	+4
		D_2	15.0	+1.7	+3
		D_3	8.1	+1.8	+4
Elevation.	Decrease.	E_1	10.0	−1.3	−3
		E_2	0.8	−1	−1

Of the three depression areas D_1, D_2, and D_3, which approximately coincide with the three depth centres A, B, and C (fig. 9) respectively, the first shows the change most markedly, the increase in the water depth reaching 3 to 4 fathoms. This accounts for

the specially great amount of the level changes at the Osaki-hana bench marks, situated nearest to the area D_1. In the two areas D_2 and D_3 the amount of the depression was a little smaller than in D_1.

Of the two elevation areas, E_1 is well defined and indicates the depth decrease of 1 to 3 fathoms. It is situated between the two depression areas D_1 and D_2, the centre being some 5 km. to the east of the Osaki-hana promontory. The small elevation area E_2 is situated to the S.W. of the depression area D_1 at the place where the inner bay joins the shallow Kagoshima strait.

The existence of the elevation areas E_1 and E_2 is by no means abnormal. On the contrary, their formation is quite similar to the elevation of the tract (III in fig. 9) about the Anei new islets at the time of the Anei (1779) eruption. From the proximity to the submarine ridge I III II (fig. 9) the principal elevation area E_1 may be supposed to have been brought into its present condition by the underground tension along the Sakura-jima and Kirishima-yama volcanic chain. It is hereby to be remembered that, with respect to the eruption of 1914, the three areas D_1, D_2, and D_3, are merely the maximum depression centres, the whole bottom of the inner bay having, with the exception of the two small elevated portions E_1 and E_2, been depressed more or less markedly. As shown in § 3, the disturbed region under and about the inner bay has, since 1915, undergone a slight elevation, and the centre of the 100 mm. upheaval line (fig. 2), which may be termed the origin of recovery, approximately coincides with the middle portion of the area E_1, at about $\varphi = 31°40'$ N., $\lambda = 130°40'$ E.

15. ***Depression volume.*** The depression volume at D_1, D_2, and D_3, is 0.149 c. km., while the elevation volume at E_1 and E_2 is about 0.025 c. km.; the resultant volume change at these five

districts taken together being 0.124 c. km. of depression. In this connection it may be noted that the maximum level depressions along the W. coast of the inner bay was indicated at the B.M. No. 2474, and along the N. coast at the B.M. No. 2483. The amount of the change at these two places in 1915 referred to 1892 were 0.949 and 0.739 m., or when referred to the epoch immediately preceding the great Sakura-jima eruption in 1914, respectively 1.10 and 0.89 m. (See p. 156.) Thus the average depression for the bottom of the inner bay, with the exception of the 5 local area D_1, D_2, D_3, E_1, and E_2, may be assumed without the risk of exaggeration to be about 1 metre. This gives the depression volume of 0.271 c. km. Further, for the region around the inner bay, the depression volume is about 0.6 c. km. (See p. 160.) Hence the total volume of the resultant depression of the ground caused by the great eruption of 1914 comes out to be approximately 1.0 c.km., which agrees with the figure previously inferred (p. 161). In round numbers this is equal to half of the volume of the lava and ashes ejected from the volcano during the outbursts in question, and the ratio is not likely to be increased in the course of time, as the restitution of the disturbed region has already set in to a marked degree (Chapter I). On the other hand, the central part of the Sakura-jima island (now converted to a peninsula) indicates a trace of some permanent elevation (p. 168). The result is that in the eruption of 1914, the Sakura-jima has given out more material than has been compensated by the subsequent depression of the earth's crust under and about the mountain, which is consequently caused to become rarer in density. This accounts for the diminution of the force of gravity generally observed in the neighbourhood of a volcano.

16. ***On the origin of Inner Kagoshima Bay.*** We have

seen that the bottom of the inner bay has with the exception of limited localities generally suffered a depression. A part of the depression has already been restituted; the ratio being, for the Osaki-hana promontory nearest to the depression centre, equal to 0.178/1.1 m. or 1/6 nearly. But it seems not likely that the entire depression should finally be cancelled. Each great eruption of Sakura-jima probably did produce a certain permanent deepening of the inner bay. In the eruption of 1914, the volume of the materials thrown out was 2.2 c. km., or nearly 1/12th of the whole mountain above the sea-level; the maximum amount of the bay bottom depression being about 4 fathoms. If the first stage in the building up of the Sakura-jima volcano consisted in submarine eruptions, the total volume of the lava brought out of the underground reservoir in the course of the subsequent time interval must be much greater than the mountain volume above stated, and we may imagine the consequent total depression of the inner bay to amount to 100 fathoms or so. In other words, the formation of the inner bay may be supposed to have been principally due to the building up of the Sakura-jima, and also of the Kirishima-yama, between which two volcanoes it is situated. The former Seto strait between the S.E. end of the "island" and the main land of the province of Osumi has already been blocked up dy the lava streams of 1914. Again, between the west end of the Sakura-jima and the province of Satsuma the water is quite shallow, with the minimum depth of only 20 fathoms at the strait centre, while the recent lava streams have narrowed the channel materially. A future lava outflow from the west flank of the volcano or an upheaval of the sea bottom may easily close up the Kagoshima channel, and reduce the present inner bay into a lake behind the Sakura-jima volcano.

17. *On the local limit of depression.* The question of the future transformation of the inner Kagoshima bay naturally leads to the consideration of the depth of a large water body existing behind a volcano or between two volcanoes. Two very interesting examples of this type of geographical configuration are found in the volcanic regions of the Usu-san and the Tarumai-dake in the S.W. part of Hokkaido. The lake of Toya, 8 km. in diameter, is situated at the back of the Usu-san, or rather between the latter and the Makkarinopli (Yezo-Fuji); and the lake of Shikots, 8×4 km. in size, between the Tarumai-dake and the Eniwa-dake, at the distance of 42 km. to the N.E. of the first mentioned lake. These two lakes as well as the large Volcano Bay itself, which derives its name from the existence of the remarkable volcanoes of the Usu-san, the Makkarinopli, and the Komaga-take along its coast, were probably formed by the depression due to the building up of the different volcanoes in the respective vicinity. The maximum water depth of the Volcano Bay, about 50 km. in diameter, is 59 fathoms, or 107 m.; while that of the neighbouring lake of Toya, whose surface is 85 m. above the sea-level, is 106 fathoms (=192 m.), so that the bottom is also 107 m. below the latter. Again, the maximum depth of the lake of Shikots, whose surface is 248 m. above the sea-level, is 197 fathoms (=358 m.). The bottom which is flat, is therefore 110 m. below the sea-level. Thus it will be seen that the bottoms of the Volcano Bay and of the two lakes of Toya and Shikots, are all nearly at one and the same level, namely, obout 110 m. below the sea-level. This probably indicates, for the region concerned, the limit of the possible crustal subsidence, by which

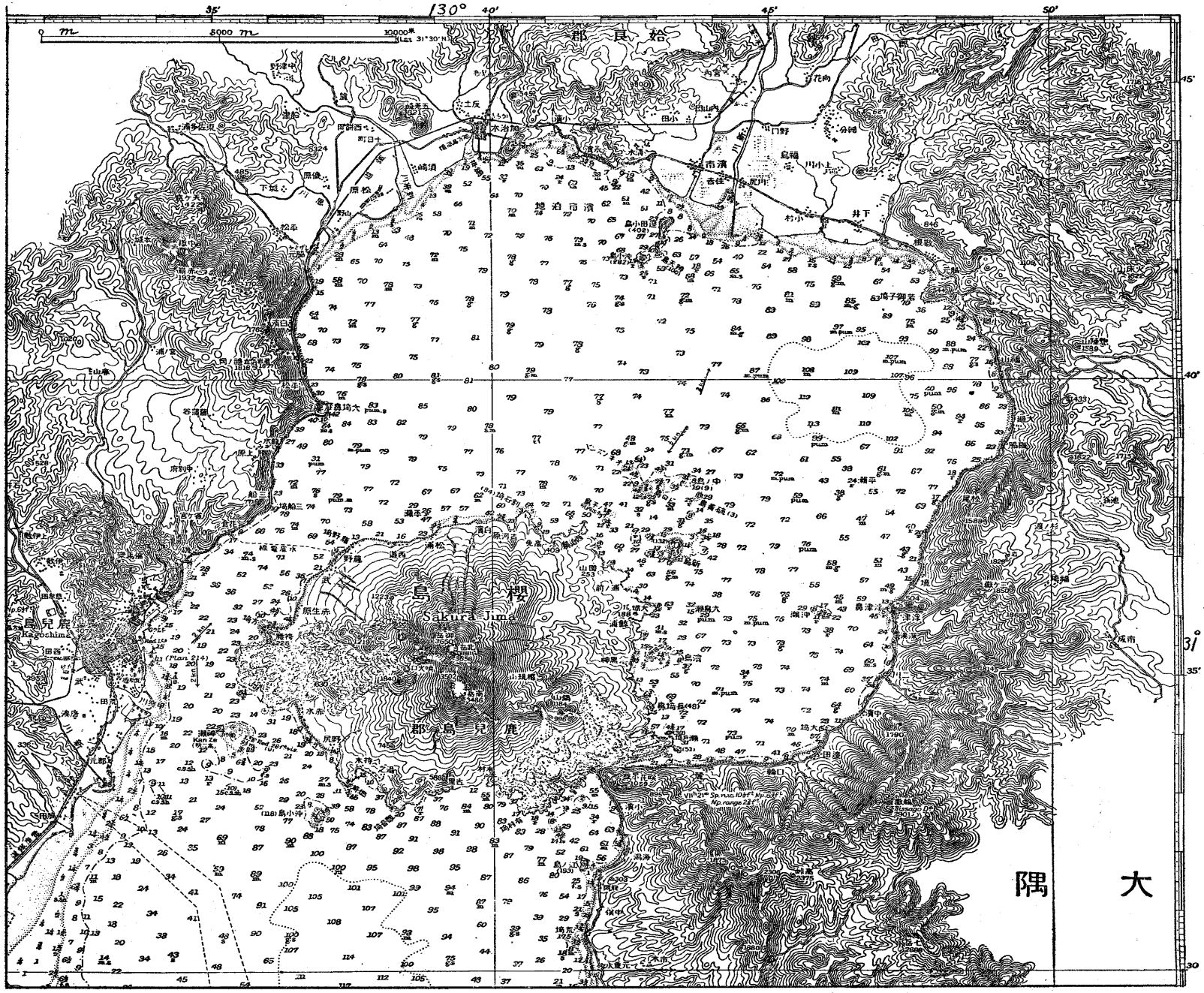
* This is the translation of my article on the subject published in the *Toyo Gakugei Zasshi*, 1917.

agency the three water bodies in question were brought into existence. It may be assumed that each volcanic district has a proper limit of the depression determined by its isostatic condition.

In the case of the Kagoshima bay, the maximum water depth of the northern or inner portion, the "lake," is 113 fathoms, and is not much different from that of the main, or southern, portion, namely, 129 fathoms. The equality of the depth will become more complete in future, as the inner bay will be depressed more or less at the occurrence of new strong outbursts of the Sakura-jima.

Fig. 11. Chart of the Inner Kagoshima-Bay after the Sakura-jima Eruption of 1914.

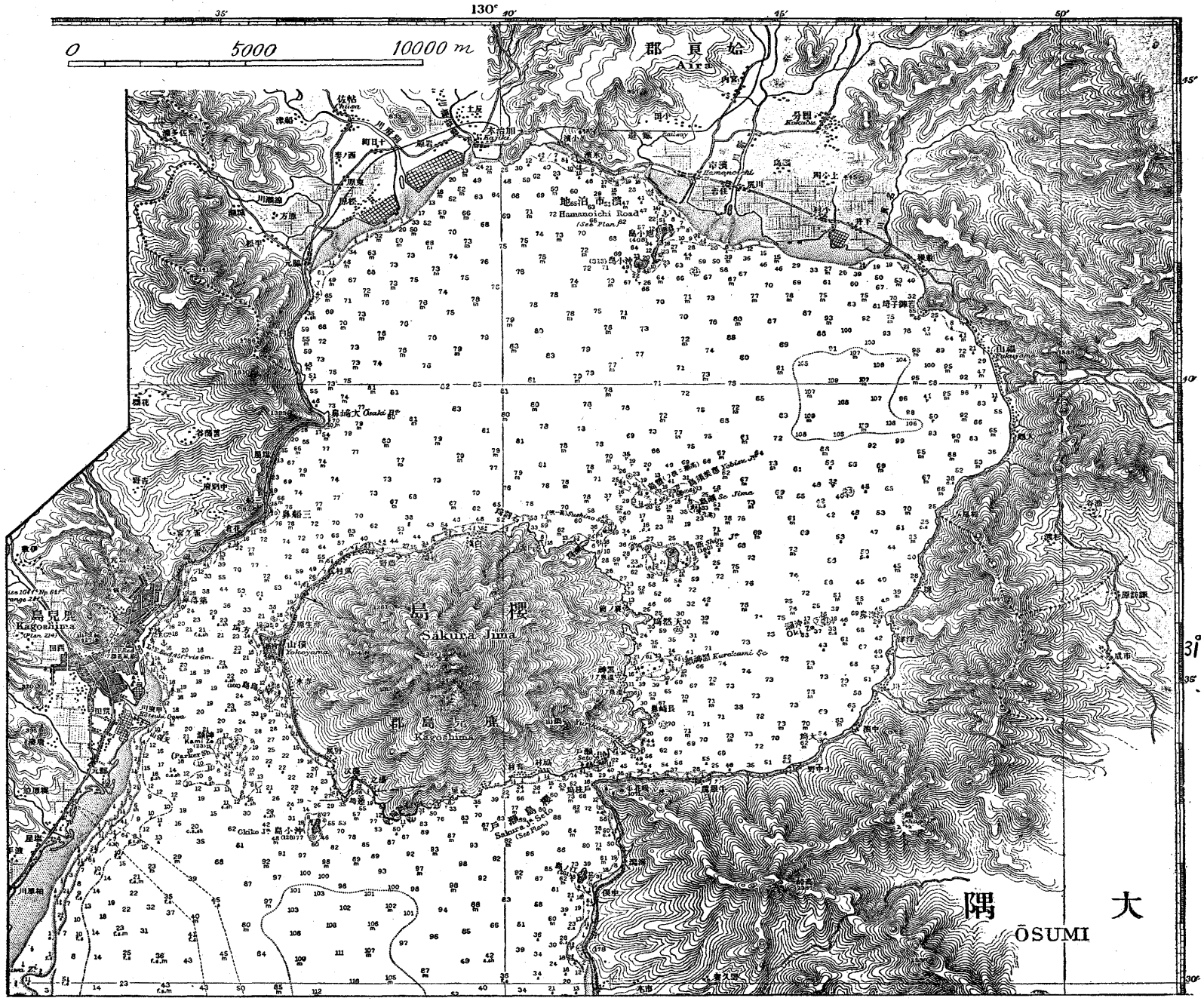
Reproduced from the Imperial Navy Hydrographic Chart No 221 (new edition), compiled from the surveys in 1916.



Soundings in Fathoms. (Height is expressed in feet above H. W. Springs.)

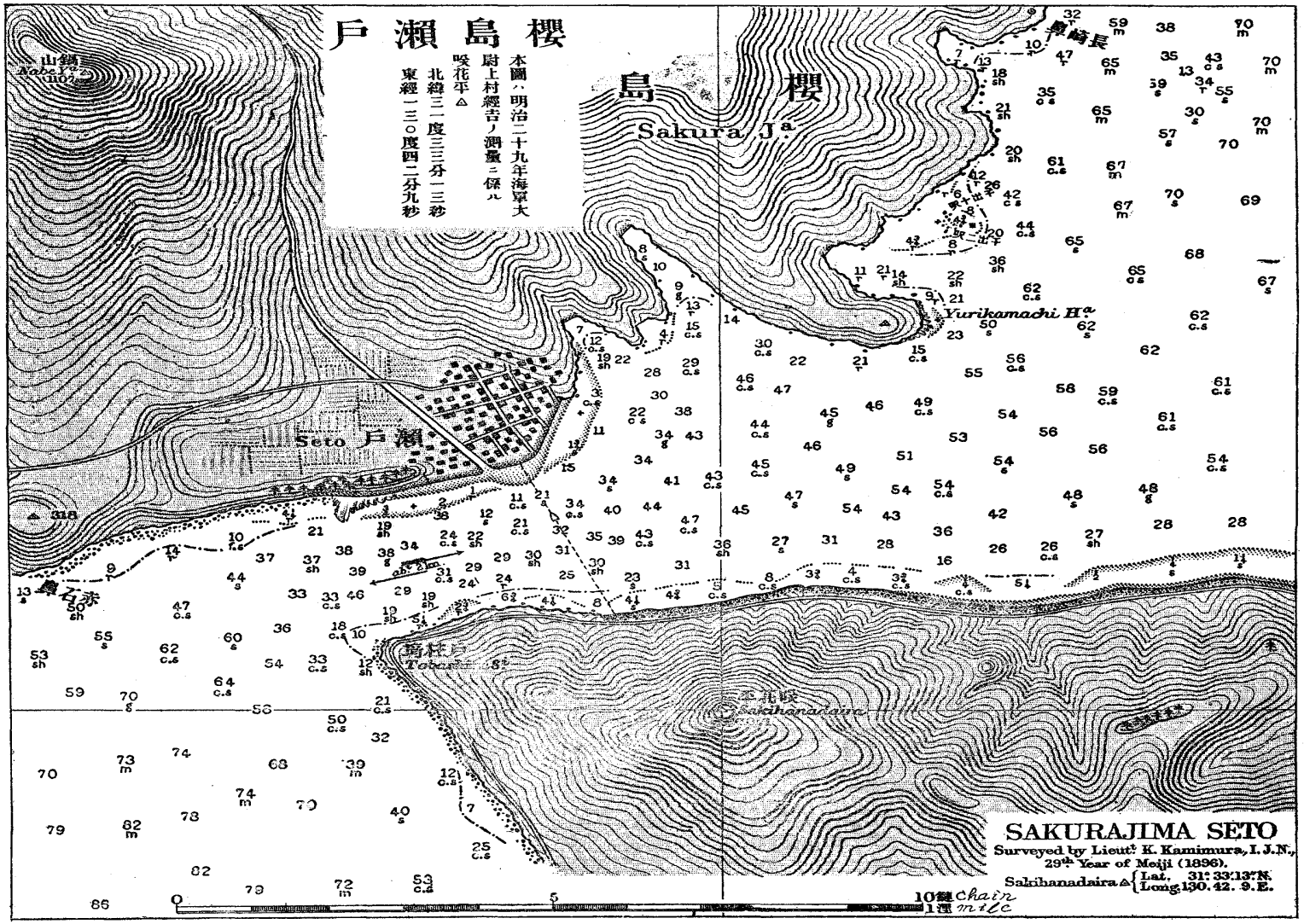
Fig. 12. Chart of the Inner Kagoshima Bay before the Sakura-jima Eruption of 1914.

Reproduced from the Imperial Navy Hydrographic Chart No. 221 (old edition), compiled from the surveys in 1896.



Soundings in Fathoms. (Height is expressed in feet above H.W. Springs.)

Fig. 13. Chart of the Seto Strait (blocked up in 1914) surveyed in 1896.



Soundings in Fathoms. (Height is expressed in feet above H. W. Springs.)