

THE SAKURA-JIMA ERUPTIONS AND EARTHQUAKES. II.

[On the Sound and Ash-precipitation Areas of, and on the Level Changes caused by, the Eruptions of 1914, with Historical Sketches of Earlier Sakura-jima Outbursts.]

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With Plates VIII—XXXII.

CHAPTER I. NOTES ON THE TIME DISTRIBUTION OF VOLCANIC ERUPTIONS IN JAPAN.

1. List of eruptions of Kyushu and Fuji zone volcanoes. As pointed out in the Bulletin, Vol. VIII, No. 1, the remarkable connection or time relation between the great outbursts of Sakura-jima, Ōshima (Izu), Asama-yama, and Unzen-dake⁽¹⁾ in the memorable periods of Anei, Temmei, and Kansei, (1777 to 1792), has been repeated in the recent extraordinary activities of these same volcanoes.⁽²⁾ To see, if any, the more general mutual relations, I have prepared, in Table VII, a list of all the known eruptions, from the earliest

(1) *Yama, san, take, or dake*, means mountain. *Shima, or jima*, means island.

(2) It is true that the Unzen-dake (near Nagasaki) has not yet made a fresh eruption. But local earthquakes occurred recently, especially since the summer of 1915, with great frequency at the base of the mountain. According to the tromometer observations made at the Nagasaki meteorological observatory there were, between June 17th and July 20th, 1915, ninety-eight shocks whose origins were mostly in or near the Unzen-dake.

times, or the 7th century, down to 1880, relating to the Kyushu and the Fuji volcanic zones, which are approximately transverse to the general arc of the Japanese islands, radiating outwards respectively at its middle and its S.W. end. The different active mountains or islands (Fig.1) belonging to these two systems of volcanic districts are 15 in number so far as Table VII is concerned, the frequency of their eruptions being as follows :—

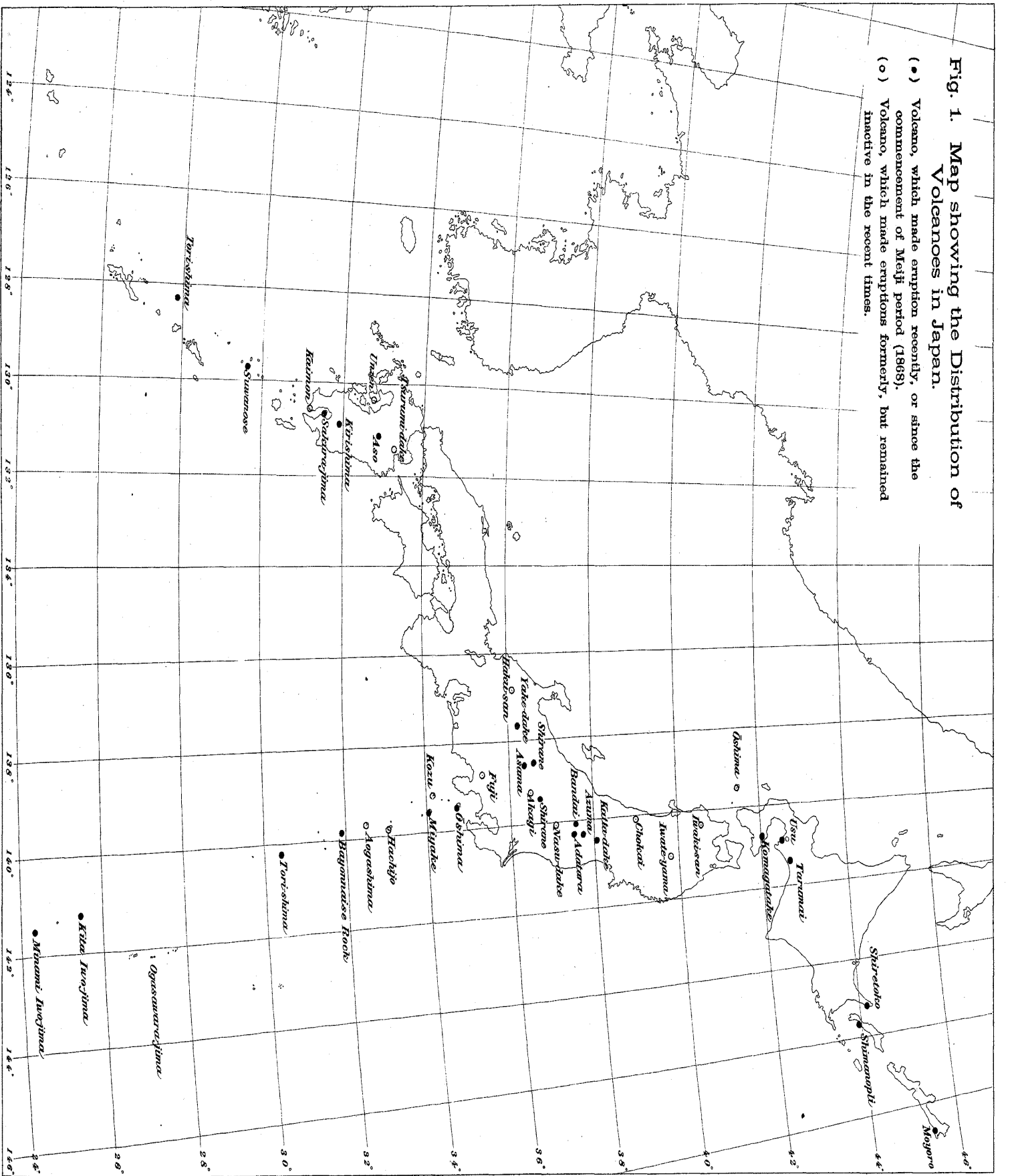
In Kyushu.		Along Fuji Volcanic Zone.	
Volcano.	Eruptions.	Volcano.	Eruptions.
Kaimon	2	Fuji	15
Tsurumi-dake	1	Asama	59
Aso	39	Ōshima (Izu)	13
Kirishima	23	Miyake-jima	11
Sakura-jima	26	Hachijo-jima	4*
Unzen-dake	3	Aoga-shima	4
Suwanose-jima	1	Kozu-shima	1
		Kita Iwo-jima	1

* (Besides 1 submarine outburst from the vicinity of Hachijo-jima.)

The conditions of activity of the different volcanoes are of course very various. Amongst the others, Kozu-shima, Tsurumi-dake, and Kaimon-dake made respectively 1, 1, and 2 eruptions during the period of about half a century, between 838 and 885. Since then, however, these three volcanoes have made no outburst at all, now for more than 1000 years. Again, Fuji made 9 eruptions in the course of 3 centuries between 781 and 1083, but remained quiet during the next 434 years, till 1517; the eruption in the latter year being followed by others in 1560, 1627, and 1700-7-8, with the average interval of 61 years. Since 1708, Fuji has remained quiet for over 200 years. On the other hand, (A), Asama, Kirishima, and Aso, and (B), Miyake-jima and Ōshima

Fig. 1. Map showing the Distribution of Volcanoes in Japan.

- (●) Volcano, which made eruption recently, or since the commencement of Meiji period (1868).
- (○) Volcano, which made eruptions formerly, but remained inactive in the recent times.



maintained their activity unabated throughout the whole historical times. The eruptions of the (A) volcanoes, which were more generally of an explosive character, were sometimes very numerous and tended to occur in groups extending over a few years or a few decades; while those of the (B) volcanoes, which were, with a few exceptions, not explosive and consisted in the outflow of lava, occurred singly, lasting sometimes several days or weeks. The eruptions of Sakura-jima had characters of both these groups, a large lava outflow being accompanied by a considerable precipitation of pumice and ash. The eruptions of Hachijo-jima and of Aoga-shima, which were limited respectively to the intervals of 119 years between 1487 and 1606, and of 134 years between 1651 and 1785, may be regarded as secondary volcanic outbursts induced by the strong activity of Miyake-jima and Ōshima.⁽¹⁾

2. Periodicity. As shown in Table I, the eruptions of Asama since the 16th century can be divided into 5 distinct groups, whose mean epochs indicate an average successive interval of 63.5 years. This is to be regarded as representing the period of recurrence of the maximum activity of the volcano.⁽²⁾ The eruptions of Kiri-shima indicated, amongst the others, more or less definitely also the prevalence of a nearly similar period, 62.7 years in length (Table I).

(1) F. Omori: Report on the eruptions of Ōshima. (Japanese). Shiinsai Yobo Chosakai Hokoku, No. 81.

(2) See the Bulletin, Vol. VI, No. 1.

TABLE I. ERUPTIONS OF ASAMA AND KIRISHIMA: EPOCHS OF
MAXIMUM ACTIVITY.

Asama.				Kirishima.			
Year.	Number of Eruptions.	Mean Epoch.	Successive Difference.	Year.	Number of Eruptions.	Mean Epoch.	Successive Difference.
685	1	(year.)	years.	788	1	(year.)	years.
1108	1			945	1	788	157*
				1112	1	945	167*
				1167—1183	2	1112	63
				1235	1	1175	60
				1524	1	1235	289*
1527—1532	3	1529				1524	55
			70	1554—1600	8	1579	
1596—1605	4	1599	55				71
1644—1669	20	1654	65	1617—1677	4	1650	
							66
1704—1733	16	1719	64	1716—1717	2	1716	
							55
1783	(Numerous)	1783		1771—2	1	1771	
Mean.	—	—	63.5	Mean.	—	—	62.7

(*) Excluded in taking the mean.

The eruptions of Miyake-jima occurred, with one or two exceptions, at fairly regular successive intervals, which varied between 39 and 72 years, giving the average length of 59.3 years. The eruptions of Ōshima and Fuji since the 16th century give respectively the approximate length of 57 and 61 years. (See Table II.)

TABLE II. ERUPTIONS OF MIYAKE-JIMA, ŌSHIMA, AND FUJI:
SUCCESSIVE TIME INTERVALS.

Miyake-jima.		Ōshima.		Fuji.	
Year, Month of Eruption.	Successive Difference.	Year, Month of Eruption.	Successive Difference.	Year, Month of Eruption.	Successive Difference.
	years.		years.		years.
July 886(?)	198(?)*			1083	
1085	69	1112			
1154	316*	Sept. 1416	304*		
Dec. 1469	65			1517	
Mar. 1535	61		267*	1560	43
Nov. 1595	47			1627	67
Mar. 1643	69	1684			73
Feb. 1712	52		93	Dec. 1700	
Aug. 1763	72	1777		1707	
		1832	45	1708	
Jan. 1811 ⁽¹⁾					
Nov. 1835	39		55		
July 1874		Dec. 1876 ⁽²⁾	36		
		Mar. 1912 ⁽²⁾			
Mean.	59.3	Mean.	57	Mean.	61

(*) Excluded in taking the mean.

(1) The Miyake-jima eruption of 1811 consisted simply in detonations, earthquakes, and some slight explosive action, being much inferior in magnitude to the others which were attended by lava outflows. It is, therefore, here provisionally excluded in taking the successive intervals.

(2) Commencement of prolonged eruptive period.

Collecting together the results relating to the mean epochs of group explosions of Asama and Kirishima and the single eruptions

of Miyake-jima, Ōshima, and Fuji, we see that the period of recurrence of volcanic activity varied between 57 and 63.5 years, giving the average value of 61 years, as follows :

Average difference between successive mean, or most active, epochs :—	
Asama,	63.5 years.
Kirishima,	62.7
Average difference between successive single eruptions :—	
Miyake-jima	59.3
Ōshima,	57.0
Fuji,	61.0
<hr/>	
Mean,	61.1 years.

This periodicity gives a certain parallelism among the time distribution of the eruptions of the different volcanoes in question. (See Table III.) Thus the Fuji eruptions of 1517, 1560, 1627, and 1700, were each followed after a mean interval of 16 years by an epoch of maximum activity of Kirishima, then after a further mean interval of 9 years, by that of Asama ; the eruption of Miyake-jima also invariably occurring in the later portion of each series. After 1700–8, Fuji became quiet, but the other three volcanoes made each an eruption between 1763 and 1783.

Beside the period of 61 years here deduced, there must exist a great many others of different lengths in the time distribution of volcanic eruptions.

TABLE III. PARALLELISM IN THE SUCCESSIVE OCCURRENCES OF ERUPTIONS OF FUJI, KIRISHIMA, ASAMA, AND MIYAKE-JIMA.

Single Eruption.	Mean, or Most Active, Epoch.		Single Eruption.
Fuji.	Kirishima.	Asama.	Miyake-jima
1517 ^(year.)	1524 ^(year.)	1529 ^(year.)	1535 ^(year.)
1560	1579	1599	1595

Single Eruption.	Mean, or Most Active, Epoch.		Single Eruption.
Fuji.	Kirishima.	Asama.	Miyake-jima.
1627 ^(year.)	1650 ^(year.)	1654 ^(year.)	1643 ^(year.)
1700	1716	1719	1712
—	1771	1783	1763

3. Alternations in eruptions of different volcanoes. In Table IV is given a comparative list of the years of eruption of Asama, Aso, Kirishima, and Fuji, grouped with reference to the activity of the first named volcano. It will be observed that the eruption of Asama occurred, on the whole, in alternation to those of Aso and Kirishima. Thus, during the six intervals of 1109–1526, 1533–95, 1606–43, 1670–1703, 1755–75, and 1816–65, Asama made no eruption at all, while Aso and Kirishima made together respectively 18, 14, 5, 4, 3, and 5 eruptions. On the other hand, during the five intervals of 1527–32, 1596–1605, 1644–61, 1704–55, and 1776–1803, Asama made respectively 3, 4, 19, 18, and 7 eruptions, while Aso and Kirishima made no outburst at all or only 1 or 2 eruptions. Between Aso and Kirishima, however, there is again an almost perfect alternation in the occurrences of their eruptions. At the same time, it is to be noted that the epochs of activity of Asama were each followed and preceded at a close interval by those of Kirishima and Aso. The activity of Mount Fuji took place nearer the eruptions of the two latter than those of Asama. (See also Table IV.)

Table V is a similar list relating to Sakura-jima, Kaimon, Unzen, Ōshima, Miyake-jima, Hachijo-jima, Aoga-shima, etc., classified according to the activity of the first named volcano. The alternate occurrences of the eruptions of Ōshima and Miyake-jima

are very clearly indicated. (See also § 2.) On the whole, however, either of these two volcanoes was in activity in the eruptive epochs of Sakura-jima. Again, the eruptions of Unzen, which took place only in 1657, 1663, and 1792, followed those of Sakura-jima in 1642 and 1779.

TABLE IV. COMPARATIVE LIST OF THE YEARS OF ERUPTION OF FUJI, ASAMA, ASO, AND KIRISHIMA.

*...Stronger outburst.

The figure within brackets is the number of eruptions during the time interval concerned.

Fuji.	Asama.	Aso.	Kirishima.
	685*		
781 800 826 864 870 937 999 1033 1083		864 867	742(?) 788 945
	1108*		
			1112 1167 1183 1235
1517		1238-1388 (9) 1434 1473 1506 1522	1524
	1527 1528 1532		
1560		1533 1542	1554-5
		1562 1564	1566 1574 1576-8
		1582 1584	1585 1587 1588
		1592	
	1596 1596 1598 1605	1598	1598-1600

TABLE IV. (Cont.)

Fuji.	Asama.	Aso.	Kirishima.	
1627		1612	1617-8	
		1631 1637		
	1644-1661 (19)	1649	1659-61	
	1669	1668	1662-4	
		1675	1677	
		1683 1691		
	1700 1707* 1708	1704 1706 1709-1733 (14) 1754 (2)		1716-17*
			1764 1765*	1771-2
1776 1777 1783* 1785 1803 (3)				
		1806		
1815				
		1826-1830 (4) 1854		
1866 1869				
		1874		
	1875 1879			

TABLE V. COMPARATIVE LIST OF THE YEARS OF ERUPTION OF
SAKURA-JIMA, ŌSHIMA, MIYAKE-JIMA, UNZEN, ETC.

*....Stronger Outburst.

Sakura-jima.	Kaimon, Unzen, etc.	Ōshima.	Miyake-jima.	Hachijō-jima, Aoga-shima, etc.
	764*(Subm., near Kokubu)	680 (Ōshima?)		838*(Kozu-shima.)
	867*(Tsurumi- dake)	856 (Ōshima?)		
	874*(Kaimon)			
	885*(")			
			886* (Miyake-j. or vicinity)	
			1085	
		1112*		
			1115	
		1416 1421		
1468				
1471* 1473			1469	
1475* 1476*				
1642			1535 1595	1487 (Hachijō.) 1518 (")
				1605 (") 1606 (Subm., near Hachijō.)
	1657 (Unzen)		1643	1652 (Aoga-shima)
	1663 (")			
1678		1684 1684		
1706			1712	
1742 1749				
1756 1767			1763	

Sakura-jima.	Kaimon, Unzen, etc.	Ōshima.	Miyake-jima.	Hachijō-jima, Aoga-shima, etc.
1779* 1780-99 (10 erups.)	1792* (Unzen)	1777* 1778* 1778* 1789 1803		1780* (Aoga-shima) 1781 (") 1783 (") 1785* (")
1860(?)	1813 (Suwanose)		1811	
			1822	
			1835	
		1870		
			1874	
		1876		1880 (Kita Iwō-jima.)
1914* (Jan.)		1912* 1912* 1914* (May)		

4. List of recent volcanic eruptions in Japan. Table VIII gives a list of the yearly number of eruptions in different parts of Japan during the 35 years since 1880, relating to 25 volcanoes (fig. 1), as follows:—

TABLE VI. NUMBER OF RECENT VOLCANIC ERUPTIONS IN JAPAN.

District.	Volcano.	Number of Eruptions.
(i). Northern part of Honshu (Main Island).	Bandai-san.	1*
	Adatara-san.	5
	Azuma-san (Issaikyo).	8
	Katta-dake (Zoo-dake).	4
(ii). Central part of Honshu (Main Island).	Asama-yama.	177*
	Yake-dake.	43*
	Shirane-san (near Kusatsu).	8
	Shirane-san (near Nikko).	1

TABLE VI. (Cont.)

District.	Volcano.	Number of Eruptions.
(iii). Islands of Fuji Volcanic Chain.	Ōshima (Izu).	5*
	Tori-shima.	1
	Submarine Eruption (near North Iwo-jima).	1
	„ („ South Iwo-jima).	2*
	„ („ Bayonnaise Rock).	3
(iv). Hokkaido and Kurile Islands.	Tarumai-san.	5*
	Komaga-take.	2
	Usu-san.	1*(1)
	Shiretoko (in Kitami).	2
	Shimanopli (in Kunashiri-jima).	1
	Moyoro (in Etrup-jima)..	1
	Shinshiri-jima.	1
(v). Kyushu and Lyukyu.	Aso-san.	11
	Kirishima-yama.	27
	Sakura-jima.	1*(1)
	Suwanose-jima.	5*
	Tori-shima (Lyukyu).	1

*....Including one or more large eruptions.

(1)....Group.

Of the different volcanoes tabulated above, Asama, Kirishima, and Aso made within the time limits under consideration very frequent outbursts, none of which were, however, of a gigantic magnitude. Of these three mountains, Kirishima broke into eruptions, on the whole, in alternation to those of Asama and Aso. (See also § 2.) On the other hand, the four volcanoes of Bandai-san, Ōshima, Usu, and Sakura-jima, each of which renews the activity after long intervals of relative rest, made very powerful eruptions during the interval since 1880.

The regional connection in the eruptions of the volcanoes belonging to the different groups is clearly indicated in Table VII. Thus, the 4 volcanoes of Group (i), situated close to each other in the boundary districts of the two provinces of Iwashiro and Rikuzen, made altogether 18 outbursts, which were limited to the 13 years between 1888 and 1900. Then followed the marked activity of the southern portion of the Fuji volcanic chain, namely, of the islands stretching from the coast of Izu to the Volcano Islands group; the explosion of Tori-shima in 1902 having been followed, during the 12 years between 1904 and 1915, by the lava eruptions of Ōshima and the submarine outbursts near the Bayonnaise Rock and the North and South Iwo-jima's. Simultaneously, the northern portion of the Fuji chain expressed its activity in the numerous volcanic explosions of Asama and Yakedake, respectively since 1899 and 1907; there being also between 1905 and 1910 the eruptions of the three volcanoes of Komagatake, Tarumai-san, and Usu-san, situated on, or close to, the coast of Volcano Bay, in Hokkaido.

On the whole, it may be said that the great lava eruption of Suwanose-jima in 1884 and the tremendous explosion of Bandai-san in 1888 were followed by an epoch of comparative rest for the 15 years, between 1889 and 1903, during which the volcanic outbursts were weak and not very numerous. Since 1904, however, the eruptive manifestations were greatly increased, both in intensity and in number, culminating in the epoch of 6 years between 1909 and 1914, during which interval there were altogether 194 eruptions from 11 different volcanoes. It was in 1914, when 7 volcanoes were in activity, that Sakura-jima made the last great eruption.

TABLE VII. LIST OF THE YEARS OF ERUPTION OF THE KYUSHU
AND THE FUJI CHAIN VOLCANOES.

*...Large Eruption.

Fuji.	Asama.	Aso.	Kiri-shima.	Sakura-jima.	Kaimon, Unzen, Suwanose, etc.	Ōshima.	Miyake-jima.	Hachijō-j., Aoga-shima, etc.
	685*					680(?)		
781			742(?)		764* [Subm. erupt. near Kokubu.]			
800*			788					838* [Kōzu-shima.]
826						856(?)		
864*		864			867 [Tsurumi-d.]			
870		867			874* [Kaimon.]			
937					885* [Kaimon.]		886(?)	
999			945					
1033							1085	
1083	1108*							
			1112			1112*		
			1167				1154	
			1183					
			1235					
		1238						
		1269						
		1271						
		1274						
		1333						
		1335						
		1340						
		1375						
		1388						
		1434				1416		
						1421		
				1468			1469	
				1471*				

Fuji.	Asama.	Aso.	Kiri-shima.	Sakura-jima.	Kaimon, Unzen, Suwanose, etc.	Ōshima.	Miyake-jima.	Hachijō-j., Aoga-shima, etc.
1517		1473 (May)		1473 (May) 1475* 1476*				1487 [Hachijō.] 1518 [Hachijō.]
1560	1527 1528 1532	1506 1522 1533 1542 1562 1564 1582 1584 1592	1524 1554-5 1566 1574 1576-8				1535 1595	
1627	1596 (May) 1596 (Aug.) 1598 1605 1612 1631 1637	1598	1598-1600	1617-8 1642				1605 [Hachijō.] 1606 [Subm. erupt. near Hachijō.] 1643

Fuji.	Asama.	Aso.	Kiri-shima.	Sakura-jima.	Kaimon, Unzen, Suwanose, etc.	Ōshima.	Miyake-jima.	Hachijo-j., Aoga-shima, etc.
	1709 1710 1711 1717 1718 1720 1721 1722 1723 (Feb.) 1723 (Aug.) 1728 1729 1732 1733 1754 (Aug.) 1754 (Aug.) 1776 1777 1783* 1785		1716 1717*	1742 1749 1756 1766 (June) 1766 (July) 1771-2 1779* 1780 (Sept.) 1780 (Oct.) 1781 (Apr.) 1781 (May) 1782 1783 1785			1712 1763 1777* 1778* (Apr.) 1778* (Dec.)	1780 ⁽¹⁾ 1781 ⁽¹⁾ 1783 ⁽¹⁾ 1785* ⁽¹⁾

(1) Aoga shima.

Fuji.	Asama.	Aso.	Kiri-shima.	Sakura-jima.	Kaimon, Unzen, Suwanose, etc.	Ōshima.	Miyake-jima.	Hachijo-j., Aoga-shima, etc.
				1790 1791		1789		
				1799	1792* [Unzen.]			
	1803(July) 1803(Nov.) 1803(Nov.)					1803		
		1806					1811	
	1815				1813 [Suwanose]			
						1822		
		1826 1827 1828 1830						
		1854					1835	
	1866 1869			1860(?)				
		1874				1870	1874	
	1875							
	1879					1876		
								1880 [Subm. near Kita- Iwojima.]

TABLE VIII. LIST OF YEARLY NUMBER OF RECENT VOLCANIC ERUPTIONS IN JAPAN, 1880-1915.

(Gothic numeral indicates large eruption.)

Year.	Vol- cano.	(i). N. Part of Honshu.				(ii). Central Part of Honshu.					(iii). Fuji Zone Islands.				(iv). Hokkaido and Kurile Islands.				(v). Kyushu and Ryukyu.					Total Number of	
		Bandai.	Azuma.	Adatara.	Katta.	Shirane. (Near Kusatsu).	Shirane. (Near Nikko).	Asama.	Yake-dake.	Tori-shima.	Vicinity of Kita and Minami Iwo-jima.	Vicinity of Bayonnaise Rock.	Ōshima.	Tarumai.	Komaga- take.	Usu.	Shiretoko.	Kurile Islands.	Aso.	Kirishima.	Suwanose- jima.	Sakura- jima.	Tori-shima.	Eruptions.	Volcanoes.
1880						1							1											2	2
1881																								2	2
1882																								2	2
1883																								1	2
1884																								2	2
1885																								1	1
1886													1	0										1	1
1887													1	1										1	1
1888																								1	1
1889	1																							4	5
1890																								2	2
1891						1																		2	1
1892																								2	1
1893																								3	1
1894																								3	1
1895																								3	1
1896																								3	1
1897																								3	1
1898																								3	1
1899																								3	1
1900																								10	3
1901																								3	4
1902																								6	1
1903																								4	3
1904																								4	2
1905																								2	2
1906																								3	3
1907																								3	2
1908																								8	3
1909																								19	3
1910																								15	5
1911																								57	2
1912																								21	2
1913																								48	4
1914																								34	7
1915																								5	4