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Notes on the Volcanic and Seismic Phenomena in the Volcanic District of Shimabara, with a Report on the Earthquake of December 8th, 1922.

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With 6 Plates

I Introduction.

Evening issues of newspapers on December 8th 1922 reported a severe earthquake which occurred early that morning in Shimabara Peninsula, in northwestern Kyushu. It aroused great excitement all over Japan, for the memory of the appalling catastrophe on Sakurajima in 1914 in consequence of the eruption in that volcanic island, was still fresh in the minds of the people. Indeed the three volcanoes, Sakurajima in southern Kyushu, Asama in Kwanto, and Unzen in Shimabara peninsula, displayed toward the end of the XVIII Century unparalleled activity, the eruptions which took place then ranking among the most disastrous events in the annals of Japan. Of these volcanoes it is Asama which came again to show most symptoms of unusual activity at the beginning of the present century. The last eruption of Sakurajima was almost equal in intensity with that of the An-ei Era (1779), bringing the island in Kagoshima Bay in direct connection with Ôsumi Peninsula on the east of it. The volcanic activities of Unzen on record are two, one in 1657, and another in 1792 with an interval of about 130 years between them; so that a recurrence of a subterranean convulsion seems not wholly improbable, if the periodicity of its paroxysms continues to hold good.

I left Kyoto and hastened to the sites of the disasters on the 9th. I found however the damage to be exaggerated in the first reports, and to be localized in small detached areas in coastal villages, on the south and west of a line drawn from Chijiwa to Dozaki. The following pages are written from personal observations and information collected in a fortnight's stay, to make clear the significance of this outbreak in relation to the volcanotectonic and seismotectonic lines of the volcanic district.

In addition to this I propose to give here from local documents an elucidation of the great catastrophe of 1793, in which case earthquakes played the rôle of precursors of activity of Unzen, and also a few salient facts about the earthquake in the northern districts of Omi in 1909, which convinced me of the validity of Prof. W. H. Hobbs' interpretation of seismic phenomena on the basis of structural geology.

I gratefully acknowledge in writing these pages the assistance of Mr. R. Shimoda, professor of geography in Nagasaki and Mr. S. Komaki, who gave me ready assistance in field work and documentary researches. My thanks are due to my colleagues of the Imperial University, Prof. Shintaro Nakamura and M. Matsuyama, who gave me valuable suggestions, and especially to the former who took the trouble of reading the proof sheets

II Geograpical and geological outlines of Shimabara Peninsula.

The peninsula lies on the western coast of Kyushu Island, and stretches southeastward from the western part of Hizen Province. It has a length of 34 km measured from NNE to SSW and an area of 465 *sq. km.* It forms a counter-part of the West Sonoki peninsula extending northwestward with Nagasaki near its southern end, both being connected with the main island by the Isthmus of Izahaya.

While the whole coast of Hizen in the north and west of the isthmus has innumerable indentations of the Rias type, unexampled in the coastal development of the Japanese Islands, and owing their origin to a submergence of land since the end of the Pliocene Epoch, the peninsula lies in the midst of a flat sea basin on the western continuation of the Inland Sea occupying a depression between North and South Kyushu, and has a comparatively simple elliptical outline with the longer axis lying from NNE to SSW, except the western side which is encroached on by Chijiwa-nada or Tachibana-wan. The almost perfect elliptical curvature of its north and east coasts is due to the conical elevation of Mt. Unzen in the centre of the peninsula. The gentle slope here merges into a flat plain and dives under the waves of the Ariake Sea and Shimabara Bay. The southwestern prolongation has a more crooked outline than the main part and terminates in the small but well protected natural harbour of Kuchinotsu, with Sezumezaki, the southern promontory of the peninsula. Along the coast we find a succession of cliffs of soft Pliocene beds which were undermined by waves and formed a narrow submarine platform exposed at low tide.

The encroaching of Chijiwa-nada on the east of a line drawn southward from the neck of the peninsula at Ainotsu on the east of Izahaya, is most probably partially due to a subsidence of the western half of Unzen-dake, an episode in the history of volcanic and seismic activities manifested since the end of the Pliocene epoch in the region.

The geology of the peninsula was first accurately mapped by D. Yamashita, geologist of the Imperial Geological Survey, who prepared Kumamoto Sheet, Scale 1 : 200,000, in 1891, and an interesting history of the active volcano Unzen-dake was compiled in his explantory text accompanying the map. But we owe to Prof. D. Sato[1] and Mr. I. Komada[2] fuller information on the structure and geomorphological evolution of the volcano, and especially to the latter, a detailed map

1) Unzen-Kwazan (Volcano Unzen) Kyoiku-gaho, Vol. XIII. 1922.

2) Unzendake-Kwazan Chishitsu-chōsahobun (Report on geology of Volcano of Unzen-dake). Report of Imperial Earthquake Committee. No. 84. 1916.

1 : 50,000, published by the Imperial Earthquake Committee in 1916. I give the geological map on a reduced scale and corrected by means of Prof. D. Sato's data in the annexed plate (Pl. VI).

As we see in the geological map, the vast mass of hornblende-andesite of Unzen-dake occupies more than three-fourths of the peninsula, while the southwestern prolongation alone belongs to Pliocene formation with associaled basic volcanic rocks. Some of the Tertiary strata are found bearing plant fossils, probably contemporaneous with these of Mogi, and others contain marine shells. A conspicuous feature of this part is the eruptions of basalts and basic andesites, whose flatly lying sheets give rise to plateaus on the northwest and south of the Minamigawa.

The volcano being polygenic in A. Stübel's sense, most of the protuberances were formed in the course of activities, after a depression encircled with a crater-wall in horse-shoe shape had taken place in the centre of the old volcano of Shimabara. Sommas of this ruined volcano, which open toward the west on Chijiwa-nada, can be traced on the north in a ridge running from east to west with a steep declivity on the southern side. Azuma-dake (868 m) is its highest elevation. The continuation of this old crater-wall on the east and south is less distinct. According to Mr. I. Komada, it is represented by Nodake (1147 m) and Takaiwa-yama (880 m), but as the northern slope the latter has not the same steepness as its counter-part, I believe that Prof. D. Satō is right in regarding Nodake and Kinugasa-yama to represent the southern crater wall, while the depression where the Jigokusan are was formed by explosion through the wall. These ruins of the oldest conical mound of gigantic dimensions have in common a less steep inclination outwards, but the gradient is much greater than that of the foot hills of detrital accumulations. The contrast seems to be due at least partly to the high viscosity of the lava which has overflowed on the block-mud bed.

In the interior of the caldera so formed we find two centres of eruption, represented by the cone of Kusenbu-dake and an explosion crater of Chijiwa-dake, and on their approximately meridional prolongation a depression with "Jigokus" (Hells), which owes its origin to an explosion on the margin of the caldera between Yadake and Kinugasa-yama later than the two preceding. This last named has numerous fumaroles and solfataras ever alive since the VIII century, to which the whole volcano owes the name "Unzen", meaning "hot springs".

The group of Fugen-dake (1360 m), or Unzen-dake proper, consists of a central cone, Fugen-dake, and of a somma encircling the north, west and south of the same, with peaks, Kunimi-dake and Myoken-dake, a little lower than it. The whole conical mound of the same, rather acidic and viscous lava, has a steep slope $>20°$ on all sides, and presents a very imposing aspect seen from the east and southeast foot. (Pl. VIII. Fig. 1.)

Mr. I. Komada gives besides the prominences four parasitic cones, of which one, Saigo-yama, lies on the northern flank, two others, Inō-yama and Maye-yama on the flank and foot of Fugen-dake on the east, and the fourth, Saruba-yama on the west. Prof. D. Sato beliebes Takaiwa-yama (880 m) to be the fifth cone that erupted on the southern flank of the outer wall.

III Geotectonic Features — Earth's Lineaments.

In order to have an insight into the geological structure of the volcanic district, we have to go back to a more remote geological past than the younger Tertiary epoch, when deposition of sediments and effusion of igneous rocks took place in the flat sea bottom connecting the waters of the Inland Sea with Tung-hai or the Chinese Eastern Sea. As recognized by Messrs. Edm. Naumann, T. Harada and B. Kotō in their researches which have appeared since 1882, older formations building up the Northern Kyushu Mountains are mostly metamorphic Palæozoic sediments intruded with vast masses of granites and other plutonic rocks. Though we lack as yet a detailed investigation into the nature of the rocks, I may be justified in assuming that contrary to the opinion of these masters of Japanese geology who regarded them as Archaean complexes, they are homologous members found in other part in the inner zone of the Japanese Islands, and owe their highly metamorphosed petrographical characters to regional metamorphism which accompanied the orogenic process in building the folded mountain system. Amphibolites and less metamorphosed basic tufaceous rocks intercalated in normal sediments are most probably of the later Palæozoic age, being older than the Rhætic plant-bearing series of Nagato. They represent volcanic products during the formation of a geosynclinal in that age.

The Palæozoic terrain with intrusions of plutonic rocks seems to have been subjected in later times to a compression from the west, apparently in connection with the formation of the insular arc of Ryukyu. The greatest disturbances must have happened simultaneously with the folding of Idzumi Sandstone which represents marine sediments deposited in a narrow longitudinal trough between the inner and outer zones of older mountains. Bending of chains of the younger Cretaceous strata, indicated in the trend of the Amakusa Islands to the south of the peninsula, is an evidence that the formation of the southern insular arc was of a later date than that of the main islands of Japan.

Of the Tertiary deposits which occupy an extensive region on the north of the Cretaceous belt, the lowest horizon is represented by the Lower Coal Measure. It is worked in Miike, Amakusa, Karatsu and other basins. Prof. M. Yokoyama regards them as belonging to the Palæogene from *Aturia ziczac* and other characteristic fossils collected in shafts and borings in various collieries of Northwest Kyushu. These early Tertiary deposits are not visible in the neighbourhood of the peninsula as is mentioned above and the sedimentary foundation exposed on its southern part is of Neogene shallow sea deposits, the same as those at Mogi near Nagasaki. If these be the topmost members of a continuous deposition during the Tertiary period, the subsidence must have attained more than a thousand metres at the centre of the basin occupied by the peninsula.

A noteworthy feature of the formation is a contemporaneous eruption of basaltic rocks, which marks an episode of the epoch throughout Northwestern Kyushu and the coasts of the Japan Sea in Kyushu and Chugoku.

The formation has disappeared on the northeast of a line drawn between Obama and Sukawa (Higashi-Ariye), and on that depressed area a new epoch, probably early Pleistocene, was opened with an equally intense volcanic activity which caused the accumulation of vast masses of basic andesites and their detrital materials on the basement of the volcanic district of Unzen-dake. The eruption of hornblende-andesite which succeeded the new subterranean convulsion, came to continue in a state not yet wholly extinguished. Petrographically speaking, the sequence is therefore basalt, pyroxene-andesite and hornblende-andesite, namely, a cycle of magmatic differentiation with decreasing basicity.

The eruption of these volcanic rocks has no doubt a close relation with dislocations which took place subsequent to the great orogenic movement. After folding and bending of Izumi-sandstone strata mountains north of the newly built chain were transversed with numerous lines of dislocation in diverse directions By inspection of a general geological map of Japan, we can easily recognize these lines or lineaments in Prof. W. H. Hobbs' sense.

Of the lineaments, two can be traced along lines drawn from Kumamoto to Moji and to Karatsu. They represent two sides of the triangular Tsukushi Mountains, which are again cut by less marked lines into separate blocks. These and the leading directrix which runs from Sagano-seki to Misumi on the northern margin of the South Kyushu Mountains bound two sides of two depressed areas between two major blocks of mountains in the island. The one on the east has also a triangular outline, but is occupied on its western part by the extensive volcanic districts of Buzen, Bungo and Higo Provinces, and the other on the west by Unzen, Tara and other small volcanic centres. It is interesting to add here that parallel with the main lineament of NW–SE trend, we find a second drawn parallel from Fukuoka SE–wards. The line divides the triangular northern block in two parts, and has in its prolongation the gigantic volcanic centre of Aso, as is the case with Tara and Unzen which are located on a line parallel to that drawn between Karatsu and Kumamoto.

Beside these lines we notice a line of dislocation with NE–SW trend in the coast lines of Nagasaki Peninsula and of Amakusa and other islands of Higo Province, and another is traced in an equatorial trend of lines joining Imari and Kurume, and Nagasaki and Kumamoto. The former when produced eastward coincides with the fault scarp of Minawa-yama, while on the latter are located Unzen and Aso, which have again in their interior several craters alligned in the same direction.

There is a third line recognized by Messrs D. Sato and I. Komada in the volcano of Unzen, The line joining Saigō-yama and the central cones, trends in an approximately meridional direction.

I believe I can see here in northwestern Kyushu four systems of lines of dislocation or lineaments which are marked more or less distinctly with approximate trends of N–S, E–W, NW–SE and NE–SW. They are of course not always expressed with the same degree of sharpness, as that with which I have attempted to plot them in the map annexed to the present paper (Pl. VII). They may remain problematical for ever to sceptical minds. I am however convinced that there is in this case the same validity of inferences that Prof. W. H. Hobbs so eloquently expounded in his Principles of Seismic Geology.[1) My own observations on the earthquake in Northern Omi in 1909[2) confirmed the same view that orotectonic and seismotectonic lines coincide with one another when the sites of disasters are plotted in detail on a topographical map, and this time volcanotectonic lines in

1) Gerlands Beiträge zur Geophysik. Bd. VIII. Heft 2. Leipzig, 1907.

2) Kōnō shinsai chōsa-hobun (Report on the Earthquake of Omi and Mino) published in the Meteorological Station at Gifu. 1909.

addition to them seem to have played an important rôle in the localization of damage in the peninsula.

IV Evolution and Structure of Unzen-dake.

From the brief orographical description of the volcano given above it is clear that the first and most intense activity was manifested in the extrusion of hornblende-andesite lava which piled up on the foundation of breccias and tuff of the same rock into a cone of gigantic size. It was however subsequently destroyed and reduced to a caldera. The demolition of the cone seems to have been caused partly by exploisions in a later stage and partly by the downfall of its central and western parts. I believe the latter process to have been of an importance not to be overlooked.

In the second period of activity which followed the demolition, the eruption took place in the centre as before. Kusenbu-yama and Chijiwa-yame were formed in the process. The explosions of the latter and Jigokus on the margin of the caldera represent a declining phase of the activity. Most of the parasitic cones probably came into existence in the same phase.

The third period was marked by the formation of Fugen-dake, which was extruded on the eastern rim of the caldera. Eruptions recorded in the last three centuries have been chiefly located on the cone, especially on its eastern flank, and have obviously been much inferior in intensity, for the eruptions have been of intermittent character, while the explosion crater of the Jigokus still preserves numerous fumaroles which have been persistently emitting sulphurous fumes for more than a thousand years. This fact points to a steady decline of volcanic energy in the district.

A noteworthy feature of the activity is the persistence of a magma of the same petrographical character throughout the three periods. The lavas of the first period do not essentially differ from those of the most recent dates. All of them belong to hornblende-andesite with subordinate amounts of hypersthene, biotite and augite. Their content of silica varies from 63 % to 68 %. In this uniformity of the products of eruption they stand in striking contrast to the adjacent volcanoes of Kyushu. Tara, Aso and others exhibit more or less distinct variation in their successive extrusions.

V Historical eruptions of Uuzen-dake (1).

The discovery of the hot spring of Unzen is attributed in local tradition to Priest Gyoki in 701 A. D. Since an authentic record[1] mentions the name of Unzen-no-Kami or "God of hot spring" in Hizen in the list of promotion of 860 A. D., the numerous fumaroles must have been well known as health-resorts a long time before that date. We cannot however conclude with certainty from the promotion of rank of a Shinto temple that it immediately followed an activity of the volcano in question, though a like procedure was taken in the case of Fuji and Aso which were active in the last half of the same century.

According to the anonymous chronicler of Shimabara-taihenki, buddhist monasteries flourished at Unzen at the time of the incursion of Khublai-Khan's army in 1281. Wide tracts of land in the peninsula were then owned by priests. The monasteries were destroyed and the land was confiscated in the XVI century by Arima, the most powerful Daimyo of Hizen, who was converted to Christianity. During the age of missing records the volcano seems to have been quiescent, or not in a state of activity violent enough to live in the memory of the inhabitants of the neighbourhood.

The first record of activity of Unzen is the eruption which began in 1657 (3rd year of Myoreki) and continued more than twenty years. The chronicler of this eruption says:

"About a hundred and thirty years ago (reckoned from about 1793), when Koriki-Sakonnoshogen was governor, Fugen-dake was in eruption. It glowed for several nights so intensely that people in the

1) Sandai-jitsuroku (History of the Three Generations). Book IV.

northern part could dispense with a lantern or a torch. The black, burnt rock (lava) can still be seen on the right on the way leading to Fugen. At that time a flood came down from the uplands of Antoku and Fukae to the villages, causing damage to the farms. It is said, the present waterless river bed marks the course of that flood ".

Toshiyuki Kanai, who compiled local documents and information with unusually sound criticism and insight in connection with his personal researches in the field, says:

" The eruption of 1657 took place in the community of Miye. The lava is now known as Furuyake, " old lava ", of which the site is found in the valley between Yemaru and Hando-iwa. The course of the coulée is marked by a ridge of rugged rocks raised from the ravine for some hundred metres. In the following year a flood from the upland (probably Akamatsu-dani) of Fukaye and Naka-koba over-ran the two villages, sweeping houses away and killing more than thirty souls. Antoku-gawara is said to have been its course ".

The lava of 1657 welled out from Hando-iwa on the northern foot is estimated to be 1200 m long and about 100 m wide. It is distinguished by its rugged relief from the surrounding rocks.

Two more eruptions in 1663 and 1664 are recorded.

In March, 1663 Fugen-dake was in activity for five days. Kuju-kushima or " Ninety-nine islands " which was the site of the eruption, is a depression east of the central peak of the volcano. The name indicates numerous mounds of mud or piles of ejected blocks which had anyhow only an existence for a short time and completely disappeared afterwards.

Another occurred between 4 and 5 o'clock on the morning of 27th January, 1664. It is said that a detonation was heard before dawn, and fumes were seen in the morning.

There is no wonder at the meagreness of decuments on the eruption of this period in spite of the recent date of its occurrence, if we consider that Koriki-Takanaga, Governor of Shimabara, was exiled to Mutsu Province on a charge of maladministration. All official and private manuscripts were lost with the dispersion of his retainers.

Thanks to the proximity of Unzen to Nagasaki we have some more information from contemporary Dutch captains about the mountain. We find it in Montanus' Atlas japannensis. It consists of extracts from a diary or report of Captain Indiik's mission to Yedo (Tokyo) in 1661 and that of Seldere's (or Zeldere's) a little later. It is to be regretted that the compiler's ignorance of the geography of Japan and his lack of prudence led him into grave mistakes, confusing places and dates, besides misspelling proper names.

We find in the narrative an active volcano Siurpurama — undoubtedly Shimabara — close to the great lake near Miaco (Kyoto), instead of in its true position on the sea-coast near Nagasaki.

On his journey back to Nagasaki, Indiik left Yedo on the 15th of April 1661 and arrived at Miaco on the 25th. " He left, eight leagues beyond this city, near the great lake, the famous Burning Mountain Siurpurama, afterwards inspected by the Dutch Ambassador Seldere. This mountain is of an excessive height, vomits forth Smoke and Flames: the Smoke alters its course according as the wind blows, and beats down sometimes in such a manner, that it not only makes the adjacent countreys at noon-day seem clouded with night, but also smothers men and beasts.

" Next this mountain is another, but not so high; three sulphur streams come flowing from them, which sometimes overflowing, rushes into the vallies, making a great smother and noise,...... The countrey round about the mountain is excessive hot, that none can stand long there, but it will burn their foot ".

As Indiik passed Simonoseki on the 11th of May and landed at Cockero (Kokura), whence he returned to Nagasaki by the land route, the volcano of Shimabara might have been sighted by the sailor from somewhere near Izahaya. If this be the case, we can infer that the volcano was constantly in activity between 1657 and 1664.[1]

We find more accurate remarks in Kaempfer's book on Japan. He says that "Unzen is a deform'd, large but not very high mountain near Shimabara. At all time the top of it is bare, whitish from the colour of sulphur, and withal resembling a Caput Mortuum, or burnt out Massa. It smokes little however, I could discern the smoke arising from it at three miles distance". Though it is not clear from the account whether it referred to the fumaroles of the Jigokus or to Fugen-dake, one thing is certain, namely, the paroxysmal phase had passed befere Kaempfer's residence in Nagasaki between 1690 and 1692.[2]

We have here to add another passage from Montanus giving Indiik's experience of earthquake in Nagasaki. The first shock on 25th November 1660 was followed by others which continued during the next month and culminated in that occurred on 3rd of January 1661. Its severity could be imagined from such facts as "the joints of the houses beginning to gape, the timber and walls tumbling down, which occasion'd a general out-cry in the city".[3]

Scanty as are the documents on the eruption, yet it is probable that the volcano was in a state of constant activity for more that ten years after 1657, in which year it began with an extrusion of a lava from the northern flank of Fugen-dake.

VI Historical Eruptions (2)--Eruption and Earthquake of 1792.

After the last account of the state of the volcano was given by Kaempfer, a century had elapsed when fresh activity occurred and

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1) Atlas Japannensis, &c. Collected Arnoldus Montanus......English'd and adorn'd...... by John Ogilby Esq. London, 1670. p. 445–449. In the narrative Montanus obviously confounded Miya (old name of Atsuta, Owari Prov.) with Miyako or Kyoto and the ferry from Atsuta to Kuwana across Isenoumi with Lake Biwa, and again the ferry with a voyage across Ariake Sea.

2) Kaempfer: History of Japan. Transl. by J. G. Scheuchzer. Vol. I. 1906. p. 165.

3) *Loc. Cit.* p. 439.

accompanied with earthquakes it brought a tragic catastrophe to the district and adjoining sea-shores of Higo Province. The activity commenced with shocks of earthquake in the winter of 1791. It was followed by eruption on the top of Fugen-dake which lasted for several months the following year, during which a considerable quantity of lava was poured out from the flank. Extremely severe shocks of earthquake concurred with the eruption, and culminated in the collapse of a part of Maye-yama, causing a *tsunami* which inflicted disastrous effects on the shores of Ariake-Sea [1]

(1) *Precursory shocks* were felt from November of 1791. The first occurred on the 2nd of the month (8th October of the Old Calendar). It was accompanied with subterranean detonation. Such a shock was felt three or four times daily, increasing in intensity about 6th December (10th November), and caused land-slips on the southeastern front of Maye-yama. At that time however the shocks seem to have been more severe in the neighbourhood of Obama on the western coast, for a case of two men being killed by rocks falling on a shed was reported from Bingushi or Yamaryo on the southeast of the village. The absence of any record in the Diary of the Nabeshima Family kept in Kojirō makes us believe the shocks not severe enough to be noticed.

Towards the end of January the detonation of mountains west of Shimabara became very frequent and intense. It was likened to thunder or firing of artillery.

(2) *Eruption of Fugen-dake*.. On the morning of 9th February 1792[2], particularly heavy shocks were accompanied with detonations

1) We find an interesting description of volcanic eruptions of Asama in 1784 and Unzen 1792 in *Titsingh's Illustration of Japan (translated from A. Rémusat's compilation* in French by Fr. Schoberl in 1822). The date of the eruption of Unzen (pp. 109–112) was referred erroneously to 1793, and the second illustration of Asama (Part I, Pl. 3) to Shimabara. The mistakes have obviously arisen in the compilation of the author's posthumous manuscripts.

2) Date of the first eruption is, according to T. Kanai, midnight of 10-11th (1 o'clock on 18th January, Old Calendar); but we accept the date in the Diary and Report kept at Kōjiro, which is an umequivocal record of the daily events of the year.

originating from Fugen-dake. At about 7 o'clock in the morning people at Kōjiro found black smoke like piled rocks coming forth from the top of the mountain. It rained the whole day. Shocks felt at Shimabara were very severe during the night. On the next day the head man of the village at Kōjiro was ordered to send a farmer on a tour of inspection but he could not go further than Yazaemon-yake, since the shaking of the whole mountain and the emission of muddy materials frightened him. Officials next send by Nabeshima, however, reached the site on the top.

According to their report, a depression with a diameter of about 50 m had been opened by an explosion in front of the temple of Fugen. Jets of boiling water gushed more than 30 m high, and with them large blocks of rock and mud were hurled up. The mud formed a large mound at the bottom of the hill.

The eruption was in its maximum intensity on the third day. Smoke was thrown up high into the sky and darkened it. Ashes fell on the neighbourhood of Shimabara. It gradually subsided, and in March the emission of mud was only 2 m high.

(3) *Extrusion of Lava in Anasako-dani.* On 25th February, fifteen days after the eruption of Fugen-dake, the ground at Biwa-no-bachi, up the valley of Anasako, began to tremble and shook off earth and rocks. The second site of activity lies on a steep declivity about 1 km northeast from the top and 4 km from Shimabara. Toward noon on the 27th dust was hurled up. During the night of 1st March a fiery light was seen at the spot. The consolidated blocks of lava pushed out of the new vent fell down to the bottom of the ravine with a tremendous noise.

The head of the new lava flow, "Shin-yake-gashira" lies beneath Hando-iwa, which is a cliff formed by a sheet of lava and is separated from Yazaemon-yake or Furu-yake by a spur called Roggi-yama running northeastward to the hilly tracts of Orihashi. The valley of Anasako had some hamlets near the mouth opening to Semboki. The coulée crept down the valley and overwhelmed the hamlets. Its serpentine course 4 km long bears the most rugged aspect imaginable and dwarf pine trees are the only vegetation grown after the lapse of a hundred years. On both sides ravines more than 100 m deep mark the former course of Anasako-dani. Its lower end in the mouth of the valley has the form of a cliff 200 m wide and 50 m high (Pl. VIII, Fig. 2 and 3).

During the time when the lava was welling out, which seems to have lasted for many months, it presented a scene of infernal aspect terrifying in the extreme the inhabitants of the neighbourhood. Pushed out by the emission of fresh red-hot melt, consolidated blocks of lava tumbled down to the bottom with a crash. This sound combined with roaring and trembling coming from underground, made a tremendous noise. The first terror soon vanished, however, and picnickers swarmed to the scene so that tea-houses were built for them on adjoining heights. Officials sent from Kojiro reported on 25th March a crowd of spectators numbering thousands on the spot. The governor of Shimabara had to issue an order prohibiting people to resort the scene, except a male representative from each family for inspection.

(4) *Other vents of eruption.* Meanwhile the subterranean convulsion found other outlets near the top of Fugen-dake. One was opened on the afternoon of 21st March at Hachi-no-kubo which lies also on Hando-iwa. It was followed on the 24th by the opening of seven more outlets 200 m northwest of the same, on the side of Furu-yake or Yazaemon-yake, as it was called in the reports of Kojiro. All these vents having underground communication with the crater on Anasako-dani, the top of Hando-iwa was torn asunder into two masses by a rent measuring 1–5 m in width across it.

The validity of the facts compiled by T. Kanai concerning these eruptions is confirmed in the report of Kojiro for 27th April. We find in the same decuments an interesting record that the distance covered by the coulée in 60 days was estimated at 21 *cho* 15 *ken* (2,320 m), i. e. approximately 40 m per day.

The eruption was going on during the time in its full activity. Clouds produced by emission of vapours from these vents hung high up in the sky, glowed in the twilight and reddened to a more fiery hue during nights. The lava coming downward menaced the town of Shimabara, which was shaken by incessant shocks all the time.

(5) *Earthquake of 21st April (1st March).* At 4 o'clock in the after-noon on this day occurred the severest shock hitherto felt. With it roaring noises came from Maye-yama. The sound was like the discharge of guns on a Dutch frigate. Sometimes it seemed to pass from the mountains in the centre to the sea and sometimes from the sea to the land. Shaken by the shocks masses of rocks and debris fell down from Maye-yama and set the trees below on fire through the heat of their friction.

The shocks were very severe and frequent for three days, more than 300 being counted during the night and more than 100 in each of the next two days. They were most intense from midnight to the morning of the second day. Six of the shocks on the first day and four on the second put doors out of place. However the earthquakes subsided gradually after the third day, although another severe shock occurred on 29th April (9th March).

The destruction known at Shimabara a week after was 61 houses and store-houses, besides 288 stables and sheds completely collapsed or badly damaged. Two men lost their lives by a falling house. This time it was severest along the eastern shore between Shimabara and Fukaye. At Shimabara the eaves of most buildings were shaken down and stone walls of the castle dislodged.

At Kōjiro on the northern-most part of the peninsula it was reported that the same shocks were felt and some ovoid gravestones, "Ishi-dōro" (stone lanterns), and "Torii" (stone gate), fell down, while at Shimabara all these stone works completely succumbed to the shocks. I conclude from these facts that their intensity was as a whole far greater than that of 8th December 1922, which we shall see later, and also that the area of the greatest intensity was in the central and eastern part of the district.

A fact of importance is the formation of crevices in consequence of the earthquake.

According to T. Kanai, the earth was rent by the earthquake at several places between Shimabara and Antoku. Two of the crevices with a trend W by N to E by S and about 1 km long are shown in an old map of the town copied by the author. They ran across the castle and were at first only a few inches wide, but widened with the increasing intensity of shocks to more than a foot. It is said that the ground sank on the southern side of these crevices. In connection with the fracture underground water was subjected to a change; springs gushed forth on the east of the castle close to the shore, while on the west up the hill beyond the castle, fountain-heads were dried for a time.

A similar crevice was produced on the west between Orihashi and Roggi measuring 1 km in the prolongation of the same direction as those on the east.

We find in a report on 31st May (11th April) at Kōjiro that a far more striking line of fracture was produced most probably by the same earthquake. It ran from Iwomi-dake to the southern slope of Azuma-dake, and thence to the north flank of Fugen-dake. The part of the crevice near Azuma-dake was seen from the road, its width being about 1 m.

When we join the three lines of fracture their trend and position coincide with the lineament marked by the depression in the interior of the northern crater-wall.

Another equally norteworthy fact is a landslip caused by the earthquake on the southeastern part of Maye-yama. The destructive process commenced at midnight, when the severest shocks were felt at Shimabara, and continued for a whole month with varying intensity. The violence with which the mountain was torn asunder and thrown downward frightened the inhabitants in the immediate vicinity, no less than the red-hot lava flowing down from Fugen-dake. In the Diary on the 22nd it is mentioned that a rumour of a coming *yamashio*, (literally meaning "mountain-flood" or landslip) was in vogue among the people in Shimabara, and put them to flight to the north and almost the whole population except samurais abandoned their homes. It continued for a fortnight, until the shocks and become weaker and less frequent.

(6) *Collapse of a part of Maye-yama.* Towards the middle of May, although the lava was continuing its downward movement, both the eruption from vents on Fugen-dake and the shocks and detonations of the earthquakes sensibly subsided and appeared to have lost almost all their destructive energy. People returned to their dwellings by and by. It was a tragic circumstance that people who had settled down again were surprised by the worst catastrophe in the whole course of the volcanic activity. It was the sudden collapse of a considerable portion of Maye-yama, which took place on the evening of 21st May (1st April). About 8 o'clock that evening the towns-people of Shimabara once more felt severe shocks of which two are said to have been particularly violent, and were followed by a crash as if thousands of thunder-bolts were united in a single stroke. After a short time loud shrieks were heard in the streets on the east and south of the town. The advancing front of a "*tsunami*" was soon perceived by a sentinel on the gate-way of the castle. Most of the populous parts of the town were engulfed by waves which came from the south three times in rapid succession.

At Kōjiro it is said that between 7 and 8 o'clock a loud roaring was heard from the sea, the noise resembling that of the turning of a windlass of a seine; people hastened to the shore, and saw the wave-front raised like the ridge of a hill; all the inhabitants of the villages on the sea-shore fled to the upland without the loss of a single life.

The scene in Shimabara after the retreat of the tsunami was beyond all imagination. The night was moonless, and the towns-people who outlived the disaster could not know what was the natural force at work that produced the cursed waves. When the morning dawned, however, Tengu-yama which formed the southeastern third of Maye-yama and commanded a narrow coastal plain stretching southward from the town, was found to have lost its eastern half, and was presenting a sheer wall cut in banded layers of white and red lava. The precipice measured some hundred metres.

The mass which made up about one-sixth of Maye-yama, which equals about half a cubic kilometre was thrown down on its eastern foot in a fan-shaped hilly tract with its margin projecting far beyond the previous shore lines. Two villages, Ima-myō of Shimabara-mura and Kita-myo of Antoku-mura, were wholly buried under a thick débâcle of the debris, besides the southern suburb of the town with its flourishing harbour, which was also devastated and converted to a desert with pell-mell heaps of the same detrital materials. Detached patches of them, "flowed mounds" as Mr. I. Komada calls them, swept on to the sea, and gave rise to islets which numbered from two to three hundred, at the time of their formation. Many of them still exist along the shore east and south of the town.

The tsunami evidently was caused by the dashing of the vast mass thrown down from Maye-yama into the sea. A circumstance which made the effect more serious was its coincidence with the hour of spring tide which is 9 h 20 m at the roadstead of Shimabara, and of which the range is nearly 5 m.

As to its amplitude, exaggerated heights, above 30 m, were given in an official report of Shimabara. According to an estimate by T. Kanai, however, of the three waves, the second which was the highest did not attain more than 10 m at Shimabara. Their destructive force can be imagined from the following passages in the report sent from Shimabara on 3rd June :

" Two strong shocks of earthquake were felt a little after 8 o'clock on the 1st of the month (21st April). A high hill called Maye-yama in the suburbs was torn from peak to foot and fell down. A mountain-flood' in concurrence with high waves driven in from the sea, swept in a moment over all the dwellings of the merchants in the town. Debris were carried out beyond the shore and piled up into innumerable hillocks, of which was formed an embankment about 4 km long a distance of 1 km from the previous shore. A dozen of seashore villages lost all their habitations. In front of the waves, trees which had trunks more than 3 m in circumference were either wrenched off at half their length or entirely uprooted. It is not yet certain if half of the population in town and village counting 27,000 survive.......

" After the great catastrophe Maye-yama is still incessantly detonating and trembling, and debris falling down. Ruins of habitations have been entirely wiped out and their sites are not to be made out. Places devastated by the sea waves as well as those overlain with mounds of debris have marshy ground or ponds in their depressions......"

In another report despatched to Yedo a week later it is stated that " the landslip of Maye-yama continues with varying intensity. Mud which is being incessantly forced out from the lower end of clefts is filling up hollows with a noise like boiling water. The issue of mud is increasing in violence in the clefts in the middle....... At a place called Uye-no-baru at one end of the rent, water gushed out from seven wells so copiously as to convert the surrounding ground to a marsh. The eruptions of Fugen-dake, Anasako-dani, Hachi-no-kubo and other places seemed for a time to have subsided, but renewed their violence, and the lava daily advances 20–30 ken (36–55 m) towards the town. It is feared from this that it may reach the castle or pass north of it to the sea, cutting off land communication with the town ".

According to the report of 12th October (27th September) the damage caused by the tsunami in Shimabara alone amounted to 9,720 men dead, 700 wounded, 3,347 houses and 2,000 other smaller buildings swept away. The devastated shore measures 76 km from Saigo to Oye. In Amakusa 343 men were drowned, and 373 houses and 439 sheds swept away. In three districts Udo, Akita and Tamana of Higo Province, 4,652 men were drowned, 811 wounded and 2,252 houses swept away. The total loss of life there was more than 15,000.

The high figure in the loss of life was brought about by that in the town of Shimabara, which amounted to 5,251 dead. Its cause was ascribed to a grievous mistake on the part of the sentinel on the main gate-way, who closed it between the first and second rushes of the tsunami, and cut off free access to the height in the castle at a moment of imminent necessity. It is said that Matsudaira-Tadahiro, governor of Shimabara, conscious of his responsibility, committed suicide shortly after the accident.

On the nature of the catastrophe, opinions are divided between geologists and seismologists. Messrs. D. Sato and I. Komada seem to conclude from the external form of Maye-yama that the collapse was an effect of a volcanic explosion which tore the mountain and threw masses of debris into the sea, in a manner similar to the formation of explosion craters met with in many volcanoes of Japan. Such a horse-shoe-shaped depression is however not limited to a crater formed by explosion alone. We have a typical example of the formation of a crater-like depression in Handa-yama in Iwashiro Province, where landslips are yearly degrading the central part of a conical hill of liparite or dacite.

As Prof. F. Omori pointed out to me there is no record of symptoms in the present case, like a fall of ash or an exhalation of vapours at high temperature which ought not have escaped the attention of eye-witnesses at the time of disaster.[1] A casual notice made by T. Kanai on the warmth of the wave is undoubtedly influenced by the opinion of a Dutch captain whose advice a doctor of the town asked

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1) I notice in Prof. F. Omori's article, Unzen-dake and Shimabara (Gakugei, No. 496, Jan. 1923, pp. 124–125) the following points in support of his view:

(1) No fall of ash was recorded in Kyushu, Shikoku and Honshu, which are on the east of the volcano and ought to have suffered its damage;

(2) No detonation was heard except in the immediate neighbourhood;

(3) Contrary to the usual course of eruption first phase with earthquake and emission of vapour; second with explcsive activity; and third with lava extrusion.

(4) No record indicating the collapse as an effect of the volcanic eruption.

on the occasion. But the hypothesis of submarine eruption, as was proposed by the sailor, is wholly unfounded.

I ascertained from the documents at Kōjiro that the earthquake of 21st May was much less intense than that of 21st April, which caused the destruction of Maye-yama, because no shock was recorded either in the diary or in the report, though a loud roaring of the sea was mentioned, as we have cited above. Another fact of importance is a curious experience of a watch-man of a rape-seed farm in Uye-no-baru during the night of 21st May. T. Kanai gives his account that "at 5 o'clock in the morning, when severe shocks of earthquake felt since the previous evening had subsided, he looked round in the darkness and was striken with the change in the surrounding topography, in spite of his shed and farm keeping the same relative position. He heard the roar of the sea in his immediate vicinity and found in the dawning that both the shed and the farm had been carried from their upland site more than one and half kilometres toward the sea-shore.

From these considerations I think it evidently untenable to interpret the catastrophe as an effect of explosive vapours imprisoned in the immediate substratum of Maye-yama, or to regard it as "an example of a simple volcanic explosion in consequence of an extreme tension of volcanic energy in accumulation."[1]

As we have stated above, the landslip began at the same time as the severest shock on 21st April, when people already felt the menace of a "yama-shio", though they never thought of a far more terrible tsunami concomitant with it. It seems not to be doubted that the meteoric water had played an important rôle in the process of demolition in this case, as is common in all landslips. A table of the mean monthly rainfall at meteorological stations in the surrounding

1) Komada, loc. cit.

region shows a maximum in April.[1] After the formation of numerous crevices, of which many reached the core of the mountain a copious quantity of meteoric water must have found its way to the depths, while the whole surface on the flank and foot sloping to the shore was during the same interval of time made pretty wet, so as to have attained a degree of plasticity which prepared a ground for the gliding of detached masses in the next severe shock of 21st May. The transportation of a whole farm in Uye-no-baru speaks eloquently for a rather gentle movement of a portion of the foot-hill slope during the downfall of the main masses of torn mountain. As for a rapid movement of the latter it is not difficult to estimate from the altitude of more than 200 m an acceleration of velocity of the motion on its reaching the beach. The presence of plastic clayey substances is unequivocally stated in the Shimabara report above cited.

The collapse of Maye-yama and the tsunami in the Shimabara Bay as its consequence have their common cause in one of the landslips following severe shocks of earthquake which loosened the mass of the mountain and faciliated the circulation and percolation of meteoric water into its core.

(7) *Subsequent eruptions, earthquakes and landslips.* Although the collapse of Maye-yama was the climax to the whole course of events caused by the activity of Fugen-dake, we have details of its later behavior which were recorded by vigilant reporters at Shimabara and Kōjiro. It is evident from the documents that the volcanic eruption did not cease until some years after the catastrophe.

Two more eruptions took place from the top of Fugen-dake. One on 19th July (1st June) was so violent that ash was reported to have

1)	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Kumamoto	67	77	128	176	173	341	281	170	169	107	67	56	1811 mm
Saga	59	75	125	184	155	326	277	148	182	105	65	53	1753 mm
Sasebo	77	85	134	201	175	350	287	202	202	116	88	73	1990 mm
Nagasaki	78	86	130	200	179	330	242	169	219	119	91	85	1932 mm
Izuhara	98	88	136	231	196	353	345	274	272	143	90	77	2302 mm

fallen on Semboki, and stones of considerable size to have been hurled up. The diameter of the new crater measured 70 m across, and was widened southward by the next eruption of 15th August (28th June). Roaring and shaking of the mountain is said to have been very violent. In the latter eruption a prodigious quantity of smoke was also emitted from vents on Hachi-no-kubo and Anasako.

According to the reports at Kōjiro, the activity did not sensibly subside until September, and renewed its violence on 3rd February, 1793. The ashes accumulated so thick near the top as to make it impracticable for officials sent on 24th March to approach the crater. The last report concerning the volcano, which is dated 8th April, states that the detonation of the mountain had not yet ceased.

Besides these records T. Kanai mentions an eruption which is said to have taken place three or four years later. In "Odake-jigoku-monogatari", a work of doubtful authenticity, we find an eruption so late as 1799, in which year a violent eruption took place between May and June. Two large craters opened on Odake (Fugen-dake), and mud and stones fell on Antoku and Koba.

The lava-flow of Anasako had not come to a stand-still at the end of August 1792, but it no longer menaced Shimabara.

The after-shocks of earthquake of 21st May came to an end in ten days, and detonation was reported to have ceased on 6th June. A shock which occurred two days after, was not severe. Another on 27th June (9th May) seems to have been severer, for a crevice about one metre in width was produced on the southern slope of Maye-yama in the commune of Antoku, and the mountain itself was wholly shrouded with dust for some days.

Frequent shocks were further felt in Shimabara and Miye, during the violent eruption of 19th July. They did not cease for a fortnight. Another severe shock is said to have occurred on 1st August (15th July). On the afternoon of 31st January 1793, one more severe shock is recorded in the Kōjiro report.

Landslips of Maye-yama were several times mentioned during the whole interval up to the spring of 1793.

A retrospect of the volcanic and seismic phenomena which were manifested in the last eruption of Unzen in 1792 makes it evident that the activity had a character differing from that of eruptions of other Japanese volcanoes in the particular severity of the earthquakes in its whole course. This fact teaches us that the significance of earthquakes in the demolition and remodelling of a volcano in its later phase of activity is not to be overlooked. Question can indeed be raised about many so-called explosion craters shown as such in reports on Japanese volcanoes, in which traces of explosive activity are not clearly proved, provided the same seismicity is prevalent in the same phase in all of them as in Unzen. I shall discuss in the concluding chapter of this paper the significance of this in connection with the cycle of evolution in Japanese volcanoes in general.

VII Earthquake of 8th December 1922.

The district had been comparatively free from subterranean disturbances for more than a century since the great volcanic activity of 1792, when in last December occurred a shock of earthquake of a grave character, almost equal in magnitude to that of Kumamoto in 1889. Of local shocks previous to this, that in 1909 was the only noteworthy one. The earthquake occurred early in the morning on 16th August, and was accompanied by 17 detonations in 24 hours. As two of them concurred with particularly severe shocks it caused a panic among visiting foreigners, but was of no serious consequences.

The fact that the seismicity in the district has a characteristic peculiarity of its own and is greater than that in the city of Nagasaki, however, is obvious from the table of shocks originating in the neighbourhood of Nagasaki which has been prepared by Mr. Goto, former chief of Nagasaki Meteorological Station and annexed to Mr. I. Komada's report. In this interesting instrumental record we find that

Date		Time of first motion h	m	s	Remarks
1914					
January	22	4	41	41	
March	7	4	17	01	
	13	15	58	16	Nagasaki, Tokitsu
	23	9	50	52	
	,,	11	33	15	Nagasaki
	26	23	13	54	
April	4	18	21	08	
	5	1	32	04	Unzen
	,,	1	35	16	Unzen
	18	20	07	51	
	21	10	24	11	
	23	14	36	40	
	25	23	42	07	
	26	23	43	—	
June	23	7	09	43	Nomo
July	18	10	51	12	Nagasaki, Shimabara, Minami-Arima, Unzen, Yagami, Izahaya, Obama, Yenoura
	26	6	11	25	
	,,	6	12	03	Nagasaki
	31	8	15	53	Nagasaki, Tokitsu, Kame-dake
August	8	1	34	28	Nagasaki, Unzen
	,,	4 (about)	30	—	Unzen (*)
	,,	19	25	02	
	,,	22	38	30	
	9	1	03	—	
	,,	7 (about)	50	—	Unzen (*)
	,,	8	21	54	Yagami
	,,	10	55	16	
	,,	11	55	17	
	10	6	14	03	Unzen
	,,	23	26	36	
	11	2	45	41	
	,,	20	59	32	
	,,	23	10	34	
	13	5	47	47	Unzen
	,,	17	22	—	
	,,	17	31	30	
	,,	18	28	—	
	,,	19	12	—	
	,,	19	18	—	
	,,	20	35	13	
	,,	22	01	44	
	14	2	42	24	Unzen
	,,	2	44	09	
	,,	4	43	23	(†)
	,,	7	56	21	
	,,	17	29	07	Unzen
	,,	17	44	58	
	16	19	21	33	
	17	5	39	—	

Date		Time of first motion h	m	s	Remarks
August	18	5	44	45	
	,,	16	05	—	
	,,	20	30	—	
	,,	20	33	—	
	,,	20	36	—	
	19	20	24	—	
	,,	12 (about)	30		Unzen (*)
Nov.	5	5	59	26	
	14	4	19	—	
	20	5	15	45	
	29	17	28	09	
Dec.	6	22	27	53	Ki.+Mi. Takaku-gori
	7	9	22	36	
	10	10	48	36	
	,,	23	41	55	
	14	15	15	24	
	24	5	56	22	
	28	12	06	03	
1915					
Jan.	1	8	25	30	
	6	16	36	08	Nagasaki
	11	5	53	31	
	13	21	33	09	
	,,	21	40	10	
	,,	23	41	38	
Feb.	8	6	43	25	Nagasaki
	10	2	35	36	
	13	11	49	37	
	20	9	08	44	
	,,	17	30	49	
	,,	22	44	58	
	21	0	23	23	Nagasaki
	27	0	30	22	
Mar.	4	18	56	26	Nagasaki, whole Mi. Takaku-gori
	,,	23	57	11	Mi. Takaku-gori
	12	2	15	—	
	24	15	42	02	
	25	01	25	46	
	,,	19	32	55	
April	3	9	18	13	Nagasaki (Detonation), Omura
	,,	9	50	41	
	5	18	03	45	Mi. Arima
	6	10	44	43	
	19	0	00	03	
					Nagasaki (Detonation),
	24	0	15	38	Nagasaki
	,,	0	47	48	
	,,	0	50	14	
	,,	11	39	51	Nagasaki
	,,	15	21	13	
	,,	16	47	55	
	25	2	04	54	
	,,	6	13	13	

(*) Not recorded in seismometer in Nagasaki.
(†) Beside these several vibrations of obscure character.

16 of 99 such shocks in 16 months from January 1914 to April 1915 have their origin in the district, and 10 in the vicinity of Unzen.

The earthquake of last December hada lso its precursors, of which one occurred one and a half months before, on 23rd October, and the other immediately before, on the afternoon of the 7th. The main shock which caused considerable damage and loss of life in the peninsula, occurred at $1^h\ 50^m$ a. m. about $9\frac{1}{2}$ hours after, several minor shocks occurring in the intervening time. Of after-shocks, a very strong one which occurred 5 minutes later, and another at $11^h\ 2^m$ were especially strong. The following is the approximate time of occurrence of the after-shocks in the next 24 hours reported by the police station at Shimabara :

h	m				h	m		
1	55	a. m.	Strong	15 shocks of varying intensity	7	47	a. m.	Very weak
3	32		Moderate		8	30		Weak
3	51		Weak		9	10		,,
4	39		,,		11	0	(*)	Very strong
4	44		Pretty strong		2	15	p. m.	Pretty strong
5	25		Weak		3	35		Weak
5	35		,,		10	30		,,
5	54		,,		10	35		,,
7	20		Pretty strong		0	30	a. m.	,,

(*) Time recorded at Nagasaki was 11 h 2 m.

The total number of macroseisms felt at Nagasaki was 110 and that of microseisms or tremors 1,798 up to 13th January. The daily frequency was as follows :

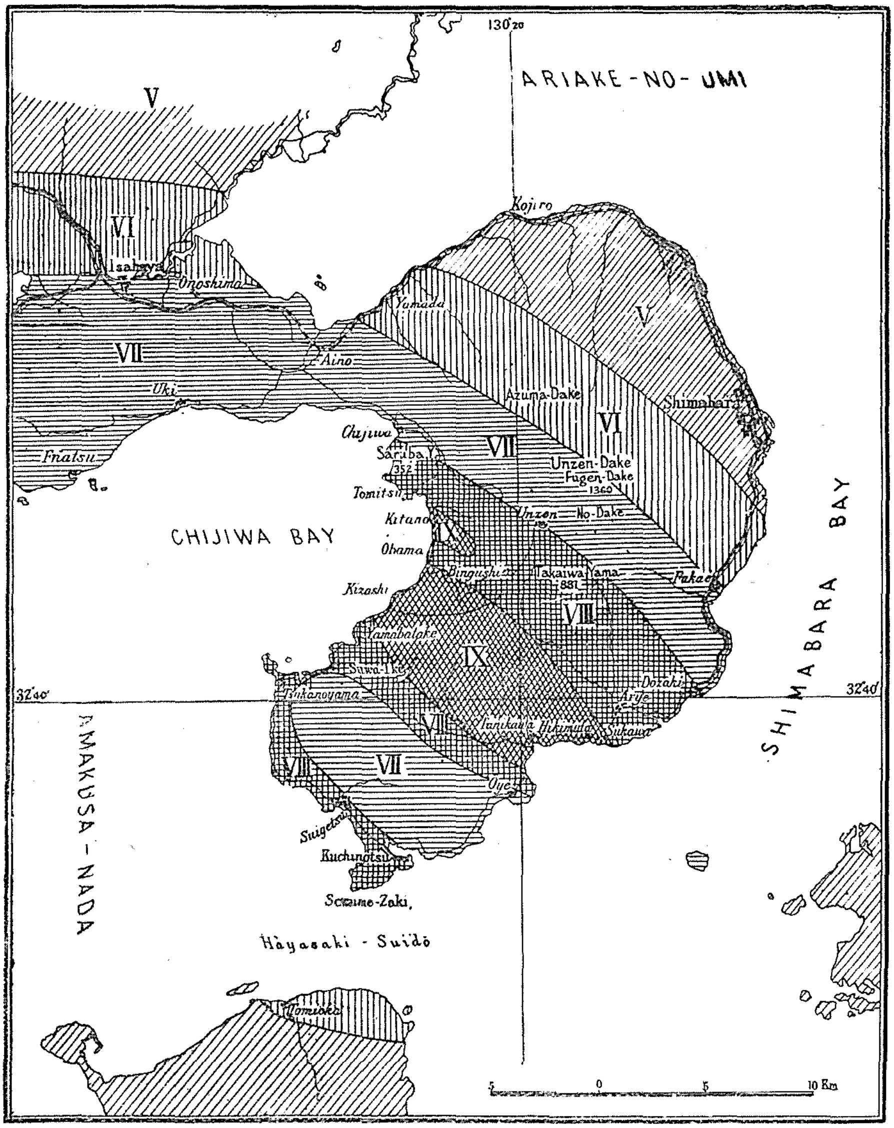
	Date	Macroseism	Micrcseism		Date	Macroseism	Microseism
Dec.	8	52	573	Dec.	16	2	42
	9	21	190		17	2	27
	10	7	150		18	—	30
	11	7	113		19	—	17
	12	2	61		20	2	21
	13	3	75		21	1	21
	14	1	51		22	4	32
	15	4	44		23	—	39

	Date	Macroseism	Microseism		Date	Macroseism	Microseism
Dec.	24	1	36	Jan.	4	1	8
	25	—	34		5	1	9
	26	—	19		6	—	18
	27	2	10		7	—	19
	28	—	23		8	—	19
	29	1	26		9	—	7
	30	—	17		10	—	21
	31	—	12		11	—	
Jan.	1	—	10		12	—	
	2	—	12		13	1	
	3	3	14				

The maximum intensity of the principal shock seems to have attained in Mercalli-Sieberg's scale the IX grade (devastating) in detached areas, while most of the severely shaken region lay between the VII and VIII grade (very strong and devastating). I think an approximate area comprising all localities where the intensity was higher than VIII may be shown by the innermost elliptic contour of isoseist VIII in the annexed map (p. 230), and that at Nagasaki, Omura and Shimabara the intensity was between the V (pretty strong) and VI grade (strong) in the same map. I have here to remark that the grades of average intensity, which are shown in an arbitrary manner from scanty and inaccurate information and personal observations, of course do not coincide satisfactorily with particular facts. It is here aimed only to give an idea of the intensity of the earthquake manifested in the district and its environment, because irrigularity in distribution of destructive effects defies such a diagrammatic representation. We have to await an accurate mapping in future publications of seismologists, the results of whose research are not available at present.

We have at present only two papers, one by Mr. S. Mayeda and the other by Dr. Sayemontaro Nakamura,[1] which deal with the deter-

1) On the earthquake in the Bay of Chijiwa. Kisho-shushi (Meteorological Magazine) Ser. 2. Vol. I. 1923.



Sketch map showing degrees of seismic intensity in Shimabara Peninsula :

V pretty strong, VI strong, VII very strong,
VIII almost devastating, IX devastating.

mination of the hypocentrum of the earthquake. Both are founded on the instrumental records of the meteorological station in Kyushu. As the latter, published in January, gives us interesting points supplementing my own results obtained by working on entirely different lines, I shall cite them in full.

As first pointed out by Prof. T. Shida, M. Matsuyama and S. Sato in 1917 and 1918, determination of the direction of the first motion of the preliminary tremor in a seismogram furnishes a valuable datum for the location of the centre and the distinction of the nature of an earthquake. Most of the instruments installed in our meteorological stations being Prof. F. Omori's simple tremometer without a damper, the initial motion alone is free from oscillation of the instrument itself, which has a disturbing effect on the results obtained, and determination of this motion affords reliable data for the purpose in hand.

In a fracture-earthquake the direction of the initial motion is found to be opposite in stations in alternate quadrants around an epicentrum, i. e. two opposite quadrants with the motion directed to, and the other two away from the epicentrum. In a depression-earthquake the motion is directed to the epicentrum in all stations in the immediate vicinity and beyond a nodal circle directed away from it.

The following are Mr. Saem. Nakamura's results obtained by inspection of horizontal components :

Nagasaki	8.8 (S)	64.8 (E)
Kumamoto	1.5 (S)	3.2 (W)
Kagoshima	23. (S)	3.3 (E)
Miyazaki	5.5 (S)	10.5 (E)
Shimonoseki	5.0 (S)	3.2 (E)
Oita	1.7 (S)	1.2 (W)

We find the direction of motion manifested in these records to be sufficiently consistent in pointing the position of the epicentrum, except in that of Oita, which markedly deviates from it. Moreover it is directed toward the epicentrum in Nagasaki, Kumamoto and Oita, while it is away from the epicentrum in other stations. The initial motion is therefore that of a fracture earthquake.

This result has been confirmed by Prof. M. Matsuyama, who gave me at Nagasaki almost exactly the same view on inspection of the same data collected in the meteorological station.

Another important of locating the epicentrum is by the duration of the preliminary tremor. In the present case Mr. Saem. Nakamura gives the following figures in seconds :

Nagasaki	2.9	Oita	17.8
Kumamoto	7.7	Miyazaki	17.9
Fukuoka	12.0	Kagoshima	17.
Shimonoseki	19.4		

He calculated from these figures the distance from the stations of observation in two ways, of which the first results, calculated by Prof. F. Omori's formula are :—

Distance from		Distance from	
Nagasaki	21.5 km	Oita	132
Kumamoto	57.1	Miyazaki	133
Fukuoka	89	Kagoshima	126
Shimonoseki	144		

The distance of the epicentrum obtained from observations at Nagasaki and Kumamoto alone is of nearly the same value, namely, 24 km east from Nagasaki, and 5 or 6 km off the coast of Obama. The result further coincides with that obtained from calculation by the duration of the preliminary tremor and the direction of its initial motion at Nagasaki alone, made public by the meteorological station soon after its occurrence.

As to the second and greater shock of $11^h\ 2^m$ p. m., its epicentrum was most probably shifted northwards from that of the main shock of $1^h\ 50^m$ a. m.

To sum up the results obtained by Mr. Saem. Nakamura, the earthquake was evidently of a tectonic origin, and its epicentrum lay in Chijiwa-nada, some kilometres off the northwestern coast of southwestern Shimabara.

This conclusion is at variance with the view of Prof. F. Omori, from whom I obtained information orally at Nagasaki, when he was still engaged in field observation. The division of opinion appears to be chiefly due to difference in interpretation of the preliminary tremors in seismograms. According to Prof. F. Omori, whose calculation has been lately made public, the result is as follows:

Station	Duration of prelim tremor.	Distance from hypoc.	Distance from epic.	Direction of prelim. tremor.	Depth km.
Nagasaki	6.6	49	34.6	E 6° S	34.5
Kumamoto	8.0	59	47.5	W 20° S	
Kagoshima	18.0	133	128.5	S 10° E	

He located the epicentrum about 2 km northeast of the village of Tanigawa and 2.5 km west of Higashi-Ariye.

I owe to Prof. M. Matsuyama the interesting piece of information that in Kumamoto the initial motion of the second great shock was directed eastward in opposition to the first. This was ascertained by Prof. T. Shida on inspecting the seismogram of Kumamoto. The fact points to the second shock most probably being of a different nature from the first, for we see here the existence of a nodal circle having a diameter greater than the distance of Nagasaki from the epicentrum but smaller than that of Kumamoto from the same. The second shock can be inferred to have been a depression-earthquake.

This is a significant fact giving an insight into the mechanism of the subsidence in the zone of the Inland Sea and its continuations on the west and east. It is not limited to being a key only for interpretation of the formation in the surrounding sea floors of the peninsula, but can be extended to the case of the whole region lying between the block mountains of the outer and inner zones of Southwest Japan.

The process is evidently that the first phase is the formation of a fracture and it is naturally followed by the subsidence of blocks so torn asunder.

In the present instance, a subsidence seems to have occurred on the north of the block forming the southwestern Pliocene plateau of the peninsula, subsequent to the formation of the fracture on its northeastern periphery.

(3) *The effects of the shocks* — The magnitude of the earthquake can be imagined from the following newspaper reports.

In Nagasaki the main shock of 1^h 50^m a. m. was accompanied by a detonation and was so severe that many people fled from their houses in dismay. Several cases of small damage were reported in the city. Among these the most noteworthy was the formation of a fissure in the dockyard of the Mitsubishi Company. The crevice is said to have been 25 m in length and 3 cm in width. The main iron pipe of the municipal aqueduct with a calibre of 10 inches was broken in three places. Brick buildings of foreigners and other brick and concrete walls ware cracked, and some chimneys fell down.

At Yagami, 4 km NE of Nagasaki, a bridge was broken by the shock, and at Tayui, 2 km further east, on the coast of Chijiwa-nada, damage to a dwelling was reported. At Izahaya, the plaster in the corners of the walls of most dwellings was cracked. At Onoshima, a village situated in a low alluvial plain, the damage was much more serious, for a dwelling wholly collapsed and another was partly damaged. The level of ground-water in the same village was disturbed by the shock for a week.

In the north of the peninsula Aino-mura suffered most severely, with one dwelling and 8 sheds knocked down, and at Yamada-mura, 4 sheds fell, but all the north and northeastern coastal villages from Moriyama to Fukaye were exempt from devastation by the earthquake.

The limits of the violent shock in the peninsula are approximately conceivable from a report that the telegraphic lines were broken in the south of Ainotsu on the west and at Dôzaki on the east. Within the limit, the shock at Chijiwa, Futsu, Fukaye, Dôzaki and Kuchinotsu was of about the same degree of intensity. Disastrous effects are manifested more strikingly on the southeast from Higashi-ariye southwestward. But even here the sites of devastation are limited to particularly treacherous alluvial ground on stream beds. Most of the habitations lie on the margin of a plateau with substrata of volcanic accumulation or Pliocene tufaceous sandstone, and strand villages on an abraded platform of the same. The comparatively low number of buildings destroyed is therefore partly due to firmness of foundation and does not indicate that the shocks were of a lesser grade of intensity than those which ravaged regions of flat lands with paddy field, as at Mino-Owari in 1891 or Northern Omi in 1909.

(5) *Seismo-tectonic lines revealed by the shocks* — Among the effects of shocks on the surface, the visible fractures are the most important. They have been reported in the most of great earthquakes which have occcrred in the last fifty years in Japan. Since the intensity of the earthquake of the 8th December was far inferior to that of Mino-Owari, of Shonai or northern Akita, the fractures are not so conspicuous as to attract inexperienced people's attention. Immediately after the accident, we found in the newspapers only a few reports on the formation of crevices. One of these reports related to the crevices on the embankment of Suwa-no-ike (Pl. X, Fig. 10) and Hikimuta.

I found another more important one on the left bank of a stream a few hundred metres south of Hashiguchi, in association with devastating effects on buildings in the hamlet. Here two or three parallel crevices up to 0.1 m wide were seen for more than 200 m along the embankment which trends from N 30° W to S 30° E across the high-road leading from Shimabara to Kuchinotsu. On our tracing the fractures northwards two more were discovered near their ends; these diverge from the former at an oblique angle across the embankment, and a small but sharply defined crack in a farm was ascertained running in the same direction as the latter, with a trend almost exactly from NW to SE. This find is of particular significance, because afterwards Prof. D. Sato collected reports of damage done to hamlets on the upland northwest of Tanigawa. The destroyed habitations, plotted on a cadastral map of the commune, coincide with the trace of the earth fractures. The line drawn on a topographic map of 1 : 50,000 scale traverses the village of Kisashi on the opposite shore, where the damage was considerable in spite of the comparative firmness of the foundations of most of the habitations. This line is in my opinion one that may indicate the approximate position of the epicentral axis of the earthquake.

At a distance of about 1.5 km to the southwest of the Kisashi-Tanikawa line we find another line drawn from west of Kanahama to Saishoji in the upper valley of the Minami-gawa, parallel in direction. On it there are located the devastated village of Yamabatake, the fracture of Suwa-no-ike, the valley of Sakashita and the west side of the low plateau extending southeastward on the east of Oye.

I believe that there is a third between Obama and Hikimuta parallel to the Kisashi-Tanikawa line, although data for the plotting of it are meagre. It is about 2.5 km distant on the northeast of the latter line and passes through the village of Bingushi on the southwestern flank of the outer crater-wall. Here shocks are chronically severe, and the only loss of life which was reported in the precursory earthquake of October 1791 occurred here, as mentioned in p. 214. The crevices and emission of muddy water on the shore of Hikimuta seem to indicate the intersection of the line with a remarkable lineament of the equatorial Minami-gawa line. The site is further the point of intersection with a less ambiguous NW–SE lineament on the southeastern shore.

A fourth NW–SE line is traced from Kizu on the western foot of Saruba-yama through Tomitsu to Kitano-mura, on the coast of Chijiwa-nada. Its southeastern prolongation is indicated on the southern flank of the crater-wall by the Ayugayeri-gawa, which runs southeastwards. The destroyed habitations of Higashi-ariye are thought to lie on this Kitano-Higashi-ariye line. Far more conspicuous are the traces of the disaster at Kitano, where the severest effects can be located across the village in the same direction.

The same NW–SE trend is marked in destructive effects manifested at Yamaryo, 1 km northeast of Katano-mura. While this fifth line is not made out southeastwards, its northwestern prolongation is clearly traced on the central heights of Saruba-yama with a ridge trending northwestwards.

The trend is also marked in a valley and low ridge on the northeastern foot of Saruba-yama. I found numerous cracks of the same trend across a chaussée leading from Chijiwa to Obama. Prof. M. Matsuyama traced the crevices northwestward to the hamlet of Kono in the valley, and found them traversing the foundations of habitations. At my request Mr. S. Komaki photographed its further prologation on a vicinal road still further northwestward, (Pl. X, Fig. 10). The striking sixth line can be plotted on a map with one drawn from Chijiwa-mura to Dôzaki across the explosion crater of Jigokus to Dozaki. I think it not improbable that the unusually copious emission of fumaroles reported to have been formed after the first great shock may have been an effect closely connected with subterranean disturbances of this line.

Tombstones in a burial-ground at Kôno which lies on the foot of Saruba-yama, were found to have been subjected to a counter-clockwise rotation as shown in a photograph (Pl. X, Fig. 11).

A fact worthy of notice is that the third (Obama-Higashi-ariye) line traverses, southeast of Bingushi, the upper valley of Oyamada, where T. Kanai reported in his journal of an excursion to Unzen, the formation of crevices in 1792, which caused leakage in a stream.

As to destructive effects manifested in the periphery of the plateau along the coast between Obama and Kuchinotsu, some sites of particularly severe shocks coincide with more significant lineaments. Some destroyed habitations on treacherous ground like that of Tsukano-yama lie at the same time at the intersection of three lineaments clearly indicated in the configuration of the coast. Landslips of a serious character on the western steep coast are also obviously due to the striking meridional fracture line intersecting with the NW–SE line on the southwestern coast.

(6) *Significance of seismicity of the volcanic district*—From a survey of the facts stated in the above pages we can infer that the earthquake of 8th December was most intense on the northeastern periphery of the southwestern plateau, and the epicentral axis of the Kisashi-Tanikawa line may approximately represent the lie of the emergences of a subterranean convulsion, and that the adjoining northwestern and western peripheries were simultaneously affected by the same shocks, and seismotectonic lines parallel to the axis and on the northeast of it were equally intensely shaken by them, especially to the north of Obama.

An interesting revelation is the effects produced in this last portion. We are placed in a position to understand the process of demolition which is going on in the old parasitic volcano of Saruba-yama. We can conclude its topography to be a resultant form produced by shocks like those manifested in the earthquake of 8th December.

The inferences obtained from the earthquake lead us to consider once more the catastrophe of 1792, in order to grasp the significance of seismicity as a factor of volcanic activity. The important rôle played by earthquakes before and during a paroxysmal outburst of a volcano is a fact well known since the eruption of Vesuvius in 63 A. D. or that of Sakura-jima in 1914. It is not so with Unzen. The first precursory shocks felt in the winter of 1791 were most probably localized on the periphery of the Pliocene plateau, where those of 8th December 1922 occurred. The coincidence suggests that those of 1791 were also due to a fracture, which originated in substrata of the plateau. The substrata are nothing but a consolidated reservoir of basaltic magma, from which a more acid andesitic magma separated and was subsequently extruded further northeastward to form Unzen-dake. The precursory shocks may be looked upon as a manifestation of a released orogenic strain upon the upper portion of a magmatic reservoir which was in a state of almost complete crystallization. In other places further northeast, where the substrata were in a less degree of crystallinity, and contained a greater amount of residual magma, the same strain could not be manifested as a purely seismic activity, but the pressure being of a more or less hydrostatic nature, necessarily induced a disturbance in the magma. This view which we may safely accept as a postulate from Bowen's researches on the differentiation of magma in its later stage of evolution, furnishes in the present case a key for a plausible interpretation of precursory shocks which are fracture earthquakes by nature, but which merge insensibly into purely volcanic or magmatic earthquakes in concurrence with outbursts of a volcano in its later phase.

The seismicity of the volcanic district of which we saw so much in the foregoing pages, evidently indicates the present state of the activity to be connected with a declining phase in the solidification of the magmatic reservoir, so that the earthquake is losing its volcanic character even in the youngest centre of activity in Fugen-dake and approaching what can be best metaphorized as unsuccessful attempts at eruption (veri tentativi falliti di eruzione). The earthquakes felt in the volcanic district in 1909 and 1922 are undoubtedly of the latter category, though we cannot say whether or not such convulsions may induce more serious consequences some day to come.

VIII. Cycle of evolution in Japanese volcanoes.

The volcanic activity manifested within our insular empire since the late Tertiary epoch is so multifarious in external form and petrographical character that no adequate generalisation has yet been attempted except in some papers written by Prof. B. Koto. In preparing the present paper I tried to take into comparison other volcanoes than Unzen, of which I had a personal experience, or about which requisite information is ready at hand. A preliminary result obtained in the attempt shows that we can recognize in most of the composite volcanic cones the vicissitudes they have undergone, which seem to signify phases in the cycle of evolution with characteristic features in each of them.

In the consideration of this subject I have to set aside those outcrops of liparites and acidic andesites, which belong to earlier dates and do not present well-defined morphological characters. Most of the extensive masses of these rocks, as for example in Chugoku, seem to represent characters attributed to the type of a surface eruption in contrast with a linear or central eruption. Extremely basic rocks, on the other hand, take the form of lava sheets, and their mode of occurrence seems to require no elaboration in deciphering their morphological evolution.

It is the extrusion of intermediate andesitic lavas and their detritus that most diverse forms and structures are produced on passing through successive phases of activity, which has either a formative, a deformative, or a formative-deformative effect on the forms acquired in previous phases. I therefore confine my attention to these andesitic types of volcanic mountains, which occupy an important place in the orography of Japan. Without entering into the problems of the petrography of andesitic rocks, I can say that the rocks in their diverse chemical and mineralogical composition constitute the most prominent members of a calc-alkaline family of magma, and their consanguinity is not to be doubted throughout the Quaternary volcanoes of Japan.

I. Phase. — Prototype of a strato-cone. — In most of these volcanoes with composite cones, their life history is not to be traced back to the beginning of their existence. They can be recognized to have been simple cones in their incipient stage of formation. Some of the volcanic islands in the Pacific Ocean to the south of Izu promise to offer us valuable data in this respect. Volcano Islands, a group of three islets, known to Japanese as Minami, Naka and Kita Iwo-jima (South, Middle and North Sulphur islands), are of a recent volcanic origin, and submarine eruptions have frequently occurred around them since the settlement of Japanese emigrants there in the last thirty years. A settler in Naka-Iwo-jima assured me in August of 1912 that a stay of a month should be long enough to enable one to witness an eruption in the submarine platform surrounding the islet. The ephemeral volcanic island near Minami-Iwo-jima described by Prof. T. Wakimizu in 1908 is one of many such eruptions.

The process of formation of Moto-yama in Naka-Iwo-jima can be best understood from a study of two submarine eruptions which took place on the northeast of Minami-Iwo-jima in 1908 and 1914. The first eruption gave rise to a volcanic cone which emerged above sea-level for 139 days and disappeared again as a prey to the destructive activity of the waves of the ocean. The eruption was repeated on the 23rd of January 1914 on the same site. This time it was much more intense. White smoke was emitted intermittently high up into the sky, and attained about 3,000 m above the sea level. After three days of continuous activity a new island about one kilometre in diameter came into existence three nautical miles to the northeast of Minami-Iwo-jima. Its altitude was estimated at about 300 m. The dimensions were about twice as great as those of the island formed in 1908.

The new island born in 1914 was sighted three weeks after by H. M. S. Takachiho, on board of which was Mr. T. Ogura, now geologist of the Imperial Geological Survey. His observation was published in Report no. 79 of the Imperial Earthquake Committee in 1915. The islet was then 120 m high and about 3.5 km (2 nautical miles) in circumference. It was a typical strato-cone (homate type) of an elliptical outline, and had its crater placed excentrically northeastward on the longer axis trending in the same direction. The foot of the cone was in places cut into cliffs which exposed a banding of layers of varying thickness in white, buff and black. These layers are most probably made of accumulated ash, pumice and fragments of obsidian, while the lava which was reported to have erupted may form the basement of the portion of the cone above the sea level.

The eruption seems to be frequently of explosive character, and produced a caldera-like depression of the crater and other irregularities on the outward slope. The decrease in altitude during three weeks' incessant activity is a significant fact in the process of formation of a volcanic cone, for on the 25th January when seen from Naka-Iwo-jima, the height of the new island was estimated to be one-third that of Minami-Iwo-jima, namely about 300 m.[1] It had lost therefore more than one-half of its altitude in the meantime. The other fact, that the site of the first eruption when sounded by a surveyor of the Hydrographic Bureau in 1911, had a depth of 233 fathoms (432 m), points to an explosive eruption to have been the principal factor in the destruction of the previous volcanic island.

We find in a nautical chart a shallow of 10 fathoms in the same direction, NNE of Minami-Iwo-jima. The spot marks doubtless another volcanic island which had disappeared by undergoing the same labour of parturition.

Naka-Iwo-jima is a volcanic island which passed through such a stage of activity, and secured its persistence by emerging from the sea-level in virtue of upheaval of the submarine platform about 8 km in diameter. The recency of its emergence is attested by the existence of reef-building corals exclusively belonging to living species on each of the terraces of tufaceous deposits, which is successively upheaved above the strand line.[2] The terraces seven to ten in number have differences from 10 to 20 m in altitude, and when seen from the north on approaching the island, its main northeastern part with a mean altitude of 100 m presents an aspect of a low plateau common in Tertiary regions in Japan. In contrast, the southwestern extremity of the island forms a promontory with a lava cone 167 m high, called Suribachi-yama or "Mortar Hill" in allusion to its crater, but better designated by the European appellation, Pipe Hill.

The two parts are connected by a low ridge insensibly sloping and tapering southwestward. Its surface is covered with volcanic

1) Report of the governor of Ogasawara-jima on the 4th of February 1914. No. 79.
2) Prof. T. Wakimizu's Report, Earthquake Investigation Committee No. 56. 1907. p. 6.

sand, and converted into a desert, in contrast with the higher terraces and steeper slopes which have a luxuriant subtropical vegetation like a savanna or a jungle. In the centre of the plateau, which is encircled by three prominences of 109, 106 and 101 m respectively, we find a large shallow depression of crescent shape with a longer diameter of about 700 m, and another of a circular outline 300 m across on the northwest of it. These depressions obviously represent older craters buried under the accumulations of later eruptions. The two vents seem to be located on a line running from northeast to southwest across the greater width of the island, and its continuation is indicated by the valley of Higashi-mura.

The central crater of the most recent formation is one on the southwest of the central depression. It is a deep chasm of circular outline with almost vertical cliffs all round. The crater and surrounding ground are bleached by vapours from fumaroles, and their variegated colours present an extraordinary infernal sight. Of the numerous fumaroles the most copious is a vent near the crater: it affords a beneficient bathing place to the inhabitants of the semi-arid island.

The sites of explosive eruptions are mostly in the submarine platform but many vents seem to have come to extinction after an ephemeral subaërial activity. One of such diatremas is Chidori-no-ana, which is said to have exploded some thirty years ago. It is a hollow some 30 m deep and 150 m in diameter, filled with blocks of tufaceous beds. No ejected lava was found about the pit, except some fragments of the same tufaceous material. The explosion was evidently of the same character as those transient activities intermittently observed off the shore of the island.

A striking character of the islet is the abnormally high temparature of the ground over the whole northeastern part. In a pit dug a feet deep it is high enough to cook potatoes.

Motoyama in the Sulphur Islands is thus a prototype of volcanoes which have come into existence through a submarine eruption. Its mode of formation is clearly illustrated by recent eruptions in the neighbourhood of the island. The same process is marked in most of the Quaternary volcanoes in Japan. Their common characteristic is the explosion, which produces variable quantities of tuffs, ash-beds and agglomeratic rocks.

In such a simple lava-cone as Kabuto-yama, Settsu Province, we find a brecciated tuff bed forming the basement of an andesitic lava. Nijo-san or Futago-yama west of Nara is another more complex type. It began with tufaceous and agglomeratic deposits of acidic andesites crowned with basic lavas resembling sanukite. The same sequence has been ascertained by me in the sanukite of Kokubu in the Province of Sanuki.

We find similar accumulations of tufaceous materials in most of the large volcanoes, of which the basement is exposed by erosion. Their natural interpretation is found in the explosive nature of a volcanic eruption in its incipient stage.

The first phase of eruption in most of the volcanoes of Japan is therefore explosive, and its products are tuffs, breccias and agglomerates forming more or less well-defined stratified deposits.

The accumulation of ejected materials may form a conical mound, if it emerge on growing above the sea-level. But it seems more commonly to remain as a flat elevation on the sea floor as long as lava is not poured over the basement of detrital materials. Moreover those flat conical mounds composed of loose accumulations of detrital materials are not capable of preserving their proper form for a long time against subaerial degradating agencies. Hence the absence of a volcano of this type except in Naka-Iwo-jima is no wonder in a country like Japan, where an abundance of annual precipitation makes its persistence more than precarious.

II. Phase:— Chronic activity — It is in the second phase that fragments of larger size and lavas are discharged from vents opened in the first phase. It seems natural to assume that one of such vents comes to be widened by continuous emission of vapours and prepares the way for extrusion of lava which lies far beneath the superficial layers of accumulated materials and substrata of older generations. The formation of a main vent may be regarded as a condition of paramount importance for the growth of a volcano of considerable dimensions.

It is not always possible to descry the basal layers formed in the first phase of an eruption in most of the great volcanoes, of which dissection is not deep enough to reveal the very foundation. But we find more commonly a thick accumulation of agglomeratic materials produced at the beginning of the second phase. In the immediate vicinity of Unzen in Kyushu, Tara-dake has agglomerates or block-muds of this stage of activity occupying the whole susono around the volcanic mountain. The same detrital beds of pyroxene-andesite are found in patches at Takeo on the north and beneath lava flows of the caldera of Aso on the east. Mr. T. Ogura considered these agglomeratic beds as products of a repetition of explosive activity, in which they were poured down in a kind of mud-flow. He thought rightly the block-muds to have been originated from a vent or vents of the same volcanic centre. In Aso Prof. T. Iki mentioned in his report an occurrence of agglomerate beds of olivine-bearing pyroxene-andesite on the southern wall of the great caldera. The deposits, which are of a considerable thickness in the volcano, are a proof of violent activity as a prelude to the eruption.

The growth of a volcanic mountain chiefly depends on the intensity and duration of the phase in its subsequent stage, in which successions of quiescence and paroxysm occur at variable intervals of time. The process of formation of a gigantic, volcantic cone in the stage of activity is well illustrated on the inner slope of Myojin-yama on the north of the caldera of Hakone. According to Prof. T. Hirabayashi, here is found along the Hayakawa a thick tuff bed, directly overlain with a thin scoriaceous lava of rusty colour; here an agglomerate bed of the Sukumo-gawa being absent, the lava is followed by Umijiri-lava about 30 m thick, and by Myojo-yama-lava 12 m thick with an intercalated ash bed 5 m thick. These alternations of lavas and ash beds are overlain with the lavas, agglomerates and muds of Myojin-yama about 300 m thick. As the last group has seven beds of lava, we can assert that at least nine times of activity in all shared on this side, in the formation of the mountain.

Agglomeratic deposits of pyroxene-andesite are found in other volcanoes adjacent to Hakone. In the old caldera of Atami are found the same deposits 200–300 m thick, overlying an equally thick bed of tuff. In Ashitaka-yama on Suruga-wan they make up the greater bulk of the whole volcanic massif. The foundation of Fuji itself is thought by Prof. T. Hirabayashi to be made of the agglomeratic deposits of a type of olivine-bearing basic andesite not distinguishable from that of Ashitaka. In all these volcanoes an eruption of violent explosive character opened the phase and accompanied most of the great extrusion of lava throughout the phase.

It must be here remarked that the actual form of a cone produced in the course of this phase of activity does not depend so much upon the chemical composition of a magma, so far as it is concerned with silica and other essential molecules usually shown in the total analysis of a rock. While there is a range of about twenty per cent of silica contained in members of the andesites of Japan, an extreme fluidity is not the attribute of the most basic variety, such as the Mishima-Omiya-lava of Fuji, which, according to Mr. Suganuma's analysis, contains only 49.14 per cent of silica. For we find 68.45 per cent of silica in Aso-lava which spread out to form an almost horizontal plateau of vast extension and of which the furthest extremities measure more than 70 km from the centre. The low viscosity of this more acidic lava finds its only explanation in an incomparably higher temperature and greater content of steam and other vapours in the magma, and these physical and chemical properties must be to a great extent controlled by the dimensions of the magmatic reservoir, from which lava is forced out in convulsion.

In this respect let us draw into comparison other volcanoes of similar petrographical character. The fact that there is a marked difference between the old caldera and other younger cones in declivity made by the hornblende-andesite lava of Unzen-dake, can best be explained by assuming a decrease in temperature and content of imprisoned vapours in the course of cooling of one and the same magmatic reservoir of small dimensions. Numerous petty volcanic domes of hornblende-andesite lava in Suo and Iwami furnish another example of higher viscosity connected with small extruded masses of the same rock. It is therefore evident that the capacity of a magmatic reservoir or of its compartment in immediate communication with the vent determines not only the magnitude of a volcano but also its form and gradient of outward slope.

The close of the second phase, which is characterized by predominantly formative effects, is thede cline of activity in the main vent. In this last stage of the phase, emission of vapours and lava becomes more and more difficult and the activity gradually loses its constancy and becomes intermittent. An alternation of quiescence and paroxysm is of course not limited to this stage alone, but a repetition of such fluctuation of activity is recognizable throughout the whole phase. The difference may be that the duration of quiescence becomes longer than in the earlier stage and a paroxysm does not produce lava and detrital materials in so copious quantities as to contribute to a considerable growth of cone.

III. Phase—Plugging of the main vent—formation of lateral cones —In the third phase commences a complete obstruction of the main vent. A plug of consolidated lava cuts the communication between the crater and the compartment of the magmatic reservoir, making a further eruption through the main vent impossible. If the consolidation has been so advanced at the same time in the whole compartment as to leave only a fraction of the original magma mobile and capable of being squeezed out, the remainder is forced out through a side canal to form a parasitic cone on the flank of the central cone.

Several such lateral vents are usually opened around a volcanic cone of larger dimensions. The residual discharge more often gives rise to the building of cones of dimensions much inferior to those of the central. They are either cinder cones like Omuro and Komuro of Amagi-san, or lava cones like the parasites of Unzen-dake above mentioned. The eruption of Fuji in 1707, which opened an explosion crater, Hoei-zan, on its southern flank, can be regarded as a case of an unsuccessful attempt to build a parasitic cinder cone. A lava flow on the eastern flank of Iwate-san near Morioka in Rikuchu Prov. was another which had succeeded in forcing out a coulée and building a cone.

Kura-dake on the west of the caldera of Aso is an interesting example of a parasitic cone. Here is manifested in the extrusion of lava the same process of differentiation as in the central cone. Prof. T. Iki found here a lava cone consisting of three layers, ranging from basic andesite at the base to more acidic on the top. This fact suggests that the lateral vent of Kura-dake derived its material from a separate compartment in which took place a more rapid cooling than in the principal reservoir feeding the main vent of the gigantic volcano.

It seems probable on the other hand that in this phase an unusually violent explosion may take place through the main vent instead of finding its way out at a lower point of the cone. We see such a case in Haruna and Akagi in Kozuke Province. These two volcanoes, commanding the north of the vast plain of Kwanto, have the same characteristic structure in the presence of small caldera and central cones on their top. In both we find the central cones consisting of more acidic andesite than the main mass, being quartz-bearing hornblende-andesite in Soma-dake of Haruna, and hornblende-andesite in Jizo-yama of Akagi. A similar relation of decreasing basicity is further noticed in the crater of Iwaki-san in Mutsu Province, quartz-bearing hornblende-andesite forming here a dome in its interior. Reservoirs in which crystallization is so very far advanced as to attain a well-defined differentiation, are not always noticeable in most of the great volcanoes in Japan.

It is interesting here to remark that those volcanoes which have later extrusions within the crater in their centre are singularly destitute of lateral cones, so common in others preserving an equally perfect conical form, as in Fuji and Amagi. There seems to exist an alternative in the process of eruption in its last phase for the lava, either to find a way through several lateral vents, or to force its way out of the central vent. We recognize in the latter mode of eruption a widening of the crater, but in none of these volcanoes does its diameter exceed more than one-fifth of that of the basal circle of the cone.

We are confronted here with a difficult question,— whether calderas of large size owe their origin to the explosion in this phase. Some of the horse-shoe-shaped craters may undoubtedly belong to this phase, as attested by the eruption of Bandai-san in 1888. This type of explosion designated phreatic is however to be best explained by Mr. Brun's theory as a sudden liberation of vapours contained in solidified lava, because in Bandai-san the ejected materials were all fragments of solid rocks and after the explosion no sign of the usual course of a paroxysm was observed. Prof. T. Kato's explanation of the process, which is founded on Prof. Doelter's view on the liberation of gases in crystallizing magma, seems to be accepted as valid in the mixed eruptions of the second phase, since this liberation it is conceivable only where the magma has already reached very near the surface.[1] On the contrary I am inclined to think the formation of most calderas of larger dimensions does not belong to the declined phase of a cycle of activity in a volcano, but to the opening of a new cycle or phase in which an eruption is once more manifested with its full violence.

The Second and Subsequent Cycles— Beside the formation of calderas as a direct effect of violent eruption, we have to recognize, with Prof. T. Iki, its indirect effect as is the case with Aso or Unzen. He thought the grand caldera of Aso most probably to have been produced by subsidence of its central part as a consequence of the outpouring of

1) Prof. C. Doelter: Petrogenesis. 1906. p. 13.

immense masses of lava from the reservoir directly beneath the vent. He rightly pointed out the absence of any appreciable debris which can be referred to an explosion of such a magnitude, even if only a portion had been hurled over the rim of the caldera. The same hypothesis seems to hold partly in the formation of the caldera of Unzen. In this case it is clear that violent shocks have shared in shattering the ancient cone, when the volcanic activity of the central crater declined in intensity. Those crevices revealed in 1792 and 1922 are only cicatrices which have never been healed.

In either case we have to regard a cycle of volcanic activity to be completed by the destruction of the edifice which has been built by the same activity in the successive stages of evolution. But we must not mistake the significance of the destructive effect for an end of the activity, especially of its first cycle. For the explosion does not imply the decline of activity in a volcano, but most often a renewal of its violence, the only apparent exception being the case af Bandai-san in 1888. In some volcanoes, like Mihara-yama of Oshima or Asama, the activity manifested in the second cycle does not seem to be inferior to the first in intensity. The cone of Asama was built in the second cycle and far outgrew the remnant of the first, which is partly visible in Mayekake-yama on its southwestern flank. In Oshima the caldera measures 3.5 km in the longest diameter, and is almost wholly filled up with lava poured out from Mihara-yama formed in the second cycle. The activity of Hakone after the formation of a grand caldera was as violent as that which had poured forth lava over the outer wall.

According to Prof. T. Kato, Komagatake in Hokkaido (Yezo) offers us a type of evolution. In the first cycle a basal lava with partly brecciated structure poured over an accumulation of probably pumiceous materials which are wholly covered with products of later effusion. These are followed by thick layers of lava, agglomerates and lapillis. The cycle is conspicuous in effusive and explosive activity. The second cycle began with an explosion of the summit which destroyed the crater. To it followed another which was the most violent in the whole history after the building of the cone, and produced a huge caldera opening eastward. The latter explosion accompanied a mud-flow spreading over the eastern half of the flank in semi-circle. The violence has a parallel only in the explosion of Bandai-san in our memory. There is on the west side a third explosion crater, of an unknown date of formation. In 1640 and 1855 Komagatake renewed explosive activity. Two milder eruptions are recorded in 1888 and 1905. We have in Komagatake a rare type of explosive activity in the second cycle. The violence seems to have been not less than that of the first cycle.

The phases of a cycle, however, depend as a whole upon the preexistent geotectonic conditions which prevail in the region. Variation in individual volcanic districts seems to be more marked in the second cycle, when the free effusion through the main vent is impeded. Many smaller volcanoes do not manifest phases which were well distinguished in their first cycle. The relation is observed even in large volcanoes like Aso. It is interesting to find that the old caldera was of a central eruption in its strict sense, while the cones of the second cycle are alligned on a striking equatorial and two or three minor meridional lines in the centre. This mode of formation indicates that when the main vent was closed after the outpouring of so-called Aso-lava, the magma found its easiest way through preexisting fractures in the predominant trend of the region, and that each of the new vents was not persistently active for a long time in the later cycle, when the reservoir was being exhausted. In the volcanic group of Kirishima-yama, were formed in succession more than a dozen of cones, which are located on lines trending N–S, NE–SW, and NW–SE. The activity shifted in this case not in the main meridional trend of the volcanic zone alone, but in the direction of lineaments of lesser importance. The result is, no characteristic phases in the older and younger cycles can be distinctly traced.

In Unzen the second cycle is marked with successive formations of vents in the interior and on the margin of the caldera, their location bearing direct connect with the chief tectonic lines of the district. The activity seems to have culminated in the formation of Fugen-dake, on shifting in an equatorial line eastward from the centre. It is an indubitable fact that the lava extruded in the second cycle became more viscous and was gradually losing its explosive character. The principal cause of this must be sought in the loss of volatile materials and the cooling in a compartment of limited dimensions of the magmatic reservoir. The last eruption of Fugen-dake is a tangible proof for a declined volcanic activity in a later phase of the second cycle.

A fact of importance is the severity of earthquakes even in the later stage. Their effects in remodelling a volcanic superstructure have hitherto been overlooked by vulcanologists in Japan. The earthquakes of 1791–92 and 1922 shows that seismicity as well as vulcanicity in a volcanic district largely depends on geotectonic lines superimposed upon the substratum, and their delineation is disclosed by shocks originating from the volcanic centre itself as well as from its neighbourhood. The formation of crevices on Azuma-dake and Maye-yama in 1792 and on the east and southeast of Saruba-yama in 1922 is particularly interesting and brings to us to a new standpoint in the study of the evolution of Japanese volcanic mountains.

I can not here deal with the question of the petrographical nature of andesitic rocks, for which chemical data are not available, as I had hoped. Some recent papers of Professors B. Koto, Y. Kodzu and S. Tsuboi, besides Mr. T. Suzuki's explanatory texts of geological sheets, give us only a dim idea on the chemical composition of andesites from certain localities of Japan. But a deplorable fact is the lack of satisfactory analytical data for important volcanoes like Fuji, Hakone or Aso, in spite of highly valuable work being performed in unveiling their morphological details. As for Unzen, however, we posess a series of analyses made in the Imperial Geological Survey on rocks collected by Prof. D. Sato, so we are in a position to learn certain salient characters in this respct.

	I	II	III	IV
SiO_2	63.31	68.31	65.38	65.47
TiO_2	....	0.27	0.42	0.61
Al_2O_3	10.60	15.64	14.34	16.29
Fe_2O_3	8.57	2.52	1.87	1.73
FeO	....	4.02	6.88	4.65
MnO	0.73	....	....	....
MgO	0.87	1.09	1.33	0.30
CaO	9.21	4.86	5.61	6.25
Na_2O	3.39	1.34	2.40	2.84
K_2O	2.90	1.01	1.55	3.12
Loss of Ignition	1.33	0.57	0.31	0.02
Total	100.91	99.63	100.09	101.28

I. Hornblende-andesite. Kusenbu-dake, a central cone of Unzen-dake.

II. Hornblende-mica-andesite. Maye-yama.

III. Hornblende-mica-andesite. Fugen-dake.

IV. Hornblende-mica-andesite. Lava-flow of Kwansei (1792).

It is a striking fact that the lava extruded in different phases shows no essential differences in chemical composition, except a slight increase in silica content. We notice here, however, a gradual decreasing basicity in the phases, that is to say, a higher acidity in lateral eruptions of Maye-yama and the Kwansei-lava than in the central eruptions of Kusenbu and Fugen. It indicates that a differentiation was goinsg on in the first cycle as well as in the second. It suggests also that the same process prevailed in other volcanoes in which pyroxene-andesite lavas alternate with olivine-bearing varieties. As is frequently the case, in volcanoes in which the central cone of more basic variety represents the last phase, it seems not always to be legitimate to conclude the process of differentiation to have been at work in reversed direction, but to regard the process in the second cycle as not completed.

Concluding Remarks.

The paper was written last spring before the great earthquake of the Kwanto districts. Multifarious manifestations of seismic energy happened to be observed by myself and my colleagues and students of the institute in their work in the field of convulsion. Preliminary notes on striking facts and a working hypothesis on the origin of this and previous great earthquakes affecting the region were lately published by me in the "Chikyu" (Globe), a magazine in Japanese devoted to geology and geography.[1] I am satisfied to find that some of the conclusions I obtained in Shimabara were confirmed by new facts of the same bearing in the recent catastrophe. Among others the significance of seismotectonic lines on the demolition of volcanic mountains was as obvious in Hakone and other volcanoes of the Izu Peninsula as in Shimabara. It is also a noteworthy fact that the hypocentrum of the first shock lies northeast of the centre of activity in Hakone volcano, and an epicentral zone forms a semicircle parallel to a zone of Tertiary volcanic and plutonic activity extending from the neighbourhoods of Matsumoto (Zenkoji), the epicentrum of the great earthquake of 1835, and of Odawara to the south of Bôshu through Sagami Bay, — a zone which runs outside of the hills of Miura and Bôshu, bearing several detached masses of Tertiary plutonic rocks. I can not but recognize the deep-seated nature of the subterranean convulsions manifested in seismicity and plutonicity, and propose for great earthquakes shaking the Circumpacific volcanic zones a hypothesis of plutonic origin, which will be set forth in detail in a future number of the memoirs. I have only to remark here that I do dot believe it necessary to modify my conclusion on the possibility of the transition from volcanic to tectonic earthquakes stated in the present paper.

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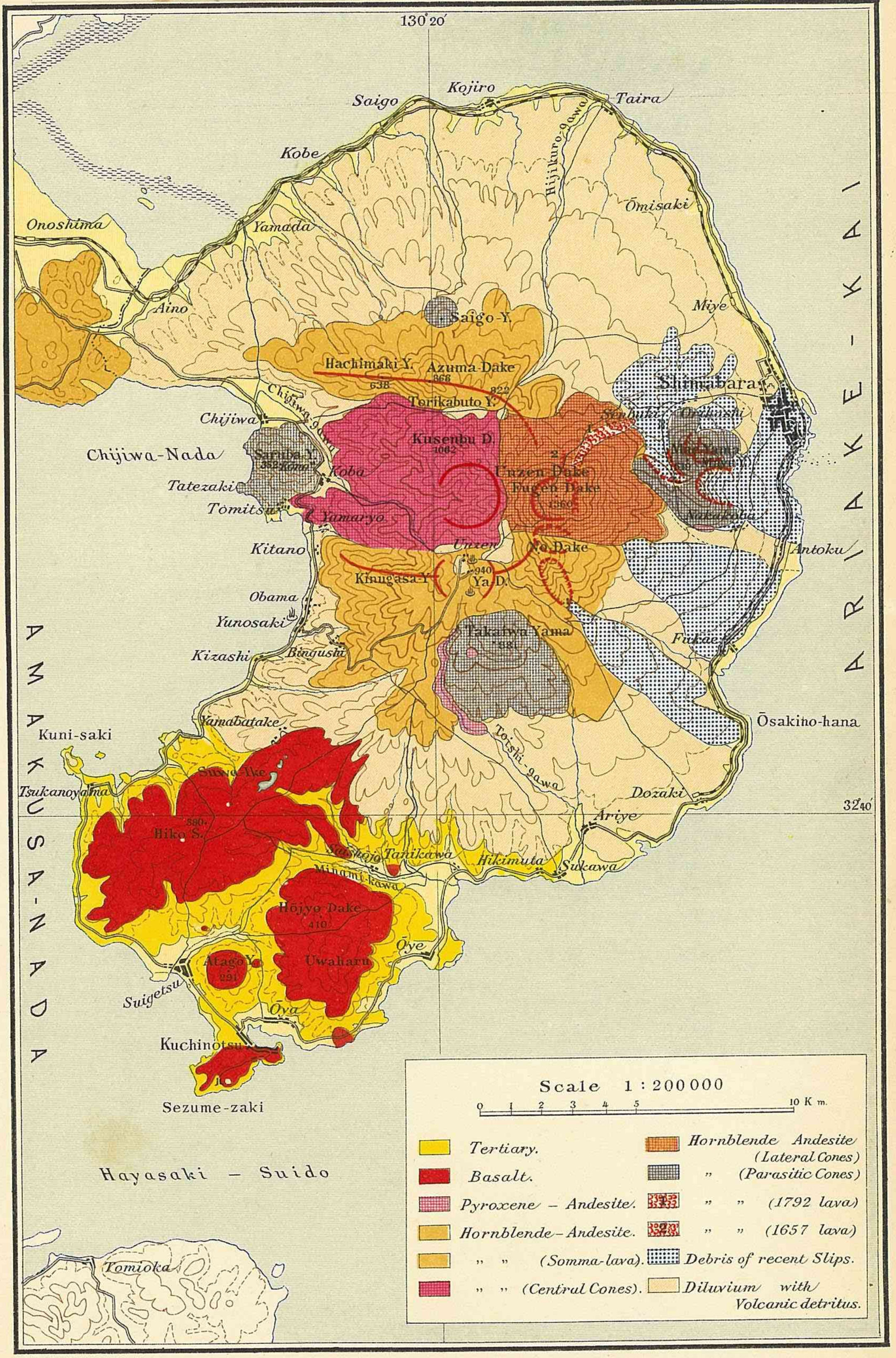
1) Contributions to the study of the great Kwantô Earthquake, 1923 :—

1. Orography and geologic structure of the Kwantô districts. Chikyu (the Globe), Vol. I, Kyoto, 1924. pp. 1–55.

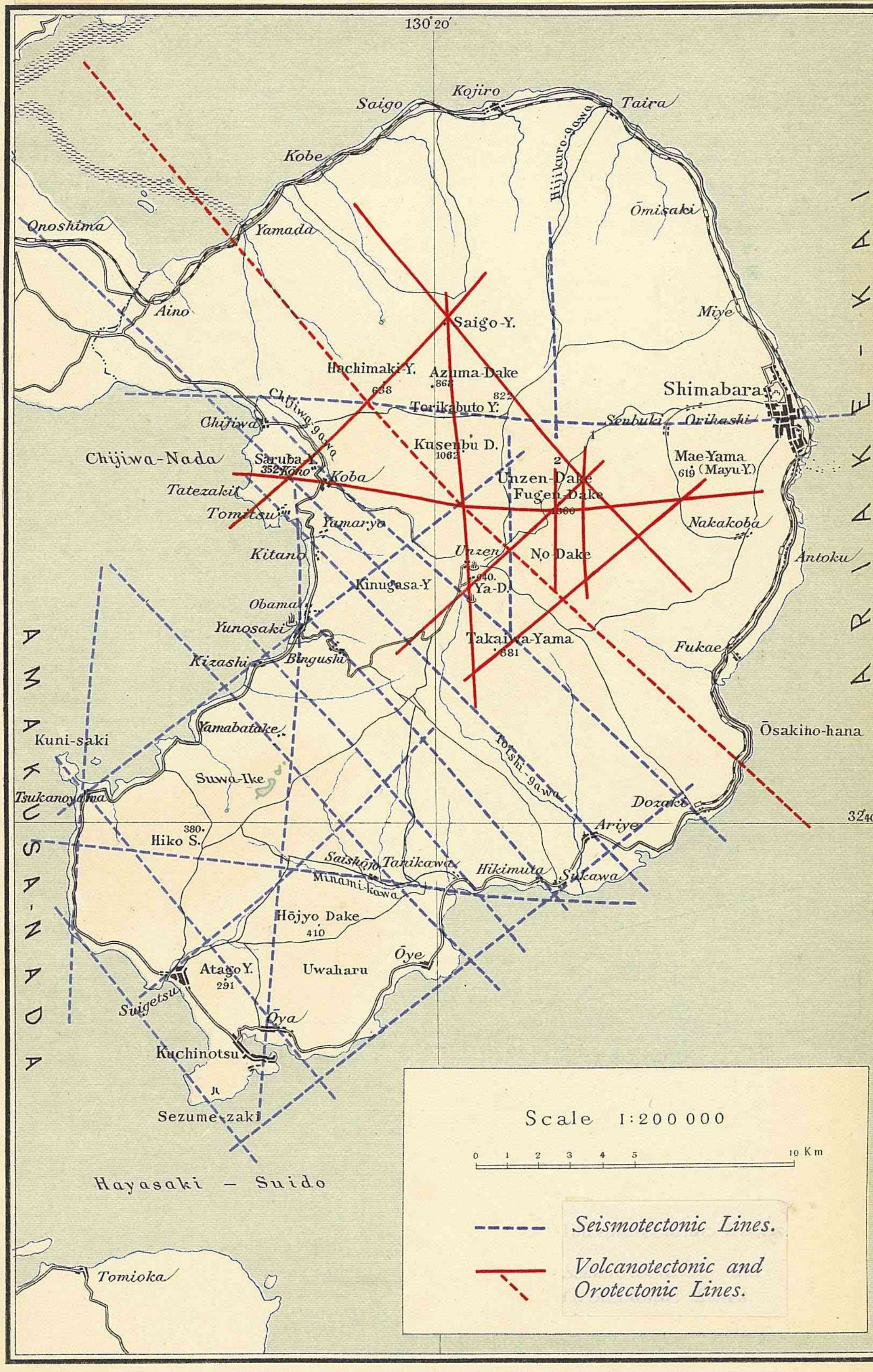
3. From Suess back to Humboldt's theory of the origin of earthquakes. *Ibid* pp. 113–155.

5. On the nature of the plutonic earthquake. *Ibid* pp. 199–231, 287–322.

9. On the significance of the so called subsidence and upheaval in Sagami Bay. *Ibid* pp. 405–446.



Geological Map of Shimabara Peninsula.



Problematical Lineaments of Shimabara Peninsula.

Plate VIII.

Fig. 1. Unzen-dake from Higashi-ariye.

Fig. 2–3. End of Lava flow of 1792 forming an escarpment near Semboki.

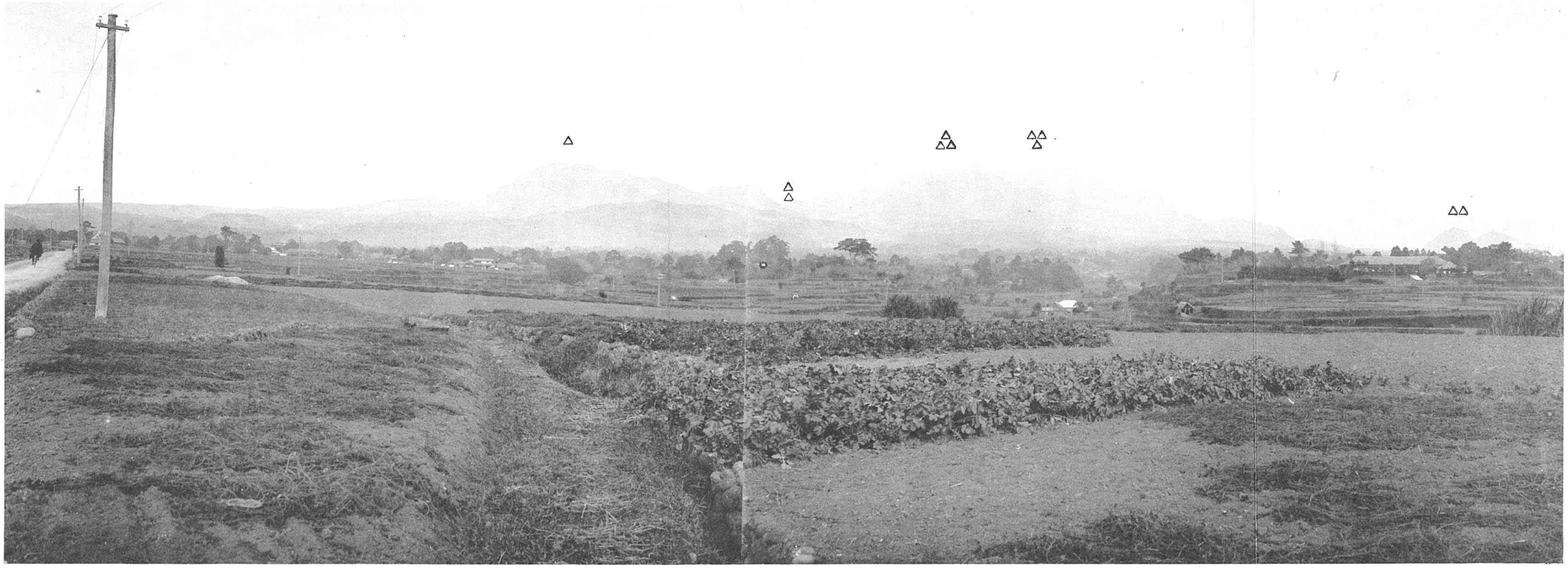


Fig. 1. Takaiwa-dake Jigokus Taka-dake Fugen-dake Maye-yama.

Fig. 2.

Fig. 3.

Plate IX.

Fig. 4.	Western slope of Chijiwa-dake near Obama.
Fig. 5.	Mayeyama seen from Semboki.
Fig. 6.	Coast southwest of Obama.
Fig. 7.	Mayeyama seen from southeast.

Fig. 4.

Fig. 5.

Fig. 6.

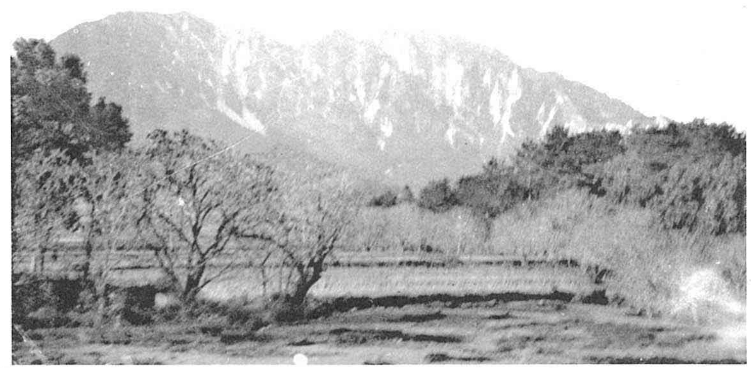


Fig. 7.

Plate X.

Fig. 8.	Crevices across an embankment south of Tanigawa.
Fig. 9.	Crevices along the same embankment (south of the fig. 8.)
Fig. 10.	Crevices on the shore of Suwa-no-ike.
Fig. 11.	Tombstones rotated counterclockwise at Kono, south-east of Saruba-yama.

Fig. 8.

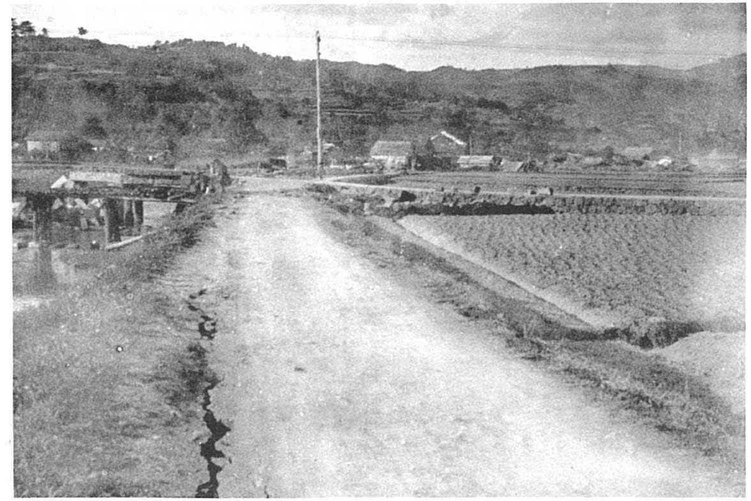


Fig. 9.

Fig. 10.

Fig. 11.

Plate XI.

Fig. 12. West of Tanigawa-hoshiguchi, with fallen houses on the fore-ground.

Fig. 13. A fallen house at Kitano.

Fig. 14. A fallen *Torii* at Hikimuta.

Fig. 15. A house partially with a demolished *magoya* forming the counter-part of one on the right side, at Onoshima.

Fig. 12.

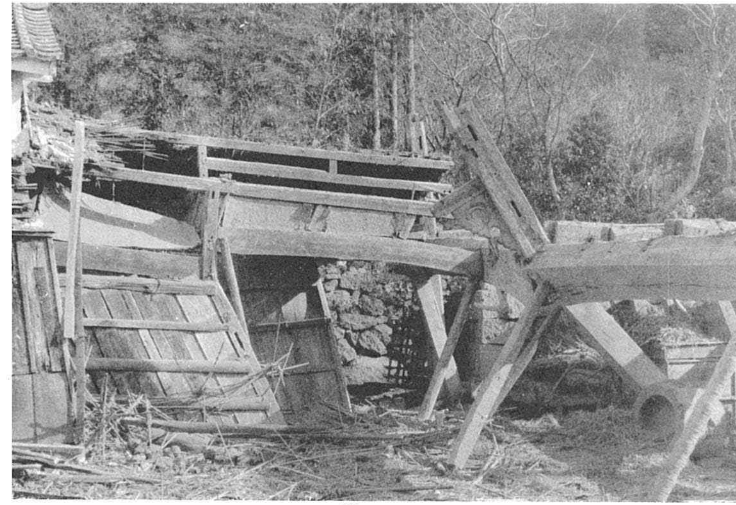


Fig. 13.

Fig. 14.

Fig. 15.