History of the volcanology in the former Netherlands East Indies

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The description of the volcanoes in the former Netherlands East Indies are analysed in order of their publication, grouping them into three parts. The first group consists of information from old Javanese sources and incidental communications in travel accounts and the like, dating from the 16th, 17th and 18th century. The second group includes scientific reports from the 19th century and the last part deals with the organised volcanological research after 1900 until the Indonesian Independence. This last part not only lists the volcanoes going from west to east but also discusses several special topics that were studied, e.g. temperatures in the crater region, sulphur in Indonesia and the caldera problem. Each chapter begins with some historical notes, including biographic details of the scientists that carried out the volcanological research.

A list of active volcanoes in Indonesia, including fumarole and solfatare fields, is given and also an exhaustive bibliography.

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Foreword

After Professors W. Nieuwenkamp and R. Hooykaas had participated in a Congress on the History of Geological Sciences in Yerevan (Armenia, U.S.S.R.), in 1968, the Geological Section of the Royal Netherlands Academy of Sciences appointed a commission to nominate co-operators to write a History of the Geology of the Netherlands and its former colonies.

In 1975, Dr G. ter Bruggen, Mr C.P.M. Frijlinck and Dr W.A. Visser were nominated to organise the description of the History of the Geology of the former Netherlands East Indies and in April 1976 Dr M. Neumann van Padang was invited to co-operate and to write a History of the Volcanology in that region. He is very much obliged to Drs C.E.S. Arps and C.F. Winkler Prins for their help in getting this manuscript printed. A special grant of the 'Greshoff's Rhumphiusfonds' for the printing of the coloured plates is gratefully acknowledged. Thanks are due to Dr Maurice Krafft, Director of the Centre de Volcanologie "Vulcain" in Cernay (France), and his wife Katia for putting at our disposal beautiful colourslides of volcanoes from Indonesia, from which six were chosen for the colourplates.

Volcanoes and volcanic phenomena always impressed the Europeans who visited Indonesia. In many publications we find communications on this subject. In order to get a good historical picture of what has been written I divided the matter into:

1) Incidental communications on volcanoes and their activity before 1800.
2) Communications of experts and laymen in the 19th century.
3) Systematic research done after 1900 by geologists of the Dienst van de Mijnbouw (Mining Department) and after 1920 by the Volcanological Survey.

In the former Netherlands East Indies the names of the volcanoes were often spelled otherwise than it is done to day. Moreover the Dutch orthography was used, i.e. oe for u. Presently, in Indonesia the orthography is sometimes different, e.g. the volcano Tjerimai is now written Cereme. Some volcanoes got other names. In this publication I do not adopt these new names, and in some cases neither their way of writing, as it would cause confusion. In other cases I followed the Indonesian orthography, e.g. Papandayan for Papandajan.

In May 1929, A. Lacroix, first president of the International Union of Geodosy and Geophysics, of which the International Association of Volcanology is a subdivision, proposed to prepare a Catalogue of the active volcanoes of the World, in which each volcano should get a number. The volcanoes of Indonesia got the group number 6 (see enclosure). These volcanoes were subdivided into nine subgroups, in which those of Sumatra got the number 6,1, those of Java 6,3, etc. A cipher behind these figures indicated the individual volcano. Moreover they were subdivided into

. volcanoes with eruptions known in historical time,
o volcanoes in a fumarolic stage, and
\+ fumarole and solfatara fields.

A triangle indicates those mountains erroneously considered to be active volcanoes.

The volcanoes of Indonesia mentioned in the Catalogue are listed in the column 'Catalogue' of the List of active volcanoes. In the column 'Dutch names and spelling' those volcanoes are mentioned of which the spelling is different in the Dutch literature. The third column comprises the volcanoes of which the spelling of the names is different in the present Indonesian publications (see Kusumadinata, 1974, 1979). A complete list of eruptions of the Indonesian volcanoes till 1941 in chronological order was compiled by Petroeschevsky (1943).

LIST OF ACTIVE VOLCANOES OF INDONESIA

		Catalogue	Dutch names and spelling	New Indonesian names
6,1-		Sumatra		
	1 +	Pulu Weh	Poeloeh Weh	
	2 .	Silawaih Agam		Seulawah Agam
	3 .	Puetsagoë		
	4 o	Burni Geureudong	Boerni Geureudong	
	5 .	Burni Telong	Boerni Telong	
	6 +	Gayolesten	Gajo lesten	
	7 o	Sibajak		Sibayak
	8 o	Sinabung	Sinaboeng	
	9 o	Pusuk Bukit	Poesoek Boekit	
	10 +	Helatoba Tarutung	Helatoba Taroetoeng	
	11 o	Bual Buali	Boeal Boeali	
	12 .	Sorikmarapi		

		Catalogue	Dutch names and spelling	New Indonesian names
	13 o	Talakmau		
	14 .	Marapi		
	15 .	Tandikat		
	16 .	Talang		
	17 .	Kerintji		Kerinci
	18 .	Sumbing	Soembing	
	19 o	Kunjit	Koenjit	Kunyit
	20 o	Blerang Beriti		
	21 o	Bukit Daun	Boekit Daoen	
	22 .	Kaba		
	23 .	Dempo		
	24 o	Lumut Balai	Loemoet Balai	
	25 +	Marga Bajur	Marga Bajoer	Marga Bayur
	26 o	Sekintjau Belirang		Sekincau Belirang
	27 +	Pamatang Bata		
	28 +	Hulubelu	Hoeloebeloe	
	29 o	Radjabasa		Rajabasa
6,2		Krakatau		
6,3		Java		
	1 o	Pulosari	Poelosari	
	2 o	Karang		
	3 +	Kiaraberes Gagak		
	4 +	Perbakti		
	5 .	Salak		
	6 .	Gedeh		Gede
	7 o	Patuha	Patoeha	
	8 o	Wajang Windu	Wajang Windoe	Wayang Windu
	9 .	Tangkuban Prahu	Tangkoeban Prahoe	Tangkubanparahu
	10 .	Papandajan		Papandayan
	11 +	Kawah Manuk	Kawah Manoek	
	12 +	Kawah Kamodjang		Kawah Kamojang
	13 .	Guntur	Goentoer	
	14 .	Galunggung	Galoenggoeng	
	15 o	Telaga Bodas		
	16 +	Kawah Karaha		
	17 .	Tjerimai		Cereme
	18 .	Slamet		
	19 o	Butak Petarangan	Boetak Petarangan	
	20 .	Diëng		
	21 .	Sundoro	Soendoro	
	22 .	Sumbing	Soembing	
	23 o	Ungaran	Oengaran	
	24 .	Merbabu	Merbaboe	
	25 .	Merapi		
	26 o	Lawu	Lawoe	
	27 o	Wilis		
	28 .	Kelud	Keloed	Kelut
	29 o	Ardjuno Welirang	Ardjoeno Welirang	Arjuno Welirang
	30 .	Semeru	Semeroe	
	31 .	Bromo		
	32 .	Lamongan		

		Catalogue	Dutch names and spelling	New Indonesian names
	33 o	Ijang Argapura	Hijang Argapoera	Iyang Argapura
	34 .	Raung	Raoeng	
	35 .	Kawah Idjen		Kawah Ijen
6,4-		Lesser Sunda Islands		
	1 .	Batur	Batoer	
	2 .	Agung	Agoeng	
	3 .	Rindjani		Rinjani
	4 .	Tambora		
	5 .	Sangeang Api		
	6 o	Wai Sano		
	7 +	Potjo Leok		Poco Leok
	8 o	Ineri	Inië Rië	Inieria
	9 .	Inië Lika		Inielika
	10 .	Amburombu	Amboeromboe	Ebulobo
	▲	Pui	Poei	
	11 .	Ija		Iya
	12 +	Sukaria caldera	Soekaria Caldera	
	13 +	Ndetu Napu	Ndetoe Napoe	
	14 .	Keli Muti	Keli Moetoe	Kelimutu
	15 .	Paluweh	Paloeweh	Rokatenda
	16 .	Egon		
	17 o	Ili Muda	Ili Moeda	
	18 .	Lewotobi Lakilaki		
	19 .	Lewotobi Perampuan	Lowotobi Perampoean	Lewotobi Perempuan
	20 .	Leroboleng	Leweno	Lereboleng
	21 +	Rian Kotang		
	22 .	Ili Boleng		Iliboleng
	23 .	Lewotolo	Warirang	Ililewotolo
	24 o	Labalekan		
	25 .	Ili Werung	Ili Weroeng	Iliwerung
	26 .	Batu Tara	Batoe Tara	
	27 .	Sirung	Siroeng	
	28 .	Yersey		
6,5-		Banda Sea		
	1 .	Emperor of China		
	2 .	Nieuwerkerk		
	3 .	Api north of Wetar		Gunungapi (Utara Wetar)
	4 .	Damar		Wurlali
	5 .	Teon		Serawerna
	6 .	Nila		Laworkawra
	7 .	Serua	Seroea	Legatala
	8 o	Manuk	Manoek	
	9 .	Banda Api		
6,6-		Celebes		Sulawesi
	1 .	Una Una	Oena Oena	Colo
	2 .	Ambang		
	3 .	Soputan	Sopoetan	
	4 o	Sempu	Sempoe	
	5 +	Batu Kolok	Batoe Kolok	
	6 +	Tempang		
	7 +	Tampusu	Tampoesoe	

	Catalogue	Dutch names and spelling	New Indonesian names
	8 + Lahendong		
	9 + Sarongsong		
	10 . Lokon-Empung	Lokon-Empoeng	
	11 . Mahawu	Mahawoe	
	12 o Klabat		
	13 . Tongkoko		
6,7-	Sangihe Islands		
	1 . Ruang	Roeang	
	2 . Api Siau	Api Siaoe	Karangetang
	3 . Banua Wuhu	Banoea Woehoe	
	4 . Awu	Awoe	
	5 . Submarine volcano		
6,8-	Halmahera		Maluku Utara
	1 . Dukono	Doekono	
	2 . Malupang Warirang	Maloepang Warirang	
	3 . Ibu	Iboe	
	4 . Gamkanora		
	5 o Telaga Ranu	Telaga Ranoe	
	5a o Todoko		
	6 . Peak of Ternate	Piek van Ternate	Gamalama
	▲Motir		
	7 . Makian		Kie Besi
6,9-	New Guinea	Nieuw Guinea	Irian Barat
	1 ▲Umsini	Oemsini	

Incidental communications on volcanoes and their activity before 1800

The oldest references to volcanic eruptions are found in ancient Javanese books, which were studied by van Hinloopen Labberton (1921). The first Europeans to describe volcanoes were the Portugese, who were in Indonesia before the Dutch arrived there. They mentioned mainly volcanoes in the eastern part of the archipelago.

In 1596 the Dutch sailor Cornelis de Houtman reached Java. In the 17th century Pieter van den Broecke (1648), Johann Sigmund Wurffbain (Wurffbain, 1686), and Johann Wilhelm Vogel (1690) mentioned their observations on volcanic phenomena. In 1724 the clergyman F. Valentijn published what he knew of the volcanoes of the archipelago. François Valentijn, born in Dordrecht in April 1666 and deceased in The Hague in August 1727, went to Indonesia in 1685, where he was appointed at Amboina as minister of the Holy Word and translator of the Bible into the Malay language. In 1705 he went to the Indies for the second time, first to East Java. Being again in Amboina since 1712 he began to collect the material for his great work 'Oud en nieuw Oost Indië'. i.e. 'Ancient and new East Indies' (1724-1726). Valentijn wrote principally what he had heard from other people.

ANCIENT JAVANESE SOURCES

Van Hinloopen Labberton (1921, pp. 135-158) found data on volcanic eruptions in ancient Javanese sources. Statues and ruins of temples, founded by adherents of the Shiwa religion on the summits of the not yet extinct volcanoes Diëng (6,3-20), Ungaran (6,3-23), Merbabu (6,3-24), Lawu (6,3-26), Wilis (6,3-27), Ardjuno (6,3-29), and Argopuro (6,3-33), prove that these volcanoes did not have had severe eruptions after 400 A.D. An eruption was mentioned of Mt Merbabu (6,3-24) in 1548 (1470 of Shaaka calendar). This eruption, however, probably was one of Mt Kelut (6,3-28). Also the eruption of 1586 ascribed to Mt Merbabu was from an other volcano.

In the ancient Javanese book Pararaton van Hinloopen Labberton (1921, pp. 148-154) found the following eruptions of Mt Kelut: 1311 (1233 Shaaka), 1334, 1376, 1385, 1395, 1411, 1450, 1451, 1462, and 1481. In a manuscript in the Kraton of Djokja he moreover found an eruption of 1548, and one of 1 May 1752. A problem with the use of these ancient sources is the fact that eruptions and earthquakes at the birth and death of princes were used to emphasize their importance and divine offspring. It is therefore more than likely that the dates of the eruptions were made to coincide with such events by either changing the date of the eruption or the date of birth (c.q. death) of the princes (see van Bemmelen, 1956).

The Central Javanese Empire, which had a flourishing period from 650 till 900 Shaaka, i.e. from 730 till 980 A.D. and of which nothing was heard since 1000 A.D., was according to van Hinloopen Labberton (1921, p. 137) devastated by an enormous eruption of Mt Merapi in 1006 A.D. An ancient Javanese stone inscription from the year 963 Shaaka (1041 A.D.) tells that the Island of Java then looked as a milk sea, that the palace (kraton) was burned and covered by the mountain, and that the king and many noblemen died. Only the king's son in law, known as Erlangga, could fly and survived the calamity. According to Kern Erlangga means 'he who escaped the floods', as 'er' or 'air' means water, and 'langgah' is Sanskrit for to escape. Van Bemmelen (e.g. 1949a) investigated the reliability of this story and found that it was supported by the geological evidence (see p. 41).

SIXTEENTH CENTURY

Gunung Api north of Wetar (6,5-3)

Portuguese sailors in 1512 mentioned streams of fire flowing from the summit along its slope to the sea shore of the small island Gunuape. According to Wichmann (1899) this island must have been G. Api, north of Wetar.

Dukono (6,8-1)

In 1550 an eruption of Mt Dukono, then called Tolo after the city of that name that was destroyed, caused great damage in its environs (Baldasser Diaz, 1559). Wichmann (1897, p. 159), Hueting (1905, p. 609), Verbeek (1908, p. 171), and Gogarten (1917, 1918) published their views on this eruption.

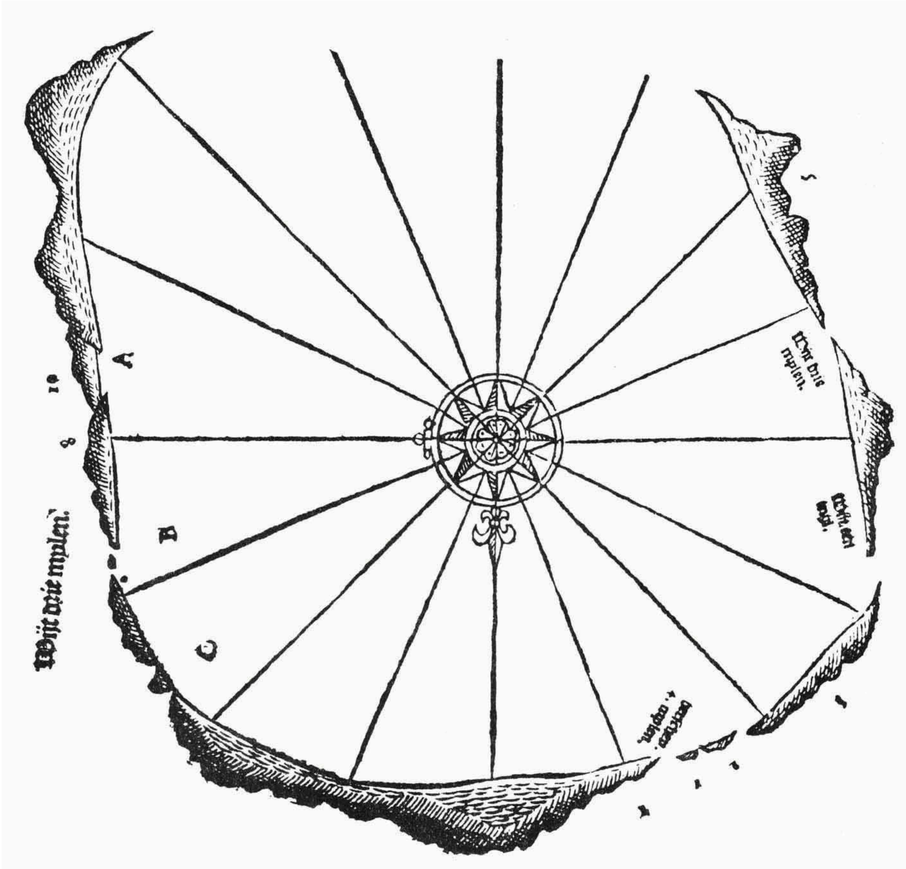

Fig. 1. Orientation sketch from the book of Willem Lodewijcksz (1598), whereupon Krakatau (5) is indicated (from Rouffaer & IJzerman, 1915, p. 61).

Krakatau (6,2)

One of the earliest Dutch communications on volcanoes in Indonesia is that of Willem Lodewijcksz (1598) who visited Java with Cornelis de Houtman. On 17 June 1596 he saw the densely wooded island Krakatau, which he called Carcata and Cercata. Sulphurous fumes rose from a barren, reddish coloured spot, indicating that the volcano was in a solfataric state of activity.

In 1915 the van Linschoten Vereeniging republished the ancient reports of Willem Lodewijcksz (Rouffaer & IJzerman, 1915). In Fig. 1 Krakatau is indicated by the cipher 5, showing the high Rakata cone in the southern part of the island.

The first known eruption of Krakatau, that of 1680 till the end of 1681, is described by Johan Wilhelm Vogel (1704, 1716), employee at the gold mine Salida on Sumatra. Vogel passed the volcanic island several times during his voyages to and from Batavia. Sailing through Sunda Straits for the third time on 1 February 1681 he was amazed to see the island Cracketovv, green and overgrown with trees on his voyage out, now completely barren and burnt. On four spots large lumps of glowing lava were seen thrown out (van den Berg, 1884, p. 9; 1904). The volcano was violently eruptive. The captain of the ship, on which

Vogel was a passenger, told that the large quantities of floating pumice were thrown out by an eruptive activity which had begun in May 1680.

According to the 'Daghregister van het Kasteel Batavia' (the daily register of the Castle Batavia) of 24 May 1681 'the old king of Bantam visited the burning island of Crakatouw', which means that the volcano was still in eruption at that time (Westerveld, 1951, p. 130).

Also on 19 November 1681, when Elias Hesse (1694; 1931, p. 7) passed the island of Cracatauw, fire and smoke were thrown out continually (see also Forbes, 1884, p. 144).

In July 1748 the shipsclerk Cristopher Hinrich Braad on board of the Swedish East-Indianman 'Hoppet', when sailing through Sunda Straits, sketched the island of Krakatau. The picture is published by Colonel Carl Axel Torén (1953, p. 25) and Neumann van Padang (1955 a, b). The island was built up of three volcanoes, drawn as three lumps. Comparing the Swedish sketch with the drawing of Salomon Müller (1844) made in 1836 (see Fig. 4, p. 15), we see that both were taken from the same direction, i.e. from the southeast, as both show exactly the same sequence of tops. The high left hand cone is Mt Rakata, the two mountains to the right of it are respectively Danan and Perboewatan. The vault in the extreme right on the sketch of Braad is Lang Island (Rakata Kecil).

Mt Raung (6,3-34)

On 17 January 1597 Lodewijcksz (1598; in Rouffaer & IJzerman, 1915, p. 180) saw from the coast of East Java a volcano above Panarucam, throwing out dark columns of smoke. As the mountain was also seen smoking from Varkenshoek (south coast of the Island of Bali) on February 2nd this active volcano must have been Mt Raung.

Lodewijcksz wrote further that an enormous eruption of this volcano in 1586 had killed 10 000 people. Thick ash clouds were thrown out in such quantities that the day turned into night during three days. According to Godinho de Eredia (in Lourenço Caminha, 1807), the catastrophic eruption of 'os Gunos de Panaruca' did not take place in 1586 but in 1593 (Rouffaer & IJzerman, 1915, p. 181).

Junghuhn (1853, III, p. 949), Landgrebe (1855, p. 268) and Bosch (1858, p. 281) followed the idea of Valentijn (1724, IV, 1, p. 77) that the catastrophe of 1593 was caused by an eruption of Mt Ringgit, but Verbeek & Fennema (1896, p. 97), Verbeek (1925, p. 189) and Taverne (1926, p. 59) proved that this was impossible, which was affirmed by the investigations of van Bemmelen (1938; 1949a, IA, p. 552) who made researches into Mt Ringgit, which appeared to be a volcanic skeleton already extinct in Pleistocene times.

SEVENTEENTH CENTURY

Banda Api (6,5-9)

Pieter van den Broecke (1648, p. 29) saw Gonnapi, i.e. Gunung Api or 'volcano' of the island of Banda, throwing out thick ash clouds and glowing stones in April 1615. This eruption was mentioned also by Valentijn (1724, III, 2, p. 16), Tiele (1884, p. 149) and Wichmann (1899, p. 124).

Twenty years later, on 18 November 1635 Johann Sigmund Wurffbain (Wurffbain, 1686; van den Berg, 1904) ascended the volcano and described the summit. From an 80 m large opening in the crater thick clouds of smoke rose, occasionally accompanied by flames.

In the 'Collection Academique à Dijon' (vol. 6, 1761, p. 663) an enormous outburst in the evening of 30 November 1694 of the volcano on the island Gounapi near Banda is mentioned. Ash, fire, stones, and lava flows destroyed the vegetation of the island. There was also an eruption in 1586 (op. cit., p. 550).

Valentijn (1724) mentioned the eruptions of Banda Api in 1586, 1598, 1609, 1615, 1632, constantly from 1690 till 1696, and 1712.

Tongkoko (6,6-13)

Mt Kema or 'des Frères' in the region of Menado had an eruption in 1694, according to Collection Académique à Dijon (1761, p. 663). The explosions were heard as far away as Amboina, at a distance of c. 650 km. This volcano must have been Mt Tongkoko, situated near the extinct Dua Sudara, i.e. 'deux frères'.

EIGHTEENTH CENTURY

Mt Merapi (6,3-25)

On the 18th of July 1786 F. van Boekhold (1792, p. 10) ascended Mt Merapi from the north side. Probably he was the first European who reached the summit, where he found a 'kale klip', a barren rock, evidently a lava dome with many yellow spots of burning sulphur. The crater wall was grown over with trees, a token that the volcano had not been active for a very long time.

G. Patuha (6,3-7) and G. Papandayan (6,3-10)

In the beginning of the 18th century the Government at Batavia knew of the existence of sulphur in the mountains Patoea and Pappandayang. The vaandrig (ensign) Cretiaun and the assay-master van Houten were sent to these volcanoes in 1706. They found so much sulphur that the Government charged the Regent of Bandung to supply 400 picol, i.e. 400 x 56 kg = 22 400 kg, of pure and fine sulphur at a price of ¾ daalder (c. 120 cents) per picol to be sent to Tandjung Pura in Krawang (see Hageman, 1870).

G. Awu (6,7-4)

Valentijn (1724, I, 3, p. 53) described the eruption of Mt Awu on the Island of Sangir as recorded in the 'Taboecan's dagregister' (Journal of Taboecan). It lasted from 10 to 16 December 1711. The map of the island (Fig. 2) which Valentijn added, is mainly correct (Kemmerling, 1923).

In the night of December the 10th the whole mountain looked as a field of fire and enormous explosions were heard. They were followed by streams of burning water (hot mud flows). In Candahar at the east foot of the volcano no house remained in tact. The number of dead people was 2030. The soldier Tho-

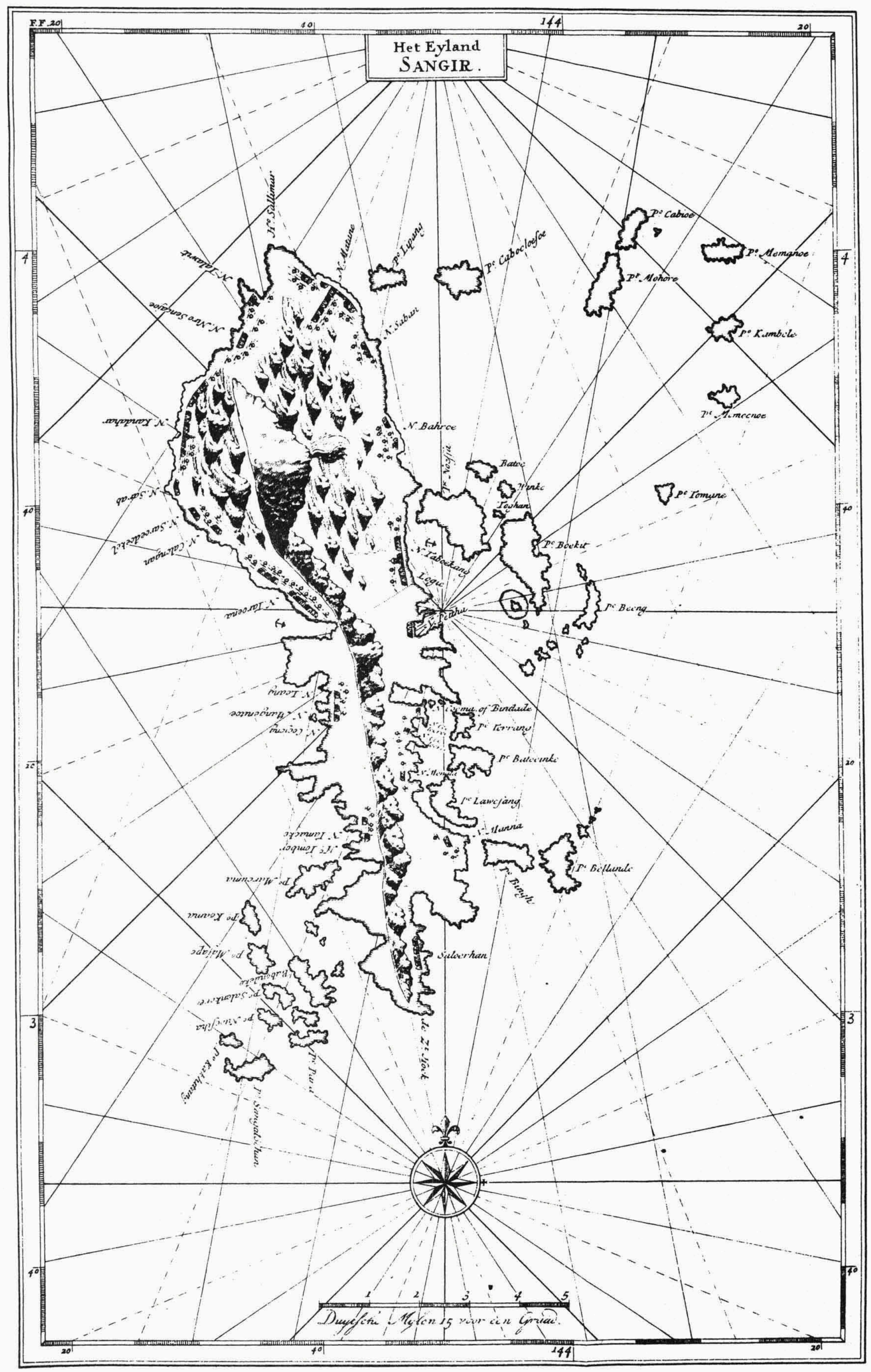

Fig. 2. The Island of Sangir, as figured by Valentijn (1724; from Kemmerling, 1923, pl. 5).

mas Justus and some natives, sent to investigate what had happened, found 400 intact corpses suffocated by the heat of the fire.

The shortly lasting but violent outburst threw out the crater lake. The mud flows which originated destroyed the villages at the foot of the mountain. The following ash and stone eruptions increased the catastrophe.

Mt Ruang (6,7-1)

Valentijn (1724, I, 3) described this volcano, but neither he nor Gemello Carreri (1719, V, p. 228) mentioned eruptions.

Api Siau (6,7-2)

The Island Sjouw was a high burning mountain (Valentijn, 1724, I, 3) which threw out ashes, stones and water. Catastrophes were rare. According to Kemmerling (1923, p. 59) the remark that water was thrown out could be right, as water was present in the eastern crater when he visited the summit. Valentijn mentioned an eruption of 16 January 1712.

Gamkonora (6,8-4)

The eruption of 1673 was accompanied by a terrible earthquake. The sea water inundated the coast, destroyed villages and killed its population (Valentijn, 1724, I, 3, p. 203).

Peak of Ternate (i. Gamalama) (6,8-6)

Valentijn (1724, I, 3, pp. 5-10) mentioned eruptions of 1608, 1635, 1653 and 1773.

Makian, i. Kie Besi (6,8-7)

The big, high mountain of this island burned frightfully in 1646 (Valentijn, 1724, I, 3, p. 90). A terrible earthquake burst the mountain, destroyed many villages and killed the people. Valentijn was of the opinion that this volcano and the one of Ternate had the same ground fire: 'magma chamber'.

Koerkofe

This extinct volcanic island in the eastern part of the Moluccas had, according to Valentijn, an eruption in 1659.

Nineteenth century, communications of experts and laymen

In this period scientists, but also laymen, contributed to a better knowledge and comprehension of the volcanoes of the East Indies, especially of the Javanese ones. To be mentioned are in the first place: Th. Horsfield (1802-1818), F.W. Junghuhn (1835-1864), R.D.M. Verbeek (1880-1910), and F. Fennema (1886-1900). The dates indicate the period in which they were active in the East Indies.

Dr Thomas Horsfield (Bethlehem, Pennsylvania, 12-5-1773 - London, 24-7-1859) worked as an army surgeon for the Dutch Government on Java and Sumatra, but in 1811 after the British occupation he transferred his services to the British flag. He was a well known botanist and zoologist, whose study on the medical herbs of Java was epoch making, and he wrote also on volcanoes. He left the East Indies in 1819 and was appointed keeper of the Museum of the East India Company in London.

The physician Dr Franz Wilhelm Junghuhn (Mansfeld, Saxony, 26-10-1809 - Lembang, 24-4-1864), being very much interested in geology and botany, made an important contribution to the knowledge of the volcanoes of Indonesia, although he had received no formal training in geology. He arrived in Batavia on 13 October 1835 as an army surgeon. His principal, Dr E.A. Fritze, who had the same interests, took care that he was lent out to the 'Natuurkundige commissie' in 1838. In 1840 he was instructed to carry out topographical investigations in the Batak Counties. In 1845 he left the medical service to be appointed as a paid member of the 'Natuurkundige Commissie'. Junghuhn published several important works, in which he described 37 volcanoes of Java, some of which were already extinct, and discussed 10 volcanoes of Sumatra and 31 of the eastern part of the archipelago.

Dr Rogier Diederik Marius Verbeek (Doorn, 7-4-1845 - Den Haag, 9-4-1926) worked as a mining engineer and geologist in the Dutch East Indies. He started his career in a coalfield of southeast Borneo and later on worked also on other islands, such as Java and Sumatra. The catastrophic outburst of the Krakatau in 1883 roused his interests in volcanology. In 1898 he became Director of the Mining Department of the Netherlands East Indies. His excellent geological work in the East Indian Archipelago, resulting in the important monographs, such as the one on Java and Madoera, which he wrote together with R. Fennema and in which 32 volcanoes are described as they found them 50 years after Junghuhn, and his 'Molukkenverslag', brought him fame. The honorary Doctor's degrees bestowed on him by the universities of Breslau (1886) and Utrecht (1925) and by the Institute of Technology of Delft (1915) may serve as an example.

After his retirement, Verbeek (1912-1925) collected and published in special issues of the 'Geologisch en Mijnbouwkundig Genootschap voor Nederland en Koloniën' (Royal Geological and Mining Society of the Netherlands and Colonies) a bibliography of all the papers on geology and volcanology of the Dutch East Indies that had appeared. N. Wing Easton (1926-1933) continued his work.

Reinder Fennema (Sneek, 21-10-1849 - Lake Posso, Celebes, 27-11-1897) left in 1873 for the Dutch East Indies after finishing his studies as a mining engineer. From 1875-1878 he was involved in the geological survey of Sumatra's West Coast and afterwards in the drilling of artesian wells. His interest in volcanoes started with the study of the causes and effects of the eruption of the Smeroe in

1885. He was also involved in the early exploration for oil on Sumatra, e.g. the Telaga Said Oilfield. In 1896 he was entrusted with the supervision of the geological and mining exploration of the residency of Menado on Celebes, where he died in 1897 in a sudden storm, while crossing the Lake Posso.

Sir Thomas Stanford Raffles, Lieutenant Governor of Java from 1811 till 1816, wrote in his History of Java (1817) on some volcanoes. He also gave new life to the Bataviaasch Genootschap voor Kunsten en Wetenschappen (Batavian Society of Arts and Sciences).

In 1816 the Natuurkundige Commissie (Board of Natural Sciences) was established in order to promote the scientific research of Nature in the Netherlands Indies. Since that time volcanic outbursts were regularly published in: 'Tijdschrift voor Neêrlands Indië'; 'Tijdschrift voor Indische Taal-, Land- en Volkenkunde'; 'Natuurkundig Tijdschrift voor Nederlandsch Indië'; but also in newspapers, such as the 'Java Bode', 'Javasche Courant' and 'Bataviasche Courant'.

Since 1850 the 'Natuurkundig Tijdschrift voor Nederlandsch Indië' published in a special chapter data on volcanic eruptions and earthquakes. In 1850 also the Dienst van het Mijnwezen (Department of Mines) was founded, of which the division of geology had to look for ores, but also had to do scientific research. Verbeek and Fennema were charged by the Government to compose a geological map of Java. In 1896 the results of their explorations appeared in a book called 'Geologische beschrijving van Java en Madoera', in which the volcanoes were amply described. On his voyage through the Moluccas Verbeek collected data on volcanoes of that region.

KRAKATAU (6,2)

The 33 km^2 large, about 9 km long and maximal by 5 km wide main island with the nearby Verlaten Island (Pulu Sertung) and Lang Island (Rakata Kecil) was sketched (see Fig. 3) by Salomon Müller (1844).

The army surgeon F. Epp (1841, 1852, pp. 96-97), who was interested in volcanoes, visited Krakatau in April 1839. He found active fumaroles.

The notorious eruption of Krakatau in 1883 was excellently described by Verbeek (1884-1885), and also by Forbes (1884). The main island consisted of three volcanoes, the 812 m high Rakata, the c. 450 m high Danan and the 120 m high Perboewatan (Figs. 3, 4). On 20 May 1883 Mt Perboewatan began to emit

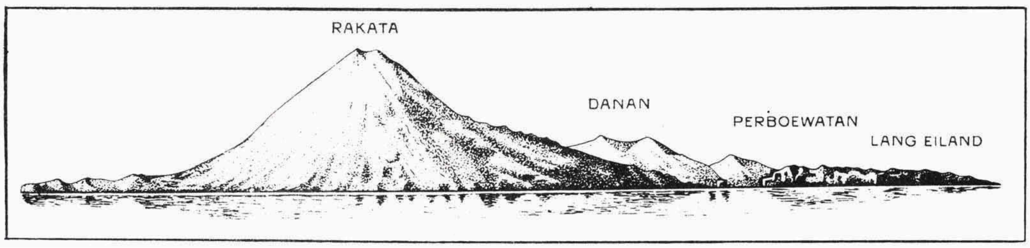

Fig. 3. The islands of Krakatau in 1836, as sketched by Müller (1844), seen from the south-east, Pepper Bay (from Neumann van Padang, 1933b, fig. 1).

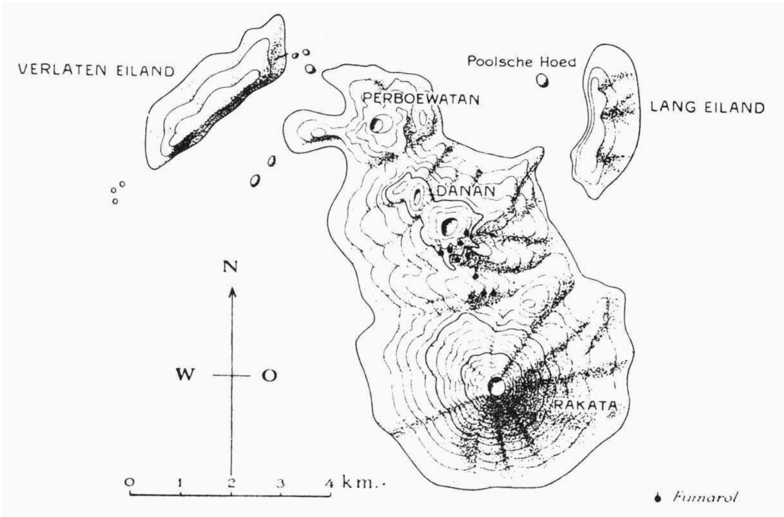

Fig. 4. The islands of Krakatau according to the topographical sketch of Captain Ferzenaar, the sketch of Müller (1844) and the data of Verbeek (from Neumann van Padang, 1933b, fig. 2).

pumice and ash. In June also Mt Danan began to erupt, and in August three craters were active. During the catastrophic activity of 26-28 August enormous quantities of ash and pumice were thrown out.

In these three days the greater part of the main island disappeared, according to Verbeek by collapse, forming a submarine basin. The emitted material covered Lang Island, Verlaten Island and the remaining part of Rakata with pumice tuff to a height of 60 m and more. Verbeek calculated the total amount of emitted materiaal to be 18 km^3, of which 95% existed of new pumice tuff and only 5% of old material. Therefore he was convinced that the caldera originated by collapse.

The collapse was accompanied by sea waves that harassed the coasts of Bantam and South Sumatra, killed nearly 37 000 human beings and destroyed 297 villages completely or partly.

VOLCANOES OF JAVA

Tjerimai = i. Cereme (6,3-17)

Of this volcano Horsfield (1816a, pp. 169-170) mentioned the eruptions of 1772 and of 1805. Both were followed by a severe pestilence in the lower districts of the regency of Cheribon.

In August 1837, Junghuhn (1853, II, pp. 160-169) visited the summit of this volcano. He saw a 300 ft (90 m) deep crater, divided into two parts, separated by a stony wall (a twin crater). According to him the eruption of 1805 destroyed the vegetation not further down than 90 m below the crater rim. Verbeek and Fennema (1896, II, pp. 946-961) also described this volcano.

Butak Petarangan (6,3-19)

Horsfield (1816b, p. 281) mentioned mud eruptions, earth quakes and fissures from Boedak (see p. 53).

Sundoro (6,3-21)

Horsfield (1816a) gave a description of this nice conical mountain. According to Junghuhn (1853, II, pp. 275-300) the summit had a flat and shallow crater bottom with two small deep pits and a crevice with fumaroles. He visited the summit in June 1838 and April 1840. An ash eruption took place in 1818. Verbeek and Fennema (1896, II, p. 384) also described this volcano.

Papandayan (6,3-10)

Horsfield (1816a, p. 158) considered Mt Papandayan to be one of the largest volcanoes of Java. The greater part of it was swallowed in the earth after a short but very severe eruption in the year 1772. Near midnight between the 11th and 12th of August an uncommonly luminous cloud was observed. Then the greater part of the mountain fell in and disappeared in the earth. At the same time immense quantities of volcanic substances were thrown out and spread in every direction. An area of 15 miles (24 km) long and full 6 miles (10 km) broad was covered. Hot substances were piled up to a height of three feet (1 m). Forty villages were partly swallowed up and partly covered by these ejecta and 2957 inhabitants perished.

Junghuhn (1853, II, p. 115), however, was of the opinion that next to a possible crumbling down of the crater wall (kratermuur), diminishing the height of the mountain by about 1000 feet (300 m), the land had nowhere sunk as Horsfield communicated. On the contrary, the foreland was heightened c. 50 feet and locally even 100 feet.

According to his calculation less than a quarter of the inhabitants of the destroyed villages perished, the greater part of them could save themselves. When he visited the volcano in July 1837, i.e. 65 years after the catastrophe, two-thirds of the gap in the crater wall were already overgrown with wood.

Verbeek and Fennema (1896, II, pp. 679-686) described the volcano as they found it more than fifty years later. They thought that the valley on the northeastern slope of the mountain originated by the pressure of the lava of a lava lake that filled the crater and broke through the crater wall. Taverne (see p. 33) rightly contested the theory of the existence of a lava lake. Verbeek and Fennema were the first to mention the terraces on the valley slopes. A more recent 600 m wide valley was situated within an ancient 950 m wide one. The southeastern slope of the younger valley was parallel to the higher, more ancient, wall.

Kawah Idjen = i. Kawah Ijen (6,3-35)

An eruption of Kawah Idjen in 1796, mentioned by Horsfield (1816a), must have been rather small or based on a mistake, as nine years later - in September 1805 - Leschenault (1811, p. 437) found the crater walls overgrown with shrubs and ferns, and the outer mountain slopes thickly wooded.

Junghuhn (1853, III, pp. 1020-1030) described his observations of the Idjen Mountains, the active crater Kawah Idjen and what he found written by Leschenault and Horsfield.

During the eruptive activity in January 1817, which lasted eight days, the acid crater lake was thrown out. When Reinwardt (1858) visited the volcano in 1821 the vegetation of the summit was still completely destroyed. Two mud streams were formed of which one flowed in an easterly direction. It reached the coast of Java south of Banyuwangi, and destroyed a large area which was still barren when Junghuhn visited it in 1844. The other flowed in a westerly direction into the valley of Banyu Pait and eventually reached the north coast.

Verbeek and Fennema (1896, pp. 76-88) also explored and described the Idjen Mountains and Kawah Idjen.

Pangerango and Gedeh (6,3-6)

According to Junghuhn (1854, IIII) these were two separate volcanoes belonging to one compound mountain. They form one of the biggest volcanoes of Java, comparable with the Tengger volcano (6,3-31) in East Java. Junghuhn was of the opinion that Mt Gedeh was a nice example of an elevation crater, an idea Leopold von Buch introduced in 1825 as Erhebungskrater. According to this theory volcanic cones originate when vertically rising magma pushed up the originally flat lying layers. In 1859, five years after Junghuhn's publication, Scrope proved that volcanic cones originate by the accumulation of the material thrown out and deposited around the eruption centre.

Contrary to Junghuhn, Verbeek and Fennema (1896, pp. 741-748) considered Gedeh-Pangerango as a twin volcano of which the latter was the most ancient one.

Mt Guntur (6,3-13)

In the days of Junghuhn (1853, II, p. 77) Mt Guntur was the most active volcano after Mt Merapi and Mt Lamongan. Every year ash and stone eruptions took place and several lava flows came down. Junghuhn described 16 eruptions for the period 1800-1843.

According to Verbeek and Fennema (1896, pp. 714-720) the basaltic lava flows originated in the Masigit crater.

Mt Galunggung (6,3-14)

From Mt Galunggung Junghuhn (1854, pp. 124-160) described amply the eruption of 8 October 1822, when an enormous black cloud of smoke rose from the crater, and hot water mixed with mud and stones streamed sidewards through an already existing, about 2 km wide gap in the eastern mountain side to a distance of 16 km. Thousands of people were killed in the region that was covered with 2.4 km^3 mud and stones to a height of 12 to 15 m. This 175 km^2 large region was called 'the territory of the 10 000 hillocks'.

Verbeek and Fennema (1896, II, pp. 58-84) were of the opinion that 100 million m^3 of water, mud and stones came down through the gap ('dalspleet') in the east-southeastern wall of the volcano from 8 till 12 October 1822. They thought that the many hillocks were secondary eruption centres above lava flows. This wrong opinion was caused by a hillock near Tasikmalaya which existed of lava and the supposition that all the mounts had the same composition.

Telaga Bodas (6,3-15)

When Junghuhn (1854, pp. 120-124) visited the crater in July 1837 he found a white-coloured aluminous lake with solfataras on its northwestern, northern and northeastern shores at a height of 5220 ft, i.e. 1592 m. Sulphureous gases were also seen at some places in the lake, heating the water. Near the death valley Padjagalan he found dead animals.

Mt Slamet (6,3-18)

In August 1838 and June 1847, Junghuhn (1853, II, pp. 171-205) visited the volcano, one of the highest and most regularly shaped cones of Java. A mountain chain connects Mt Slamet with the Diëng volcanoes in the east. The small flat summit had a circular, 214 m large and 46 m deep, crater in its west-southwestern part. North of it a sandy plain was bordered by an 8 to 30 m high wall of lava beds from which fumaroles emanated. White fumes rose from the crater. Eruptions were known of August 1772, October 1825 and September 1835.

Verbeek and Fennema (1896, II, pp. 406-433) paid special attention to the northern slope of the volcano. West of the Slamet cone they recognized the remains of an old volcanic mountain. They described the summit as an old horseshoe-shaped crater, open to the northeast, and a deep, 280 m large, active crater in its southwestern part.

The Diëng Volcanoes (6,3-20)

Junghuhn (1853, II, pp. 207-275) was of the opinion that this region was a large caldera of which the rim was formed by the mountains Prahu, Nogosari, Bismo, and Srodjo (see Fig. 18 on p. 55). Many volcanoes originated within the caldera. Apart from extinct ones, he mentioned six active cones, further hot wells and some death valleys. Verbeek and Fennema (1896, II, p. 385) copied the opinion of Junghuhn concerning the Diëng mountain, changing only some details.

Mt Sumbing (6,3-22)

Junghuhn (op. cit.) only mentioned this volcano. At the foot of the volcano south and north of Temangung, Verbeek and Fennema (1896, II, pp. 946-957) found numerous small cones, which they thought to have originated from explosions at the surface of lava flows, now covered by tephra of later eruptions. They called them wrongly 'boccas', which are small craters at the top, the flank or the foot of a volcano.

Mt Ungaran (6,3-23)

The not yet extinct volcano had an indistinct crater, surrounded by three tops. Solfataras were found on the southern slope of the mountain.

Mt Merbabu (6,3-24)

Junghuhn, who climbed the volcano in November 1836, found a wooded summit, consisting of several tops. He mentioned some fumaroles and mud wells, but no eruptions.

Mt Merapi (6,3-25)

In 1838 and 1840 Junghuhn (1853, II, pp. 371-419) found in the northeastern part of the summit an old crater wall called Pusunglondon, built up of lava layers. A sandy former crater bottom was situated between this wall and the active crater, in which a dome-shaped lava plug had risen. Junghuhn mentioned the shifting of the crater in a westerly direction. The new lava flowed over the northwestern and western crater rim and the mountain slope, downwards as far as the upper course of the Blongkeng ravine. Glowing pieces of lava tumbled down during many years after the eruption of 1832. In 1840 solfataras were seen between the lava blocks in the crater.

Junghuhn mentioned the eruptions of 1560, 1664, 1678, 1768, 1822-23, 1832, 1837, and 1846-47. They were accompanied by lava flows and lava avalanches, some of which destroyed villages, formed mud flows and caused the loss of human lifes. The severe eruption of 1664 was also described by Crawfurd (1820, p. 509).

Mt Kelut (6,3-28)

Junghuhn (1853, III, pp. 643-702) was the first European reacht the crater rim of Mt Kelut on 16 September 1844. From the northwest rim he saw the crater lake, untill then unknown, situated between steep, hundreds of feet high walls.

Junghuhn mentioned the eruption in the year 1000 documented by Raffles (1817, II, p. 95); further that of 1811 and of 1826. The mud flows of these eruptions, which took place without preliminary symptoms, destroyed many villages. The eruption of 1848, lasting from 7 till 9 o'clock a.m., was accompanied by scorching clouds.

Verbeek and Fennema (1896, p. 166) mentioned moreover the eruption of 1864 and the catastrophe of 1875. The rocks of these eruptions were pyroxene-andesites, and according to Lorié (1879) also hornblende-andesites.

Tengger and Mt Bromo (6,3-31)

The Tengger Mountains were visited by Junghuhn (1853, III, pp. 784-853) in 1844. He published a good sketch of the caldera, which he called a crater. The sketch agrees very well with the present day topographical map. Of the four eruption centres in the caldera Mt Bromo was the only active crater. In March 1838 its crater contained a little lake, which already existed in 1825 (van Herwerden, 1845).

Mt Raung (6,3-34)

Junghuhn (1853, III, pp. 887-910) ascended Mt Rawon, as he called the volcano, in October 1844. His description agrees with those of later investigators. He knew of no eruptions, which means that the outburst mentioned by Lodewijcksz (see p. 8) was unknown or already forgotten at his time. The summit of the volcano being barren and savage, Junghuhn however was of the opinion that a great eruption must have taken place in one of the last centuries.

Verbeek and Fennema (1896) mentioned two partly collapsed and eroded crater rims, west of the large Raung crater, with diameters of 3480 m and 3000 m.

Mt Lamongan (6,3-32)

The completely isolated volcano Mt Lamongan rose in a flat country. It was visited by Junghuhn (1853, III, pp. 1103-1132) in July 1838, November 1844 and in 1847. The volcano was built up of two cones, of which Mt Tarub was the most ancient one. Mt Lamongan originated on the south-southwestern slope of Mt Tarub when its crater was choked.

The volcano was surrounded by a number of small lakes ('ranus') which according to Junghuhn were caused by collapse. In his opinion they could not be explosion holes because ring walls and fumaroles are missing. These 'ranus' indeed are maars.

Junghuhn mentioned eleven outbursts between 1799 and 1847.

Mt Patuha (6,3-7)

On 13 June 1887 Kawah Putih one of the craters of Mt Patuha contained a shallow lake which was white from the suspended sulphur. A strong ebullition of gases took place in the western part of the lake (Verbeek & Fennema, 1896).

Wayang-Windu (6,3-13)

According to Verbeek and Fennema these mountains were two border volcanoes of a caldera of which the plain of Pengalengan was the bottom and of which the western rim had disappeared.

MT TAMBORA (6,4-4)

Junghuhn (1853, III, pp. 1249-1260) described the catastrophic eruption of Mt Tambora on Sumbawa, one of the Lesser Sunda Islands, after what he read in Raffles (1817, pp. 25-28), Ross (1816) and the Javasche Courant of 22 July 1820. He had the wrong idea that the neighbourhood of the sea had influenced the intensity of this outburst.

The volcano which was thought to be extinct, emitted a dense cloud for the first time in 1812. On 5 April 1815 eruptive activity started again, followed by a catastrophic outburst from April 10th till 12th. In these three days the volcano lost nearly a third of its height, which was reduced to about 2550 m. During the three following months, till July the 15th, the volcano was active with reduced power. According to Junghuhn 318 km^3 of ash and stones were thrown out, depositing a thick layer of ash on the islands of Sumbawa and Lombok, and causing the death of 56 000 people. A sea wave, caused by the disappearance of the protruding Cape Lengan into the Java Sea, lasted only three minutes. It dragged away houses and trees in the Gulf of Bima and threw big ships on the shore.

Zollinger (1855) visited the volcano in August 1847. He found a great quantity of light-coloured and black pumice. It had an ovally shaped crater (caldera) with a diameter of an hour's walk (5 km) and a depth of c. 1700 feet (510 m), perpendicular walls, a feeble bowlshaped crater bottom, and solfataras along an elongated little lake. Zollinger thought that the volcano originally had a height of 4200 m.

Verbeek (1885, p. 135) thought the quantity of emitted material to be 150 km^3. Anyhow, the amount of ash and dust was such that 1816 was called the year without a summer, because in Western Europe and North America there was snow and frost in June, July and August.

VOLCANOES OF THE BANDA SEA AND HALMAHERA

In 1899 Verbeek (1908) made a study of some of the volcanoes of the eastern part of the archipelago, where he visited those of the Banda Sea and of Halmahera.

G. Api N of Wetar (6,5-3)

On April 8th 1899 steam and SO_2 gases rose from the central crater of this island volcano north of Wetar.

Damar = i. Wurlali (6,5-4)

This big volcano, also called Dammer and Daam, had a crater Wuarlili or Loolsuni with solfataras.

Teon = i. Serawerna (6,5-5)

This island, also called Tewer, was a simple volcano.

Nila = i. Laworkawra (6,5-6)

A young cone surrounded by an old mantle.

Serua = i. Legatala (6,5-7)

A truncated cone surrounded by an old rim of lava and breccias.

Manuk (6,5-8)

A truncated cone with a central crater from where SO_2 gases rose.

Mt Dukono (6,8-1)

A compound volcano of young cones.

Peak of Ternate = i. Gamalama (6,8-6)

The summit of this volcano contained two concentric craters of which the rim of the inmost one was 15 m higher than the other. Within the inmost crater was a 105 m high eruption cone of loose blocks of lava. This volcano was also described by Junghuhn (1854) and Wichmann (1899). The volcano was frequently active.

Makian = i. Kie Besi (6,8-7)

According to Verbeek (1908, pp. 141-143) the irregularly shaped square island had two craters. Eruptions were known of 1646, 1760, 1861, and 1899. Gaade (1925) published a map of the 1450-1500 m wide and c. 500 m deep crater, which is the southern crater of Verbeek. Verbeek's northern crater is the upper part of an erosion valley.

Systematic volcanological research after 1900

Since 1850 the chapter 'Vulkanische verschijnselen en aardbevingen, waargenomen in de Nederlandsch Indische Archipel' (Volcanic phenomena and earthquakes observed in the Netherlands Indies Archipelago) appeared every year in the 'Natuurkundig Tijdschrift voor Nederlandsch Indië'. After the foundation of the Volcanological Survey (see below), Kemmerling (1921d) and Taverne (1923-1925) published in this magazine 'Vulkanologische Berichten' (Volcanological Tidings), describing the volcanoes investigated in that period.

From 1921 till 1941 thirteen volumes of 'Vulkanologische en Seismologische Mededelingen' (Volcanological and Seismological Communications) appeared with detailed treatises written by Kemmerling, Taverne, van Es, Stehn, Neumann van Padang, Esenwein, and Hartmann. The Bulletin of the Netherlands Indies Volcanological Survey, publishing in English the observed data, appeared every month in the beginning, then once every two months and since 1931 quarterly. Much volcanological information was published in the Proceedings of the Pacific Sience Congresses. In 1926 Stehn (1928a) communicated at the Pacific Science Congress in Japan on the volcanological work in the Dutch East Indies during 1923-1926. The IV Pacific Sci. Congr. took place on Java in 1929.

Papers on Indonesian volcanoes are to be found in the journals 'de Mijningenieur', 'de Ingenieur in Nederlands Indië' and 'de Tropische Natuur'. In 'de Bergcultures' articles were published on how the population could be protected against eruptions.

Also in the Netherlands, essays were written on volcanoes of the East Indies, especially by Escher, Brouwer, Umbgrove, and Kuenen.

Georges Laure Louis Kemmerling (Maastricht, 26-1-1888 - Amsterdam, 26-5-1932) studied at the Mining Academy of Freiberg in Saxony and at the University of Freiburg im Breisgau, where he got his Doctor's degree. From 1911 till 1913 he worked as a geologist for the Nederlandsche Koloniale Petroleum Maatschappij. After having been assistent to Professor G.A.F. Molengraaff in Delft in 1914, he went back to the former Netherlands East Indies where he was employed in the Mining Department in 1916.

In 1917, after getting acquainted with the volcanoes Batur and Agung, he became interested in volcanology. He described the volcanoes of Western Sumatra and the catastrophic eruption of Mt Kelut in May 1919. He made a special study of its mud flows, and of the glowing avalanches of Mt Merapi. In 1920 he was appointed Director of the newly established Volcanological Survey. In May 1926 a serious illness caused him to take a leave to Holland. This illness, of which he never recovered, prevented his return to the Indies.

Berend George Escher (Gorinchem, 4-4-1885 - Oosterbeek, 11-10-1967) was an influential promotor of the foundation of a volcanological survey in the Netherlands East Indies. After having studied geology at Zürich (Switzerland), where he got his Doctor's degree in 1911, he became an assistant to Professor Dubois in Amsterdam and custodian at the Technical University in Delft. Being on Java in 1918 and 1919, he got interested in volcanic phenomena, particularly in those of Krakatau and Mt Kelut. After he was nominated to the Chair of Geology at Leiden University in 1922, becoming at the same time Director of the 'Rijksmuseum van Geologie en Mineralogie' (National Museum of Geology and Mineralogy), his interest in volcanoes remained. From 1948 till 1956 he was President of the Volcanological Section of the International Union of Geodesy and Geophysics.

Charles Edgar Stehn (Altona, Germany, 10-11-1884 - Dehra Dunn, India, May 1945) studied geology in Bonn, where he obtained his Doctor's degree in July 1914. In November 1921 he went to the former Netherlands East Indies where he became assistant to Dr G.L.L. Kemmerling, Director of the Netherlands Indies Volcanological Survey, in February 1922. Four years later, in May 1926, he himself was appointed Director of the Survey. The Second World War brought an end to his successful career. Being a German he was put in an internment camp by the Dutch authorities and later transported to Dehra Dunn in British India, where he died.

During his 18 years with the Volcanological Survey he made 150 volcanological tours, studied 41 active volcanoes and published 34 papers.

Reinout Willem van Bemmelen, born at Batavia (Jakarta) in the former Netherlands East Indies on 14 April 1904, studied mining engineering and geology in Delft, where he obtained his Doctor's degree in 1927. In the Netherlands East Indies he worked as a geologist on Sumatra and Java. He was especially interested in tectonophysics and volcanology. After the Second World War he was nominated professor of geology at the University of Utrecht. For his outstanding scientific achievements he received many honours, a.o. the 'Van Waterschoot van der Gracht Medal' of the Royal Geological and Mining Society of the Netherlands in 1970, the 'Wollaston Medal' of the Geological Society of London in 1977, and the honorary doctor's degree from the University of Uppsala, also in 1977. The results of van Bemmelen's work can be characterized by three key words: 1) Geology of Indonesia, 2) Undation Theory, and closely related with the latter 3) Gravity tectonics (see Katili & Hartono, 1979).

Maur Neumann van Padang, born in Padang Pandjang in the former Netherlands East Indies on 18 April 1894, studied mining engineering in Delft and geology in Berlin, where he obtained the Doctor's degree in October 1924. As an Assistent of Professor Hans Reck he was charged with the study of the volcanic islands of Santorini in Greece.

He arrived in the Netherlands Indies in May 1928, where he was appointed to the Volcanological Survey.

After the war he was pensioned off. Back in Holland Professor B.G. Escher, President of the International Volcanological Association, charged him with the compilation of a 'Catalogue of the active volcanoes of Indonesia', which appeared in 1951. In 1954 he was appointed Editor of the 'Catalogue of the active volcanoes of the World', which he was till 1967. In that time he succeeded in getting 21 parts of the Catalogue published. In 1969 he was invited to participate, as honorary vice president, in the First International Scientific Congress of the volcano of Thera (Santorini).

VOLCANOLOGICAL SURVEY

In 1918 Escher developed a 'Program of activities to be done by a division or commission of volcanology in order to establish a Volcanological Survey'. This Survey had to observe the dangerous volcanoes regularly, make maps of the crater regions and take temperatures of the fumaroles at the summit of the volcanoes. He further pleaded to found a volcanological institute with its own archives, library and museum.

Escher's suggestions had success. In 1918 the 'Natuurkundige Vereeniging' (Physical Society) at Batavia established a Volcanological Commission ('Vulkanologische Commissie') that charged the geologist Dr G.L.L. Kemmerling to study some volcanoes of the West Coast of Sumatra. The results of his investigations were published in the first Vulkanologische Mededeeling (Volcanological Communication) in 1921.

Already in September 1909 the Loemadjang Commissie was established that led to the formation of the Semeroefonds (Semeroe Fund) on 15 April 1910 (Vissering, 1910, p. 89; Neumann van Padang, 1950, p. 541). This foundation, however, only had the purpose of helping the victims of disasters and not to study volcanic phenomena. It came into being after a catastrophe in the night of 29 to 30 August 1909 caused by mud flows which destroyed c. 8 km^2 of arable land with 38 villages, killing 208 persons. These mud flows originated on the slopes of Mt Semeru by long lasting heavy rains.

After the catastrophic eruption of Mt Kelut in 1919 a 'Vulkaanbewakingsdienst' (Volcano-Watching Service) was founded as a subdivision of the Dienst van de Mijnbouw (Department of Mines). This survey studied how the population could be protected from volcanic eruptions: 1) by studying the type of the volcano, 2) by finding out a possibility to predict an eruption, 3) by investigating the menaced regions, 4) by developing a system to warn and evacuate the population of these regions, and 5) by trying to reduce the effect of an eruption.

Since December 1922, when the 'Vulkaanbewakingsdienst' was called 'Vulkanologisch Onderzoek' (Volcanological Research), the volcanoes of the archipelago, especially of Java, were visited and studied regularly. Some volcanoes were guarded permanently from fixed observation centres. That was the case with Mt Tangkubanparahu (6,3-9) and Mt Papandayan (6,3-10) because of the poisonous gases, dangerous for the tourists who visited the craters. Warning-boards were placed on the spots the tourists had to ayoid.

Mt Merapi (6,3-25) and Mt Kelut (6,3-28) were guarded permanently because of the catastrophic eruptions and Kawah Idjen (6,3-35) because of the danger the crater water, rich in sulphureous acid, could cause when it flowed to the lowland uncontrolled.

To find a relation between the temperature changes of the solfataras in the crater and the activity of the volcano, the temperatures were measured regularly, in some cases daily. The assumption that a rise of these temperatures preceded an eruption was not confirmed in the controlled cases (see p. 49).

Seismographs had to register the movement of the magma. In 1927 seismographs were present at the observation stations of the volcanoes Merapi, Papandayan and Kelut. The observation station Maron at the west-southwest foot of Mt Merapi, at a distance of 6 km from the summit, had an Omori tromometer, as used in Japan. It registered horizontal shocks. The observation stations of Mt Papandayan and Mt Kelut, situated near the crater on the summit of these volcanoes, had Wiechert seismographs which registered vertical shocks. In March 1929 Mt Papandayan also got a Wiechert seismograph to note horizontal shocks.

In 1923 Taverne published a synopsis of what the 'Vulkaanbewakingsdienst had done over the past five years together with the 'Koninklijk Magnetisch en Meteorologisch Observatorium' (Royal Magnetic and Meteorological Observatory) at Batavia (Visser, 1921).

The 'Vulkaanbewakingsdienst' remained long (until 1940) the only governmental volcanological service, by which all the volcanoes of the country were studied and kept under close observation. Elsewhere, e.g. Japan, Hawaii and Italy, universities carried out volcanological research and founded volcanological stations.

VOLCANOES OF NORTH SUMATRA

In July 1904 Volz (1912, pp. 228-233) visited several volcanoes.

Seulawah Agam (6,1-2)

He mentioned an eruption in the 300 m wide Van Heutz crater in January 1839.

Burni Geureudong (6,1-4)

This twin volcano was visited in the same year. Active solfataras were found in the crater which was open on its northeastern side. The two maars on the southeastern slope were also observed by Tichelman (1933). The earthquake of October 1935 did not alter the condition of the hot wells, the solfataras and the geysers.

Burni Telong (6,1-5)

According to Volz this parasitic cone of the Geureudong (6,1-4) had an eruption in 1856.

Mt Sinabung (6,1-8)

This is a regularly built simple volcano with a twin crater within an old crater wall. Solfataric activity was strong. In 1912 the summit of the volcano was mapped. Of the four craters, I to IV, the dimensions and depths were given by Neumann van Padang (1951, p. 13). Shifting of the explosion centre of crater III caused its elongated shape in a northwestern direction and the origin of crater IV. According to Hoekstra (1893) the volcano emitted ash clouds in 1881 (see also Umbgrove, 1931, p. 237).

KRAKATAU (6,2)

On the occasion of the first 'Nederlandsch Indisch Natuurwetenschappelijk Congres' (Netherlands East Indies Natural Science Congress) Escher (1919c) wrote an excursion guide for the participants who visited the islands. He sketched the changes the volcano underwent in the course of time (Fig. 5).

The IV Pacific Science Congress took place on Java in 1929. For the participants of the excursion to Krakatau Stehn (1929c) wrote a book in which he described amply what Verbeek and Escher had written. Then followed a description of the activity of Anak Krakatau that began on 29 December 1927 with submarine eruptions from a spot in the caldera sea near the steep northeastern submarine ridge in the basin. The eruption products built up a cone which rose above the sea level on 26 January 1928 as a low elongated island. It was called Anak Krakatau (child of Krakatau). Surf eroded this island and in February it already had disappeared.

The eruptions continued and on 28 January 1929 a new crater rim appeared, Anak Krakatau II, which lasted till July the 3rd. Stehn made a special study of the ebullitions: the upwellings of the sea, the water cones and the water fountains that accompanied the eruptions. In the Bulletins of the Netherlands Indies Volcanological Survey of the years 1929 till 1940 the activity and the origin of Anak Krakatau III and IV since 12 August 1930 were described. A violent eruption of Anak Krakatau was observed in May 1933 by Stehn. The eruption clouds, reaching a height of 4000 m and even more, were accompanied by rumblings and electric discharges.

The fact that 50 years earlier the catastrophic outburst of Krakatau had taken place was commemorated by Stehn (1933e) in 'Die Umschau' and by Neumann van Padang (1933b) in 'Tropische Natuur'. Moreover Neumann van Padang

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Fig. 5. The history of the volcano Krakatau, as sketched by Escher (1931b).

IA - The hypothetical big original volcano.

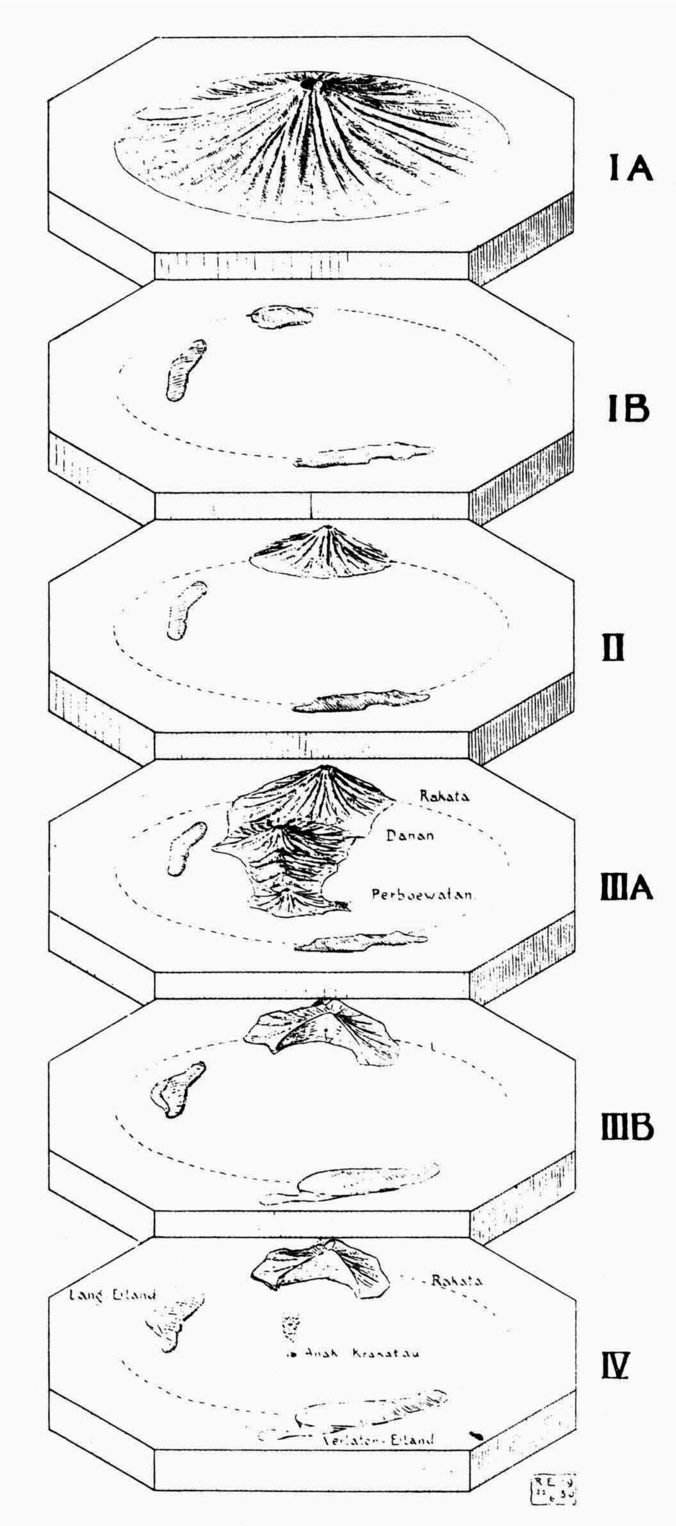
IB - Three small islands, remnants of the foot of the original volcano, remained on the border of a large caldera.

II - A basaltic volcano, Rakata, originated on the southern border of the caldera.

IIIA - North of Rakata, the andesitic volcanoes Danan and Perboewatan originated.

IIIB - Situation after the catastrophic eruption of 1883, showing the sea above the new caldera.

IV - This figure was added in 1930 to the figure of Escher (1919c) after the origin of the eruption centre Anak Krakatau in the middle of the caldera.


IA
IB
II
Rakata
Danan
Perboewatan
IIIA
IIIB
Lang Eiland
Rakata
Anak Krakatau
IV
Verlaten-Eiland

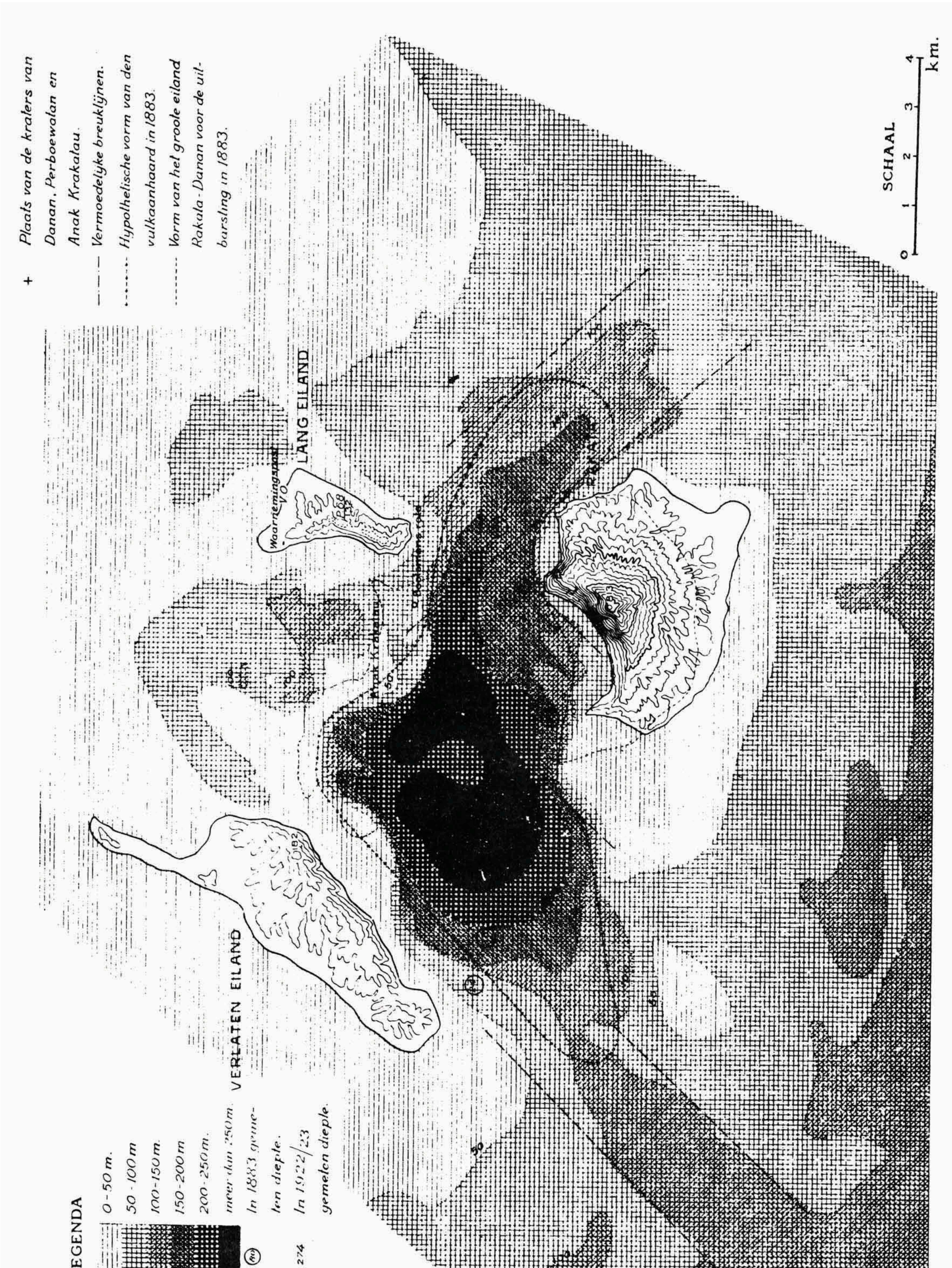


Fig. 6. Map of the Krakatau islands with depth of the caldera bottom; depth figures from Escher, 1928 (from Neumann van Padang, 1933b, enclosure).

tried to explain the peculiar shape of the caldera, which was not funnelshaped and circular, but irregular with submarine valleys in southeastern and southwestern directions, i.e. in the prolongation of the NW-SE directed Semangka Rift zone on Sumatra, and perpendicular to it (see Fig. 6). On the intersection of these two rift zones a weak spot originated where the hypomagma rose and formed a magma chamber, the shape of which was strongly influenced by the presence of the ruptures. The shape of the caldera indicates moreover that the basin originated by collapses along these tectonic fractures.

In two diagrams Neumann van Padang (1936c) showed the changes of Anak Krakatau (A.K.) from January 1929 till December 1935. Diagram I shows the origin and disappearance of A.K.II and A.K.III and the growth of A.K.IV. The NE-SW directed sections in diagram 2, made through the same place of the crater, show that the crater rim of A.K.III was situated more than 100 m NE of that of A.K.II whereas the explosion centre had moved 125 m to the south, i.e. in the opposite direction. The eruptions did not always take place at the same spot. On July 8th the eruption took place not only in the crater of the island but also at a place about 500 m south of it (Stehn, 1935b, pp. 166-167).

VOLCANOES OF JAVA

The volcanoes of Java had always aroused special interest because their eruptions could cause major catastrophes on this rather densely populated island (see p. 7, 41). Java also being the administrative center of the former Netherlands East Indies, it was only natural that new methods were first applied here.

Taverne (1926) observed the volcanoes of Java from an aeroplane. From this height he got a good view of the volcanoes and their environs. Often details were seen which could not be found on ordnance maps.

After having mentioned the influence of eruptions on the morphology of the landscape, he described the different shapes of volcanoes. Taverne distinguished monoconic and polyconic volcanoes. The monoconic or simple volcanoes had kept their conical shape. To these he reckoned the Mts Slamet, Tjerimai, Sundoro, Sumbing, Merapi, Kelut, Raung, and Tangkubanparahu. Of the polyconic or compound volcanoes Gede-Pangerango, Patuha-Kawah Putih, Guntur, Tarub-Lamongan, and Merapi-Kawah Idjen the transformations were great.

These transformations took place above fissures, generally diagonal to the main direction of the folding. Such fissures were also recognizable in monoconic volcanoes, e.g. in the shifting of the crater in the summit of Mt Slamet, already mentioned by Verbeek. The volcanoes Sumbing - Sundoro and Merbabu - Merapi are situated above SW-NE directed fissures.

In a list and a graph Taverne mentioned the eruptions that took place on Java from 1800 till 1924. As the volcanoes Semeru, Lamongan and Bromo were very active in that period, the number of years in which eruptions took place was great in East Java, 124 against 57 in West Java. The repose periods between the eruptions were of unequal duration.

Mt Kelut (6,3-28)

In the night of the 22nd to 23rd of May 1901 an eruption of Mt Kelut took place. L. Houwink (1901) was charged to investigate what happened and to advise what could be done to prevent catastrophes. According to him 12 days before the eruption raised activity was observed in the crater lake. The ejected lake formed lahars (mud flows) that filled the ravines to a height of 58 m, and reached the village Blitar in a short time. Relatively little damage was done because of the many bifurcations of the lahars. More damage occurred in the following months when the rains removed the deposited mud. Houwink was of the opinion that Blitar could only be saved when the crater lake was removed.

Six months before, in May 1900, J. Homan van der Heide (1904) was instructed to investigate if the crater lake could serve as a water reservoir that would supply the necessary irrigation water during the dry monsoons. He advised to throw up a dam in the ravine through which the crater water flowed away.

Eighteen years later, in the night of 19 to 20 May 1919 a catastrophic eruption took place, described by Kemmerling (1921b). He paid much attention to the destructive mud flows, and distinguished cold, hot, eruption and rain lahars. At the end of his work he described the eruptions of 1000, 1334, 1586, 1752, 1776, 1811, 1826, 1835, 1848, 1864, and 1901.

The first lahars which came down were cold, consisting of the upper part of the crater lake, not yet heated by the eruption material. Then the hot lahars followed, containing hot eruption material. All the lahars also contained old material from the bed and the walls of the ravines. Approximately 30 to 40 million m^3 of water passed the 20 to 30 m wide and 80 to 100 m deep Durga Cleft and streamed into the valley of Lahar Badak. Within 45 minutes 131.2 km^2 of cultivated land was covered by mud and debris to a height of 1¼- 2½m, and to a distance of 35 to 40 km from the crater. More than 5000 people were killed and 104 villages were totally or partly destroyed.

Later on in the same year lahars were formed by heavy rains (rain lahars), causing also great damage. In the beginning these were still hot, as they contained hot material from the ravines; gradually they cooled.

Lahars also occurred on volcanoes without a crater lake. They are known from the volcanoes Merapi (6,3-25), Semeru (6,3-30), Lamongan (6,3-32), and Raung (6,3-34).

After the crater lake was thrown out in 1919 the volcano ejected ash and bombs during several hours. Kemmerling estimated the total amount to be 100 million m^3 of ash and 40 million of debris. The rock consisted of hornblende-containing hypersthene-andesite, hypersthene-augite-andesite, pyroxene-andesite, and hornblende-augite-andesite. The inclusions were diorites.

Junghuhn mentioned a height of 4257 ft (= 1297 m) for the level of the crater lake in 1844. His heights being too low according to the Topografische Dienst (Ordnance Survey) the water level at that time must have been at a height of 1375 m, and the lowest part of the crater rim 1405 m a.s.l. In 1873, when the ordnance map of Mt Kelut 1:20 000 mentioned the real heights, the western crater rim was 145 m lower, and the water level 123 m lower than in 1844. The Durga Cleft, which the crater water had to pass to flow into the Lahar Badak, must have originated after the great eruption of 1848 (Kemmerling, 1921b, p. 102), and that of 1864 (Hageman, 1865).

The catastrophe of 29 January 1875 was not caused by an eruption. The western crater wall was pushed away by the pressure of the crater lake. Then 40 million m^3 of water came down (Cool, 1908).

Safety measures

In 1905 the first measures were taken to protect Blitar against cold lahars by building a dam near the bifurcation of Lahar Badak into Lahar Tomas and Lahar Blitar. The dam was destroyed in 1919.

From 1907 till 1908 a 7 m deep gully was dug in the lowest part of the western rim. The lake was kept at this level by a concrete dam with locks. But there was still 40 million m^3 of water in the crater. In 1907 the mining engineer Hugo Cool suggested to dig a tunnel in the crater wall in order to keep the crater empty. This suggestion was received with approval, but it was never carried out.

A week after the eruption of 1919, in the course of lectures held in Batavia, Buitenzorg and Bandung, Escher (1919b, d, e, 1920a; see also Stehn, 1929a, p. 19; Neumann van Padang, 1950, p. 553, 1958, pp. 79, 88-92, 1960a) recommended to remove the water from the crater. A committee appointed by the Government suggested 1) to lower the surface of the lake and to keep it low by means of a pumping installation, or 2) to build a drainage tunnel.

In July 1919, some two months after the eruption, van Rummelen (1953, p. 8) drew up a project to drain the crater by means of siphons. On 19 July 1919 he mailed an official letter to the Minister for the Colonies on this matter. As a result, the Mining Department decided to have a drainage tunnel dug, because the crater was empty and they hoped to be ready before water in the crater could cause any danger.

In September 1919 the tunnel was started in the left wall of Lahar Badak at a height of 1110 m. H.G. von Steiger was charged with the execution. This project, however, had to be altered because of a lava plug which rose in the crater in December 1920. In March 1923 the lake water had already risen to 67 m above the level of the tunnel.

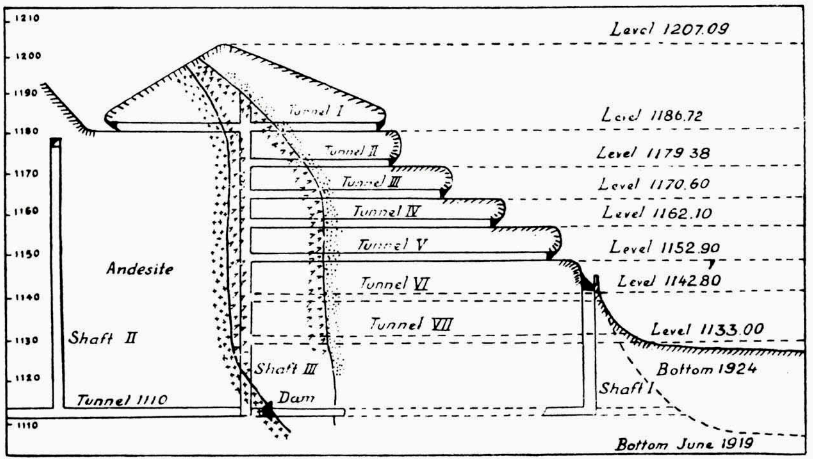


Fig. 7. The tunnels in the eastern crater wall of Mt Kelut (from van Hettinga Tromp, 1926; see also Stehn, 1929c, p. 19).

After a thorough geological survey by Taverne (1924b, pp. 51-67), H. van Hettinga Tromp (1926) worked out a project to lower the surface of the lake gradually by driving horizontal tunnels (Fig. 7) and to remove the water by means of siphons. The water level was so brought to a height of 1133 m a.s.l., leaving back 1.8 million m^3 of water in the crater, that was less than 1/20 of the quantity it could contain. Due to intercrateral downfall the water content was reduced to 1.6 million m^3 in 1936.

Together with Government Officials a 'Handbook for safety measures for the Kelut' was composed by Stehn.

On 31 August 1951, after a repose of 32 years, a new eruption took place. Since the quantity of water in the crater was small, no mud flows of any considerable size were formed. Damage was only caused by ejected material in the surroundings of the crater to a distance of 6 km, an area of virgin forest land. Only some people who happened to be near the summit were killed, among these three observers of the Volcanological Survey doing their duty (see van IJzendoorn, 1953; van Rummelen, 1953).

Mt Raung (6,3-34)

The ovally shaped crater had, according to the mapping of the Topografische Dienst (Ordnance Survey), a diameter of 2280 m in a NW-SE direction and of 1760 m perpendicularly to it. Brouwer (1915, p. 58) thought the 600 m deep crater to have orriginated by collapse.

Verbeek (1908) already remarked that the flows on the outer slope must have come from a higher point. This is in harmony with a legend (Stöhr, 1864, p. 452) that said that the summit had been much higher, which means that a catastrophic eruption must have taken place in historical times (see p. 9).

Brouwer (1914. 1915, pp. 60-65) described seven eruptions, those of 1597, 1638, 1730, between 1787 and 1799, between 1800 and 1808, 1815/ 1816, and 1849, all mentioned by Bosch (1858). Brouwer mentioned moreover the eruptions of 1864, 1881, 1896/97, 1902, 1903/04, and 1913. In 1913 a 100 m high cone was formed at the bottom of the great crater.

He examined the rocks of the volcano wall, which were olivinebasalt, pyroxene-andesite with olivine, augite-andesite, hypersthene-augite-andesite, and amphibole-hypersthene-andesite.

Taverne (1924b, pp. 50-51; 1925b, pp. 162-164) described the weak eruptions of 1923 and 1924. He was of the opinion that the mud flows that destroyed the village Tambon in 1638 came from Mt Ranti and not from the Raung as Bosch (1858, p. 279) asserted.

Richard (1935) succeeded in reaching the caldera bottom in June 1932. In August he mapped the region. The temperatures of the fumaroles were low, 92-128°C. The young volcanic cone which originated in 1913 and increased in height and diameter by the eruptions of 1927, 1928 and 1929, was situated somewhat excentrically to the east. In 1933 its height was about 110 m. The rock samples Richard collected were described and chemically analysed by Koomans (1935) as basalts and andesites.

In the western foreland of Mt Raung is a region with thousands of small hillocks. The highest part of the landscape begins in the horseshoe-shaped depression of Mt Gadung, a volcanic skeleton west of Mt Raung. Junghuhn (1853, III, p. 886) regarded these hills rightly to be remainders of erosion. Verbeek and Fennema (1896, p. 95) were of the opinion that they were hornitos, i.e. small lava cones built up on a lava flow (see also p. 17).

Kemmerling (1921e, p. 13) considered these hills to be monadnocks, i.e. remainders of an eroded peneplain, that existed before the origin of the volcanoes. With reference to the arrangement of the hills Neumann van Padang (1938b, and 1939a; see also van Bemmelen, 1949a, I, p. 194-195) argued that the collaps of the western sector of the above mentioned volcano caused a landslide that covered the landscape to a length of 50 km and a width of 10 to 20 km. The hillocks were the remnants of this landslide. Here therefore is a similar landsacpe as exists in the foreland of Mt Galunggung (see pp. 17, 34).

Telaga Bodas (6,3-15)

Taverne (1924a) who visited Telaga Bodas in 1923 was of the opinion that it formed a compound volcano with Mt Galunggung (6,3-14). He distinguished in Telaga Bodas four craters of which K.I till K.III originated by shifting from south to north. K.IV (Kawah Saat) south of K.I was the youngest eruption centre.

In an unpublished report of 1939 Neumann van Padang concluded on petrographic arguments that K.IV was situated in the crater bottom of the oldest Tjamar crater, as its rocks consisted of basalt, while the rocks of K.III consisted of the younger augite-hypersthene-andesite.

Ten years before Taverne visited the crater, Wolvekamp (1915) had to investigate if an eruption of this volcano could have the same catastrophic result as that of Mt Galunggung in 1822 (see p. 17). The volcanic activity was very low in 1913 and Wolvekamp even was of the opinion that the water of the crater lake could be used to irrigate the rice fields. A sample of the mud contained 36% of sulphur (see also p. 51).

In 1819 Reinwardt (1858) found much sulphur in the crater water, in 1837 the water was not very sulphureous (Junghuhn, 1854), in 1853 Maier found less than 2½% of S in the water. In 1918 a large part of the crater bottom was dry (Kemmerling, 1921d, p. 36) and the quantity of sulphur in the mud was great.

Mt Papandayan (6,3-10)

Taverne (1924b, pp. 36-40; 1925b, pp. 102-137; 1926) described the phreatic eruptions of Kawah Baru and Kawah Nangklak in the years 1923 till 1925.

According to Taverne (1926) the breach in the northeastern wall of the volcano originated by explosions of his crater K.5, which he supposed to have been behind the strongly weathered Warirang terrace, excentric of the present, still active crater. The valley in the northeastern wall he thought to have been already in existence. He rightly disputed the idea of Verbeek and Fennema (1896) that a lava lake in the crater would have destroyed the northeastern wall and caused the origin of the breach, as fresh lava was nowhere found in the valley. The opinion that glowing clouds killed 2957 persons in 1772, however, cannot be right, as no lavadome, necessary to form glowing clouds, or remainders of it are found in the crater.

For the participants of the IV Pacific Science Congress who intended to visit the volcano, Neumann van Padang (1929a, b) wrote the excursion guide. According to him the northeastern crater wall was weakened by NE-SW directed volcano-tectonic fractures, already observed by Verbeek and Fennema, and moreover by N-S directed ones. Long lasting solfataric activity and strong weathering undermined the region so much that explosions not stronger than the phreatic ones which took place in 1923-1925 (Taverne) were sufficient to cause the collapse of that part of the crater wall and mountain slope. These eruptions might have been in Taverne's K.5. Through this opening sulphur mud from the crater and strongly weathered white-coloured old lava bricks, rich in silicic acid, came down as an avalanche and caused the catastrophe.

Mt Galunggung (6,3-14)

The original crater of Mt Galunggung (van Es, 1924) was situated on the summit of the volcano. By shifting in a southeasterly direction crater II originated. It probably contained a lake, the water of which was thrown out by each eruption, forming a valley in the east-southeastern slope of the mountain, that gradually became deeper and larger. A renewed shifting in a southeasterly direction formed the Warirang crater or crater III.

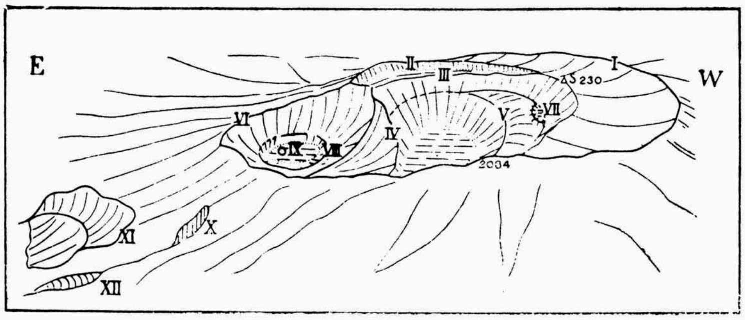
Van Es described the eruption of July 1918. Contrary to the opinions of Junghuhn and Verbeek & Fennema (see p. 17), van Es thought that an obliquely directed glowing cloud was shot through the horseshoe-shaped breach, destroying within one minute everything to a distance of 10 miles. In his opinion the destroyed region was indèpendent of the direction of the ravines. Therefore the destruction could not be explained by mud flows.

Escher (1925) made a thorough study of the 'dix milles monticules' in the foreland of Mt Galunggung. All these hills consisted of fine material mixed with small and big lava blocks. Of the 3648 mounts which Escher counted, 2571, that is more than 2/3 of them, were lower than 10 m, 6 between 50 and 60 m, and 2 had a height of 60 to 70 m. The content of all these hills together was 142 million m^3. The volume missing from the breach in the mountain was 2.866 km^3, i.e. 20 times as much. As the hillocks and their subsoil have the same composition Escher thought that they together are the equivalent of the failing part in the volcano wall, firstly formed by erosion and finally by a big landslide. This landslide happened when crater III destroyed the southeastern wall of crater II. The material of the wall together with the enormous quantity of water of the crater lake formed the landscape with the 10 000 hillocks. According to Junghuhn this happened in 1822.

Tangkubanparahu (6,3-9)

Taverne (1925b, pp. 174-193) described the crater and its eruptions which took place at intervals of 17, 50 and 14 years. So there was evidently no regularity. He distinguished four craters situated on a W-E directed line (1926, pp. 71-78).

In June 1924 three pupils of the H.B.S. (high school) perished in an erosion gully of the crater Kawah Ratu, presumably because of the inhalation of too much H_2S gas. One year later in this same crater the corpse of a man was found. That is why since June 1925 on all the approaches to the crater signs were placed to warn the tourists of the danger they could meet.



I Panggoejangan Badak -- crater.
II The oldest rim of Kawah Oepas.
III A younger rim of Kawah Oepas.
IV The oldest rim of Kawah Ratoe.
V The youngest rim of Kawah Oepas.
VI A younger rim of Kawah Ratoe.
VII Kawah Baree.
VIII The craterrim of Kawah Ratoe 1910.
XI The eruptionpoint of 1926 (Kawah Ecoma)
X Kawah Djoerig.
XI Kawah Domas, Kawah Badak, Kawah Djarian.
XII The „Death Valley" of Kawah Siloeman.

Fig. 8. The crater region of Mt Tangkubanparahu (from Stehn, 1929a, p. 10).

In the excursion guide Stehn (1929a) recognized two volcanic valleys (X and XII) and ten craters or their remnants (Fig. 8), of which the most western Pangguyangan Badak crater was the oldest one, as Taverne (1926) already stated.

Studying the geological history of this volcano and its environs van Bemmelen (1934a, fig. 22, 1934b, 1949a, p. 641) found that the young volcanoes of the Sunda Complex crowned the Bogor Zone, an anticlinorium of strongly folded Neogene strata. This Sunda Complex with Mt Tangkubanparahu collapsed after the accumulation of too much volcanic material on the plastic strata. This was historically the first case that Haarmann's (1930) gravitational tectogenesis, called secundary tectogenesis by van Bemmelen, was applied to the volcanoes of Java. Moreover, this explanation of the tectonic history of the Sunda Volcano Complex was the first application of the method of tephrachronology, i.e. chronology based on the study of successive deposits of volcanoclastics. Van Bemmelen (1934a, b) studied the relation between the folding phases of the Tambakan Mountains and the eruption products of Mt Tangkubanparahu and the Sunda Volcano during its break down. He distinguished four stages of evolution:

1) Quarternary growth of the volcano;
2) Slight doming up by endogenic magmatic forces at the end of the Quarternary;
3) First collapse in recent, prehistoric time; formation of the Lembang Fault;
4) Second collapse in historical time; formation of arcuate rifts through the summit.

In February 1937, a 30 m long tunnel shaped shelter was built in the southern rim of the Kawah Upas at a height of 1893 m. Its volume being 47 m^3, it had enough oxygen to keep 3 to 4 persons of the Volcanological Survey 16, respectively 12, hours out of danger.

Kawah Kamodjang (6,3-12)

Taverne (1926, pp. 27-30) described in detail the morphology of Kawah Kamodjang. He did not consider this solfatara field to belong to the Guntur complex, since it is separated from it by an old 2000 m high volcanic ridge, which was already changed by erosion.

Verbeek and Fennema (1896, p. 721) were of the opinion that Kawah Kamodjang was situated on the southeastern side of a caldera with a radius of 1900 m.

Stehn (1929b) described the fumarole fields and mud wells of this region. The temperatures found here were 90-94°C. In 1918 van Dijk proposed to gain energy from the volcanoes in the Dutch East Indies. This matter was critically discussed by Escher (1920d), Taverne (1925c), Stehn (1927b), and van Bemmelen (1928). In February 1926 test borings were started (Stehn, 1929b, p. 7). The boreholes I, II and IV were abandonned, borehole I because of the spurting mud well which originated close by. Borehole II touched a powerful blower at a depth of 18.60 m, but after closing the bore pipe the gases disappeared somewhere underground. Borehole IV was driven to a depth of 105 m. The temperature of the escaping steam was 140°C, but the pressure was very low and therefore the steam was useless.

Boring III near Kawah Panggilingan emitted nearly pure steam from a depth of 60 m with a pressure of 2½atm. The amount of steam streaming forth was calculated to be 8000 kg/hour, able to generate electric energy of 900 kw.

In September 1926 boring V was drilled to a depth of 128 m. Here the temperature of the gas was 123°C. In December 1928 the pressure of the escaping gas was about 5 atm, and the temperature was 140°C. The pressure and the temperature of the two successful borings III and V were taken daily until April 1934, when the observation station was temporarily closed. The temperatures were checked again in April 1938 and May 1939. Both had not altered much (Neumann van Padang, 1960b).

The investigations of the gases in Kawah Kamodjang showed that in 12 years of observation the temperature and the pressure of the gases in boring III were higher in the beginning and decreased but little since 1928. In boring V the temperature of the gases remained almost constant, the pressure however diminished considerably from 4 and almost 6 atm to ½ atm.

Mt Merapi (6,3-25)

The eruption of 1930 - The catastrophic outburst of Mt Merapi in 1930 was the cause that in 1931 and following years many articles appeared on this volcano (Escher, 1931a, c, 1933a; Grandjean, 1931; Harloff, 1931; Hartmann, 1933, 1935b, d; Kemmerling, 1931a, b). The great outburst was also described by Neumann van Padang (1931a, b, c, d; 1932, 1933a, 1958, 1960a), discussing several subjects connected with the eruption.

Shift of eruption centre - The shifting of the eruption centre in a westerly direction took place from 1883 till 1930 over a horizontal distance of 450 m. In 1883 a lava dome was observed in the summit. In 1911 another and higher one (West Dome) originated west of it at a distance of 130 m from the centre of the dome of 1883 (see Fig. 9). In 1922 lava broke through the volcano wall, 180 m

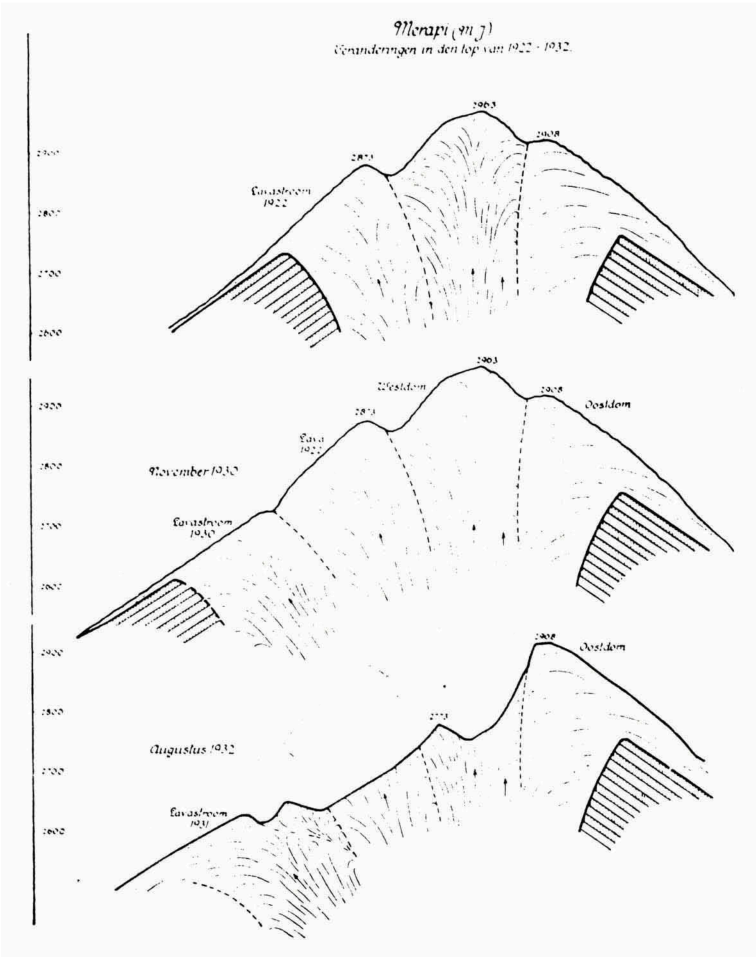


Fig. 9. Cross section through the summit of Mt Merapi, showing the dome of 1883 ('Oost-dom'), the West dome, the lava of 1922, the outflow of 1930, and the situation after the eruption of December 1930 (from Neumann van Padang, 1936b, fig. 5).

west of the West Dome, and in November 1930 the lava appeared on the western slope at a height of 2725 m, 450 m west of the first dome. Because of this shifting only the western slope and foot of the volcano were in danger of being destroyed.

The seismograph - The importance of a seismograph to predict an eruption shows part of the seismogram of 23-24 November 1930 (Fig. 10). It is registered by the Omori tromometer at the observation station Maron, 6 km WSW of the summit of the Volcano Merapi. After the micro-seisms in the first two weeks of November, on November the 22nd the first quake of importance took place, that was five hours before the first detonations were heard. The seismogram now became more turbulent. When the lava broke its way through the wall of the volcano, accompanied by detonations, roaring and avalanches, from 22 till 25 November the strongest tremors were registered. As soon as the glowing lava had appeared on the mountain slope, the tremors became weaker (Neumann van Padang, 1933a, p. 9-18, 1958, p. 113).

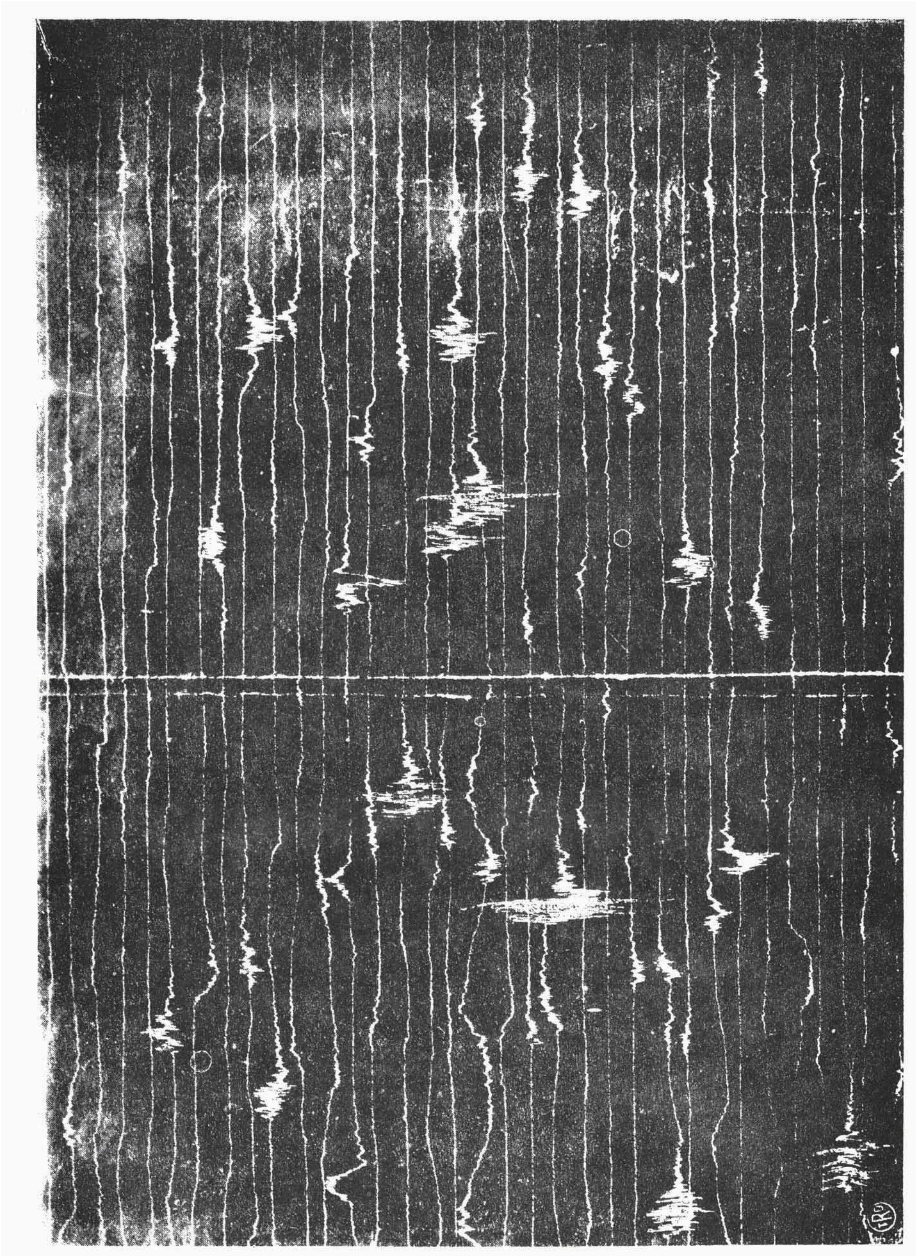


Fig. 10. Part of the seismogram of the Merapi on 23-24 November 1930 (from Neumann van Padang, 1933a, foto 2).

Four years later, on 17 November 1934, a very strong seismic restlessness started at 17.49 h on the seismogram of Babadan, the observation station 4 km WNW of the crater. That is why Stehn (1935a, p. 123) brought the observation posts Babadan and Krindjing into a state of alarm and warned the government and the population of the threatened regions that he expected an outburst. Because of the rain fall the volcano was invisible. All the attention therefore was concentrated on the vibrations of the seismograph and the sounds. At 18.18h a heavy roaring and thundering noise was heard. As it approached with great

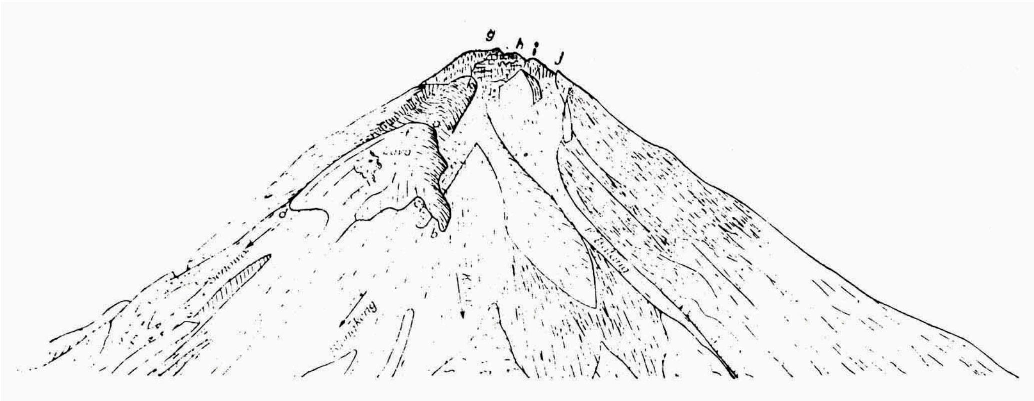


Fig. 11. The lava outflow on the western slope of Mt Merapi on 2 December 1930, seen from Maron (from Neumann van Padang, 1933a, fig. 1).

quickness the alarm signal was given that glowing avalanches came down. Within seven minutes they covered a distance of 7 km in the Senowo ravine. As the inhabitants had left in time the villages in the danger zone, no human lifes were lost.

The preliminary stage - The volcanic activity of Mt Merapi began in 1930 with a preliminary stage which lasted two and a half weeks. Than the main eruption took place during two days, followed by lava outflows during nine months. The existance of such a preliminary stage is important. It has been proven for all the studied great eruptions. This is of great importance, because it gives the staff of the Volcanological Survey time to take the necessary measures to warn the population of the menaced regions.

The glowing avalanches - Special attention was given to the problem of the nuées ardentes, a phenomenon Lacroix (1904) mentioned for the first time when he described the eruption of Montagne Pelée on Martinique in 1902. He was of the opinion that a cloud of gas, laden with volcanic ash and debris, was shot in a more or less horizontal direction with a of velocity about 150 m/s, reaching and destroying St Pierre at a distance of 6 km from the summit within 40 seconds.

During the activity of Mt Merapi in 1930 the glowing clouds were downwards rolling clouds which originated above avalanches of glowing magma debris, from which the comprising gases escaped explosively (Neumann van Padang, 1933a, p. 22).

In 1930 the new lava appeared on the volcano slope for the first time on November the 25th (Fig. 11). It flowed downwards slowly, whereby the lower edge crumbled and hurled down. In the first half of December about 6 million m^3 of viscous lava had appeared, having the shape of a large flat lava dome. On 18 December the increased activity began which lasted two days. Thick ash clouds were seen above the volcano. Between 8 and 9 o'clock the first glowing avalanches and clouds came down. In the following two days a 1350 m long breach was formed in the volcano wall. The glowing avalanches originated by the downfall of a great part of the new lava mass. They followed the 60 to 100 m deep ravines and their curves, while the clouds which developed by the explosions in the avalanches whirled on top of them and kept their own direction. In the curves they shot forward, dashed against the air in front of them, where they were hindered in their movement, and thus came sooner to a standstil then the heavy masses in the ravines.

The direction of the valleys was of paramount importance to the spreading of the material and the shape of the destroyed regions. Therefore it was possible to indicate on a map the regions that might be destroyed, so that the Government Officials could know from where the population had to be removed in case of danger.

Safety measures - The volcanic activity of November 1930 was immediately reported by the observation station at Maron. The inhabitants of the highest hamlets were advised to leave. In that area, therefore, the casualties were small. The eruption, however, was much greater than was expected, and the catastrophe took place in the lower regions, at 8 to 10 km distance from the summit, where 1369 people were killed. The 3000 fugitives were helped by the Government with accomodation, cloths, food, and household goods. A part of the population moved to other regions.

Observation station - Maron being destroyed, a new observation post was built at Babadan, 4 km WNW of the summit. From here the crater could be seen very well. By telephone the Director of the Volcanological Survey and the Government Officials could be informed of what happened. Subsidiary stations were established at Krindjing and Ngepos. A 'Handbook for the volcano station Merapi' was composed by Stehn (1935c), Director of the Volcanological Survey, together with Government and Army Officials. A new Handbook was composed in 1941 by van Bemmelen (1941).

Refuge tunnel - Near the station a bomb proof shelter in the form of a tunnel was constructed in which the personnel could find safety within 15 seconds. The inside of the tunnel, built of reinforced concrete, was 12½ m long and 2½ m wide and high. The entrance could be made air tight. By means of a peep-hole it was possible to establish if it was safe to leave the tunnel. Cylinders containing compressed oxygen made it possible to remain in the tunnel for a prolonged period. Water, food and tools were available. A seismograph was placed in the back of the tunnel (Neumann van Padang, 1933a, p. 110, 1960a, p. 187).

Maps of the menaced regions - In order to have an idea which regions were in danger when a major eruption would take place a map was projected on which they were indicated. Such a map for Mt Merapi was composed by Neumann van Padang (1933a, pl. I, 1958, p. 113, 1960a). Neumann van Padang (1937b, d) projected similar maps for the regions that were in danger when Mt Raung (6,3-34) had a catastrophic eruption, and for the foot of Mt Tjerimai (6,3-17).

Stehn (1936a, b) drew such maps with instructions what had to be done to safeguard the population at the foot of Mt Kelut (6,3-28) and Mt Semeru (6,3-30). Earlier Stehn (1930c, 1933a, b, 1934a) reported which practical utility the Volcanological Survey had had for the population of the East Indies.

Mud flows - Just as happened at Mt Kelut (6,3-28) the rains that fell during the months after the great eruption formed mud flows (lahars) that caused great damage at the foot of the volcano. Bridges were swept away, rice fields covered with sand and debris. Schmidt (1934) made a thorough study of these rain lahars and their origin.

Outburst of 1006 - Van Bemmelen (1941, pp. 70-72, fig. 17; 1949a, I, pp. 560-561, fig. 272) advanced volcanological arguments to prove the truth of the cataclysmic outburst of 1006 A.D. (see p. 7). He showed that the present summit of Mt Merapi is surrounded on all sides by an older part, deeply carved by erosion and built up of olivine-basalt, and presumably in later stages also of augite-hypersthene-andesites.

The western part of this volcano subsided with respect to the eastern portion along a number of arcuate, more or less hyperbolic slipfaults, which are concave to the west. The sliding movement was obstructed in the west by the buried edge of the Menoreh Mts. The Gendol Hills were caused by the crumpling of the foot of the older (11th century) Merapi. At the same time the central part of the older Merapi was destroyed causing the disaster in Central Java (see Fig. 12).

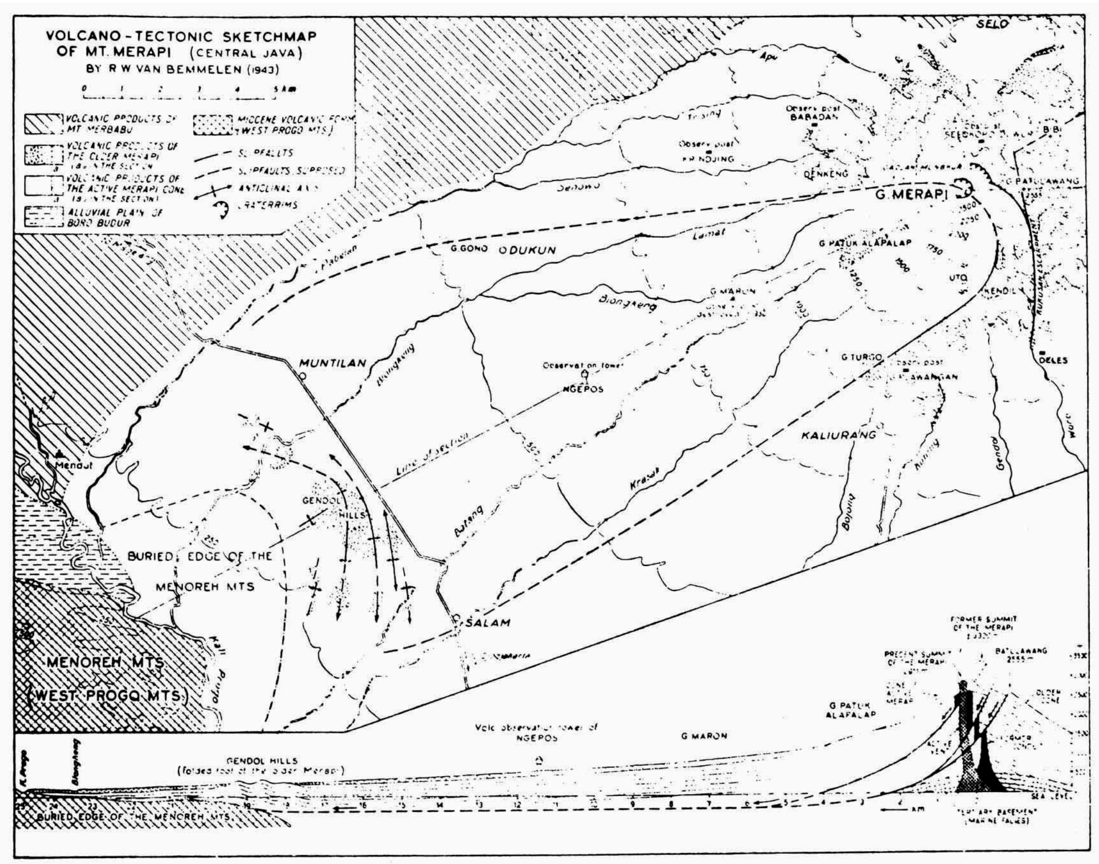


Fig. 12. Geological sketchmap and section of Mt Merapi and its western foot (from van Bemmelen, 1956, fig. 272, p. 561).

The present active Merapi cone rises above the ruins of the destroyed volcano. The amount of magma produced by the new volcano in the last century and a half has been estimated by van Bemmelen (1941, p. 71) to be about 1 km^3. If the mountain has maintained the activity in the last nine centuries, about 6 km^3 must have been produced during that time. This estimation accords fairly well with the present size of the active cone. Therefore it is quite likely that the older Merapi represents the remnants of the volcano destroyed by the terrific outburst in 1006 A.D.

VOLCANOES OF THE LESSER SUNDA ISLANDS

Mt Tambora (6,4-4)

Pannekoek van Rheden (1918) visited the volcano in October 1912 and August-September 1913 and mentioned its geographical position and height as it was ascertained by the 'Topographische Dienst' (Ordnance Survey). The 8747 Rhineland feet (2746 m) high mountain was situated at 8°14'30"S and 17°57'30"E. The highest part of the crater rim rose 2800 m, the lowest part c. 2500 m a.s.l. A stratovolcano with numerous adventive cones originated above a c. 1800 m high shield volcano (aspite). Pannekoek van Rheden estimated that the great eruption of 1815 had destroyed 30 km^3 of the mountain.

Petroeschevsky (1949) visited the volcano in May 1947. He repeated in detail what the former authors had written and calculated the total amount of ejected ash and pumice at c. 100 km^3. Junghuhn estimated it at 318 km^3 and Verbeek at 150 km^3 (see p. 20). These estimates were so different because:
1) the ash was spread over a very large, inaccurately fixed region, and
2) it happened 40 years before Junghuhn, 70 years before Verbeek and 130 years before Petroeschevsky made their calculations, so that personal opinions about thickness and extension of the deposit could not be avoided.

Mt Tambora produced pumice in large quantities comparable to those of Krakatau. Floating islands of pumice 3 miles long were observed in April 1815. Four years after the eruption these pumice islands still inconvenienced the navigation.

According to Petroeschevsky (1949, p. 696), the total number of victims was 92 000, i.e. 48 000 on Sumbawa and 44 000 on Lombok. This is more than assumed by Junghuhn.

In 1947 the diameter of the caldera was estimated to be 6 km, and the depth 600-700 m. Solfataric activity was almost exclusively located at the foot of the caldera wall, as Pannekoek van Rheden observed.

A. Kraeff (in Petroeschevsky, 1949, pp. 701-703) determined the rocks Petroeschevsky collected. They were olivine-basalts, leucite-basanites and leucite-tephrites already mentioned by Pannekoek van Rheden, and further glassy lava bombs rich in bytownite and biotite.

Neumann van Padang (1971) compared the catastrophic eruptions of Mt Tambora with similar eruptions of Krakatau and Santorini.
1) All three volcanoes have remains of former volcanoes, destroyed in pre-historic time. Here it is the Kadiende Nae Mountain (Pannekoek van Rheden, 1918, p. 120).

2) After a period of dormancy of many centuries, activity began again in 1812. Three years later the preliminary explosions began on 5 April 1815.
3) Then followed the catastrophic main eruption which took place from April 10 till 12th, followed by the collapse of the central part of the volcano and the formation of a caldera.
4) Pumice was produced in great quantities. Remarkably the pumice is not found in great thickness in the surroundings of Mt Tambora as was the case with Krakatau and Santorini.
5) The catastrophic eruption was accompanied by sea waves. They were small here as the Tambora caldera was formed above sea level.

Paluweh = i. Rokatinda(6,4-15)

Paluweh had a partly barren, partly wooded summit when Kemmerling saw the island, which was already mentioned on Portuguese sea charts. Francis (1856, p. 141) called it Luca Raja, Buddingh (1861, p. 279) Palowe. In August 1928 the volcano was in eruption. A great quantity of ash and pumice was thrown out (Stehn, 1928c, p. 75). From August till 29 September 1928 Neumann van Padang (1930) visited the island and mapped it.

Paluweh (see Fig. 13) culminates in the 875 m high stratovolcano Ili, situated excentrically on the southern half of the island. Several small adventive cones disturbed the regular feature of the crater region Rokatenda. In the collapsed area south of the summit, where the renewed activity took place, six ancient craters and three lava domes were found. Three new craters were formed south of the summit and around an old cone. On September the 9th a fourth crater originated.

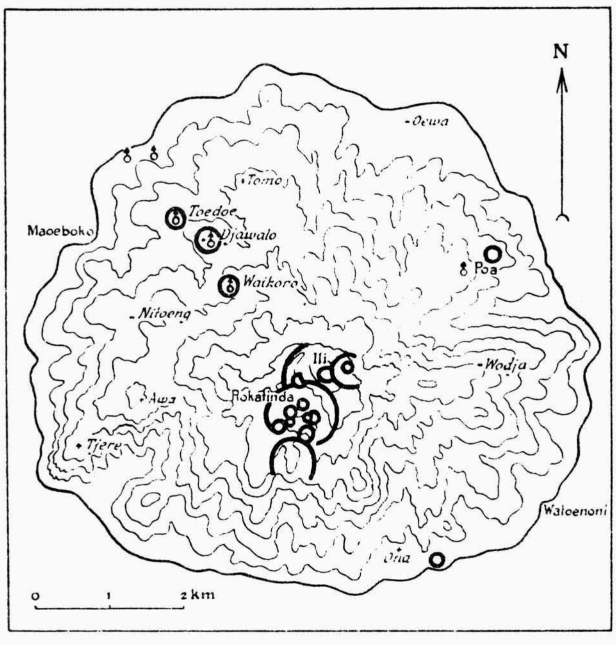


Fig. 13. The Island of Paluweh and its eruption centres (from Neumann van Padang, 1930, 16, fig. 5).

The eruptions of August 1928 were accompanied by sea waves, which overflowed the coast of the island itself to a height of 5-10 m and killed 128 people. The amount of ash and pumice, that destroyed the southwestern part of the island, was estimated to be 19½ million m^3, corresponding to c. 4.6 million m^3 of lava. In addition 8 million m^3 of lava formed a new lava dome.

Kemmerling (1927, 1929a, 1936) visited the volcanoes of Flores in 1924 and 1925 and described 14 volcanoes:

Wai Sano (6,4-6) - This is an elliptic lake situated in a 2½ to 3½ km large caldera. Solfataras were found there.

Potjok Leok (6,4-7) - It is an irregular caldera with fumaroles.

Inielika (6,4-9) - This is a volcanic cone rising from the bottom of the caldera Lobobutu. On the complex summit 10 craters were found. The only known eruption took place in November 1905.

Inieria (6,4-8) - The very regular, 2205 m high ash cone has a small crater. The pyroxene-andesitic lava was described by Pannekoek van Rheden (1913).

Ebulobo or Amburombu (6,4-10) - The volcano is principally built up of effusive rocks. A lava dome occupied the 250 m wide crater.

Iya or Endeh Api (6,4-11) - This volcano is situated at the extreme south of the peninsula of Endeh. Sulphureous gases rose in the rather deep crater. The rocks are hypersthene-andesites and hypersthene-basalts with or without olivine (Gisolf, in Kemmerling, 1929a, p. 123-126).

Sukaria (6,4-12) - The large caldera has a diameter of 8 km. It originated in a complex of several volcanoes (Fig. 14).

Kelimutu (6,4-14) - This volcano has three craters, each of which has a lake with a different colour, being blue, green and red. The green lake contained free sulphur, the red lake iron.

Egon (6,4-16) - It has a complicated summit consisting of a somma wall with a diameter of 1250 m. A lava dome formed the north side of the summit. In April 1925 the 200 m deep crater contained a shallow green lake.

Dobo - Kemmerling (1926a) mentioned the volcano Dobo as being active. This however was an error caused by a wrong communication.

Lewotobi Perampuan (6,4-19) - It has a truncated shape and is a twin volcano with Lewotobi Lakilaki (6,4-18), which has a pointed cone.

Leroboleng (6,4-20) - Its last eruption took place in 1881.

Stehn (1940) described his inquiries into the volcanoes Ili Muda (6,4-17), Lewotobi Lakilaki, Lewotobi Perampuan, Leroboleng, and Riang Kotang (6,4-21).

Fig. 14. The eastern part of central Flores, with the volcanoes Ia, the Sukaria Caldera and Kalimutu (from Kemmerling, 1929b).

Hartmann (1935a, c, 1936a, b) visited the volcanoes Batu Tara (6,4-26), Sirung (6,4-27), Ili Werung (6,4-25), Ili Labalekan (6,4-24), and Lewotolo (6,4-23).

VOLCANOES OF THE SANGIHE ISLANDS AND HALMAHERA

Mt Ruang (6,7-1)

Koperberg (1910, pp. 236-239) published his investigations on the activity of Mt Ruang, adding some notes on Api Siau (6,7-2) and Soputan (6,6-3). According to Koperberg parts of the edge of the lavadome of Mt Ruang tumbled down the mountain slope in 1870. Bergsma (1872, p. 260) mentioned strong eruptions on 27 August 1870, causing a great loss of houses, annimals and crops.

The next great eruptive activity took place from 22 till 25 April 1904 (Koperberg, 1910, p. 246). On 9 May 1904 there was a 300-350 m wide and 200 m deep crater in the summit. In the course of 1904 the volcano was repeatedly active. A new lava dome was formed from where a lavastream flowed over the southern slope as far as the sea. The lava dome was destroyed by violent explosions which set in on 29 May 1914 (Brouwer, 1916). A new crater was formed, which in July 1915 was 400 m wide and 150 m deep. Glowing avalanches on the eastern and southeastern slopes set the forest on fire. The lavas of Mt Ruang were remarkably uniform in character and composition. They were essentially hypersthene-andesites with occasionally olivine and amphibole. The lava of 1914 had a silica content of 57-60% SiO_2, and was less fluid than that of 1904.

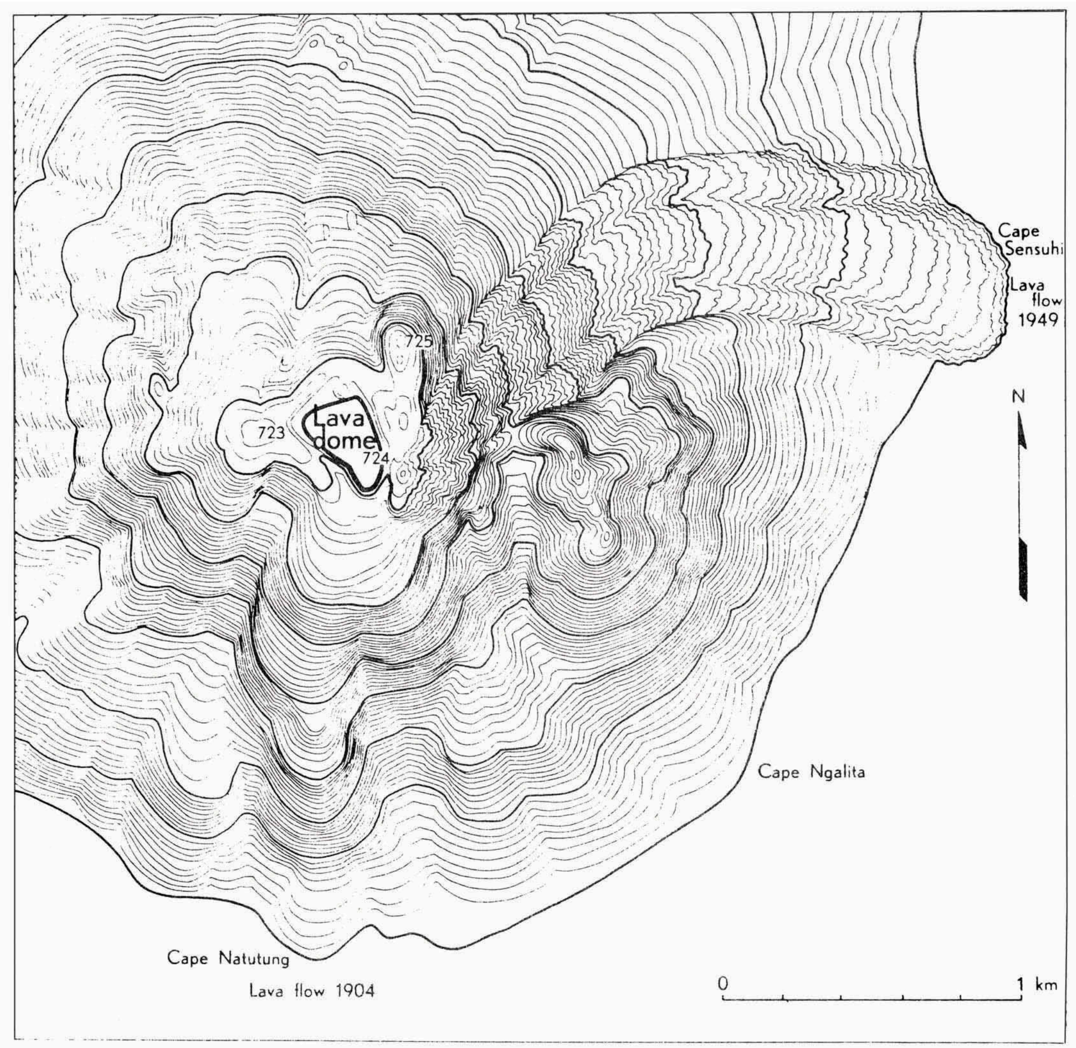


Fig. 15. The summit of Mt Ruang and the lava flow of January 1949 (from Neumann van Padang, 1959, fig. 5); contour intervals 10 m.

When Kemmerling (1923, p. 85) visited the crater in April 1921 he found it as Brouwer described it. The viscous lava built a dome, which at last flowed over the crater rim and came down the mountain slope very slowly, about 9 m per day. Kemmerling (1923, pp. 78-86) described and critically evaluated the descriptions of the 16 eruptions between 1808 and 1918.

In September 1946 Petroeschevsky visited the volcano. He found solfataras with a temperatur of 480°C in crater K3, and therefore expected a coming eruption. Since the activity of this volcano can be compared with that of Mt Merapi in central Java, the slopes and the foot of Mt Ruang were continually in danger of being destroyed. Consequently, Petroeschevsky advised the Government to declare the island unfit for habitation and to evacuate the 900 people who had settled there again after 1937 (Neumann van Padang, 1959, p. 113). The expected eruption took place nearly three years later, in January 1949. Stone eruptions were seen from 5 till 13 January, and on January the 19th a lava flow started to move in a northeastern direction (Fig. 15).

Fig. 16. The crater region of the Peak of Ternate in 1939 (from Neumann van Padang, 1951, p. 265).

Peak of Ternate = i. Gamalama (6,8-6)

This volcano was described by Gogarten (1918) and Kemmerling (1920). The 61 eruptions known till 1939 had changed the shape of the crater region. When Neumann van Padang (1951, p. 265) visited the summit in July 1939 the crater region was mapped again. In the southern part of a large 300 by 250 m oval crater K.1 (Fig. 16) a 180 by 140 m large and 90 m deep crater K.2 originated. North of K.2 two small shallow crater pits K.3 and K.4 were visible. A segment of an old crater wall was visible about 400 m south and 50 m lower than the above mentioned crater K.1, indicating that the volcanic activity moved in a northerly direction.

Makian = i. Kie Besi (6,8-7)

The island was mapped by Gaade (1925). The caldera, i.e. the southern crater of Verbeek (see p. 22), had a diameter of 1450-1500 m. Verbeek's northern crater, however, proved to be the upper part of a basin shaped valley.

Poei or Medja

Van Bemmelen (1949a, I, pp. 189-190) still mentioned Poei and Motir as active. Poei, however, is an entirely overgrown cone with a 200-250 m large and 25-30 m deep crater (Neumann van Padang, 1951). The eruption of 1671 related to this volcano by Veth (1876), Wichmann (1891) and Pannekoek van Rheden (1920) was according to Kemmerling (1929a, p. 52) one of Mt Iya. Forrest (1779, p. 39) mentioned an eruption of the volcano of Motir, but Gogarten (1918, p. 157) and Petroeschevsky, who visited the volcano in March 1949, declared the volcano to be entirely extinct.

UMSINI

When Feuilletau de Bruin (1936) visited the solfataras in the crater of the Peak of Ternate in 1915 his porters told him that similar fumes occurred in a basin of Mt Umsini in the Arfak Mountains of New Guinea. That is why Stehn (1936a, p. 6) added Umsini as volcano no. 114 to the list of active volcanoes, although with a question mark. Wichmann (1899, p. 141) already considered Umsini to be a volcano which presumably had an eruption in May 1864, but later on (1925, p. 87) he denied the existence of this volcano.

Van Bemmelen (1949a, I, p. 388) was of the opinion that the volcanic Ternate Zone geotectonically could be traced eastward along the northern edge of the Vogelkop (Birdhead) in the Tamrau-Arfak range with the Umsini volcano. This volcano was listed as 6,9-1 in the Catalogue of the active volcanoes of the World (Neumann van Padang, 1951). Hédervári (1976a, b) thought that 'if the underthrusting of the oceanic lithosphere is really in progress along the northern and northeastern coast of Birdhead Peninsula, as it is suggested by Hamilton on his tectonic map of 1974, then the possibility for the existence of volcanoes in the N and NE part of Birdhead Peninsula is given.' In April 1954 J.L.H. Bemelmans, however, communicated in a lecture at Delft that he tried in vain to find this volcano, and on aerial photographs no cone or crater was visible in the Arfak Mountains. Sumadirdja (1977) wrote that there was a height Umcina at 1°05'S - 133°57½'E in the Arfak Mts but there was no volcanic activity and Sumartadipura (1977) stated that no volcanic formations were visible on the aerial photographs of 1959. That is why this 'volcano' has to be deleted from the list.

TEMPERATURES IN THE CRATER REGION

The Volcanological Survey in the former Netherlands East Indies had the aim to protect the population against the danger caused by volcanic eruptions. The phenomena studied at volcanoes with recent eruptions were important because of the fact that they might give information of a coming eruption. The general opinion has always been that one of the preliminary events of an eruption consists of an increase in temperature of the solfataras in the crater region (Sapper, 1931). Such a rise would have been a simple, clear and useful indication of an approaching eruption. Then the Volcanological Survey could warn the population at the foot of the volcano in time for a coming danger. That is why the temperatures of the solfataras of several volcanoes of Java were regularly measured. The above mentioned supposition, however, appeared not to be true. In all the cases the temperatures of the solfataras had been controlled, no rise was observed in the period before the volcano had an outburst.

Mt Papandayan (6,3-10) - The phreatic eruptions of Mt Papandayan in 1923-1925 have been studied by Taverne (1924b, 1925b, 1926). Since 1920 the temperatures of the fumaroles were regularly measured. No relation could be found between the important fluctuation of the temperatures of Kawah Mas or the other fumaroles in the crater of Papandayan and the explosions of 1923 till 1925 in Kawah Baru and Kawah Nangklak.

Mt Merapi (6,3-25) - Since 1924, though with intervals of many months, the temperatures of the solfataras in the summit of the volcano were controlled regularly (Neumann van Padang, 1933a, 1963a). To get a good idea of the changes of the temperatures they were put in a graph (1933a, pl. II).

The temperatures of the solfataras of the East summit dome fell from 260°C in 1924 to 150°C in 1930. Those of the West dome, west of the East dome sank from 210°C in 1924 to 95°C in 1930, and so on. The strong rise in temperature in the Batang region in June 1925, when a temperature of 700°C was measured and at the same time many other solfataras in the summit were very hot, did not lead to an eruption. The eruption of November 1930 (see p. 36) began when most of the temparatures at the top were very low (45-170°C), with exception of those in the Senowo breach, where a temperature of 600°C was found since 1927.

After a repose period of 9 years Mt Merapi erupted again in December 1939 (Stehn, 1939a, p. 2, table 3; Neumann van Padang, 1963a). In general the temperatures had decreased since Ocober 1938, and a few days before the new eruption cycle, which lasted from December 1939 till September 1940, all the temperatures were very low.

Mt Slamet (6,3-18) - The summit of Mt Slamet is occupied by one crater and three old crater rims. Several fumaroles with temperatures of 60 to 95°C were found in the steep northern crater wall K.2 at a distance of 400 m from the centre of the active crater K.4 and 200 m from its northern wall. Neumann van Padang (1933c, 1963a, p. 332) published a table with the temperatures of these fumaroles from 1923 till 1932 and the data of the eruptions in this period. The temperatures were sometimes lower, sometimes a little higher. No relation could be found between the temperatures and the eruptions.

Anak Krakatau (6,2) - The activity which ended on 17 February 1932 was followed by a repose period of nine months. From 9 to 12 November the island was surveyed and mapped (Stehn, 1932a; Neumann van Padang, 1933b). The crater lake had a length of 400 m, a width of 125 m and a depth of only 4.10 m. No traces of fumarolic activity were found along the border of the lake, no ebullitions were seen in the water. At a depth of 20 cm in the sand near the lake a temperature of only 31°C was found.

Two days after the inspection, on November the 14th, 100 to 300 m high eruption clouds were reported. This eruption phase lasted till December, but it was followed by nine other phases till June 1934. In May 1933 the ash clouds reached a height of 6800-7000 m (Stehn, 1933a). This very strong period of activity began without a perceptible increase of temperature in the crater region.

From 1-7 June 1939 Anak Krakatau had a weak volcanic activity (Stehn, 1939b, p. 22). From June 14th till 17th the island was surveyed by personnel of the Volcanological Survey. Dense steam was still rising from the crater lake on June the 14th. The next day the lake had a temperature of 55°C. On the day that followed, the temperature of the lake water had fallen to 47°C. The gas ebullitions were less. On June the 17th the temperature of the lake water was 30°C. Gas ebullitions were feeble. It is worth mentioning that it had not rained during that time, so that this fall in temperature was not caused by rain water.

At 16 o'clock of that day the surveyor Umar Ali had a look at the crater. There was no steam nor gas ebullition to be seen. So he continued to work. About one hour later the magnetic needle of the boussole tranche montagne began to swing to and fro. This suspicious phenomenon was the reason why he packed the instruments at once and why the observer and the personnel fled to the motor boat which was waiting near the coast. Then the first eruption clouds rose from the crater, followed by others. Bombs, ashes and hot gases covered the island, so that the surveying personnel left Anak Krakatau just in time. This new phase of strong activity had eruptions that reached a height of more than 3000 m. Again we see that the activity did not begin with a rise of temperature, nor with an increase of fumarolic activity.

Recapitulating we see that eruptions of Mt Merapi, Mt Papandayan, Mt Slamet, and Anak Krakatau were not preceded by an increase in temperature of the crater fumaroles.

At the I.U.G.G. Congress at Berkeley in 1963 Dr G.A. Taylor remarked that the eruptions on New Britain in 1941 were neither preceded by rising temperatures. No change occurred in the temperatures of the crater of Mt Matupi (5,2-14) before it erupted. At the volcano Langilar (5,2-1) the temperatures were almost constant during the six months period of observation in the year it erupted in 1954 (Neumann van Padang, 1963a, p. 336).

SULPHUR IN INDONESIA

The results of the inquiry into the quantity of sulphur that occurred in the craters of the volcanoes of Indonesia was published anonimously in 1925. Sulphur-containing volcanoes on Java were Kawah Putih (6,3-7), Tangkubanparahu (6,3-9), Telaga Bodas (6,3-15), Kawah Karaha (6,3-16), Papandayan (6,3-10), Tjerimai (6,3-17), Diëng (6,3-20), Welirang (6,3-29), and Kawah Idjen (6,3-35). In Sumatra much sulphur was found in the crater of Sorikmarapi (6,1-12). Van Bemmelen (1949a, II, pp. 179-185) gave a review of what is published about sulphur.

That Kawah Putih, one of the craters of Mt Patuha, contained much sulphur was already known in 1707 (see p. 10). Reinwardt (1858) found here a bluish lake with deposits of sulphur, Junghuhn (1854, IIII) only wrote that the lake was copper green and yellowish. Verbeek and Fennema (1896, II) found the bottom of Kawah Putih on 13 June 1887 covered with a shallow lake, which was white because of sulphur, and the water of which tasted of alum. A rather strong ebullition of gas was visible in the western part. Van Bemmelen (op. cit. p. 182) mentioned the occurrence of a deposit of sulphureous mud corresponding with c. 500 000 metric tons (= 500 Gg) of pure sulphur in 1925. After exploitation by the 'Zwavelonderneming Kawah Poetih' there were still c. 30 Gg in 1941.

The sulphur content in the crater of G. Tangkubanparahu was of minor importance (14 Gg of S).

Telega Bodas contained a sulphur mud deposit similar to that of Kawah Putih. The last exploration has demonstrated the existence of about 300 Gg.

The mud in the craters of Mt Diëng proved to contain c. 150 Gg of S.

In the crater of the 3156 m high Mt Welirang sulphur occurred as incrustations of solfataras. Natives exploited it, but only small quantities could be won (Hartmann, 1932).

Of Kawah Idjen the available quantity amounted to about 60 Gg of sulphureous mud corresponding with 36 Gg of S.

The only known sulphur deposit of Sumatra is situated in the crater of Sorikmarapi (6,1-12). According to the investigation of the Netherlands Indies Government in 1920 there were 220 Gg of sulphur mud with an average of 56% of S and 320 Gg of sulphur mud with an average of 27% of S. Moreover, on the northeastern slope of the volcano 14 Gg mud with an average of 93% of S was found. Kemmerling (1921a, pp. 51-76), who visited the crater in August 1918, already mentioned the great quantity of sulphur, which he estimated to be 1½ million kgt.

In Celebes (Sulawesi) considerable deposits of sulphur mud were found in Kawah Masem - a crater of Mt Soputan (6,6-3) -, Batuh Kolok (6,6-5), and G. Mahawu (6,6-11).

Molengraaff (1918) mentioned a sulphur deposit of some importance on Pulu Damar (6,5-4).

The total reserves of sulphur in Indonesia (van Bemmelen, 1949a, II, p. 179) amount to:

Java	600 Gg,
Sumatra	250 Gg,
Celebes	150 Gg.

BELT OF ACTIVE VOLCANOES

Kemmerling (1926a) published a list of 90 active volcanoes which he divided in: A) volcanoes with eruptions known in historic time, and B) volcanoes in a fumarole stage.

They are found on the rim of a large continental shield. In 1912 Molengraaff for the first time distinguished in the East Indian Archipelago two stable regions and a labile region with a strong relief of the sea bottom between them. One of the stable regions is the above mentioned continental shield, formed by the continuation of the Asiatic continent. The volcanoes are situated in a small strip (Fig. 17) on the west side of Sumatra to the island of Krakatau. Here it bends to the east and runs over Java and the Lesser Sunda Islands to the Banda Archipelago, where it curves first to the north and then to the west. In 1922, Molengraaff explained this arc of the Banda archipelago by the drift in a northwestern direction of the Australian continent. The length of the volcanic zone is about 4700 km, i.e. a distance from Madrid to the Urals.

Van Bemmelen (1951, p. 18) considered this volcanic belt to be one of the geotumors, which originated between the Sunda mainland and the Indian Ocean. The geanticlines formed mountain chains and island arcs with geosynclines or basins between them. West and south of this Sunda Land is a backdeep, the oil-bearing basins of East Sumatra and North Java, followed by the above-mentioned volcano belt of Sumatra and the geanticline south of Java. Outwards follows an interdeep, the non-volcanic outer arc (including the islands west of Sumatra), the foredeep, and finally the 'foreland' formed by the bottom of the Indian Ocean, and farther to the east the Australian Continent.

Escher (1933d, pp. 682-683) argued that considerable plutonic chambers are necessary to get volcanism. These chambers can only be expected where tension prevails in the earth's crust, formed by vortex currents in the substratum.

About 400 km N of the eastern end of this belt there are two volcanic zones: the eastern Halmahera zone with a length of 200 km, and the other, c. 400 km long, beginning in the Minahassa (North Celebes) and running over the Sangihe Islands to the volcanoes of the Philippines.

Stehn (1927a) published a list of 103 active volcanoes, 13 more than Kemmerling (1926a) did. These were 60 A and 43 B volcanoes. In 1936 (Stehn, 1936a) appeared a corrected and more extensive list. The number of active volcanoes had risen to 125. Moreover group B was subdivided into B - volcanoes in a fumarole stage, and C - solfatara and fumarole fields. The archipelago had 76 A, 29 B and 20 C volcanoes.

Van Bemmelen (1943a, p. 5-14) listed 130 volcanoes: I numbered consecutively, II tabulated geographically and III alphabetically. His volcanoes no. 63 Poei or Medja and no. 101 the volcanic island Motir, however, are extinct ones (see p. 48).

Petroeschevsky (1943) published a register of the activity of these volcanoes from the year 1000 till 1941. Since 1841 there were 1007 volcanic eruptions, that is an average of 10 volcanoes in eruption in one year.

Neumann van Padang (1951, p. 262) called Telaga Ranu caldera (6,8-5) Todoko volcano after its southern summit, as Stehn (1936a, p. 6) and van Bemmelen (1943a, p. 11; and 1949a, I, p. 189) had done before, but according to Verstappen (1964, p. 309) Telaga Ranu and Toduku (6,8-5a) are two separate

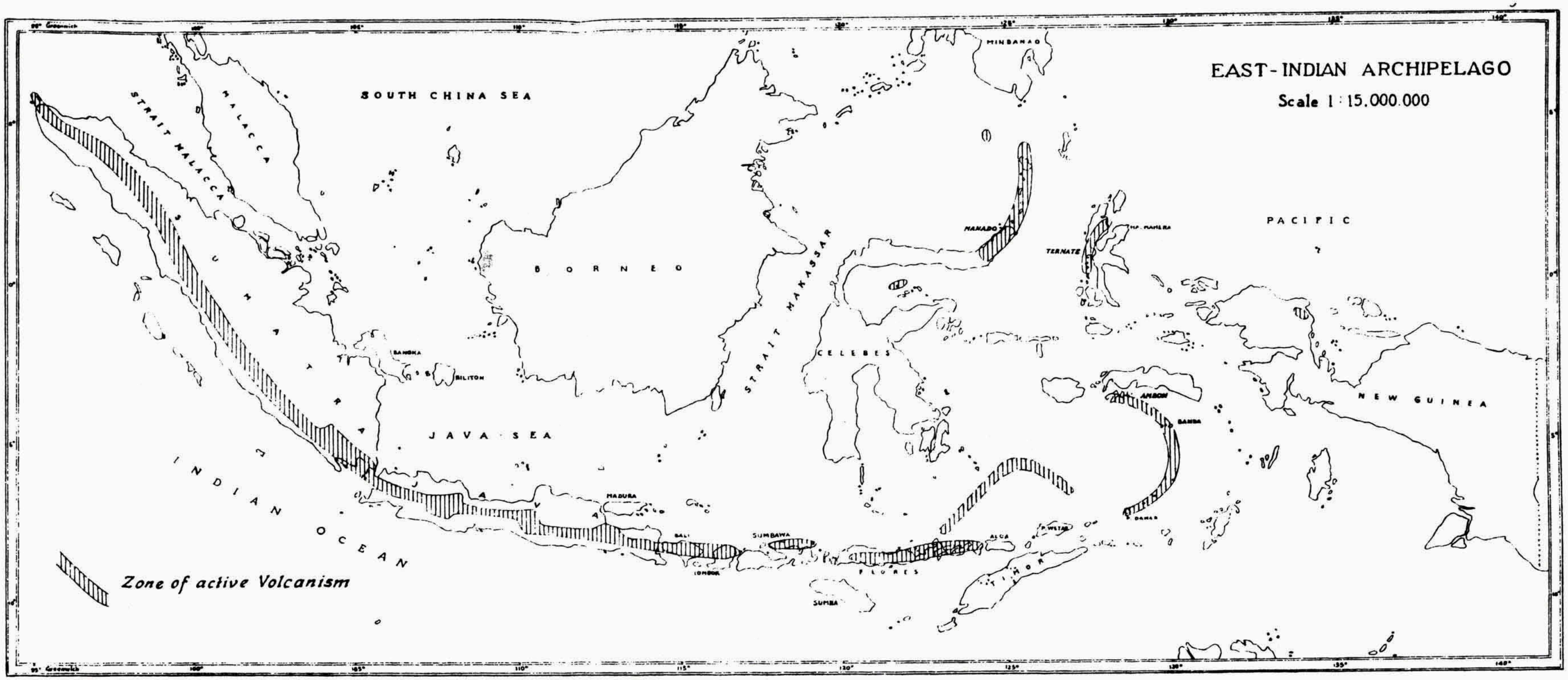


Fig. 17. Belt of active volcanoes in Indonesia (from van Bemmelen, 1943b, fig. 2; see also 1949a).

volcanoes. In view of the solfataras found in the 2 km large caldera, Toduku is to be considered a B-type volcano.

PHREATIC ERUPTIONS

Butak Petarangan (6,3-19) - Violent shocks in 1928 at the southern foot of Butak Petarangan formed cracks, which were followed by mud and stone eruptions. Three vents with a diameter of 10-20 m originated. A great part of the hamlet Timbang was destroyed (Stehn, 1928a, p. 59). Highly concentrated suffocating gases flowed out from the craters.

In October 1939, the same region was affected by earthquakes followed by mud eruptions (van Bemmelen, 1949a). The explosion holes originated on N-S directed open fissures, in which the surface water sank to a great depth, where it exploded. Horsfield (1816b, p. 281) already mentioned mud eruptions of the volcano 'Boedak', in connection with earthquakes and cracks in the earth.

Pematang Bata (6,1-27) - Enormous phreatic eruptions took place in the Suoh plain in South Sumatra (Stehn, 1933f, 1934b). This square shaped marshy plain was geologically mapped by van Bemmelen (1933). It was a volcano-tectonic depression surrounded by faults. Along the northwestern boundary hot springs and solfataras were found. Near the spot called Pematang Bata, in July 1933 two large explosion craters originated, one being 1½-2 km large, the other ½-1 km. More than hundred smaller explosion craters were encountered over a length of 5 km and an average breadth of 1½ km. The mud was thrown up to a height of 1100 m. The wooded plain was changed into a barren, mud-covered field.

This phreatic activity was also preceded by an earthquake, which had split the bottom of the Suoh plain. Water of the marshy field sank in the fractures to a depth where it came into contact with layers heated by the underlying magma. The water turned into steam and escaped explosively.

THE CALDERA PROBLEM

In the years before and after 1929, the problem of the origin of calderas was the topic of lively discussions among the Dutch volcanologists.

Akkersdijk (1929) was of the opinion that:

1) The Tengger Caldera consisted of one main volcano with several adventive cones.
2) During a violent outburst the summit had collapsed forming a large caldera including the Valley of Sapikerep.
3) A group of nested volcanoes had re-occupied the caldera and the valley of Sapikerep.
4) A second violent outburst formed the present Sandsea caldera and the Tjemorolawang ridge.
5) Finally the present group of nested volcanoes in the Sandsea Caldera was formed and the Valley of Sapikerep originated as well as the basin of Ngadisari (see Fig. 18).

Escher (1927, 1929, and 1930) thought the Tengger Caldera to have originated by coring out of a central vent by the action of an ashladen gasstream dur-

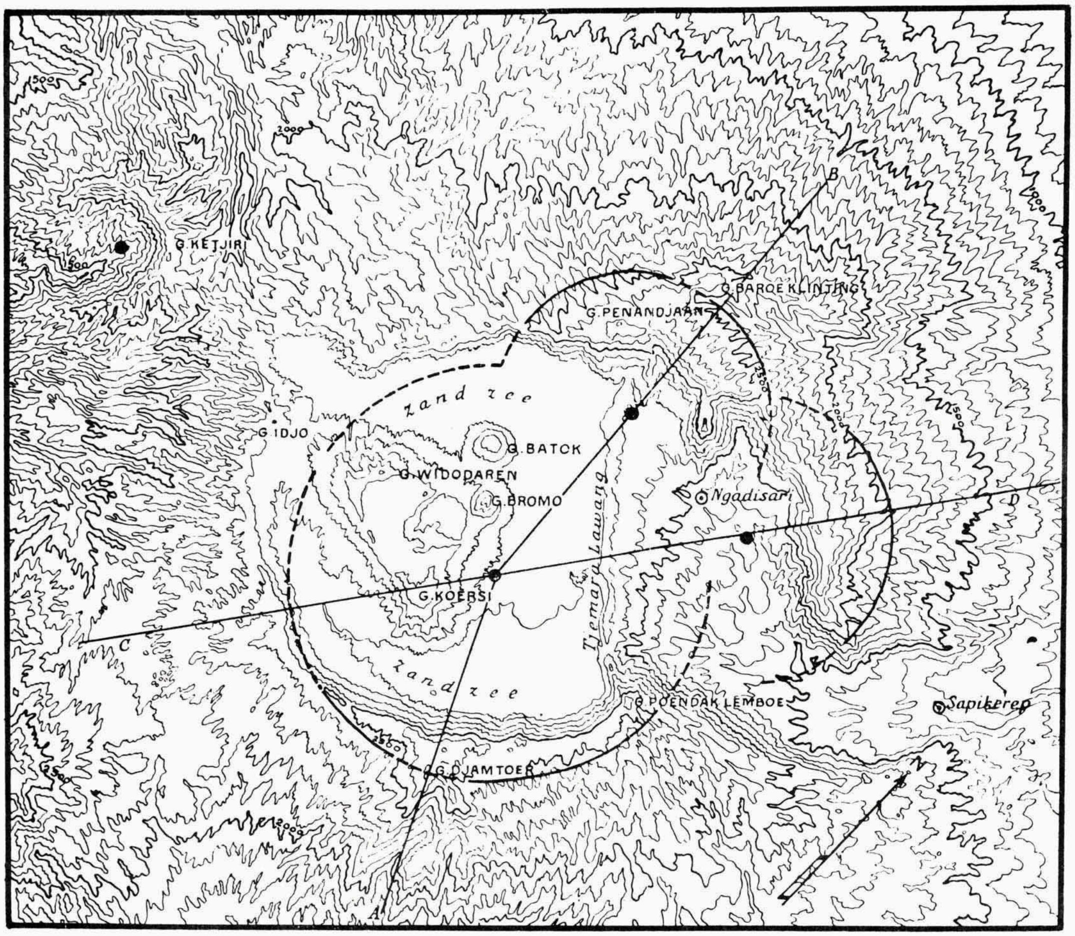


Fig. 18. Map of Mt Tengger and the shape of the calderas according to Escher and Akkersdijk (from Akkersdijk, 1929, fig. 1).

ing the intermediate gas phase as Perret (1924) described from the eruption of Mt Vesuvius in 1906. Escher thought a cylindrical vent with a diameter of 1 to 2 km and a depth of 15 to 50 km could form a caldera of 10 km in diameter and 250 m deep after the walls had crumbled off and filled the vent. He (1927) distinguished six stages in explaining the origin of the Tengger Caldera.

A) Origin of a twin volcano, as Verbeek and Fennema supposed.
B) Formation of the valley of Sapikerep by erosion.
C) A gas phase in the eastern (Ngadisari) crater which formed a steep, funnel-shaped vent, and ended in the formation of a caldera.
D) A funnel-shaped vent was blown out in the western crater, ending in the formation of the Sandsea Caldera.
E) Lava in the western caldera flowed through the eastern caldera into the Valley of Sapikerep.
F) Finally erosion altered the shape of the Valley of Sapikerep and secondary cones originated in the Sandsea Caldera.

Van Bemmelen (1929, 1930, 1931, 1932) objected in general the theory of the Perret phase as a possibility to form a caldera because of: the scarcity of old material in the ejectamenta, the improbable excessive length of the vent, the ineffectiveness of the coring out mechanism for great dimensions. Moreover, this hypothesis only explains calderas of the central type.

According to him the hollow form of the surface could be explained better by collapse. During the paroxysmal eruptions huge amounts of magma were blown out. The removal from the magma hearth occurred quicker than the refilling from deeper sources. Consequently, the roof of the magma chamber was deprived of its support and collapsed. Already Verbeek was of the opinion that the Krakatau caldera originated by collapse (see p. 15).

Sandberg (1927, 1930a, b, 1931, 1932) defended the theory that calderas and craters were genetically the same phenomenon. Van den Bosch (1929, 1930, 1931) also took part in the discussion on the origin of calderas.

SUBMARINE VOLCANOES

Nieuwerkerk (6,5-2), Emperor of China (6,5-1), Yersey (6,4-28) - In September 1925 broken water was seen at the place where Nieuwerkerk was inserted as a coral reef in the sea chart no. 112 of 1893. Because of the soundings conse-

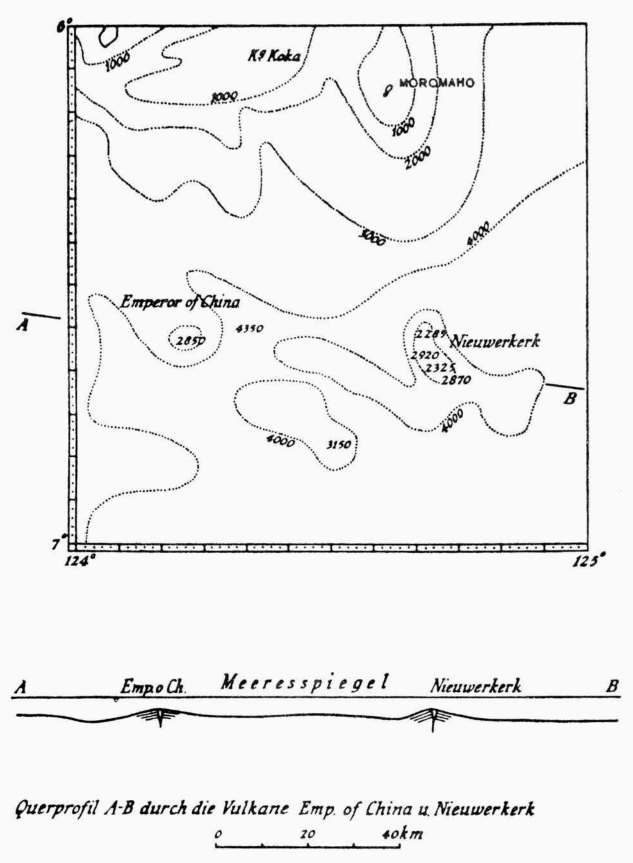


Fig. 19. Sea chart with the submarine volcanoes Nieuwerkerk and Emperor of China (from Neumann van Padang, 1938a, p. 80).

quently carried out at this place, which showed a depth of 2300 m, this reef was expunged from the sea chart of 1927. Boerema (1930) was of the opinion that the disturbance could only have been caused by the activity of a submarine volcano. Stehn (1930b, p. 147) accepted this opinion and put this spot, and those of the 'coral reefs' Emperor of China and Yersey, in his list of active volcanoes. A few years later soundings were carried out by the Snellius Expedition; van Riel (1934) found at these places, where 37 years before coral reefs were inserted in the sea chart, submarine mountains rising 1500 to 1900 m above their surroundings (Fig. 19).

Drawing cross sections through these submarine mountains for his descriptions of the submarine volcanoes of the world, Neumann van Padang (1938a) found that Emperor of China gave the impression of being a shield volcano, whilst Nieuwerkerk appeared to be a twin volcano (Fig. 20), of which the summits rose at a mutual distance of more than 7 km from each other.

Banua Wuhu (6,7-3) - is a submarine volcano west of the Island of Mahengetang. Its eruptions formed a 90 m high island in 1835, but only a few rocks were left in 1848 (Wichmann, 1898). The volcano also had eruptions in 1889, 1895, 1904, and from July 1918 till April 1919. The 70 m long and 12 m high island of 1919 (Brouwer, 1921a; Kemmerling, 1923) had disappeared before 1935. Wichmann (1898) and Brouwer (1921b) made a study of the rocks, which were a hypersthene-andesite and a hornblende-andesite.

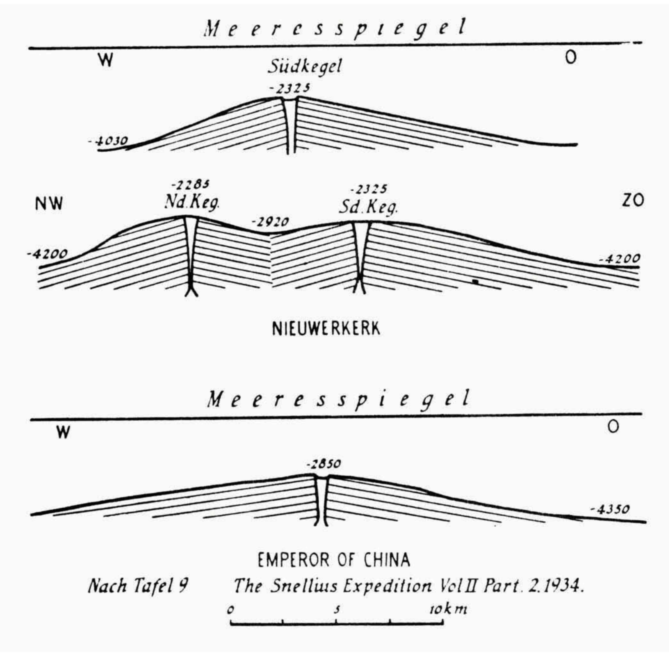


Fig. 20. Cross section through the volcanoes Nieuwerkerk and Emperor of China (from Neumann van Padang, 1938a, p. 80).

CHEMICAL DIFFERENTIATION OF THE VOLCANIC ROCKS

Paluweh (6,4-15) - The rocks collected on the Island of Paluweh were studied by Esenwein (1930). The chemical analyses and the Ls-, Fs- and Qs-diagrams of the examined samples showed the rocks of Paluweh to belong to a relatively little differentiated volcanic series.

The most recent lavas, hornblende-hypersthene-vitrophyre-andesites with 59.06 to 60.08% SiO_2, were clearly richer in SiO_2 than the older lavas which are hornblende-augite-hypersthene-basalts with 48.58 to 58.34% SiO_2 (Fig. 21).

Mt Diëng (6,3-20) - Umbgrove (1929) established the relative age of the volcanoes of Diëng by comparing their contacts. He concluded that G. Prahu and G. Bismo were the oldest volcanoes, then G. Srodjo originated, followed by the volcanoes Pagerkandang and G. Pangonan, and finally the volcanoes Prambanan and Pakuwodjo-Kendil came into existence. Neumann van Padang (1936a) examined the age by studying the petrographic and chemical composition of the rocks and came practically to the same result (Fig. 22). The most ancient layers consisted of basalt with 51.19% SiO_2; they are found in the wall of Telaga Mendjer. Afterwards the andesites with olivine crystals of G. Bismo originated, which are slightly richer in silica. The cones of andesite without olivine followed, found in Pagerkandang (53.08% SiO_2), Pangonan (55.64% SiO_2) and G. Srodjo (55.76% SiO_2).

Northwest of and a little outside the Diëng Mts originated the Butak Petarangan volcano, consisting of andesite with hornblende crystals (57.5% SiO_2). The volcanic cones G. Kendil and G. Pakuwodjo, of which the latter still had an eruption in 1826, were the last to develop. Their lava consists of biotite-andesites with 60.48% and 62.93% SiO_2.

The successive volcanoes of the Diëng Mts thus in the course of time became richer in silica.

Mt Slamet (6,3-18) - The rocks of Mt Slamet consist of olivine-basalt. They were studied microscopically and chemically by Neumann van Padang (1939b). The chemical analyses showed that: the ancient lava flows were poorest in silica with

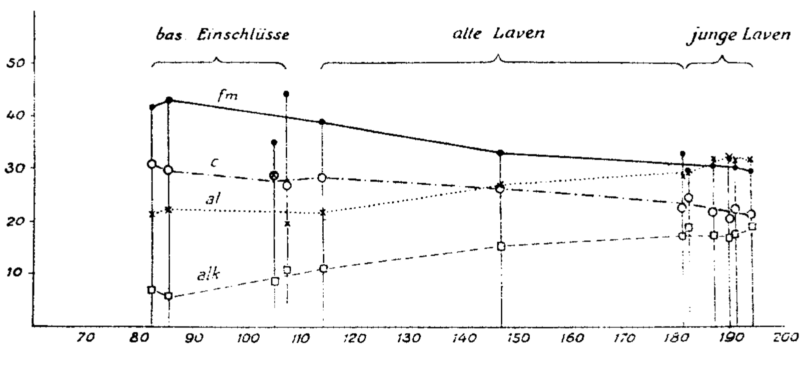


Fig. 21. Chemical differentiation of the rocks of Paluweh (from Esenwein, 1930, fig. 7 p. 134).

Fig. 22. The Dieng Mts (from Neumann van Padang, 1936a, fig. 1).

48.98 to 50.48% SiO_2, the lavas of the summit contained 52.28-52.77%SiO_2, the lava of the 1932 eruption was richest in silica with 54.06% SiO_2. The magma differentiation of this volcano had the same trend as that of Paluwah and the Diëng Mts.

G. Talakmau - This compound volcano (Fig. 23) was visited by Neumann van Padang (1940, 1951, p. 22) in March 1938. By studying the rocks of the different summits he found that the rocks of the morphologically youngest eruption centre, lava dome C, were richer in silica (61.40% SiO_2) than the rocks of crater B (59.69% SiO_2), while the rocks of the morphologically oldest crater A had the least SiO_2. Here also, the magma became richer in silica in the course of time.

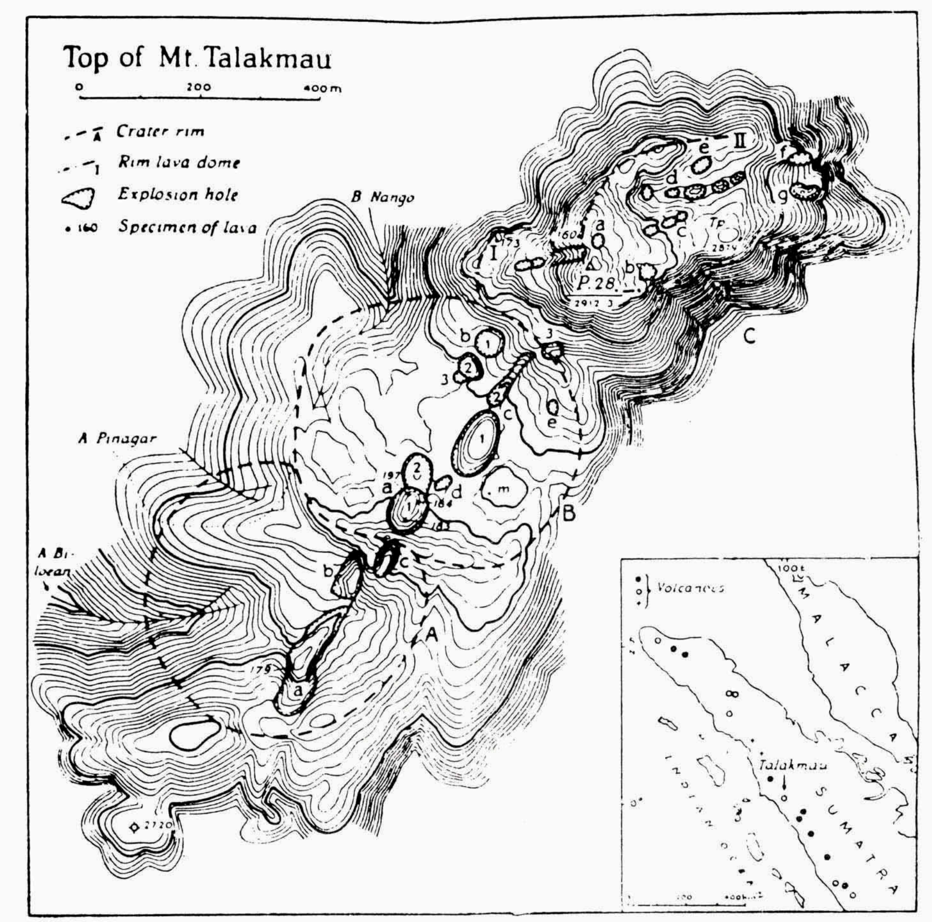


Fig. 23. The summit of the volcano Talakmau with the craters A and B and lavaplug C (from Neumann van Padang, 1951).

Mt Ruang (6,7-1) - Here the lava of 1914 was richer in silica than that of 1904 (see p. 45) showing the same tendency.

Krakatau (6,2) - Van Bemmelen (1943b, p. 58, fig. 7; 1949a, I, p. 205) discussed the connection between the Krakatau activity and the chemical composition of its magma, which varied from basaltic with 50.25% SiO_2 to highly acid. It proved that the cataclysmic volcanic outbursts, which were connected with collapse and caldera formation, occurred when the magma had a silica content of c. 70%. Each new cycle of regrowth began with basic eruptions. In his fig. 7 (see Fig. 24) he showed the relationship between the silica content of the eruption products in the course of the volcanic cycle.

This empirical consideration had, according to van Bemmelen (1943b, p. 60), the practical bearing that a repetition of a major outburst, followed by collapse and tidal waves, is not to be feared as long as the chemical composition of the magma had not changed from basaltic to acid.

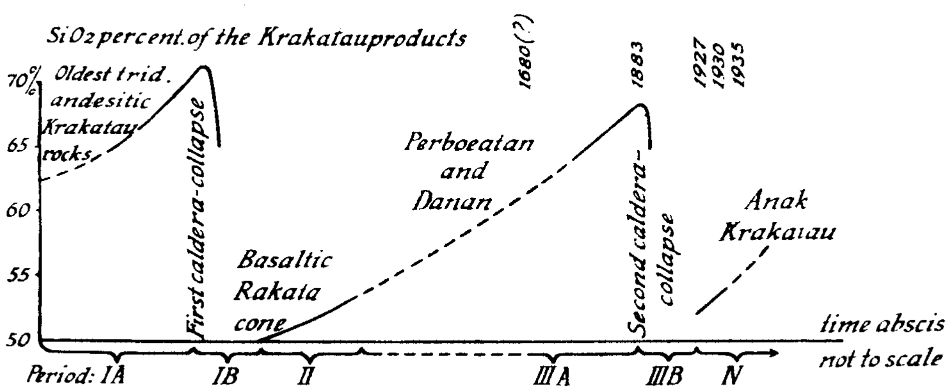


Fig. 24. Evolution of the magma of the Krakatau group with regard to the silica content of its eruption products (from van Bemmelen, 1943b, fig. 7).

From the preceding we see:
a) that the volcanoes of Indonesia were built up of a magma that gradually became richer in silica, and
b) that the possibility of a catastrophic eruption grew as the silica content became higher. This question was important for the Volcanological Survey because it enabled them to predict the severity of an outburst.

ERUPTION CYCLES

Merapi - The eruption of Mt Merapi began on 22 November 1930. Till 18 December lava with relatively little gas was poured out. On 18 an 19 December a magma rich in gas erupted, threw out a part of the volcano wall and formed glowing avalanches and glowing clouds, which destroyed 20 km^2 of arable land. The fact that the catastrophic eruption took place nearly one month after the beginning of the activity, attracted the attention of Neumann van Padang (1931b, 1933a, c). If this phenomenon, that a main eruption is preceded by a preliminary stage, is normal, it would be of great importance for the Volcanological Survey to safeguard the population. Something similar had happened during the outburst of Mt Merapi in 1920. According to Kemmerling (1921c) lava avalanches began on July the 25th. On 12 October, i.e. 2½ months later, the great main eruption followed.

Krakatau - The notorious Krakatau eruption of 1883 began with a preliminary stage on May the 20th (see p. 14). More than three months later, on August the 26th, the catastrophic main phase took place, which lasted two days. A concluding phase followed till the end of February 1884.

Vesuvius - The volcanic activity of Mt Vesuvius (1,1-2) began with a preliminary stage in August 1903. About 2½ years later, on 8 April 1906, the main stage followed, the intermediate gas phase of Perret (1924), who described this eruption amply.

Montagne Pelée - On 24 April 1902 Montagne Pelée (16-12) began with the ejection of black ash clouds (Lacroix, 1904). Two weeks later, on May the 8th, the catastrophic main eruption followed, that destroyed St Pierre.

The fact, that the main eruption takes place some time after the beginning of the activity, is of great importance for the Volcanological Survey. It gave them time to take measures to protect the population against disasters.

Neumann van Padang (1931c, p. 676-679) suggested an explanation why the main eruption did not occur in the beginning of the activity. The general idea is that the magma rises from a great depth to form a magma chamber at a depth of 2-5 km below the surface of the earth. At this depth there is a pressure of 600 to 1500 atm and a temperature of 80-170°C, whilst the magma itself has a temperature of more than 1000°C. Therefore the cooling by the surroundings is great. During the repose period, the border zone of the magma chamber (R in Fig. 25) cools down and becomes rigid (a in Fig. 25). During the cooling, crystals develop and at the same time the gases, dissolved in the magma, rise. A zone G, rich in gases, is formed between the cooled and rigid border zone R and the original magma mass M. The increasing concentration of gas in zone G causes pressures that will set the upper part of the magma in motion and squeeze the still liquid part of the border zone R into the crater pipe. Depending on the quantity and concentration of the gas, this magma will appear effusively or explosively, as a preliminary stage. The underlying magma takes the place of the magma that is thrown out. Finally the magma G, rich in gas, will reach the surface, often in a catastrophic outburst.

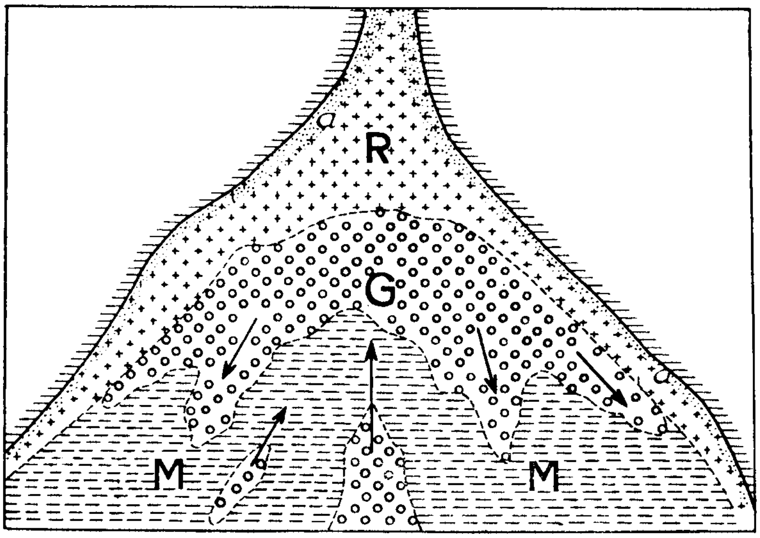


Fig. 25. Schematic cross section through the upper part of a magma chamber (from Neumann van Padang, 1931c, fig. 1).
R is the cooled, but still liquid, hot border zone;
a is the most cooled down outside border;
G is the magma rich in gases, that is formed underneath the border zone R;
M is the original magma;
the arrows indicate the direction of the convection currents.

ERUPTION RAINS

The relation between eruptions and rains that are caused by the eruption, and which would not have fallen otherwise, was studied by Neumann van Padang (1934a, b, 1935, 1937c). If great volcanic eruptions would always be accompanied by rains, mud flows will inevitably originate causing damage in the foreland of the volcano. Eruption rains will always originate when the eruptions take place under water, e.g. with submarine volcanoes as is the case with Krakatau. Volcanoes with a crater lake, e.g. Mt Kelut, will also cause eruption rains. In all the other studied cases the eruptions were not accompanied by eruption rains.

In August 1883 the submarine eruptions of Krakatau caused eruption rains in the neighbourhood of the volcano. At a great distance in South Sumatra and West Java it rained in 1883 in the week before and after the eruption. But from August the 26th till 31st, i.e. during and immediately after the catastrophic eruption, no rain was observed (see Neumann van Padang, 1934a, p. 171, fig. 2). The moisture which might have been present in the atmosphere was absorbed by the ashes and could not come down as rain.

During the eruptions of Mt Slamet since 1926 it rained less during the eruptions than before and after its activity.

POST-WAR PERIOD

After the war, from 1945 till 1954, the Volcanological Survey in Bandung sent Petroeschevsky to several volcanoes, such as Krakatau, Mt Ruang Motir, Tambora, and some more. Together with Klompé he described the volcanic activity in Indonesia.

The eruption in 1951 of Mt Kelut was described by van Rummelen (1953) and van IJzendoorn (1953).

Professor B.G. Escher in Leiden, being president of the Volcanological Section of the International Union of Geodesy and Geophysics, charged Dr M. Neumann van Padang to compile a Catalogue of the active volcanoes of Indonesia (1951). As editor of the Catalogue Neumann van Padang later on participated in several congresses of the I.U.G.G. and published several articles on the subject.

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Plate 1

The volcanic eruptions of Mt Merapi (6,3-25) in 1865 by day and by night, as painted by the reknown Raden Saleh. The paintings belong to the collections of the Rijksmuseum van Geologie en Mineralogie (National Museum of Geology and Mineralogy of the Netherlands).

Plate 2

Photographs by M. and K. Krafft.

Above : The active volcano Mt Dukono (6,8-1) on Halmahera Island is notorious for its great eruption of 1550.

Below : Two of the three coloured crater lakes of the volcano Kelimutu (6,4-14) on the Lesser Sunda Island Flores. The green lake is rich in free sulphur, while the dark red lake contains iron.

Plate 3

Photographs by M. and K. Krafft.

Above : The volcano Mt Agung (6,4-2) on Bali. The last eruption of this volcano in 1963 caused much damage and a large number of casualties.

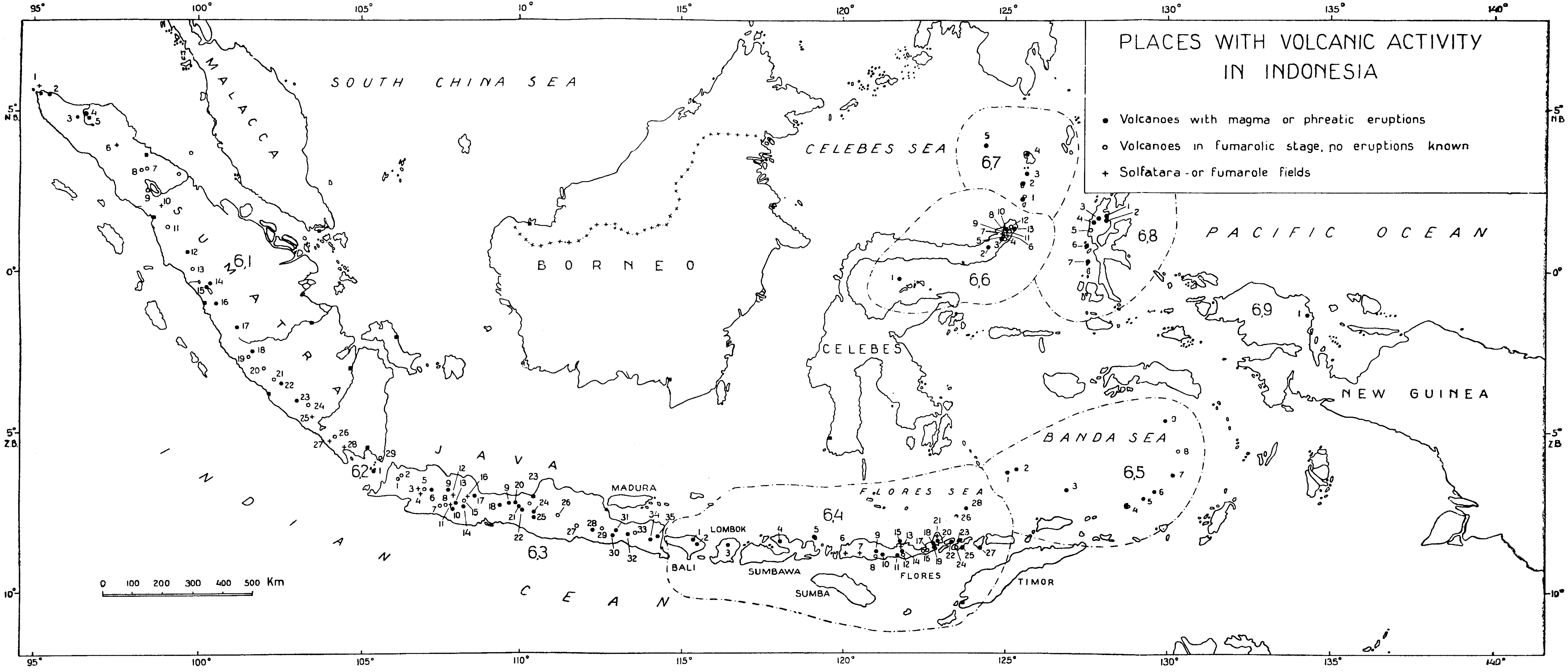
Below : The extinct cone 'Batok' belongs to the Tengger caldera complex on eastern Java and displays a regular pattern of erosion gullies (see Fig. 18).

Plate 4

Photographs by M. and K. Krafft.

Above : The violent eruption in 1982 of the regularly active volcano Mt Galunggung (6,3-14) on western Java produced enormous quantities of volcanic ash.

Below : Anak Krakatau (in 1979), the central crater of the Krakatau caldera (6,2) arose above sealevel in 1927 and has grown ever since to a volcano with a diameter of ca 1 km in 1982 (see Fig. 5).



N.B. = Northern latitude, Z.B. = Southern latitude.

Plate 1

Plate 2

Plate 3

Plate 4