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16. *Volcanological Survey of Indonesian Volcanoes.*
Part 4. A Gravity Survey in Central Java.

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1. Introduction

Java Island, Indonesia is a part of the circum-Sunda arc which is very similar in tectonics to the Japanese arc, a part of the circum-Pacific one. The idea of the island arc structure was originally developed in this region by the many pioneering works in gravimetry, magnetism, seismicity, volcanism and geology. The literatures of earth sciences of Java are too numerous to mention by name. Today we can readily refer to the summarized book "The geology of Indonesia" by R. W. van Bemmelen (1949), to which the authors owe their knowledge of Indonesian volcanisms and geology.

The gravity measurements at sea were started by Vening Meinesz (1932 and 1934) in 1923 and were made at 281 stations in the world by 1930. The first and most important results of the surveys were obtained along the Indonesian Archipelagoes. A part of the results is reproduced

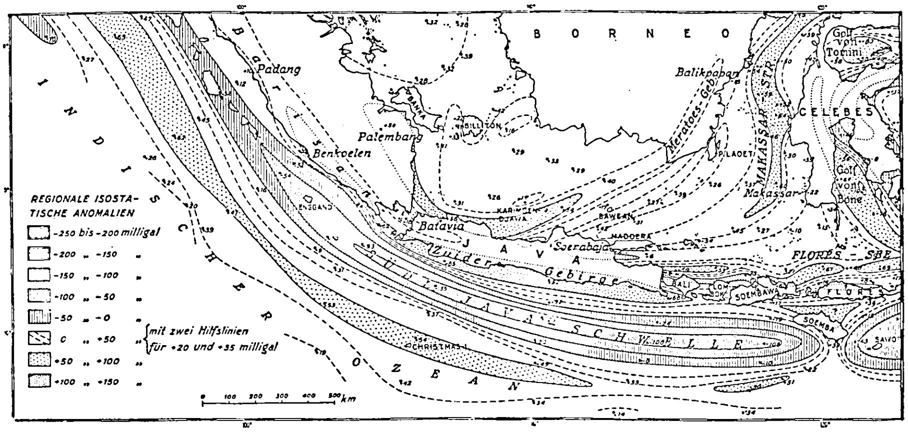

Fig. 1. Distribution of the isostatic anomalies along a part of the Indonesian Archipelagoes (reproduced from van Bemmelen's book, 1949).

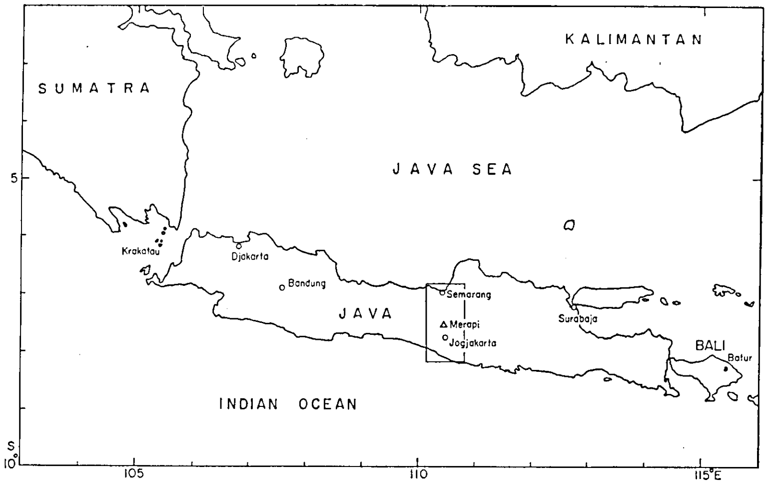

Fig. 2. Java and Bali Islands.

in Fig. 1, with reference to the present land survey in Central Java. Our transverse survey in Central Java is a continuation of the sea-profile along 110 degrees in east meridian surveyed by the Submarine Hr. Ms. K XIII. The authors would like to add a humble contribution to the knowledge of the gravity field in this region, in special relation with volcanoes.

2. Gravity survey

A gravity survey in Central Java was carried out intermittently in August and September, 1968, and the gravity meter used for the survey was a Model "G" of LaCoste & Romberg type. Through the period, the base of our survey was at Kaliurang in the north suburb of Jogjakarta. The drift of the gravity meter reading was about 0.3 mgal for a month since Aug. 21 and during the period, the surveys in Central Java and on Batur Caldera, Bali were made. The total of measurements were referred to the gravity station at the Earthquake Research Institute, the University of Tokyo, of which the gravity value was 979.80205 gal. The connecting route with Tokyo was extended to Djakarta, Bandung and Jogjakarta in order, respectively within a day. The difference of gravity between the bases at Djakarta (Hotel Indonesia) and Kaliurang (Wisma Merbabu) was measured twice as 163.74 mgal (Aug. 17—Aug. 21) and 163.88 mgal (Sept. 24—Sept. 25). The authors deem the latter value better because the connection was made in a shorter time. As reported in the previous paper, the connecting error between Djakarta and Tokyo was 0.07 mgal, and therefore the accuracy

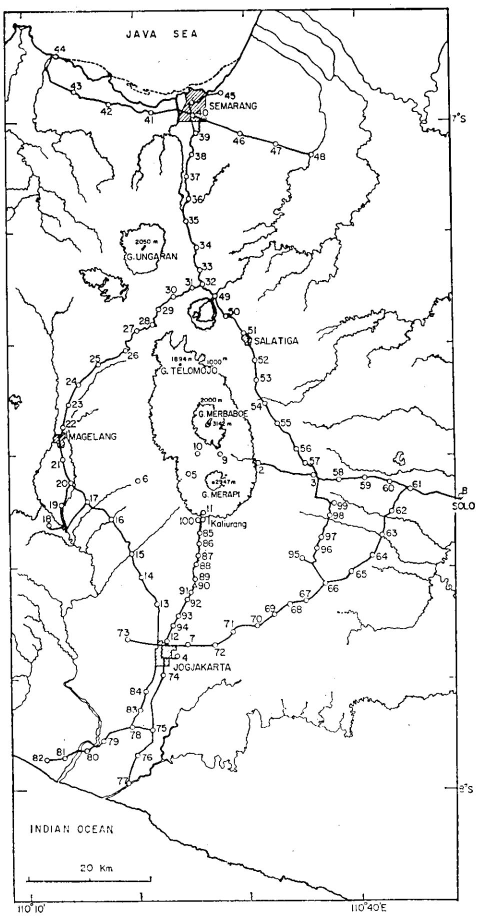

Fig. 3. Distribution of the gravity points.

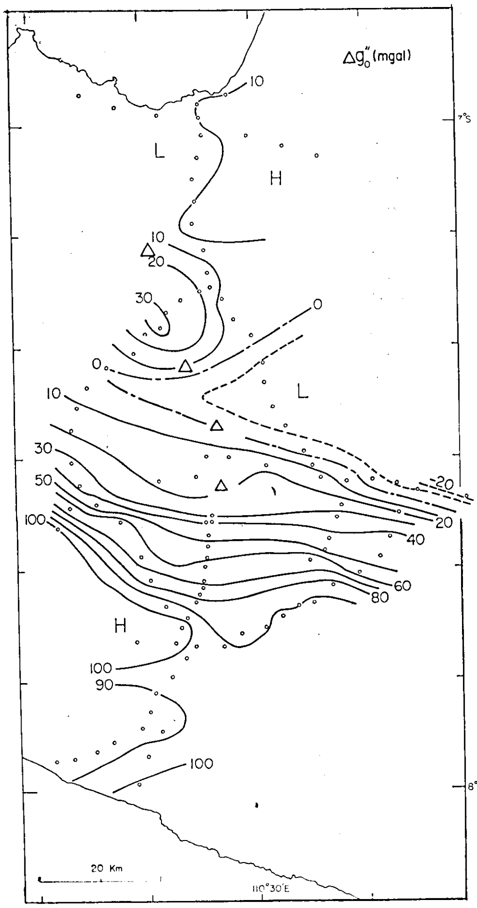

Fig. 4. Distribution of the Bouguer gravity anomalies. Unit is mgal. Triangles denote Quaternary volcanoes.

of all measurements in Central Java is about 0.1 mgal in reference to the E. R. I., Tokyo.

The observation points were 100 in number as shown in Fig. 3. At the centre of the surveyed region, there are active volcanoes Merapi and Merbabu and to the north-west, Butak Petarangan, Diëng, Sendoro and Sumbing are active. The surveying route crosses Java from the south coast to the north coast and encircles Merapi and Merbabu. The present survey did not aim at studying these volcanoes themselves while a branch of the surveying route approached to Merapi. The photos of of some observation points, Nos. 1, 3, 4, 5, 7, 10, 32 and 101, were shown in Fig. 8 of the previous report (Yokoyama and Hadikusumo, 1969). In the survey, we tried to occupy the triangulation points and

Table 1. Gravity values observed in Central Java.

Gravity point	Long. 110°E	Lat. 7°S	Height (meter)	Normal value (mgal) 978,	Observed value (mgal) 978,	Free-air anomaly (mgal)	Bouguer anomaly (mgal)
1. Kaliurang, Wisma Merbabu	25:8	35:7	893	139.0	*996.25	132.8	39.3
2. Tjepogo	30.9	30.8	960	137.0	*960.25	119.5	19.0
3. Bojolali	35.8	31.9	424	137.5	064.32	57.7	13.3
4. P.P.M. Jogjakarta	23.3	48.0	106	143.9	218.32	107.2	96.0
5. Babadan Observatory △	24.6	31.6	1278	137.3	*891.81	148.9	15.1
6. Iron bridge	20.0	32.2	670	137.4	015.24	85.7	14.5
7. Palace Hotel, Jogja.	24.3	46.9	122	143.4	214.85	109.1	96.4
8. Hotel Sahid, Sala	48.9	33.9	95	138.3	096.31	−12.6	−22.6
9. Selo Observatory △	27.4	29.9	1654.4	136.7	*817.04	190.9	17.7
10. Djrakah Observatory △	25.4	29.9	1291.5	136.7	*889.66	151.5	16.3
11. Plawangan Observatory △	25.9	35.1	1295.9	138.7	*896.81	158.0	22.3
12. Terban, Jogja.	22.4	46.6	122	143.2	223.85	118.3	105.5
13. Djaban, S.H. 197	21.7	43.3	197	141.9	195.97	114.8	94.2
14. Medari, bridge	20.3	40.8	266	141.0	162.24	103.3	75.5
15. Djagang, bridge	19.4	38.7	322	140.2	140.32	99.5	65.8
16. Goelon, bridge	17.6	35.6	348	138.9	135.10	103.6	67.1
17. Bentingan, crossroads	15.5	34.1	311	138.3	119.22	76.9	44.3
18. Koedjon, S.H. 257	12.1	36.1	257	139.1	186.61	126.8	99.9
19. Kedon, S.H. 261	13.2	34.3	261	138.4	151.69	93.8	66.5
20. Blondo, S.H. 308	14.1	32.4	308	137.7	114.17	71.5	39.3
21. Mertojoedan, S.H. 347	13.4	30.2	347	136.8	099.35	69.6	33.3
22. Kramat, near △ T335	13.4	27.3	388	135.7	075.42	59.4	18.8
23. Pajaman, near △ T336	13.9	25.3	405	134.9	063.20	53.3	10.9
24. Setjang, S.H. 470	14.8	23.6	470	134.2	040.31	51.1	1.9
25. Kaliampo, S.H. 574	16.6	21.8	574	133.6	016.70	60.2	0.1

(to be continued)

Table 1. (continued)

Gravity point	Long. 110°E	Lat. 7°S	Height (meter)	Normal value (mgal) 978,	Observed value (mgal) 978,	Free-air anomaly (mgal)	Bouguer anomaly (mgal)
26. Larangan, crossroads	19.0	20.7	634	133.2	015.65	78.1	11.7
27. Gemawang, near S.H. 678	20.0	18.8	678	132.4	018.40	95.2	24.2
28. Bedono	21.4	18.3	687	132.2	025.04	104.8	32.9
29. Sindan, bridge	22.0	16.9	478	131.8	063.32	79.0	29.0
30. Ngampin, S.H. 492	23.3	15.8	492	131.3	054.86	75.4	23.9
31. Pringapoesan, S.H. 530	25.1	15.0	530	131.0	043.36	75.9	20.4
32. Bawen, S.H. 547	26.0	14.7	547	130.8	037.84	75.8	18.6
33. near Q 105	25.8	13.2	534	130.4	036.62	71.0	15.1
34. Bergas-lor, crossroads	25.6	11.2	483	129.6	036.62	56.1	5.5
35. Boegangan, near △ T532	24.5	08.9	367	128.8	068.28	52.7	14.3
36. Bandanejo, crossrroads	24.8	06.9	324	128.0	072.21	44.2	10.3
37. Banjoemanik, S.H. 285	26.0	05.0	285	127.3	075.80	36.4	6.6
38. Ngesrep, crossroads	25.1	02.9	225	126.6	083.42	26.3	2.7
39. Tjandi, S.H. 81	25.6	01.1	81	125.8	117.86	17.1	8.6
40. Randoesari, S.H. 4	25.4	*59.4	4	125.3	134.24	10.2	9.7
41. Segaran, S.H. 18	21.6	*59.2	18	125.2	128.08	8.4	6.5
42. Mangkang	17.7	*58.3	8	124.9	127.22	4.8	3.9
43. Sikopek S.H. 4	14.6	*57.3	4	124.5	124.22	1.0	0.5
44. M. Kendal	13.0	*54.0	1	123.3	125.79	2.8	2.7
45. S. Klajaran, near △ T782	27.9	*57.4	3	124.6	133.62	10.0	9.6
46. Plamongan, near, △ T651	29.5	01.2	15	125.9	133.98	12.7	11.1
47. Dolok, near △ T681	32.8	02.1	14	126.2	138.85	17.0	15.5
48. Tegawanoe, S.H. 10	35.9	03.0	10	126.6	144.77	21.3	20.2
49. Toentang, bridge	27.2	45.7	466	142.9	053.86	54.8	6.0
50. Tapen, crossroads	28.1	47.6	495	143.6	051.07	60.2	8.4

(to be continued)

Table 1. (continued)

Gravity point	Long. 110°E	Lat. 7°S	Height (meter)	Normal value (mgal) 978,	Observed value (mgal) 978,	Free-air anomaly (mgal)	Bouguer anomaly (mgal)
51. Salatiga, S.H. 578	29.8	19.2	578	132.6	019.10	64.9	4.3
52. Isepisep, near △ T593	30.8	21.6	678	133.5	*984.52	60.2	−10.8
53. △ T594	30.9	23.3	731	134.2	*969.47	60.8	−15.7
54. Tengaran, bridge	31.6	25.4	719	134.9	*971.58	58.5	−16.8
55. Ampel, bridge	32.6	27.2	678	135.7	*983.20	56.7	−14.3
56. Penggoeng, S.H. 544	34.3	29.5	544	136.5	024.71	56.1	− 0.9
57. Plosokerep, S.H. 487	35.1	30.8	487	137.0	044.01	57.3	6.3
58. Modjosongo, crossroads	38.1	32.3	279	137.6	087.42	35.9	5.7
59. Kroekeman, near S.H. 192	40.4	32.1	179	137.5	094.17	11.9	− 6.9
60. near △ T953	42.7	32.5	145	137.7	097.35	4.4	−10.8
61. Kartosoero, S.H. 123	44.5	33.2	123	138.0	102.66	2.6	−10.2
62. Djaboeng, △ T919	42.8	35.1	133	138.7	131.54	33.9	19.9
63. Gatak 2, crossroads	41.9	37.2	136	139.6	153.34	55.7	41.5
64. Kepoh 2, S.H. 133	41.0	39.0	133	140.3	159.18	59.9	46.0
65. S.H. 151	39.2	40.3	151	140.8	167.67	73.5	57.6
66. Ngingas, crossroads	36.7	41.5	167	141.3	188.90	99.1	81.7
67. Tegaljoso, S.H. 162	35.0	43.1	162	141.8	200.91	109.1	92.4
68. Plawikan, S.H. 166	33.4	43.4	166	142.0	197.80	107.0	89.7
69. Tangkisanpos	32.2	44.3	162	142.3	202.74	110.4	93.5
70. Tadji, bridge	30.6	45.3	151	142.7	200.91	104.8	89.0
71. Road to Sala, S.H. 136	28.4	45.8	136	142.9	202.15	101.2	87.0
72. Ngangkroek, S.H. 121	26.8	47.0	121	143.4	210.00	104.1	91.3
73. Bontoetan, S.H. 119	19.0	46.4	119	143.2	234.17	127.7	115.2
74. Salakah S.H. 82	22.0	49.7	82	144.6	220.59	101.3	92.7
75. Bakoelan, near △ T734	20.8	54.6	35	146.5	226.11	90.4	86.8

(to be continued)

Table 1. (continued)

Gravity point	Long. 110°E	Lat. 7°S	Height (meter)	Normal value (mgal) 978,	Observed value (mgal) 978,	Free-air anomaly (mgal)	Bouguer anomaly (mgal)
76. Kragilan, S.H. 18	19.7	56.9	18	147.5	240.32	98.3	96.5
77. Kebonongan, river bank	18.9	59.3	9	148.4	247.75	102.1	101.2
78. Gandon, S.H. 36	19.2	54.5	36	146.4	222.99	87.7	83.9
79. S. Pakodja	16.7	55.5	24	146.9	226.91	87.4	84.9
80. S. Srandakan, S.H. 13	15.2	56.4	13	147.3	229.13	85.3	84.5
81. Galoer, near S.H. 8	13.2	57.0	7	147.5	231.35	86.0	85.3
82. Galoer, S.H. 4	11.6	57.2	4	147.6	235.01	88.6	88.2
83. Bantoel, S.H. 51	20.0	52.8	51	145.8	221.86	91.8	86.5
84. Kraniil, S.H. 64	20.5	51.1	64	145.1	222.42	97.0	90.4
85. 23 km to Jogja.	25.6	36.9	716	139.5	041.35	122.8	47.9
86. near Sanatorium	25.4	37.9	606	139.9	068.67	115.8	52.4
87. 19 km to Jogja.	25.4	39.0	512	140.3	095,21	112.8	59.3
88. △ T826	25.2	39.7	438	140.6	114.06	108.6	62.8
89. Degolan, S.H. 342	25.1	41.1	342	141.1	139.88	104.3	68.6
90. △ T824	25.1	41.7	310	141.3	150.36	104.7	72.2
91. Tjandi, S.H. 271	24.7	42.3	271	141.5	163.22	105.4	77.0
92. 11 km to Jogja.	24.4	42.9	246	141.8	175.61	109.7	84.0
93. S.H. 186	23.5	44.4	186	142.4	202.25	117.2	97.8
94. 6 km to Jogja.	23.0	45.2	155	142.7	214.61	119.7	103.6
95. Mranggen, S.H. 280	34.6	39.2	280	140.4	148.20	94.2	64.9
96. Soespekan, S.H. 263	36.0	38.4	263	140.1	135.37	76.4	48.9
97. Soespekan, S.H. 282	36.4	37.4	282	139.7	123.73	71.1	41.6
98. △ T925	37.2	35.5	290	138.9	114.58	65.2	34.9
99. Kopen, S.H. 277	37.6	34.4	277	138.5	107.60	54.6	25.6
100. Kaliurang, △ T845	25.4	35.7	915	139.0	*991.94	135.4	39.5
101. Hotel Dibya Puri, Semarang	25.3	*58.3	7	124.9	133.83	11.1	10.4

*6°S   *977,

the spot heights as far as possible, of which heights were indicated in the unit of meter on the topographic maps. In addition to these points, many other points were occupied and their heights were determined by the barometric and interpolation method between the known heights. During the survey, a base barograph was operated at the base station, Kaliurang, in order to make corrections for atmospheric variations. The barometers were those of American Paulin System, by which one could read the heights at 0.5 m intervals, but the accuracy of height determination usually depends on the atmospheric conditions. It is not so reliable between distant points even if atmospheric variations are corrected by the barographic observations at the base. In this respect, the interpolation method may be more practical. In the present survey, the error of height determination may be less than 5 m corresponding to about 1 mgal in the Bouguer anomaly.

All observed gravity values are listed in Table 1.

3. Gravity anomalies in Central Java

The Bouguer gravity anomalies in this area are calculated as shown in Table 1, where the mean density of the land is assumed to be 2.5 g/cc, the vertical gradient of gravity to be normal, *viz.* 0.3086 mgal/m and the topographic corrections not being taken into consideration because we selected the gravity points at gentle topographies as far as possible. The accuracy of the anomalies is about 1 mgal excluding the topographic corrections which may be rather large at the summit of Plawangan (gravity point No. 11) as clearly seen in an anomaly profile (Fig. 7).

The distribution of the Bouguer anomalies in Central Java is shown in Fig. 4. It is noticeable that the high anomaly amounting to 100 mgal at the southern coast sharply decreases at a gradient of 100 mgal/30 km and is almost zero in the northern half. A geological sketch map of this region after the Geological Survey of Indonesia is shown in Fig. 5 where there are Quaternary volcanoes as follows: Butak Petarangan, Diëng, Sendoro, Sumbing, Ungaran, Telomojo, Merbabu, Merapi and Lawu (Fig. 6). Comparing the distribution of the gravity anomalies with the geological map, one does not find any systematic relation between them at respective volcanoes. This is clearer in a gravity profile in the North-South direction shown in Fig. 7, where the anomalies along the central route from the south toward Merapi drop between those along the eastern and the western routes. In the figure, the anomaly at Plawangan (No. 11) deviates from its group due to the large topographic effect.

Next, the results of marine gravity surveys approximately along the longitudinal line of 110°E by Vening Meinesz will be supplemented by the above ground survey from the coast of the Indian Ocean to the coast of the Java Sea. At the upper part of Fig. 8(a), the Bouguer anomaly

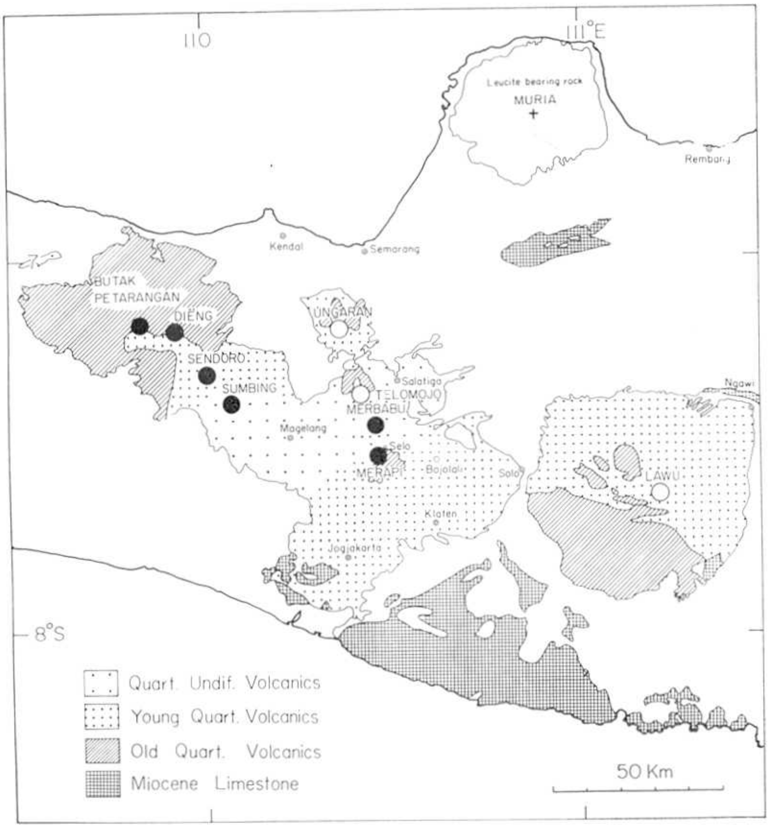

Fig. 5. Geological sketch map of Central Java after the Geological Survey of Indonesia. ● Volcanoes with magma or phreatic eruptions, ○ Volcanoes in fumarolic stage, no eruptions known.

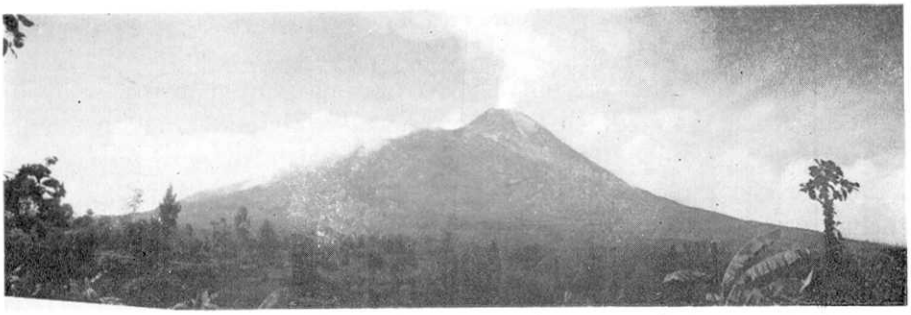

Fig. 6(a). Merapi seen from the eastern foot.

Fig. 6(b). A morning scene from the summit of Merapi facing north. From the west, Sumbing, Sendoro, Telomojo and Merbabu.

Fig. 6(c). Merbabu (left) and Telomojo seen from the north.

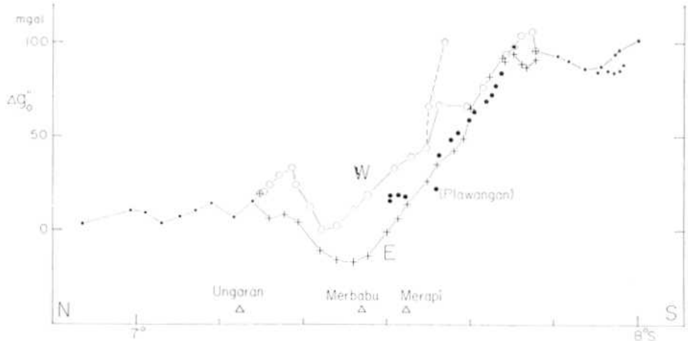

Fig. 7. A gravity profile from the coast of the Java Sea to the coast of the Indian Ocean.
hollow circle: along the western route around Merapi
large solid circle: along the central line passing Merapi
cross: along the eastern route around Merapi

profile obtained by the present survey is represented by a solid line connecting with the modified Bouguer anomaly profile obtained by Vening Meinesz. The modified Bouguer reduction consists of a topographic reduction for the zones A-O and an isostatic reduction—according to the regional system—of the zones 18-1 of the Hayford-Bowie system. At the middle part of the figure, a profile of the topography and the andesitic volcanoes are shown and at the lower part, the hypocentres of the earthquakes which occurred in the area of longitudinal breadth 500

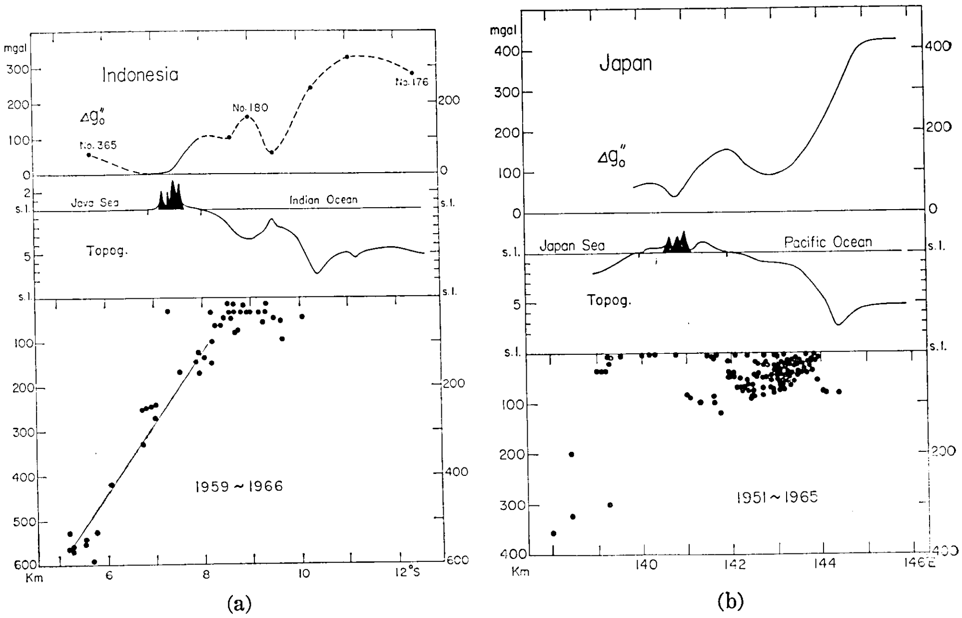

Fig. 8. Geophysical profiles across the Indonesian and the Japanese island arcs. From the top, gravity anomalies, topographies (black parts denote the Quaternary volcanoes), and earthquake foci.
a) Indonesian arc along the longitudinal line of 110°E.
b) Japanese arc along the latitude line of 40°N.

km during the period 1959 to 1966 are projected on the profile plane after Hatherton and Dickinson (1969). As seen in the figure, the volcanoes have been formed at or around the local minimum of the gravity anomaly, in other words, at the locally thick crust, and beneath the volcanoes, both shallow and deep seismic foci seem to be rather few so far as this particular profile is concerned. The same items are figured for Japanese island arc as shown in Fig. 8(b). The profile passes Tōhoku District (the northeastern part of Honsyū) along the latitude line of 40°N. The Bouguer gravity anomalies were obtained by the Geographical Survey Institute of Japan on the land and by Tomoda and Segawa (1967) on the Pacific Ocean. The seismic data are concerned with the area of latitudinal breadth 250 km and with the earthquakes of magnitude larger than 4.5, which occurred during the period 1951 to 1965, after Katsumata (1967). The above relation deduced from the Indonesian data also holds good with the Japanese data.

Hatherton and Dickinson (1969) found much correlation between K, the level of potash content in lavas erupted from an andesite volcano, and h, the depth to the centre of the inclined seismic zone beneath the volcano. They suggested that this may imply whether the magmas have different compositions at various depths along the seismic zones or

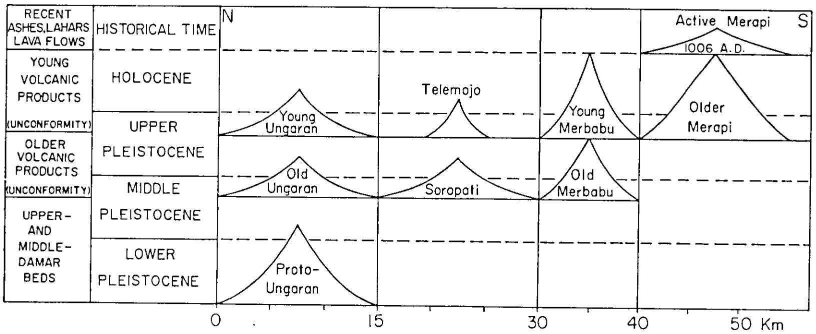

Fig. 9. Development of volcanic structures of the transverse row Ungaran-Merapi after van Bemmelen.

the magmas make evolution during ascent from these zones.

The relations between volcanisms and the structures of the crust and the upper mantle, if any, will be an important problem in volcanology and the data demonstrated above may afford us some suggestions as to the future studies.

Returning to the volcanic edifices in Central Java, some remarks will be made on some volcanoes after van Bemmelen (1949): The development of volcanic structures along the line Ungaran-Merapi is shown in Fig. 9, where it has shifted from the interior side towards the exterior side. The row of volcanoes Merapi-Telomojo is situated at the western end of the Solo Zone and the Ungaran complex is situated at the western end of the Kendeng Zone. According to Vreugde (1935), who compiled the results of the torsion-balance surveys by the Bataafsche Petroleum Maatschappij, the Kendeng Zone is characterized by strongly negative Bouguer anomalies. These are also verified by the present survey as shown in Fig. 4. According to van Bemmelen, Ungaran is a a volcano-tectonic depression and Merbabu has three radial sector-grabens. However, the results of the present preliminary gravity surveys can not make any comments on these structures, because the present surveys did not cover sufficiently these areas. More detailed surveys on each volcano may be desirable in the future.

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16. インドネシア火山の調査
その 4 中部ジァヴァにおける重力測定

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インドネシア火山の日本・インドネシア協同研究の一部として，著者らは 1968 年 8 月，9 月にかけてカリウランに滞在中に，中部ジァヴァの南北横断測線について重力測定を実施した.

この地域には，活火山メラピを南の縁として，北へ第四紀火山が連なつている．またこの地域を通る東経 110 度線にほぼ平行して，Vening Meinesz の海上重力測定の結果がある．今回の重力測定の目的は，この結果の陸地部分の空白を補うことである.

Bouguer 異常値は南岸で約 100 mgal であるが，約 30 km の内陸地点から急激に減少している．その勾配は約 100 mgal/30 km に達する．そして中央部から北では異常値は小さく，平坦である．個々の火山の構造は，重力異常の分布に大きく影響しているようには見えない．しかし，火山群が，Bouguer 異常の極小値を示す周辺に存在していることは，何らかの意義があるように思われる．参考までに，日本の東北地方の北緯 40 度線に沿つての，Bouguer 異常，地形および地震の震源分布をも示した.

中部ジァヴァの個々の火山の構造を，重力異常値を用いて議論するためには，より密な測点の分布が必要である.