Sci. Rep. Kanazawa Univ.,
Vol. 27, No. 1 pp. 71-83
June 1982

Gravity Anomaly over the Northern Part of the Central Japan. (1)

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(Received May 29, 1982)

Abstract Gravity surveys were carried out at 2277 points over the northern part of the Central Japan (35°40′-37°20′N, 136°-138°20′E) by means of the LaCoste & Romberg gravimeter (model G) No. 348. Based on 5506 data including 3229 data measured by several institutions in and around the surveyed area, a complete Bouguer anomaly map was drawn over the central and northern parts of the Central Japan (35°20′-37°20′N, 136°-139°E). All of the data were refered to the International Gravity Standardization Net 1971.

Terrain correction terms were calculated for all data over 80km (40′NS × 60′EW) around each measurement point using the 500 meter-mesh mean height data file. Density was assurmed 2.67 gr·cm^{-3}.

Altitude of measurement points were obtained from either leveling points related with construcion of dams and hydraulic power stations, triangulation points, spot heights, or contour lines of precise topographic maps.

The complete Bouguer anomaly map thus obtained involves a lot of geophysical and geological information. Some examples of good correlation between gravity anomaly and topography and geology were pointed out, preliminarilly.

1. Introduction.

The region of the central Japan is one the most important area in Japanese islands to discuss such basic problems as an establishment of isostasy, formation of mountain ranges, crustal structures of islands arcs, deformation of geoid surface, etc.. Distribution of gravity is essentially related with all of them.

Gravity surveys over the Central Japan have been carried out by TSUBOI et al. (1954) using a Worden gravimeter and also by GEOGRAPHICAL SURVEY INSTITUTE (GSI) (1964) using a North American gravimeter, respectively. Their measurement points,

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however, were situated only at the first and second order leveling stations along main national roads, most of which, in Japan, are running along various types of geologic structures such as faults and folds. A gravity anomaly map based on the distribution of gravity stations like those cited above were probably difficult to reflect true information of underground structure. Fig. 1 illustrates both the measurement points done by GSI(1964) and the contour lines of complete Bouguer anomaly calculated by HAGIWARA (1967) based on the GSI data. This was only one information for the complete Bouguer anomaly

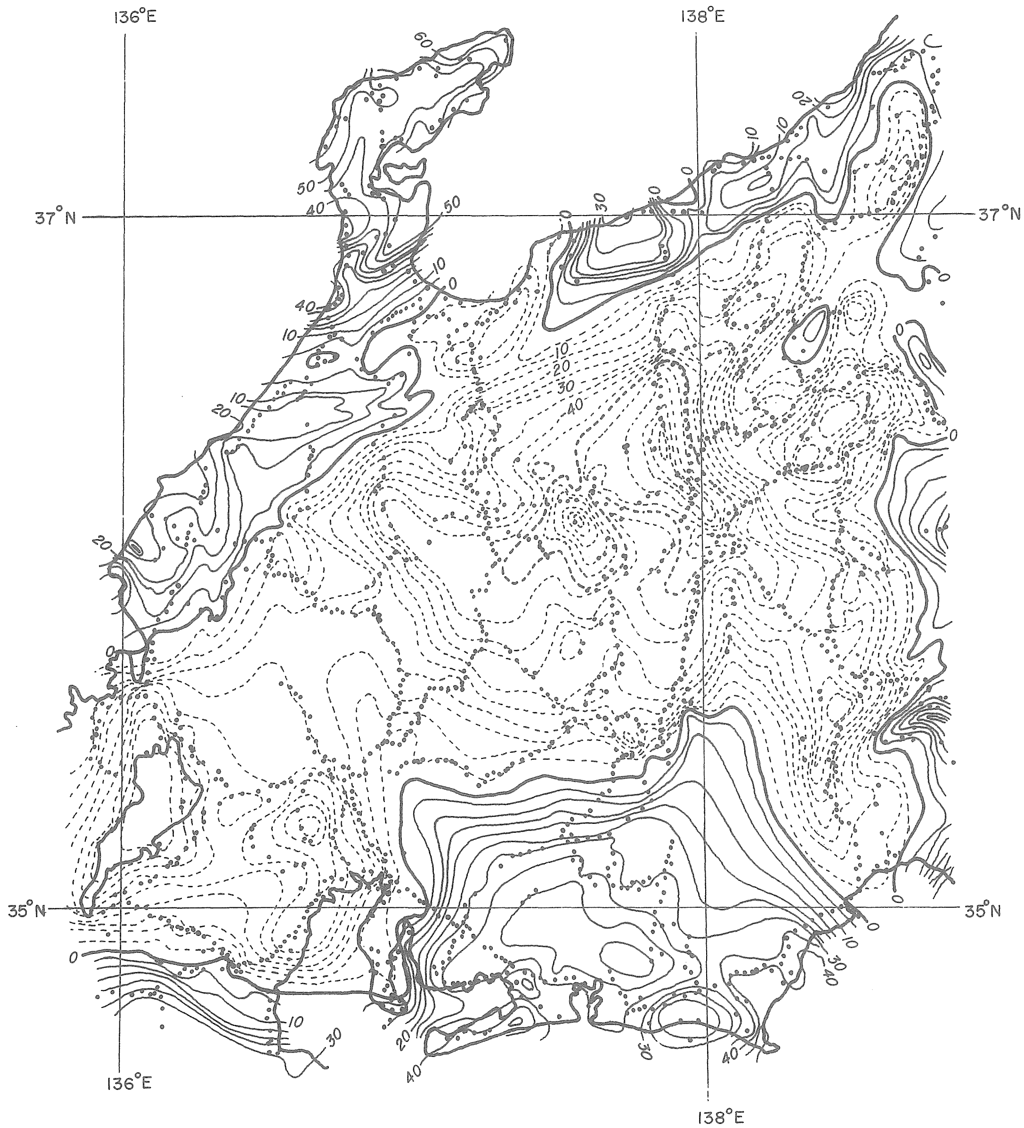

Fig. 1 Distribution of measurement points of Geographical Survey Institute (1964) and the complete Bouguer anomaly calculated by HAGIWARA (1967) (reproduced from HAGIWARA, 1967)

over the Central Japan before the present study.

To improve these situations we planned to survey at the deepest parts of the mountaineous regions as possible as we do. Starting from the top of Note Peninsula (KONO et al., 1975; 1981), measurements more than 2200 were carried out over the northern part of the Central Japan.

After the works by TSUBOI et al. (1954) and by GSI (1964), several institutions were also made gravity measurements in an around our surveyed area. To make clarify the distribution of the gravity anomaly over central and northern parts of the Central Japan, gravity data in this area were collected from various sources, and recalculated systematically applying the same data processing system for all data. Finally, a terrain corrected Bouguer anomaly, i.e., Complete Bouguer Anomaly (C.B.A), was obtained.

As a unit of gravity, a conventional unit 'mgal' ($=10^{-3}$cm$\cdot$sec^{-2} $=10^{-5}$m$\cdot$sec^{-2} $=10$ gu) is employed in this paper.

2. Surveyed area and Method of measurements.

Major topography and main location names in surveyed area are illustrated in Fig.2. The area is situated in the central part of the Japanese islands and is widely occupied by high mountain ranges some of which are higther than 3000 meters. Within the area, various types of important geologic elements are distributed: main tectonic lines such as Itoigawa-Shizuoka tectonic line (ISTL) or Fossa Magna, Hida outer belt (HOB) and Median tectonic line (MTL); principal rocks of Japanese islands such as Hida metamorphic rocks which are called as a basement of Japanese islands, Nohi rhyolitic rocks and so-called Green-tuff rocks; Quaternary volcanoes such as Hakusan, Tateyama, Myoko, Asama, Ontake, Norikura, Haruna and Fuji; many active faults such as Atotsugawa, Atera and others; etc..

The region mainly occupied by our own data are plain and mountaineous regions from Tsuruga (Fukui Prefecture) in west to Naoetsu (Niigata Prefecture) in east along the Japan Sea coast line (35°40′-37°20′N, 136°-138°20′E). It covers about 13,000 sq.km and a number of measurement points amounted to 2277. In and around the region, there were gravity data measured by several institutions: Metal and Minning Agency of Japan (MMAJ) (1972, 1976, 1978; unpublished) were measured 1506 gravities (270 data were employed in this study) around Hakusan-Takayama region; a group of Nagoya University (YAMAMOTO et al., 1982) were measured 552 gravities at the Central mountaineous region between Takayama-Matsumoto; groups of Earthquake Research Institute of Tokyo University (TAJIMA, 1975; TAJIMA and IZUTSUYA, 1974; JITSUKAWA et al., 1974; YOKOYAMA and TAJIMA, 1960) were measured 251 gravities between Nagano-Asama and around Mt.Fuji; a group of Kyoto University and Shizuoka University measured 124 gravities around the Fukui plain, and GSI newly measured 2032 gravities (unpublished) using LaCoste & Romberg gravimeters all over the area shown in Fig.2. All of those data (3229) were analyzed combining with our 2277 data. Distribution of total 5506 measurement points (some of which are overlapped) are plotted in Fig.3 with different symboles for different data sources. The region where only the GSI data exist (south and east of the region) is also included for future anlysis such as a digital filtering of gravity anomaly.

Gravity stations measured by us were chosen as their distribution becomes as possible as homogeneous over the surveyed area. To realize this, we entered all of roads and trucks, some of which might accept only a 4 Whell-drive Jeep. The gravity stations were chosen mainly from either leveling points related with constructions such as dams, hydraulic power stations and railway stations (along the Kurobe Valley), triangulation points, or spot heights in precise topographic maps (Town planning Map issued by each town (1 : 2,500-1 : 10,000); National Base Map (1 : 2,500-1 : 5,000) issued by GSI; Topographic Map of 1 : 25, 000 issued by GSI). If not available of those information, but if there was a road or

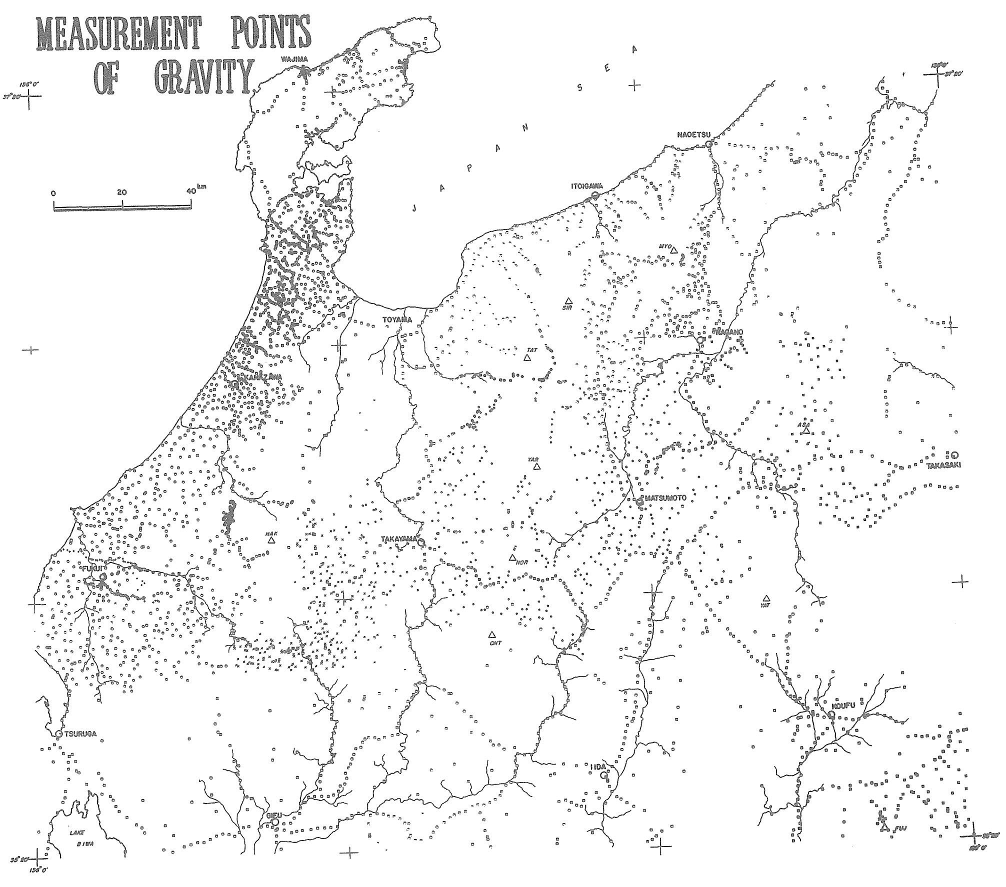

Fig. 3 Distribution of gravity measurement points (total 5506) which were measured by the following institutions: ○: Kanazawa University (this work); ×: Metal and Minning Agency of Japan (1972, 1976, 1978; unpublished); □: Geographical Survey Institute (1964 and unpublished); ◇: Nagoya University (YAMAMOTO et al., 1982); ＊: Earthquake Research Institute of Tokyo University (TAJIMA, 1975; TAJIMA and IZUTUYA, 1974; JITSUKAWA et al., 1974; YOKOYAMA and TAJIMA, 1960); +: Kyoto and Shizuoka Universities (SATOMURA et al., unpublished)

truck, we measured gravity at a point where its location can be confirmed on precise topographic maps, and then determined its altitude from contour lines. In a highly rugged mountain area like in our field, an aneroid type altitudemeter was not usefull for the altitude determination. An accuracy of the altitude determination for the leveling points, triangulation points, spot heights, and points determined by contour lines was esimated less than 0.1cm, 2cm, 2m and 10m, respectively. At each gravity station, we remained a marker -nail and also took photographs to make possible to return again the same point in future for gravity measurments or height determination.

3. Data Processing.

Calculations of absolute gravities and gravity anomalies were based on both the International Gravity Standardization Net 1971 (IGSN 71) (MORELLI et al., 1974) and the Japan Gravity Standardization Net 1975 (JGSN 75) (GSI, 1976) not only for the data measured by us but also for all of the other data employed here. The gravity values measured by us were determined referring the value at the Fundamental Gravity Station in Kanazawa University setteled by GSI (1976):

$$g_0 = 979\ 857.90 \pm 0.01 \text{ (S.D.) (mgal)}$$

Practically, we employed the gravity value at the Room 166 in the Department of Earch Sciences, Faculty of Science, Kanazawa University (we call 'KUFS166') :

$$g_0' = 979\ \ 857.990 \text{ (mgal)}$$

which was gravimetrically connected with both the g_0 and the International Fundamental Gravity Station in Kyoto by several times.

Gravity measurements near Kanazawa were closed in the same day. For a gravity survey far, say 60km, from Kanazawa, measurements were closed in the same day at a reference station setteled temporarily near an inn and were also finally closed at the station in Kanazawa University when the survey was terminated.

The Normal gravity was calculated by using the formula given by IGSN 71 :

$$\gamma = 979\ 031.85(1 + 0.005\ 278\ 895 \sin^2\psi + 0.000\ 023\ 462\ \sin^4\psi) \text{ (mgal)}$$

An attraction by the moon and the sun (Earth's tide) was corrected by the theory given by LONGMAN (1959). 1.16 and 0 degree were assumed for the gravimetric tidal factor (G -factor) and a phase-lag, respectively (International Association of Geodesy,1980). As a kind of correction for the Normal gravity which involves an attraction of air-mass, the atomospheric correction, Atm, was applied :

$$\text{Atm} = 0.87 - 0.009\ 65 \times 10^{-3} h \text{ (mgal)}$$

where h is an altitude of gravity station in meter. A vertical gradient of gravity was assumed to be 0.3086 mgal $\cdot$ m^{-1}.

A Bouguer correction was calculated assuming an infinite plate of thickness h, $2\pi G\rho h$, and a mean density $\rho = 2.67$ gr $\cdot$ cm^{-3}. Attraction of topography surrounding measurement points (Terrain correction), Tr, was computed basically referred to HAGIWARA (1967)but originaly developed by our laboratory (KUBO, 1980 MS) introducing an analytical solution of columns given by BANERJEE and GUPTA (1977). Topographic data used in the computation were the 500 meter-mesh mean height data file (KONO, 1978) provided by GSI. The height data around 80km (40′NS×60′EW) of each measurement point were taken into computation. An error of the calculation was evaluated less than 10% (KUBO, 1980). Fig. 4 shows an example of cross-check of terrain correction terms calculated by us and MMAJ and Nagoya University. MMAJ used the Kane's method (KANE, 1962) and their results were estimated more accurate than ours, because they used more detailed height data near measurement points. Nagoya University also used more detailed mesh data file (the 250m-mesh mean height data file provided by GSI). However, no systematic difference was recognized between ours and their results, and both were coincide with each other within 2 or 3 mgals, which were sufficient enough accuracy for this study. Contribution of ocean bottom topography to the terrain correction was neglected, since a digital height (bathymetric) data file is not yet available. This means that the Bouguer anomalies near the coastal lines were underestimated about at most 2 mgals. The maximum contribution of ocean bottom topography to the terrain correction was examined employing the bathymetric data off Itoigawa where the steepest slope was observed in the surveyed area.

The data which were originally determined by the Potsdam system (all of the MMAJ data and a half of the ERI data) were subtracted 13.8 mgal from their absolute gravity values to convert the IGSN 71 system (GSI, 1976). After that, the same data processing was applied.

Therefore, the complete Bouguer anomaly was defined as follows:

$$\Delta g_0'' = g - \gamma + Atm + 0.3086h - 2\pi G\rho h + Tr$$

where the earth's tide correction was already involved in g. The accuracy was estimated about 0.1 to 5 mgals depending on the accuracy of the terrain correction terms.

4. Results.

Fig. 5 shows the distribution of the Complete Bouguer Anomaly (CBA) drawn by using 5506 data. Contour intervals are 2 mgals. The CBA is positive in the Japan sea side and is decreasing toward mountaineous region. The maximum and the minimum are appeared at the top of the Noto Peninsula (64 mgal) and in the northern part of the Matsumoto basin (−78 mgal), respectively. Contour lines of zero mgal are running roughly parallel to the

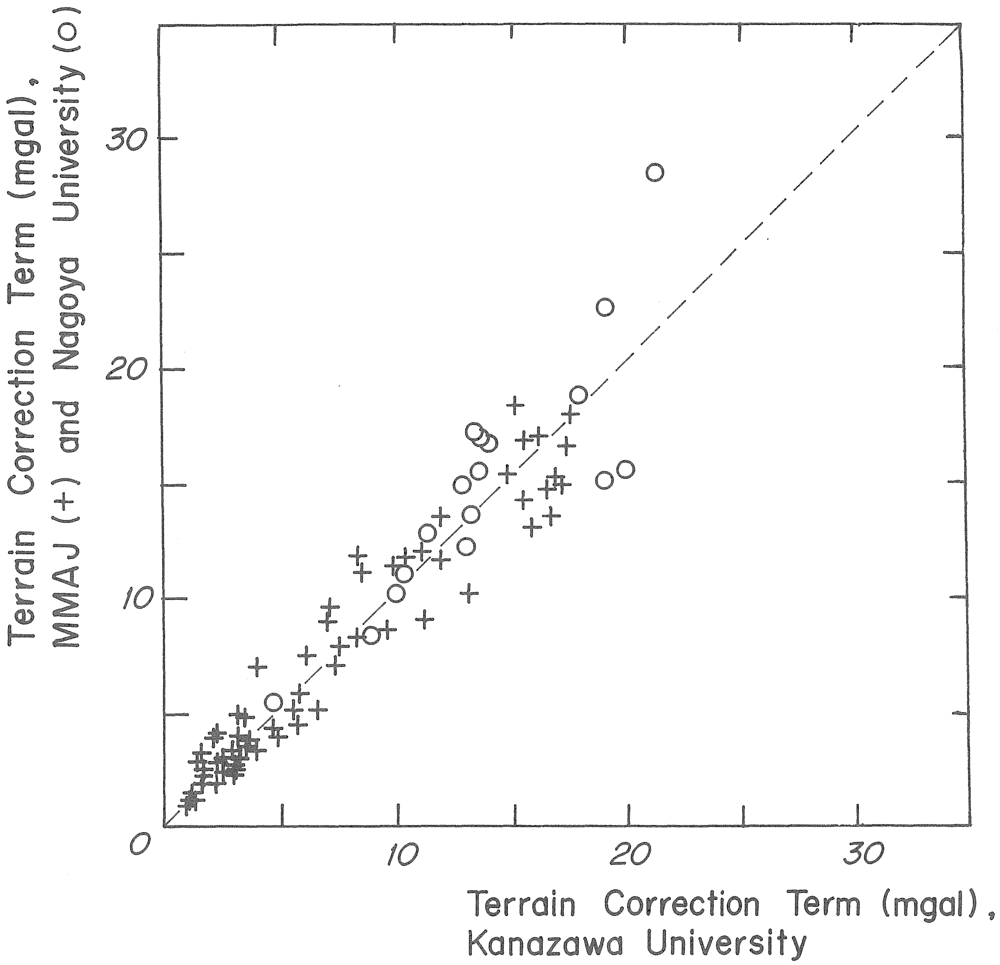

Fig. 4 Comparsion of terrain correction terms calculated by Kanazawa University, Metal and Minning Agency of Japan and Nagoya University for the same stations.

Japan sea coastal line at about 20km inland side.

There are many differences in distributions of the CBA in Fig. 1 and Fig.5. One of the largest difference is a separation of region of the strong negative anomaly in the central mountainous region. For this point, the data obtained by the group of Nagoya University played an important role. The other local distributions of the CBA show the following characteristics : Remarkable distributions of the positive CBA are appeared in nothern and southern parts of the Noto Peninsula, west of Itoigawa, south of Nagano, south of Takasaki, and east of Mt. Fuji (*FUJ*). All of them are relatively greater then 40 mgals and are increased steeply from surroundings. Remarkable negative anomalies are also appeared in the Matsumoto basin, Hida mountains from Shirouma(*SIR*) to Ontake(*ONT*), and its extension toward Hakusan(*HAK*). Those are also steeply decreased from

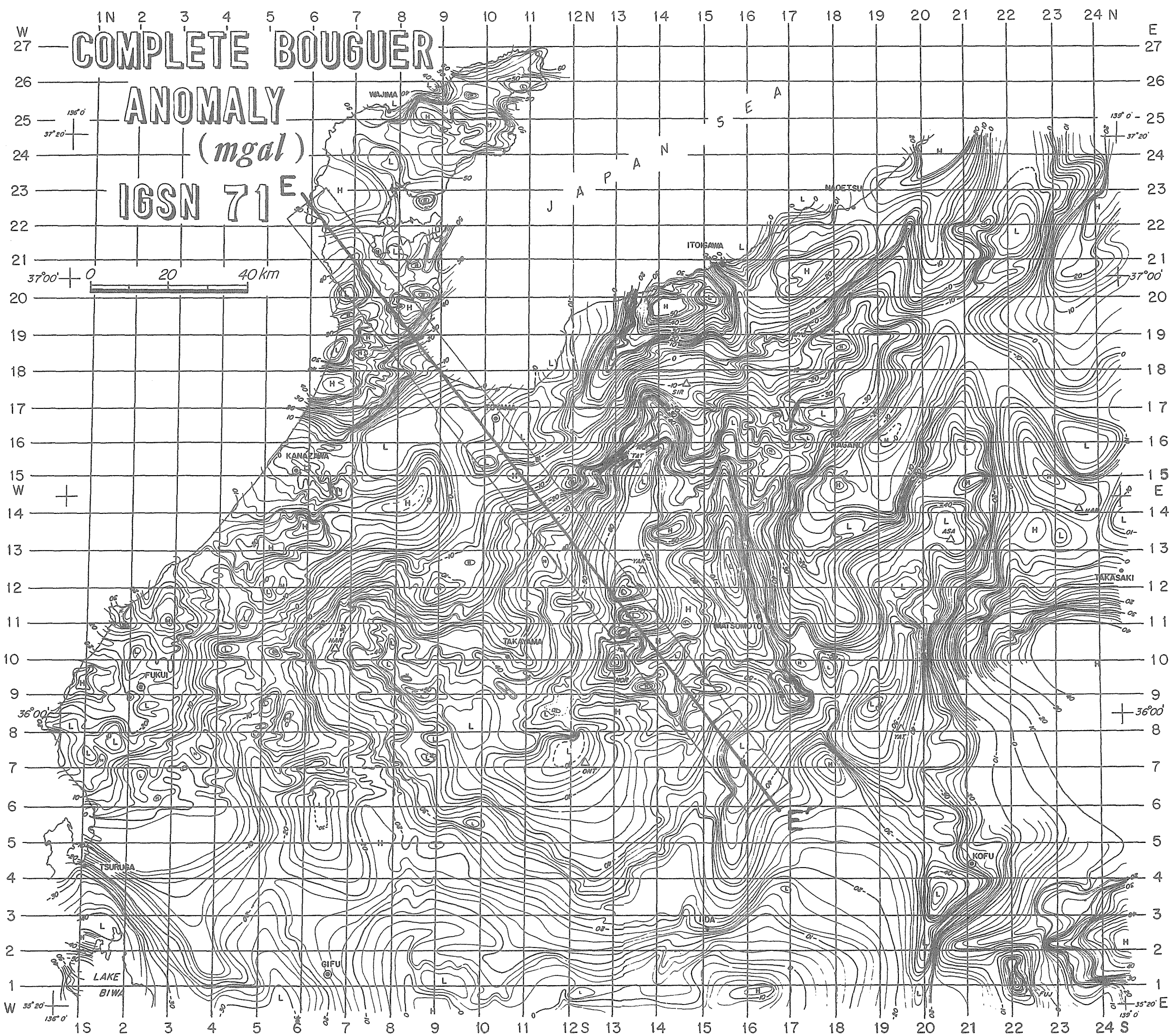

Fig. 6 Index map for Figs. 7,8 and 9.

surroundings. The Itoigawa-Shizuoka tectonic line (ISTL) which was very difficult to recognize in Fig. 1 is clearly appeared from Itoigawa to Shizuoka through Matsumoto, Suwa and Kofu. Those characteristic distributions seem well correspond to geology and topography. For example, the reversed L-letter pattern of strong negative anomaly from Shirouma to Hakusan through Ontake can be correlated with a principal distribution of granitic and Nohi rhyolitic rocks, which are estimated as intruded mainly in Cretaceous period. On the other hand, the positive CBA in southern part of the Noto Peninsula suggests a hidden distribution of Hida metamorphic rocks underneath. There are plenty of examples to show good correspondence between distributions of steep gradient of the CBA and of (active) faults : Atotsugawa, Atera faults, etc. . It can be pointed out that the most of Quaternary volcanoes are located in bottom or slope of local negative anomalies, and many of them such as Mt. Fuji, Yatsugatake (*YAT*), Asama (*ASA*), Ontake, Norikura (*NOR*) and others seem that they are accompanying with their own local negative

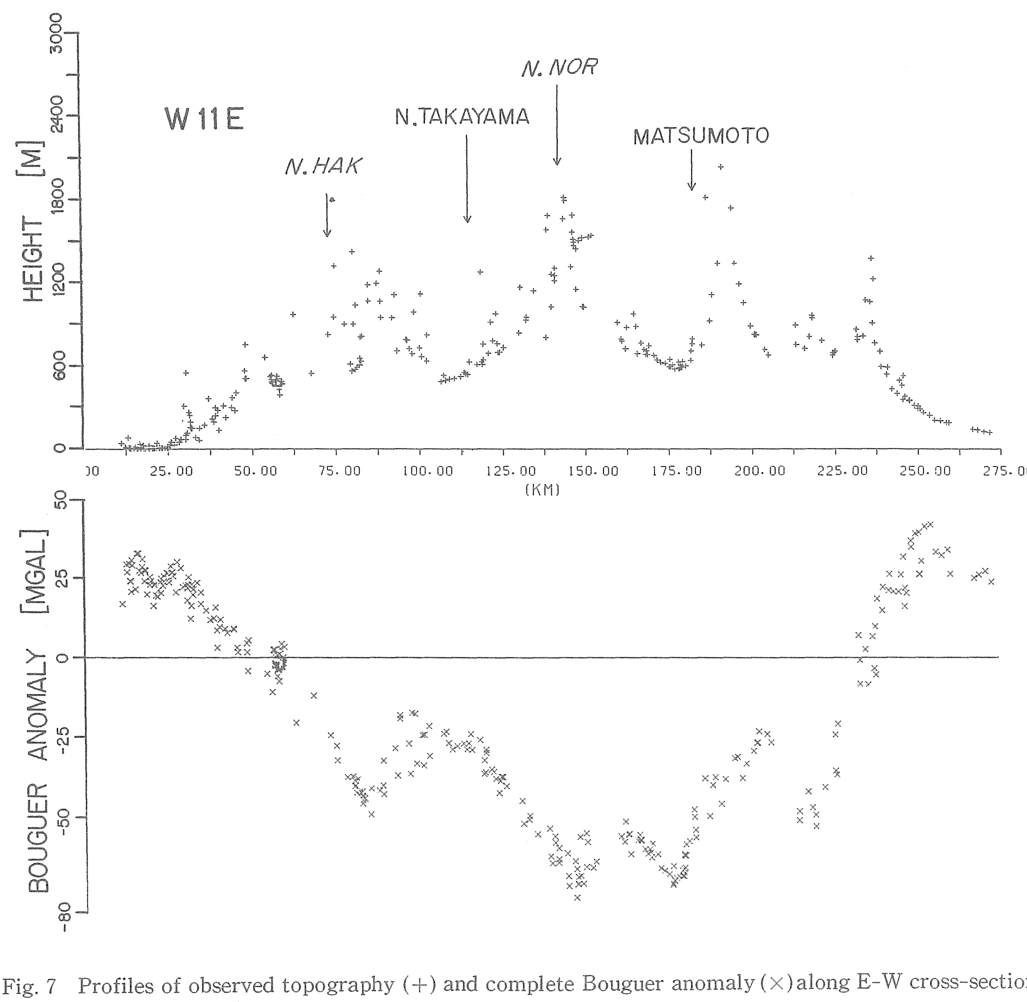

Fig. 7 Profiles of observed topography (+) and complete Bouguer anomaly (×) along E-W cross-section. Location of the profile is indicated in both sides of Fig. 6.

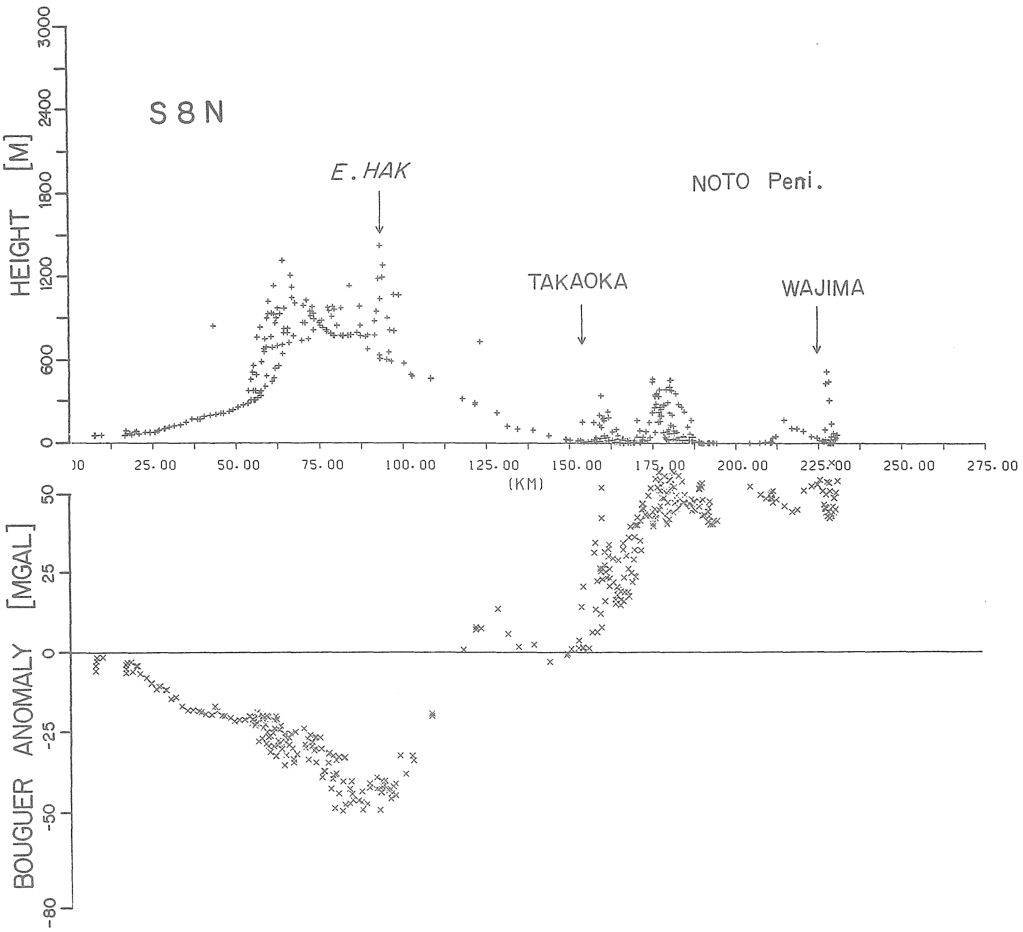

Fig. 8 Profile of observed topography (+) and complete Bouguer anomaly (×) along N-S cross-section. Location of the profile is indicated in the top and bottom of Fig. 6.

anomalies around them. From this point of view, it seems that Mt. Haruna (*HAR*) locates a little peculiar site, i. e., locally positive region, although the gravity data are scanty around it.

Figs. 7 to 9 show cross-sections of the CBA and an altitude of gravity stations. Each location is indicated in Fig. 6. Fig. 7 is a section from Fukui to Matsumoto through north of Hakusan and Takayama. As is shown in the figure, the CBA have strong correlation with topography but not simple negative correlation. The region of western half from north of Norikura shows strong negative correlation between the CBA and topography and its wave length is 60-70 kms. On the other hand, eastern half from Mastumoto, a phase of distributions of the CBA and topography is completely shifted. Therefore, a relationship between the CBA and topography which have wave lengthes of less than 70km should be explained by employing different causes for different areas. Fig. 8 also demonstrate some

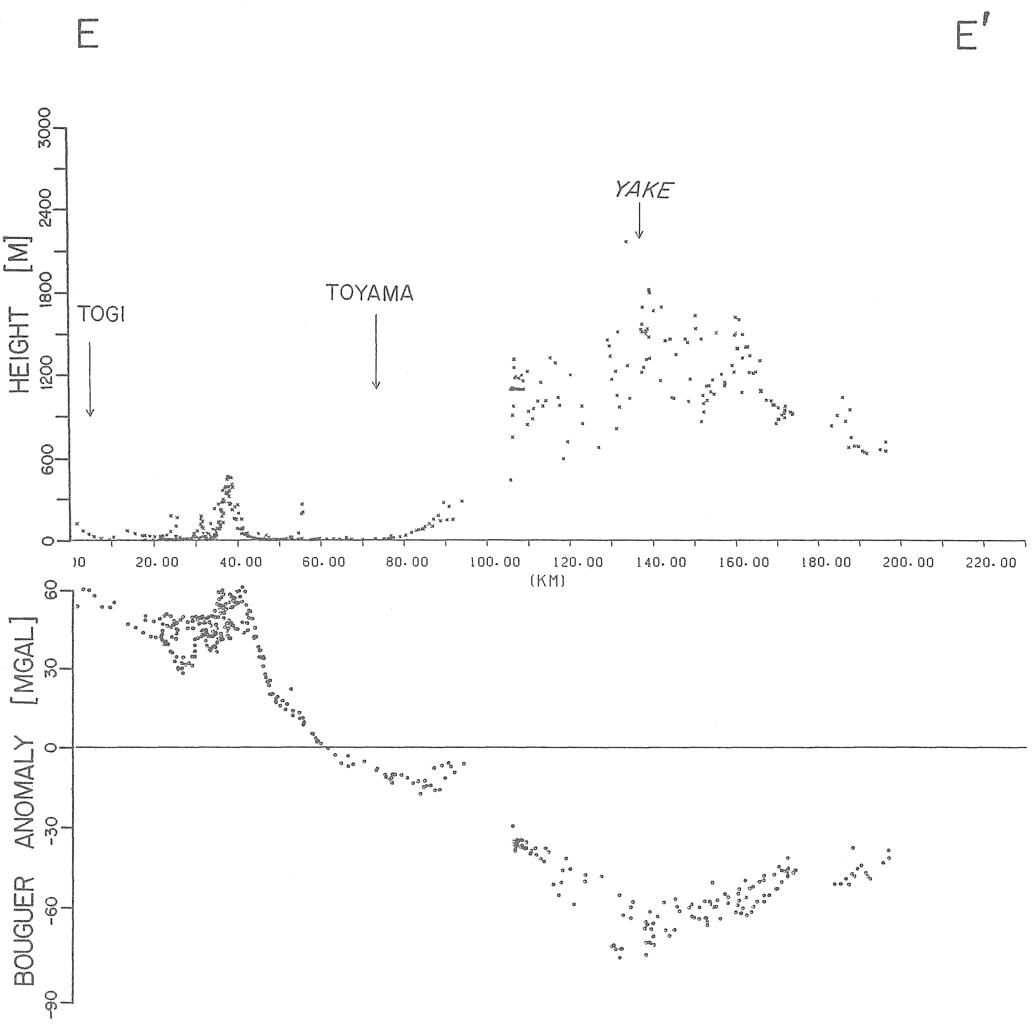

Fig. 9 Profile of observed topography (×) and complete Bouguer anomaly (○) along the E-E′ section. The location of profile is indicated in Fig. 6.

characteristic patterns of the CBA and topography along N-S sections from Wajima to the south. Fig. 9 is a profile crossing the Hida Mountains from Noto Peninsula to the Central part of the Japanese islands. All of cross sections which were indicated in Fig. 6 will be appeared in the next paper.

Results of analysis on relationships among geological and geophysical phenomena and the CBA will be discussed elsewhere. Numerical results of our observed data will also be published when the final cleaning of data is finished.

Acknowledgement

We were deeply indepted many individuals and organizations through the investigations. We would like to express our sincere thanks to all of them, particulary: Hokuriku Electric Power Co. Inc. (S. Ibuki, Y. Uchida, S. Sakai); Kansai Electric, Co. Inc. (H. Takano, K. Sasagawa); Toyama Prefecture (K. Matsumoto, A. Komori, K. Yamashita); Kurobe Kanko Co. Ltd. (K. Shijima); Kurobe Keikoku Railway Co. Ltd. (O. Yoshimura); Ministry of Construction (S. Kazama, H. Kanazu, S. Nagai, K. Hirata, K. Masuda, H. Shinjo, N. Watanabe); Electric Power Develoment Co. Ltd. (S. Nakaie); Mitsui Engineering Co. Ltd. (F. Miyoshi); S. Fujii and I. Kawasaki (Toyama University); Y. Fukao (Nagoya University); S. Akabane (Shinshu University); F. Takeuchi and K. Hirano (Kyoto University) and T. Higashino (Ishikawa Prefecture). The following students (at that time) were also greatly contributed in gravity measurements: H. Ogawara, Y. Omote, H. Nakano, N. Sakaki, M. Fujii, M. Uyeno, S. Kishi and H. Tohda.

We also would like to express our heartiest thankness to: Geographical Survey Institute and K. Tajima, Metal and Minning Agency of Japan and Y. Baba, H. Tajima of Earthquake Research Institute of Tokyo University, and M. Satomura of Shizuoka University, they kindly provided their invaluable and unpublished gravity data to this study.

This study was partly supported by a fund for specified research of the Ministry of Education, Science and Culture, Japan.

Figures in the this report were drafted by Mr. K. Nakamura and the manuscript was typed by Mrs. Y. Fukuda of Kanazawa University.

Computations were carried out in the Data Processing Center of Kanazawa University (FACOM M-170).

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