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THE UTILIZATION OF VOLCANO ENERGY.

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Geophysical Evidence for the Availability of Geothermal Energy in New Britain

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ABSTRACT

This paper combines some of the results and interpretations of geological mapping, seismic refraction, marine seismic, and gravity surveys to show that large tracts of New Britain could be favourable targets for geothermal power development.

It is shown that the fractured and faulted lithosphere is assocaited with grabens and rifts in which mantle material has risen to within 10 to 15 km from the surface. The grabens and rifts are marked by volcanism in which the dominant volcanic rocks are olivine - and tholeiitic - basalts, with a sprinkling of more acid volcanics ranging from dacite to andesite.

Following A. Rittman the basalts are believed to have originated in the asthenosphere when the lithosphere was broken up under a tensional stress regime; the acid volcanics were formed by magmatic differentiation within the crust. It was argued that ideal geothermal reservoirs are capped with altered ash deposits or other nonpermeable volcanics. To feed such reservoirs conduits are required which are naturally located on fault or shear zones. The two areas selected as favourable for future geothermal power development are located between Talasea and Lolobau Is., say around Hoskins; and near Rabaul, between Matupi Harbour and Matupi.

As a type area, the rift between the Gazelle Peninsula and New Ireland resembles the Afar triangle, at the northern end of the Great Valley Rift system of Africa.

DISCLAIMER

INTRODUCTION

This paper outlines the geological and geophysical features which are believed to make New Britain an attractive target for geothermal power development.

In support of the above proposition the paper discusses:

(a) geological and marine seismic investigations with special references to fracture and fault patterns, and

(b) the results and interpretation of seismic refraction and gravity surveys.

Finally, the ideal properties of a geothermal reservoir are discussed. The region between Lolobau Island and Talasea, and the Rabaul volcanic area are recommended as possible areas for geothermal power development.

GEOLOGY

The geology, summarized by R. J. Ryburn in Brooks (1971) and in Wiebenga (1973) need not be repeated.

However, of particular interest is the system of parallel block faults that characterized the area (some of the faults are shown in Figure 5).. Many of the fault lines are dotted with basic rocks, indicating that melted rock has leaked upwards through the fault and fracture zones. Seismic reflection surveys in the Bismarck Sea, St. George's Channel, and Solomon Sea show much the same pattern (Brooks, et al. 1971) suggesting that the region has been subjected to a tensional stress regime which kept the conduits along the fracture zone open. The fault system which created the Rabaul Caldera and its associated volcanics will be discussed later.

Generally the composition of volcanic rocks ranges from tholeiitic basalt to andesite or tonalite. However, Taylor (1970) reported the occurrence of alkali volcanics (alkali basalts?) on the string of islands, northeast from New Ireland, located on the boundary of the Ontong Java Plateau (Wiebenga, 1973). It is generally accepted that alkali basalts originate in the asthenosphere; hence it may be concluded that the basaltic material leaked to the surface along the boundary of the Ontong Java Plateau.

SEISMIC SURVEY RESULTS

Data and methods for the seismic survey refraction surveys carried out around New Britain and New Ireland during 1967 and 1969 have been reported by Brooks (1971) and Finlayson et al. (1972). Figure 1 shows the shots fired and the recording stations deployed during those two surveys. Figure 2 shows the detailed surveys within Rabaul Caldera that were attempted as part of the overall survey.

As yet no satisfactory interpretation of the apparent inconsistencies of the data has been given.

The results presented here were obtained by a method of analysis devised by the senior author. The method, called the BMR method, resembles the well known time term method, but one characteristic is that it is easier to apply. The BMR method deserves a separate paper, which the authors are presently preparing. In this presentation, only the results of the analysis will be given as the topic is existence of geothermal energy in the context of Rabaul Volcanics.

The crustal structure of the region including New Britain, New Ireland, Bismarck Sea, St. George's Channel, parts of the South Pacific Ocean is given in Figure 3. That area of the South Pacific Ocean which is denoted on the map of Figure 1 as S6 contains a shallow ocean bottom topographic relief known as the Ontong Java Plateau. The plateau is about 2 km below sea level and is about 400 km wide at its widest portion.

The profile of S3 - S4 of Figure 1 which cuts across New Britain in the middle is given in Figure 4. The structure covering Solomon Sea, New Britain and Bismarck Sea is given.

From the crustal profiles the following features can be distinguished:

(a) A shallow subsurface ridge northeast of New Ireland, through Green Island, Feni Island and Lihir Island Group, formed by extrusives along the western fault boundary of the Ontong Java Plateau.

(b) Volcanic subsurface ridges in the Bismarck Sea and St. George's Channel associated with graben structures or rifting.

(c) A horst-like feature between Doilene and Kilinwata, bounded by block faults.

(d) A graben like structure between St. George's Channel and Baining Fault. (For locations of Baining Fault, see Figure 5). The Rabaul volcanic complex and caldera are associated with this graben.

(e) Whenever positively detected, the areas where the intermediate layers (6.7 to 7.1 km/sec refractors) appear to be shallow, are located on fault or shear zones.

(f) Shallow mantle material appear along rift zones, faults, or shear zones, or in areas marked by volcanism; e.g. graben or rift zones in St. George's Channel, in the Bismarck Sea, in central New Britain (Au'una), along the trench, and in the volcanic zones between Talasea and Doilene, and at the Rabaul volcanic complex.

(g) The region from St. George's Channel eastward to the Ontong Java Plateau (S6 of Figures 1 and 3) form a series of horsts and grabens.

(h) Ridges in mantle topography in central New Britain.

GRAVITY INVESTIGATION

On a topographical and geological map the Rabaul Volcanic complex, caldera walls, and caldera seem to form a separate unit. However, on the Bouguer anomaly map (Fig. 5) the caldera area is only a small part of a large 30 mgal Bouguer gravity low area. The gravity anomaly between the Baining Fault and Keravat River Fault, and St. George's Channel suggests the presence of a northwest-southeast graben open to the southeast but closed towards northwest. Figures 5 and 6 show various gravity profiles perpendicular to the graben axis. Arbitrarily, but also because it fits the local conditions, the gravity regional value is assumed to be +100 mgal, and this value is used as the local gravity zero reference level. The inset in Figure 6 shows a plot of $\Delta S \Delta g$ for various cross-sectional areas. The significance of $\Delta S \cdot \Delta g$ appears from Gauss' relation:

$$C \, \Delta M = \Delta S \cdot \Delta g$$

where C is a constant, ΔM a 2-dimensional anomalous mass, ΔS the area, and Δg the gravity anomaly. The plot shows that along the graben axis $\Delta S \Delta g$ is a maximum for profile A. The Bouguer gravity map suggests that the positive anomaly coinciding with the southwestern caldera wall can be explained by an intrusion parallel to the graben axis.

The total gravity profile is the effect of various superimposed anomalies which are modelled by masses (blocks with a specified density differential using geologic and seismic information controls).

Density of blocks can be inferred from seismic data by using density velocity relation such as one by Woollard (1962).

From these considerations, the following interpretations were arrived at:

(a) The major negative anomaly is caused by the Rabaul block, and possibly by the block just west of the Rabaul block. The southwestern and northeastern boundaries are formed by the Keravat River and Matupi faults (see Figure 5). A 2 km down throw of the graben floor will account for the gravity anomaly.

(b) Southwest from the Baining fault, the blocks with +0.07 t/m^3 density differential can explain the gravity increase and steep gravity gradient.

(c) Under St. George's Channel a steep gravity gradient can be explained only by a heavy layer (+0.3 t/m^3 density differential) close to the surface, probably immediately underneath the sea bottom.

(d) Sharp positive gravity anomalies near Matupi Fault can be explained by higher density intrusions.

From the above interpretations, the hypothesis presently favoured is that the Rabaul graben or block formed gradually, between the Keravat River and Matupi Faults, and filled with volcanics as the process continued.

Whereas the graben formation requires fault throws in the order of kilometers, the Rabaul Caldera is a recent collapse structure superimposed on the graben and associated with faults of very much smaller magnitude. The southwestern or western boundary of the caldera coincides with a sharp positive anomaly which is explained by an intrusion into a zone that is still active as shown by recent eruptive activity.

The eastern or northeastern caldera boundary coincides with the Matupi Fault zone, also still active as indicated by a series of volcanoes with intriguing local names as the Mother, North Daughter and South Daughter.

From the viewpoint of exploration for thermal energy, the Rabaul graben could be a favourable structure. There is every chance for the presence of layers of lava flows and volcanic ash. Some of the lava flows could form a suitable cap rock to prevent steam and volcanic gas from escaping to the surface. Conduits on faults or fractures from lower levels within the crust are partly open as shown by contemporary volcanism. Suitable targets for further exploration are located in many places in and around the Rabaul area.

GEOTHERMAL RESERVOIRS

Ideal conditions for geothermal reservoirs are much the same as those for oil reservoirs, i.e. the reservoir rock should have sufficient permeability and porosity. In the instance of oil reservoirs rapid escape of oil and gas is prevented by an impermeable caprock above an anticline, or oil and gas are locked in stratigraphic traps. Sometimes oil and gas are prevented from migrating because caprock and fault-clay blocks further migration. In the instance of geothermal reservoirs, the impermeable cap formations may consist of altered ash deposits or any volcanic material of low permeability.

To feed geothermal reservoirs, there must be conduits for magmatic material, steam and gases. Basaltic volcanoes are generally located on crustal fracture or fault zones. Hence, geothermal reservoirs with their associated conduits are located on or near these fault zones with basaltic volcanism.

In New Britain the area between Talasea and Doilene (see Figure 1) is a favorable area for geothermal reservoirs: grabens and fracture zones are common, mantle material is located at relatively shallow depth, and basaltic volcanism is dominant (Fisher, 1957). According to Johnson (1970, 1971) there are olivine and tholeiitic basalts, believed to have originated in the asthenosphere, and rhyolites and dacites, generated by magmatic differentiation within the crust (Rittman in Runcorn, 1967).

A second favorable area is located near Rabaul. Fisher (1957) describes the volcanic activity of Vulcan, associated with andesitic pumice, and the Matupi complex, associated with olivine basalts.

The Matupi complex is located on faults, shown to be a part of a major graben. Hence, the area between the Matupi and Matupi Harbor may be considered a favorable drilling target for geothermal energy.

CONCLUSION

Geological and seismic refraction surveys showed central New Britain and the adjoining Bismarck Sea to be areas of fracturing and faulting, characterized by basaltic volcanism. Following Rittman it is believed that the basalts represent partly molten mantle material, generated in a tensional stress regime. In the area, mantle material has been located within 15 km depth. The area was shown to be a favourable region for geothermal reservoirs.

Geological, seismic refraction, marine reflection and gravity surveys proved the existence of graben or rift structures, near Rabaul, Gazelle Peninsula, and in St. George's Channel. Within the graben is the Rabaul caldera, marked by basaltic and andesitic volcanism. Seismic refraction surveys showed that in the rift area mantle material comes within 12 km depth. A favourable drilling target for geothermal reservoirs was indicated at the foot of Matupi Volcano, close to Matupi Harbour.

Finally, the zone between the Gazelle Peninsula and New Ireland resembles in many respects the Afar Triangle at the northern end of the Central African rift system.

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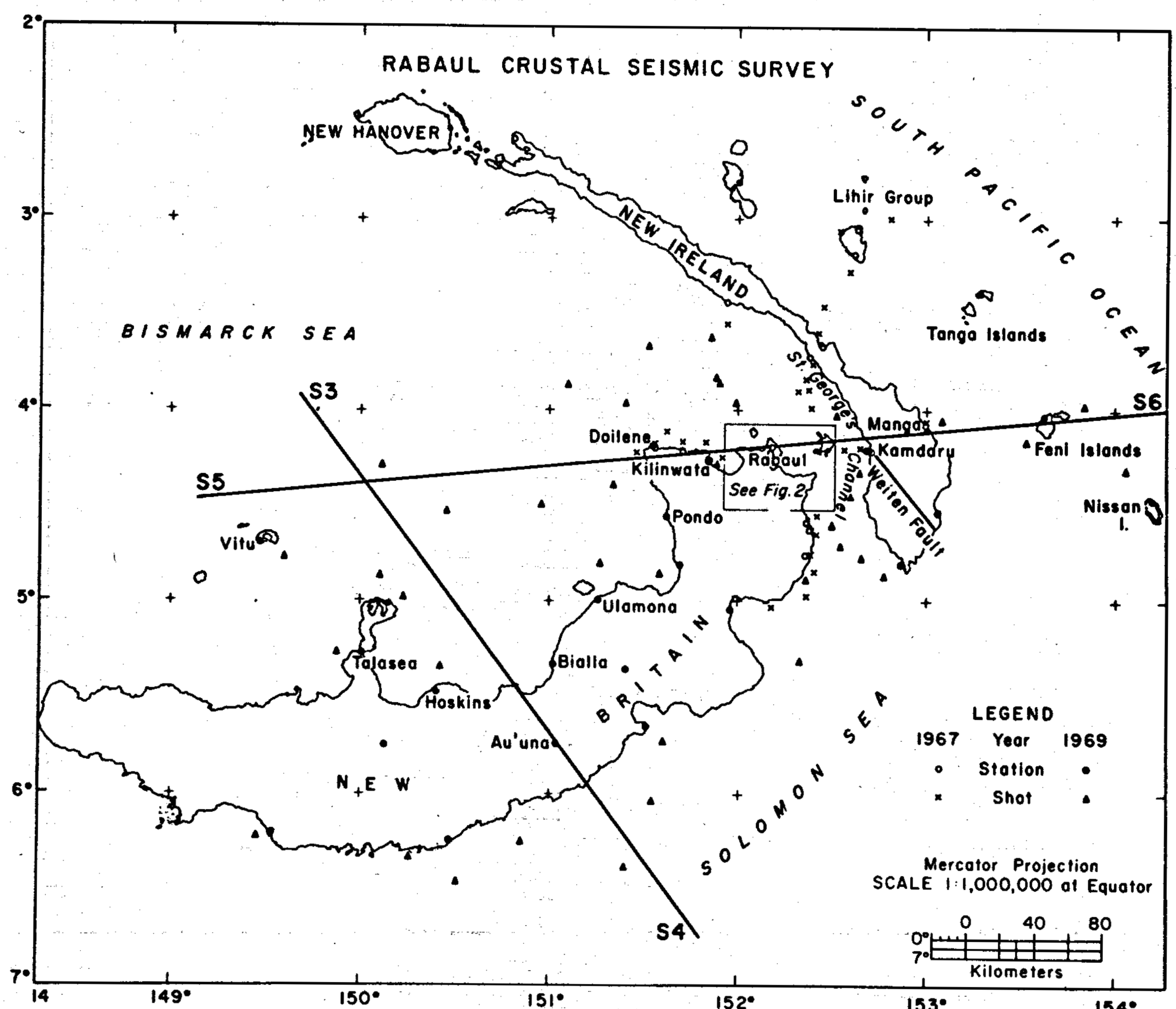

Figure 1. Locations of Shots and Recording Stations of the Rabaul Crustal Experiments. Crustal Section across S5-S6 is given in Figure 3; that across S3-S4 is given in Figure 4.

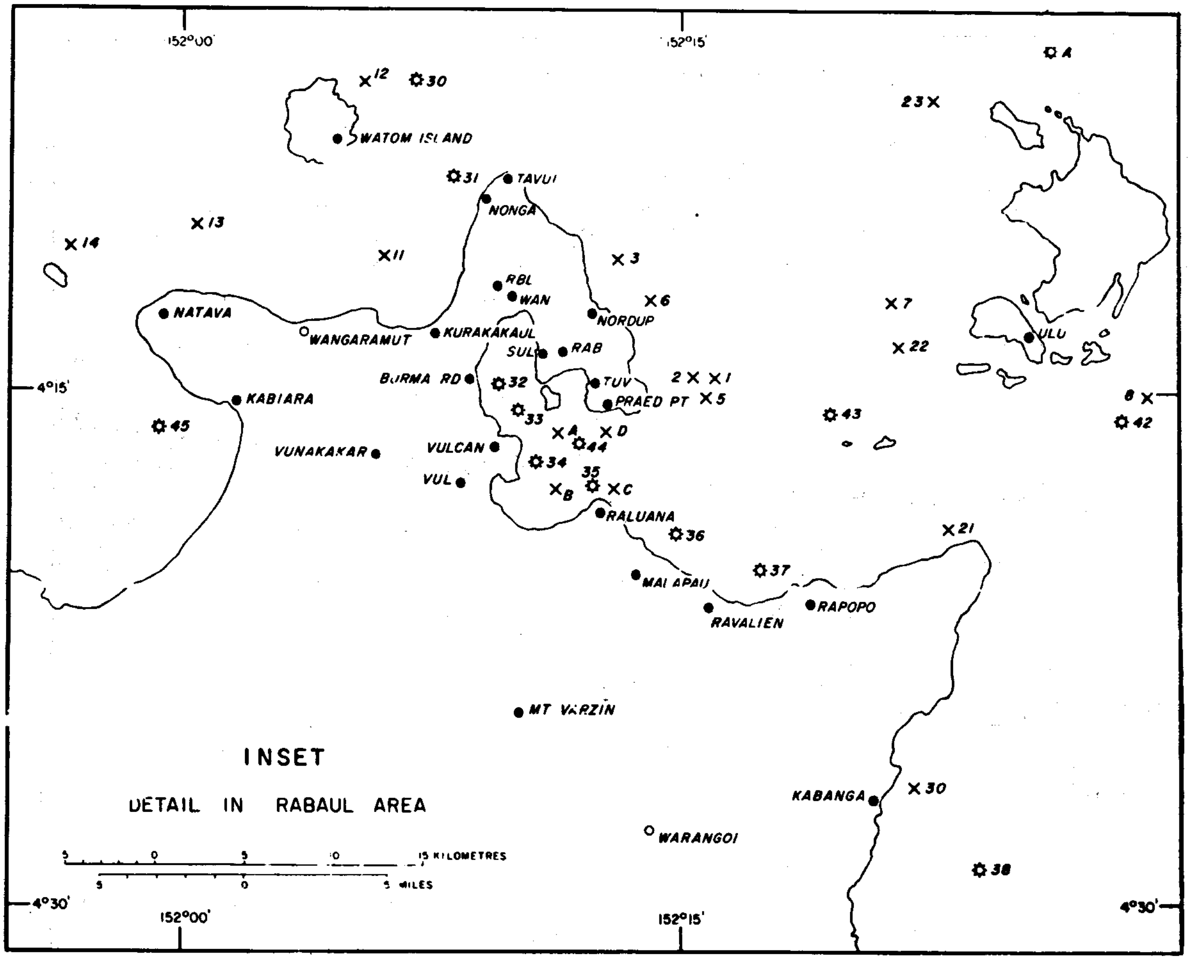

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Figure 2. Locations of Shots and Recording Stations of the Rabaul Crustal Experiments. X's are shots of 1967 experiment; radiating circles are shots of 1969 experiment.

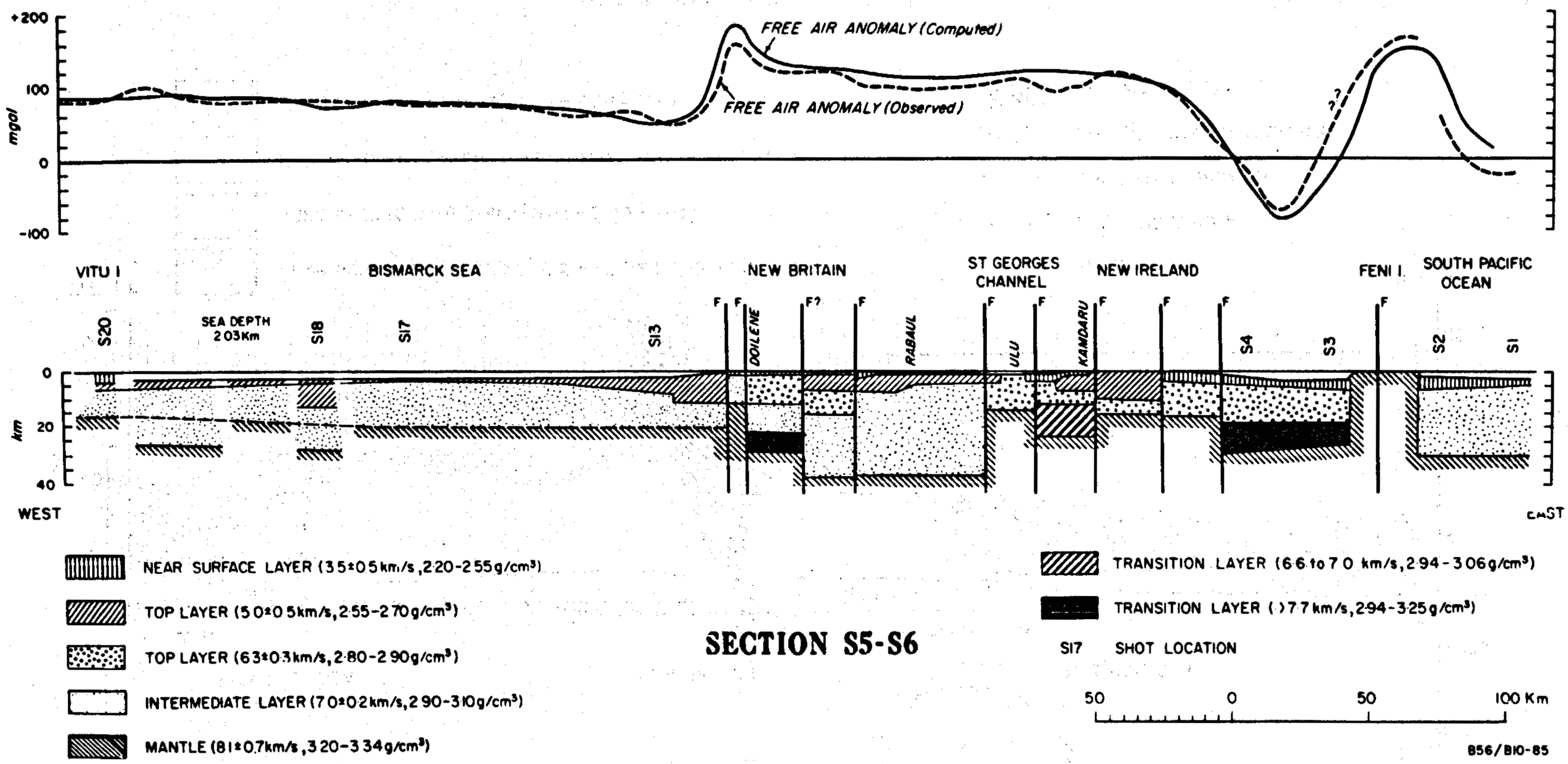


Figure 3. Crustal Section along East-West Line (S5-S6 in Figure 1) through Rabaul. No vertical exaggeration.

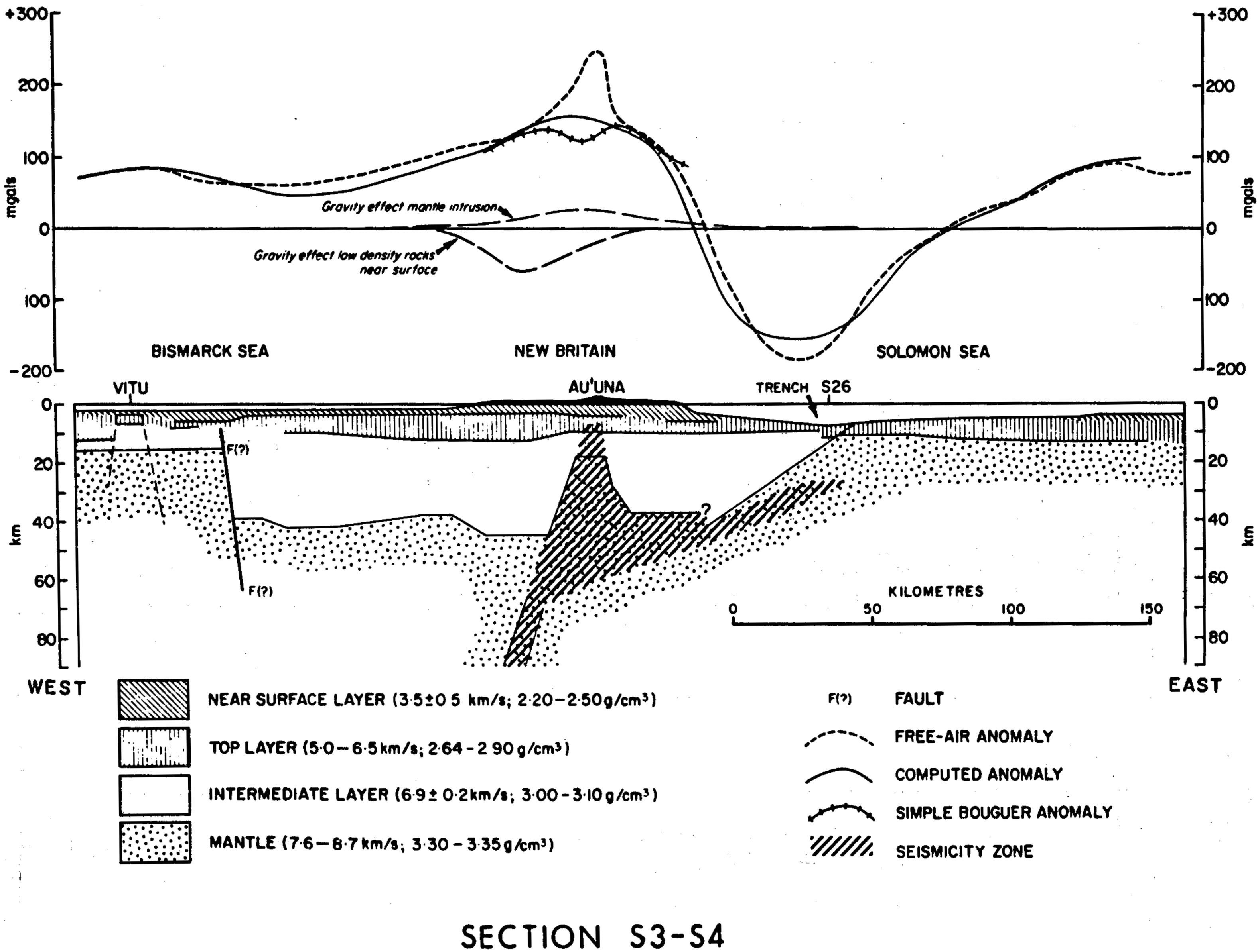
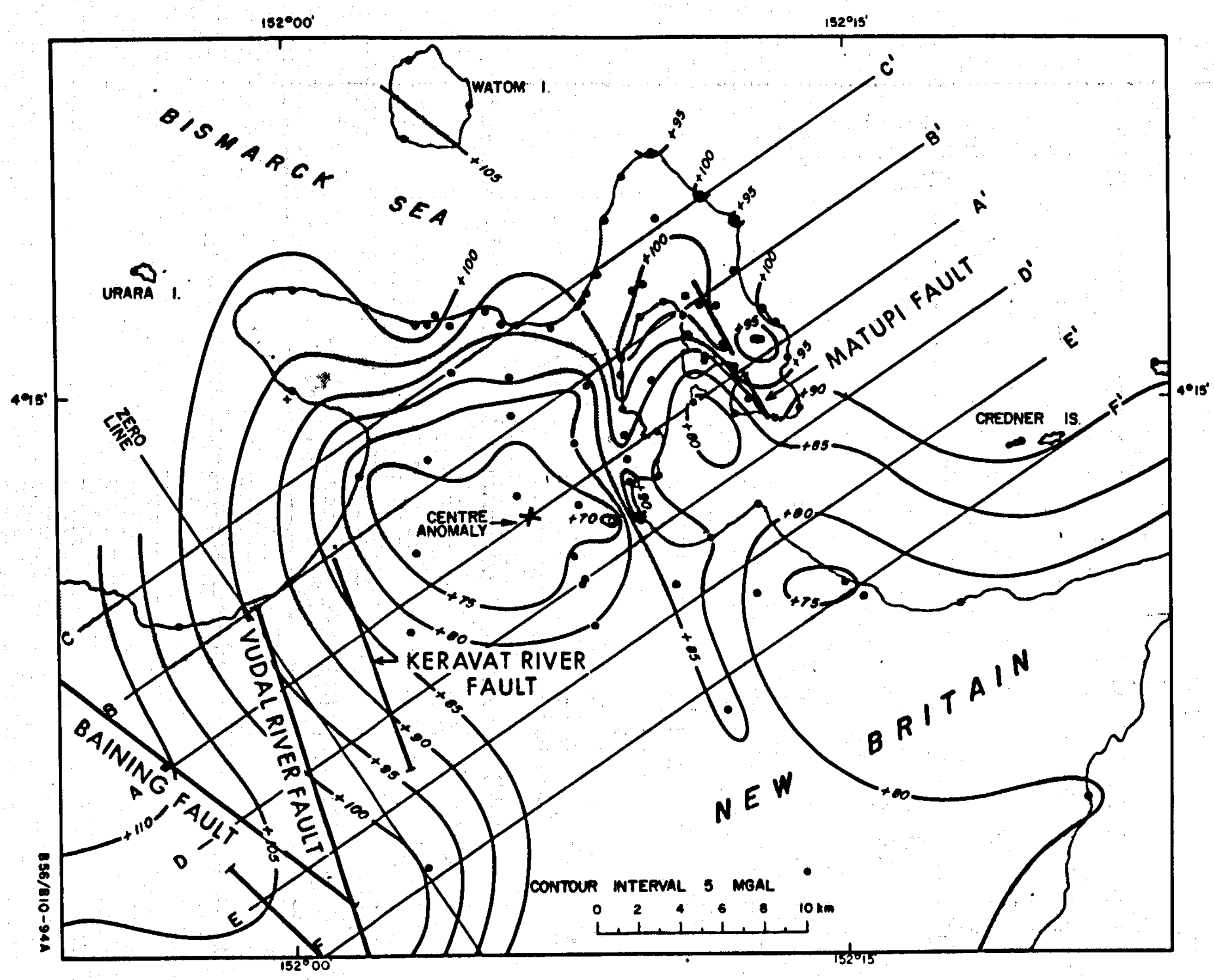


Figure 4. Crustal Section through Central New Britain (S3-S4 in Figure 1). No vertical exaggeration.



BOUGUER ANOMALIES

Figure 5. Bouguer Anomaly Map around Rabaul.

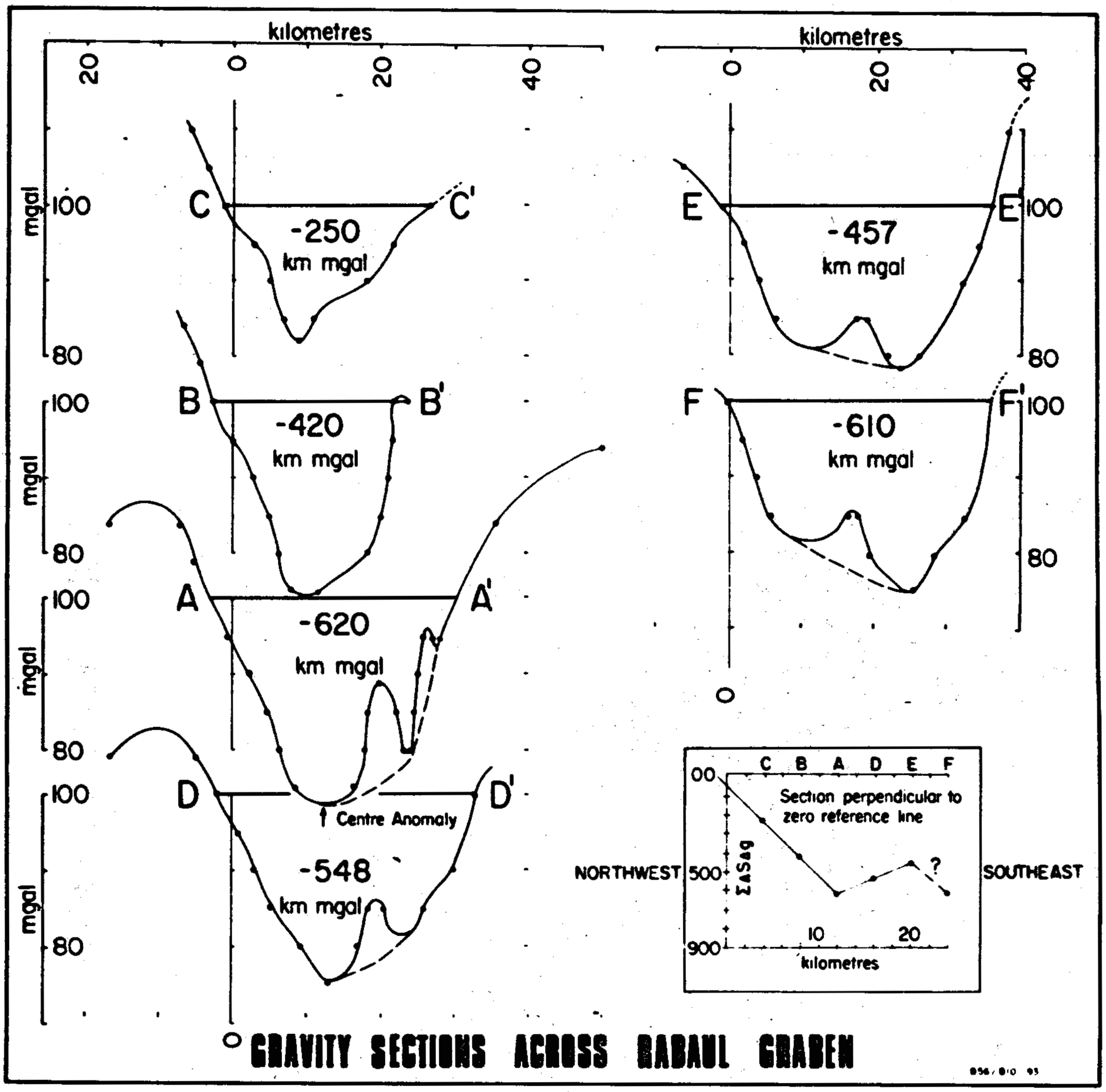


Figure 6. Gravity Sections across Rabaul Graben.

Discussion of Wiebenga Paper

Higgins

I think there's a point here. If I may, not being a geologist, let me comment on what I hear being said. If there is extreme topographic relief, as there is in these areas where volcano deposits are found and there is normal strike/slip faulting caused by very-long-range compressional force, and if you examine on a very small scale the elevation and mineralogical differences, it seems to me you could very easily interpret or overinterpret what was lateral motion as a horst/graben type of formation. I don't mean to say that's bad geology; it's very hard with basalt that is out of sequence to find marker beds and things. It's not like the sedimentary or other kinds of areas where you can say, "Yes, I know that one is up with respect to that one." We can just look at the topography and velocity profiles.

Furumoto

In this area, we are leaving plate tectonics alone because it's a hot topic that's very emotional. They claim this area is in compression because you have trenches. Fine. In general, it could be compression; but, in this small area, it could be tension. That's what we think; tensional forces seem to crack open these things. In Rabaul, we've had negative anomalies; in other places, there are very high positive anomalies.

Higgins

I didn't want to bring in causative arguments, but only the interpretation of the details of the geologic and topographic features on a very small scale. How small is small, that's the real question.

Furumoto

We are concentrating now on what a volcano is on Rabaul. We are leaving alone all these people who like to move continents. We have to give an answer to the people of Rabaul as to when to get out of there. Also, there is the question, "Do they have energy for a new nation?" They don't have oil; they haven't found any oil. They have to import all their oil. For example, you think it's bad around here. In some of the towns in New Guinea, they turn off the generators at 10:00 PM because that's all the oil they have; and they've been doing this ever since lights came to them. So they need a source of energy. We're concentrating on this and on the question. "Can we predict when it's going to erupt so they can get the people out of Rabaul?" We're looking at minor problems and not worrying about moving continents.