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The gravity field and tectonics of the Nansha Islands (Dangerous Grounds)

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Abstract: Gravity surveys of the Nansha Islands in the southern part of the South China Sea (the Dangerous Grounds) have been undertaken by the China Sea Institute of Oceanology, Academy Sinica. More than 19,000 line kilometres of gravity profiles were measured between 1984 and 1994 in the region 106–118°E, and 4–15°N. The accuracy of the gravity data is approximately + 2.5 mgal. The area surveyed can be split into three zones according to the observed gravity variations. These three zones are: 1) the Zengmu Basin (Sarawak Basin) Province where the gravity variation is mostly controlled by variations in sediment thickness, 2) the Reed Bank Gravity High Province which includes the highest measured gravity values in the South China Sea and where gravity variations are influenced mostly by changes in deep crustal structure, and 3) the Nansha Trough (Palawan Trough) Gravity Low Province with the lowest gravity values in the Nansha Islands. Crustal thickness has been modelled from the gravity data along several profiles. The results indicate a crustal thickness of approximately 25 km for the Reed Bank, a thickness of 20–25 km in the reef areas, a thickness of approximately 20 km in the trough areas, and a thin and denser crust of 17–20 km thickness beneath the Zengmu Basin.

INTRODUCTION

From 1984 to 1994 the South China Sea Institute of Oceanology, Academia Sinica, undertook investigations of the geological and geophysical features of the Nansha Islands of the Southern part of the South China Sea (the Dangerous Grounds) with measurements made along 30 main profiles. More than 19,000 line kilometres of geophysical data were collected covering the area 106–118°E, and 4–15°N.

THE GRAVITY FIELD OF THE NANSHA ISLANDS (DANGEROUS GROUNDS)

From study of the gravity data (Fig. 1) this area can be split into three distinct zones, namely the Zengmu (Sarawak) Basin, the Reed Bank and the Nansha (Palawan) Trough gravity provinces, with the gravity variations due to differences in geological structure between these three zones.

The Zengmu (Sarawak) Basin gravity anomaly province

This province is located on the Sunda Shelf. The most conspicuous gravity feature is the zone of high values over the thickest sedimentary section of Zengmu basin. This is in contrast to the regional pattern of low gravity values over zones of thick sedimentary section. The high gravity values are due to crustal thinning which must have controlled the basin development, resulting in the thickest sedimentary section overlying the thinnest crust.

The Reed Bank gravity high

This region includes the highest gravity values measured in the South China Sea which exceed +100 mgal. It is delineated by a belt of steep gravity gradients with a change of as much as 110 mgal in only 18 km. Such large changes are due to fundamental differences in crustal structure (Ben-avraham and Emery, 1973; Bol and Hoorn, 1980) — in this case the transition between continental crust of the Reed Bank and oceanic crust of the South China Sea.

The gravity anomaly at the continental-oceanic boundary is positive with amplitudes of up to + 50 mgal, and is negative over the continental slope and ridge with values as low as – 50 mgal. There is often an almost linear gradient between these peak and trough values. Figure 4 illustrates a hypothetical crustal cross-section across the continental-oceanic boundary with computed gravity responses (following Dehlinger, 1987). Figure 4 illustrates the correspondence between the slope of the Moho across the transition and the corresponding gravity gradient.

The 1989 gravity survey traversed from the Central Basin of the South China Sea to the Reed Bank (Su and Huang, 1987; Su *et al.*, 1989; Su *et al.*, 1991). Seismic refraction data indicates an oceanic crust beneath the Central Basin with a

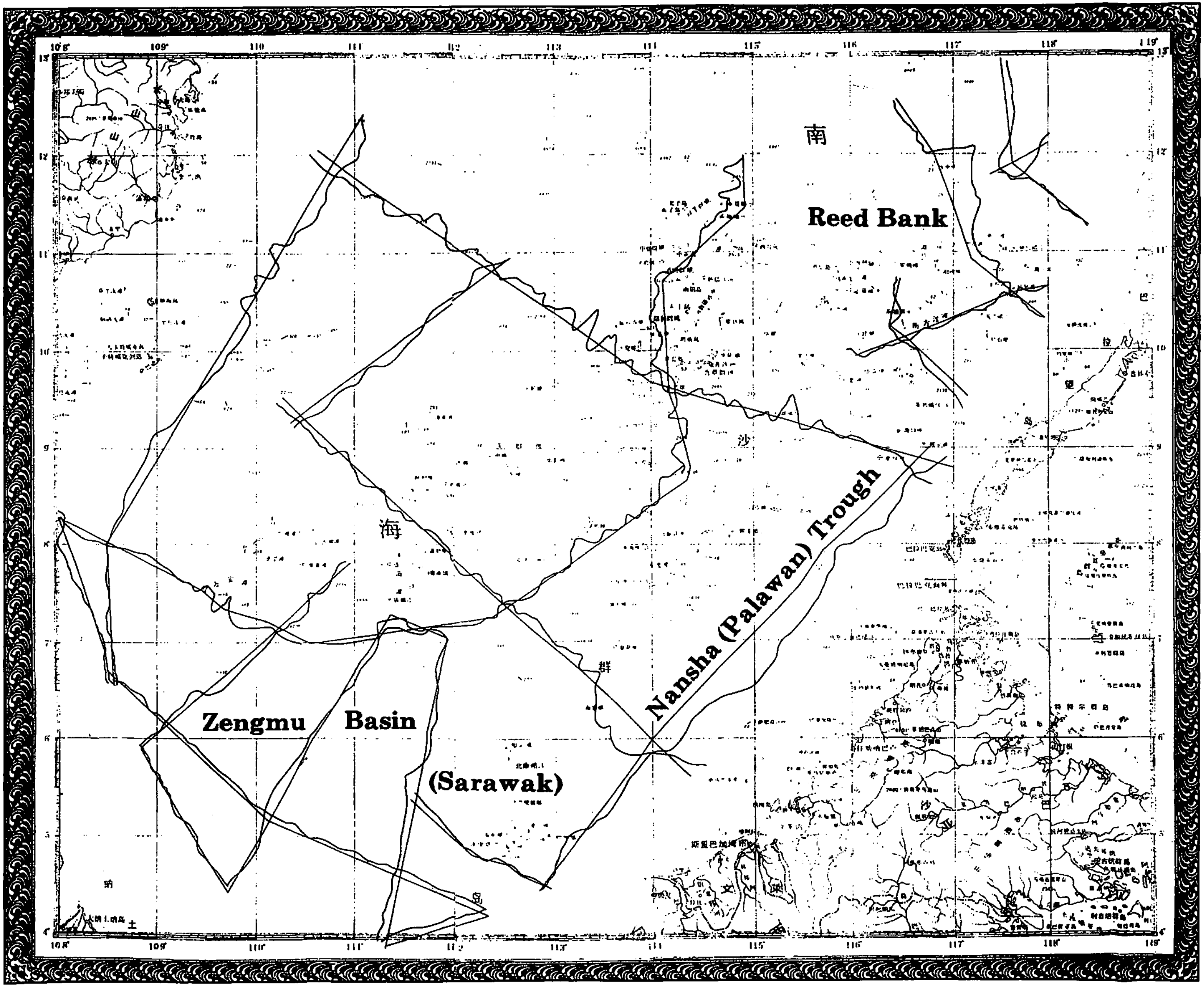

Figure 1. Gravity profiles in Nansha Islands (Dangerous Grounds).

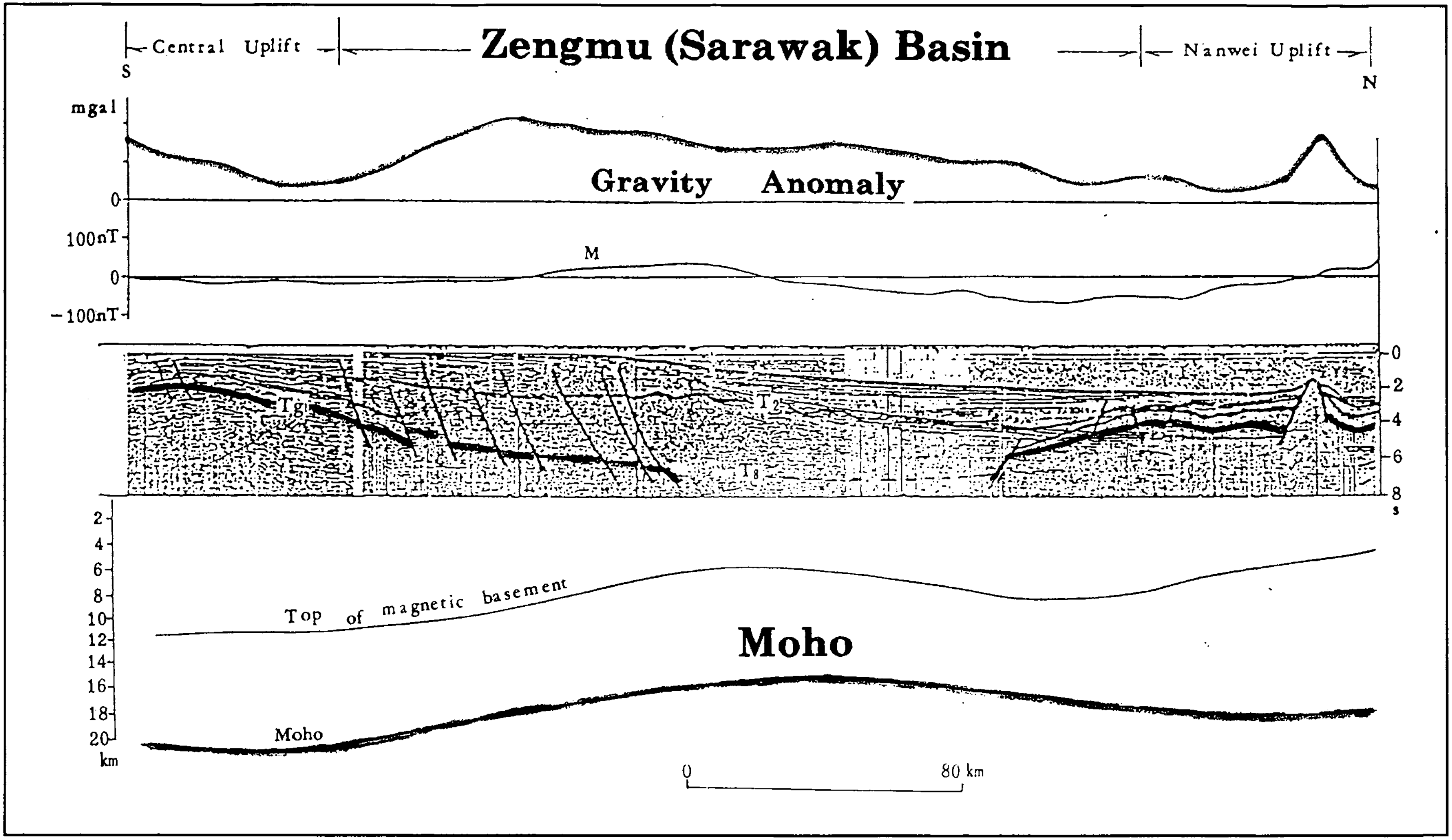

Figure 2. Gravity anomaly and geological structure in Zengmu (Sarawak) basin.

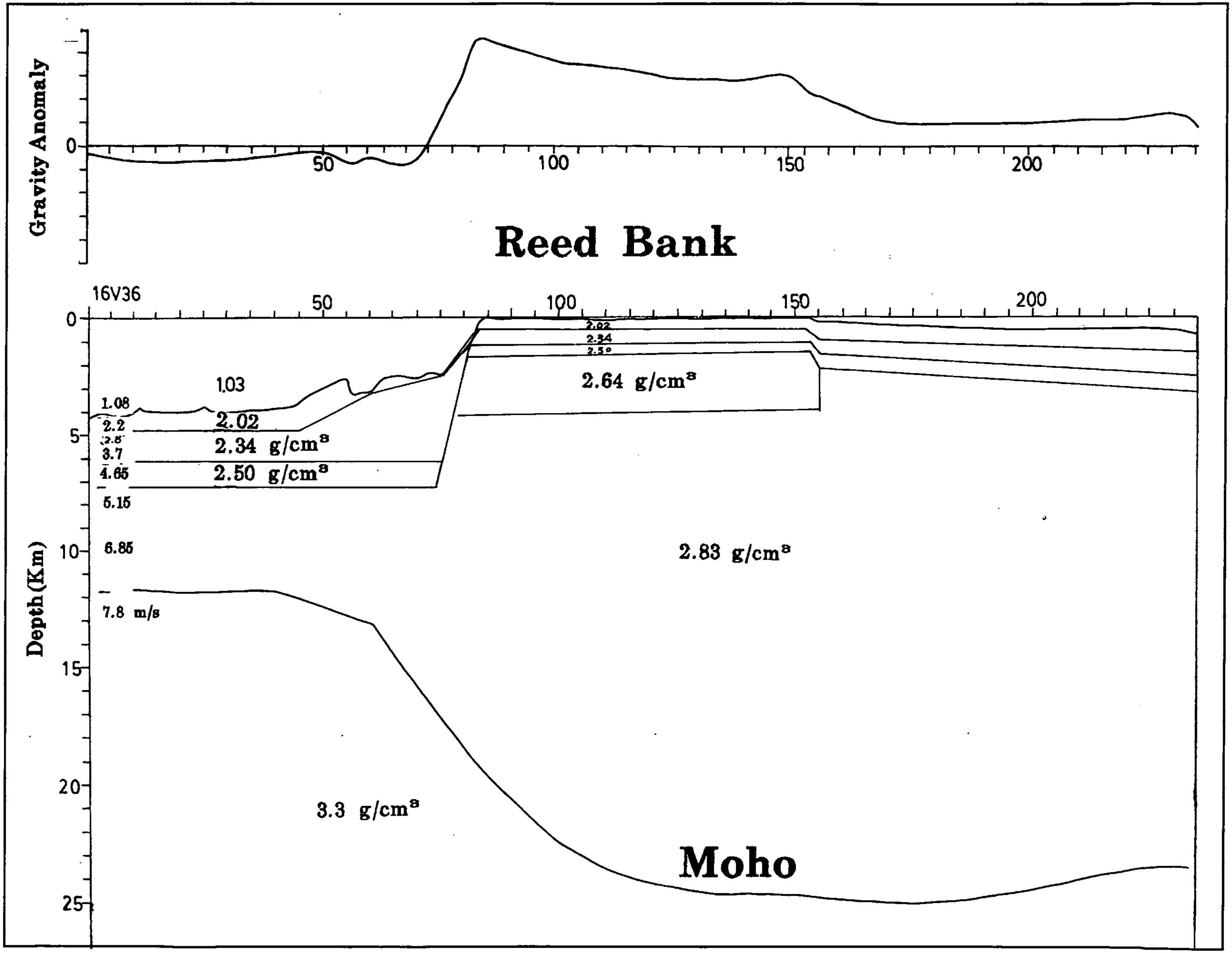

Figure 3. Gravity anomaly and crustal structure in Reed Bank.

depth to the Moho of around 11 km. Drilling data confirms that the crust beneath the Reed Bank is continental. The gravity survey therefore clearly traverses an continental-oceanic transition zone and the model of Figure 4 is valid for the interpretation of this data. The gravity anomaly is positive over the continental crust of the Reed Bank, has its steepest gradient over the crustal boundary, and is negative over the oceanic crust of the Central basin.

The Nansha (Palawan) Trough gravity low

The Nansha Trough has one of the most conspicuous gravity signatures of the study area. It is marked by a negative gravity anomaly of less than – 80 mgal which is significantly less than the previous reported minimum of – 62 mgal. The gravity minimum coincides with the axis of the trough and is 45 km from the location of the previous reported gravity minimum. The gravity profile correlates with bathymetry with steep gradients over both sides of the trough which are controlled by faults between the Dangerous Grounds and Borneo. A northwest trending gravity gradient marks the southern end of the trough where it borders the Sunda Shelf on the east and extrapolates to the Tinjar Fault which has been mapped onshore.

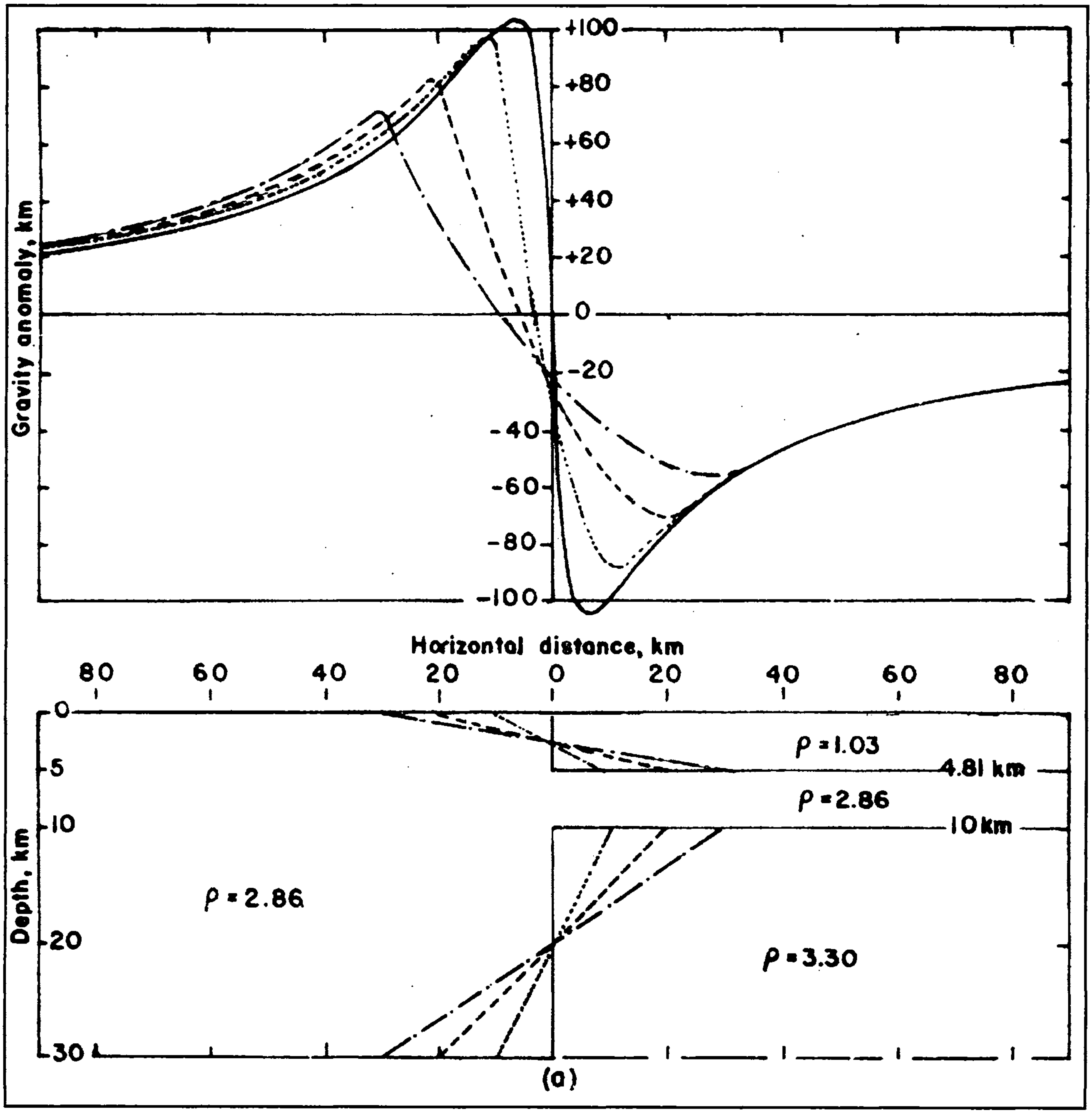

Figure 4. Gravity edge effect in COB (continental oceanic boundary) (after Dehlinger, 1987).

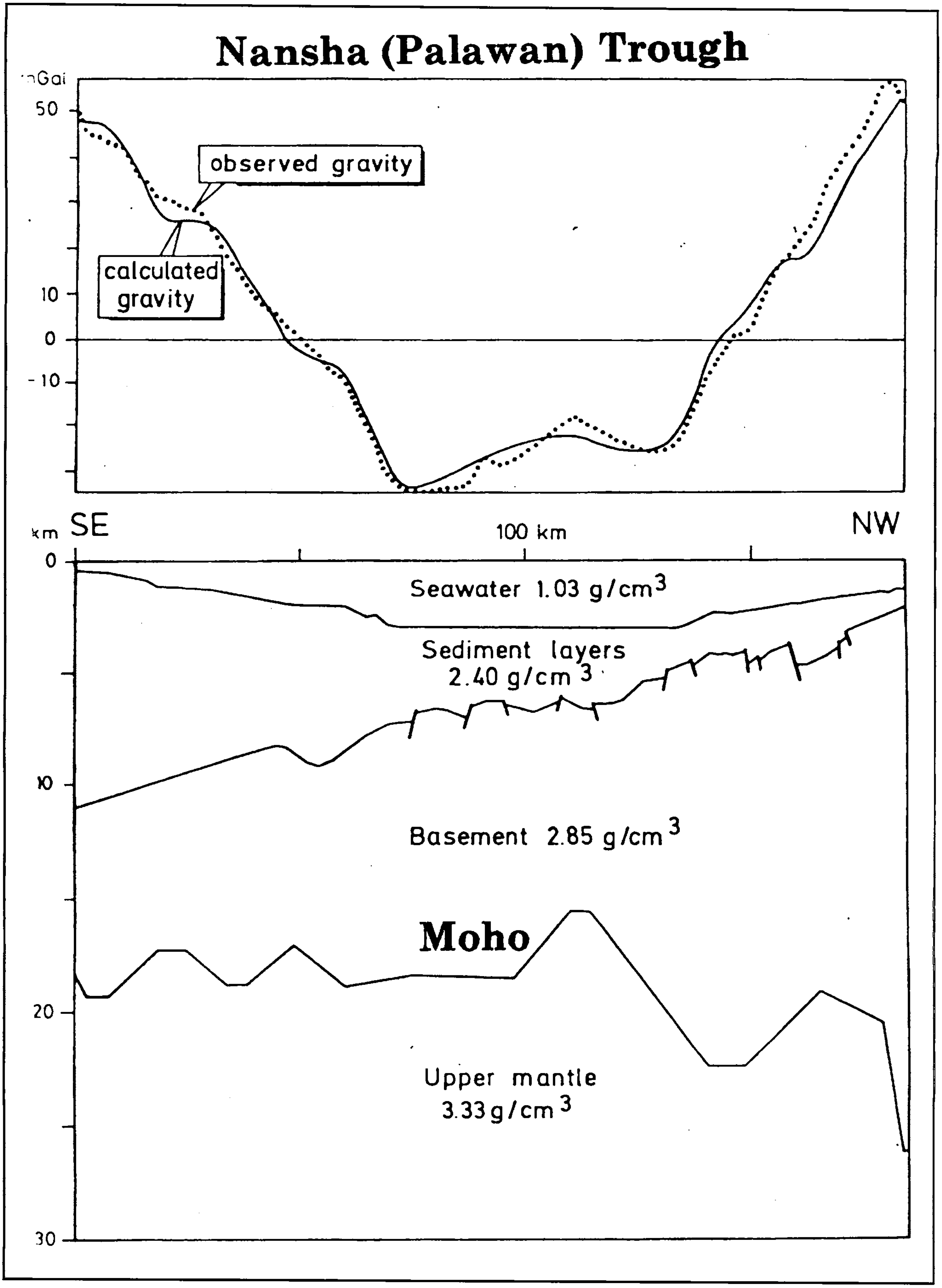

Figure 5. Gravity anomaly and Moho depth in Nansha Trough (after Hinz and Schluter, 1985).

The gravity gradient suggests that this fault extends offshore where it separates the trench and the Sunda Shelf (Dash, 1971).

The axis of the gravity low shows displacements and lateral variations in the minimum value. One of the displacements of the anomaly axis corresponds to an offshore extension of the Balbac Fault which appears to traverse the trough. The gravity anomaly over the trough has a "V" cross-section and a width of approximately 110 km similar to the width of the bathymetric feature. There are shorter wavelength positive gravity variations within the trough which are similar to those over basement extrusives in the reef areas of the Dangerous Grounds (Hinz and Schluter, 1985). These anomalies may suggest that the trough area was previously a part of the reef which has subsequently sunk in response to tectonic forces.

CRUSTAL THICKNESS IN THE NANSHA ISLANDS CALCULATED FROM GRAVITY DATA

Crustal thickness can be estimated from the seismic and gravity data that has been acquired. For the gravity interpretation a backstripping method was adopted to remove the influence of water and sediment layers so as to calculate the gravity contribution of the deeper crustal structure (Chuji, 1956). Seismic refraction data acquired near the Natuna islands provided an initial control point for gravity inversion which was undertaken using the sin X/X method. Results indicate that the crustal thickness in the Zengmu Basin is 20–25 km with an inverse relationship between water depth and crustal thickness. Crustal thinning is believed to be due to crustal extension. Interpretation of line N2 as shown in Figure 2 indicates that the crustal thins to as little as 15 km at the centre of the basin.

An integrated model of the crustal structure of the Reed Bank from gravity and seismic reflection and refraction data is shown in Figure 3. Seismic data in the Central Basin north of the Reed Bank is sparse with only lines 15V36 and 16V36 reaching the depth of the Moho. Line 15V36 shows a maximum depth to the Moho of 11.9 km with a P-wave velocity of 7.6 m/sec. Corresponding values for line 16V36 are 11.6 km and 7.6 m/sec. Line 16V36 was used as the control for crustal modelling because it is the nearer of the two to the Reed Bank. Densities of 2.02–2.34 g/cm^3 were used for the sedimentary layers, with a density of 2.50 g/cm^3 for the intermediate velocity layer. Mesozoic metamorphic dredge samples were obtained from the Reed Bank which are believed to have a thickness of approximately 2.5 km. A density of 2.64 g/cm^3 was used for this layer based on measurements for similar rocks from the northern region of the South China Sea (Hayes, 1978; Ru and Pigot, 1986; Jin, 1989). Resulting computations indicate a crustal thickness of about 25 km for the Reed Bank with slightly lower values of 20–24 km for adjacent areas, confirming the continental crustal model for this region.

Dr. J. Fritsch (pers. comm.) obtained crustal thickness values of 20 km for the centre of the Nansha (Palawan) Trough with slightly higher values than ours of 25–27 km for the reef areas (Fig. 5). This slight discrepancy may be due to different model starting assumptions. We conclude that most of the reef areas of the Dangerous Grounds have a crustal thickness of about 25 km, with a thickness of 20–25 km between reefs and a thickness of about 20 km in the trough areas.

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