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CRUSTAL STRUCTURE, FROM GRAVITY DATA, OF A COLLISION ZONE IN THE CENTRAL NEW HEBRIDES ISLAND ARC

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ABSTRACT

We investigate the main crustal structures involved in the collision zone of the eastern d'Entrecasteaux Zone with the central New Hebrides island arc, using primarily gravity data and supporting seismic-refraction and magnetic data. Over the arc, gravity anomalies trend north-south and include a complex western gravity high, a median gravity low, and an eastern gravity high. Large variations in the crustal thickness of the arc are deducible from the velocity structure of the upper crust and from two-dimensional gravity calculations. Beneath the median gravity low, the 12- to 13-km-thick crust includes 4 to 5 km of strata within the North Aoba basin. In contrast, the western and eastern gravity highs are underlain by 20-km-thick crust that characterizes the islands of the Western and Eastern Belts. The thin basement of the basin may be either a piece of old trapped oceanic crust or attenuated island-arc crust. Because of the thin crust, collision-induced fractures developed that facilitated formation of the large Ambrym and Aoba volcanoes. Along the Western Belt, gravity and magnetic anomalies outline faults and old buried volcanoes. Large gravity and magnetic anomalies located near the north coast of Espiritu Santo Island may indicate a fault zone intruded by igneous rocks. Small sedimentary basins, such as the Malakula and Banks basins, are evidenced in the gravity data by local depressions in the western gravity high. Across the Eastern Belt, an asymmetric thick crustal root, together with other geologic and geophysical evidence, supports the model of incipient backarc thrusting along Maewo Island.

On the downgoing plate, the eastern d'Entrecasteaux Zone is flanked by two east-west-trending gravity lows related to the North Loyalty and West Santo Basins. The d'Entrecasteaux Zone itself has a gravity pattern that includes a southern gravity high (over the South d'Entrecasteaux Chain), a central low (over the Central d'Entrecasteaux Basin), and a northern high (over North d'Entrecasteaux Ridge). Seismic-refraction and gravity data show that the crust of this submarine mountain zone does not differ greatly in thickness and structure from the surrounding oceanic crust. The South d'Entrecasteaux Chain is probably composed of volcanic edifices built upon oceanic crust, whereas North d'Entrecasteaux Ridge appears to have a thicker and shallower, high-velocity crust. The uppermost 5 km of oceanic crust vary greatly in the velocity and density of rocks between the d'Entrecasteaux Zone and the adjacent basins. These variations may be responsible for some tectonic effects of the collision, such as complex structure in the accretionary wedge of the forearc, uplifting of the islands, and flexure of the sedimentary basins.

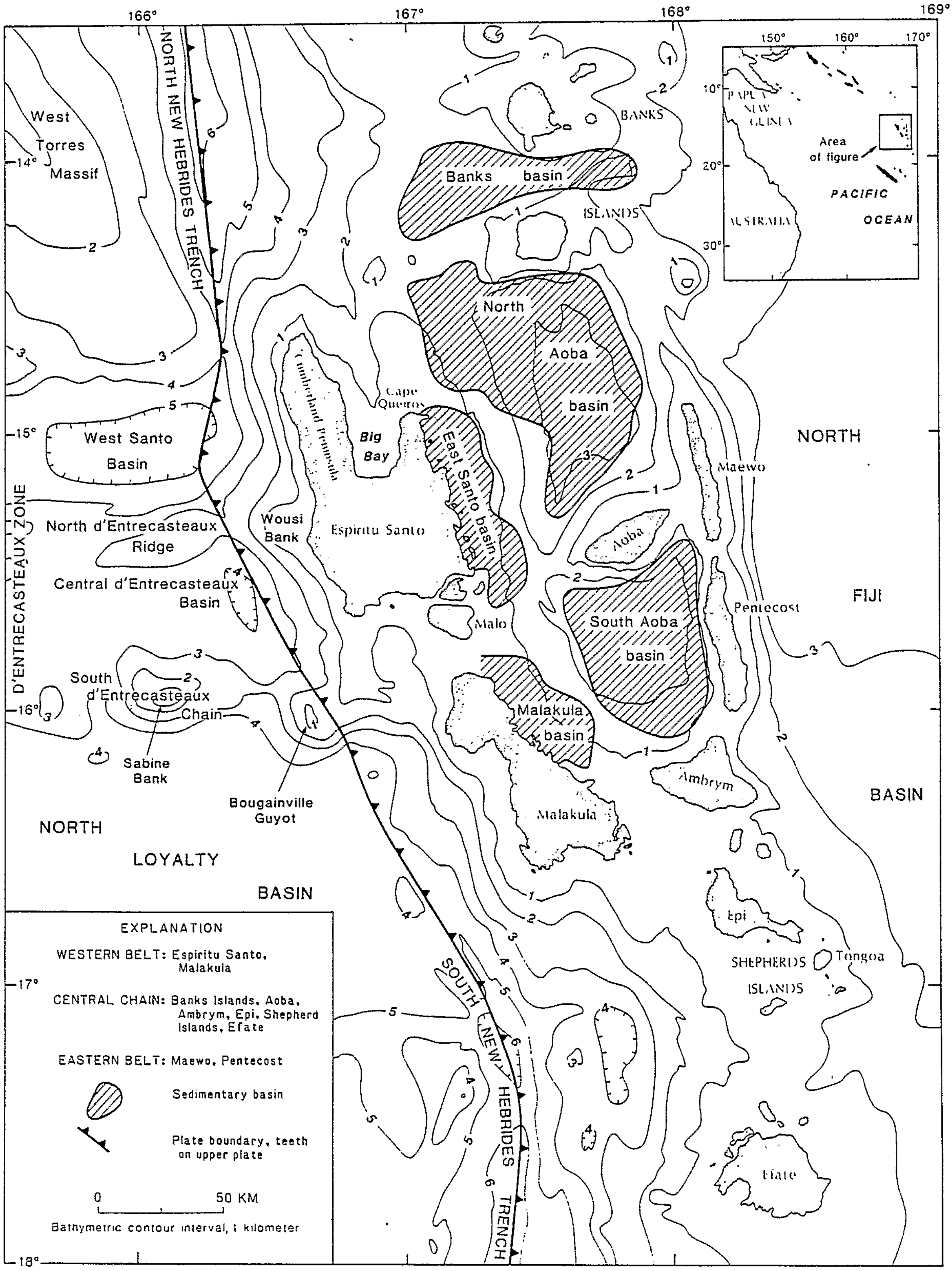

Figure 1. Geographic features and major sedimentary basins of the central New Hebrides Arc.

Table 1. Sources of seismic-reflection data and gravimeter characteristics for the New Hebrides Arc used in this report.

YEAR	ORGANIZATION	SHIP	PROJECT	REFERENCE	GRAVIMETER	DRIFT (mGal/d)
1982	ORSTOM[1]-CCOP/SOPAC[2]	*Coriolis*	Geovan II	Collot, Daniel, and Burne (1985)	S-51	0.12
1982	ORSTOM	*Coriolis*	EVA XI	---	S-51	0.23
1982, 1984	U.S. Geological Survey	*S.P. Lee*	Australia-New Zealand-United States Tripartite-CCOP/SOPAC	This volume	S-53	0.18 0.34

[1] Office de la Recherche Scientifique et Technique Outre-Mer

[2] United Nations Economic and Social Commission for Asia and the Pacific, Committee for Co-ordination of Joint Prospecting for Mineral Resources in South Pacific Offshore Areas.

INTRODUCTION

Between lat 14°30′ and 17°S, the d'Entrecasteaux Zone collides with the New Hebrides Arc and disrupts the arc structure. Disruptive effects are evident in the deep-water intra-arc North and South Aoba basins, which are bounded by mountainous islands of the Eastern and Western Belts and intruded by active volcanoes of the Central Chain (Figure 1; Macfarlane et al, this volume; Greene and Johnson, this volume). In this report, we use gravity data and magnetic and seismic-refraction profiles to analyze the crustal structure involved in the collision of the central New Hebrides Arc with the d'Entrecasteaux Zone.

DATA COLLECTION AND PROCESSING

All the data presented in this report were collected during the following cruises: GEOVAN II, EVA XI, and *S. P. Lee* SOPAC I and II (Table 1). On the GEOVAN II and EVA XI cruises, gravity data were collected with a LaCoste and Romberg[1] gravimeter (No. S-51, borrowed from the National Ocean Survey of the U.S. National Oceanic and Atmospheric Administration), mounted on a two-axis stabilized platform. Gravity, spring-tension, cross-coupling and total-correction data were recorded continuously on a paper-strip chart; gravity readings were also recorded on magnetic tape at 1-minute intervals. During the SOPAC I and II cruises, gravity data were also collected with a LaCoste and Romberg gravimeter (No. S-53), similarly mounted on a two-axis stabilized platform. Gravity, spring-tension, and cross-coupling data were recorded continuously on a paper-strip chart, and every 20 s on magnetic tape.

The beginning base station for all cruises was the Star Wharf in Port Vila, Efate Island, Vanuatu (G=978617.49 mGal). The base station (G=978536.8 mGal) at the Wharf in Luganville, Espiritu Santo Island, was also used for data ties during the SOPAC I and II, GEOVAN II, and EVA XI cruises. These gravity base stations were established by the French Office de la Recherche Scientifique et Technique Outre-Mer (ORSTOM) and correlated with the Noumea, New Caledonia, base station (Jezek, 1976). The Star Wharf in Port Vila was the ending base station for the GEOVAN II and EVA XI surveys. The ending base station for the SOPAC I and II cruises was the fuel pier at Honiara, Solomon Islands (G=978245.2 mGal).

Gravity data were automatically corrected for spring tension and cross-coupling during the GEOVAN II and EVA XI cruises. However, a malfunction of the cross-coupling-correction circuits during GEOVAN II was not repairable at sea, and so these errors affect the final data, as discussed below. The

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[1] Any use of trade names and trademarks in this report is for descriptive purposes only and does not constitute endorsement by the U.S. Geological Survey.

Table 2. Crossing errors in free-air gravity (in mGal) calculated from data collected on four surveys of the central New Hebrides Arc and the eastern d'Entrecasteaux Zone.

	SOPAC I	SOPAC II	GEOVAN II
SOPAC I	4.0 ± 3.6	---	---
SOPAC II	-4.3 ± 7.9	4.6 ± 5.2	---
GEOVAN II	23 ± 10.9	25.1 ± 10.1	13.3 ±10.4
EVA IX	-5.2 ± 12.7	-8 ± 10.4	-38 ± 20.6

digitally recorded gravity data collected from the SOPAC I and II cruises were computer corrected for spring tension and cross-coupling terms after the cruise. The gravity data were then corrected for latitude according to the IGSN (International Gravity Standardization Net) 1971 ellipsoid. Eotvos corrections were calculated from the digitally recorded navigation data. Plots of gravity and Eotvos-correction values were edited to remove noisy data or data obtained during turns. Free-air gravity data were plotted on a map, and crossing errors were analyzed.

The quality of the data collected during all the cruises varies considerably. We use the SOPAC I gravity data as the base to which all the other gravity data are referred because the SOPAC I data display the smallest crossing errors (Table 2). The SOPAC II gravity data average 4.3 mGal lower than those of SOPAC I and are augmented by this value to minimize crossing errors.

The malfunction of the cross-coupling-correction circuits during the GEOVAN II cruise is shown by large values in the crossing-error analysis (Table 2). Fortunately, the GEOVAN II lines have more than 50 crossings with SOPAC I and II lines. These crossing errors indicate that although the free-air anomalies calculated for the GEOVAN II cruise are all lower than those calculated for either SOPAC cruise, the relative variations of gravity along the GEOVAN II and SOPAC profiles agree. To minimize crossing discrepancies, GEOVAN II free-air anomalies were augmented by a different value for each profile. This correction was calculated as the average of the crossing discrepancies of the profile with crossing SOPAC profiles. An estimate of the postcorrection crossing discrepancies, calculated for 179 crossings, indicates a mean discrepancy of about 4.3 mGal, with a standard deviation of 3.9 mGal (Figure 2). Discrepancies at line intersections were also analyzed for the 10 crossings within an area that includes the Vanikolo basin region, north of the study area. These few crossings do not significantly modify our results for the central N
Hebrides Arc.

Onshore gravity data over the main islands the central New Hebrides Arc are sparse (Malahc 1970). They have been corrected, at lat 15°S, for t –16-mGal difference (Dehlinger, 1978) between t 1967 International Formula used in this study a the 1930 International Formula used by Malah (1970), and they have been incorporated into c map in the form of simple Bouguer anomalies (Figu 3a,b).

CRUSTAL STRUCTURE FROM GRAVITY ANOMALIES

Free-air anomalies calculated within the surv area range from –250 mGal over the New Hebric Trench to +200 mGal over Maewo and Pentec Islands. In this section, we describe main grav anomalies (Figure 4) along the platform of the c tral New Hebrides Arc (Greene, Macfarlane, a

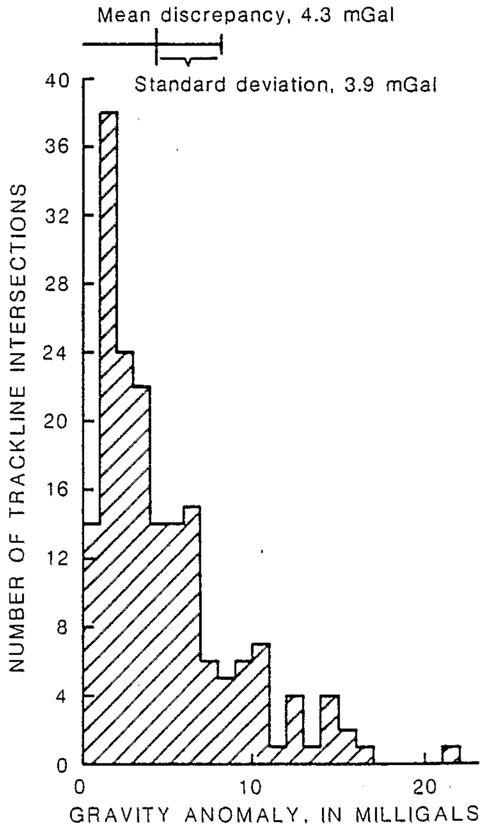

Figure 2. Histogram showing discrepancies in gra ity measurements at trackline intersections.

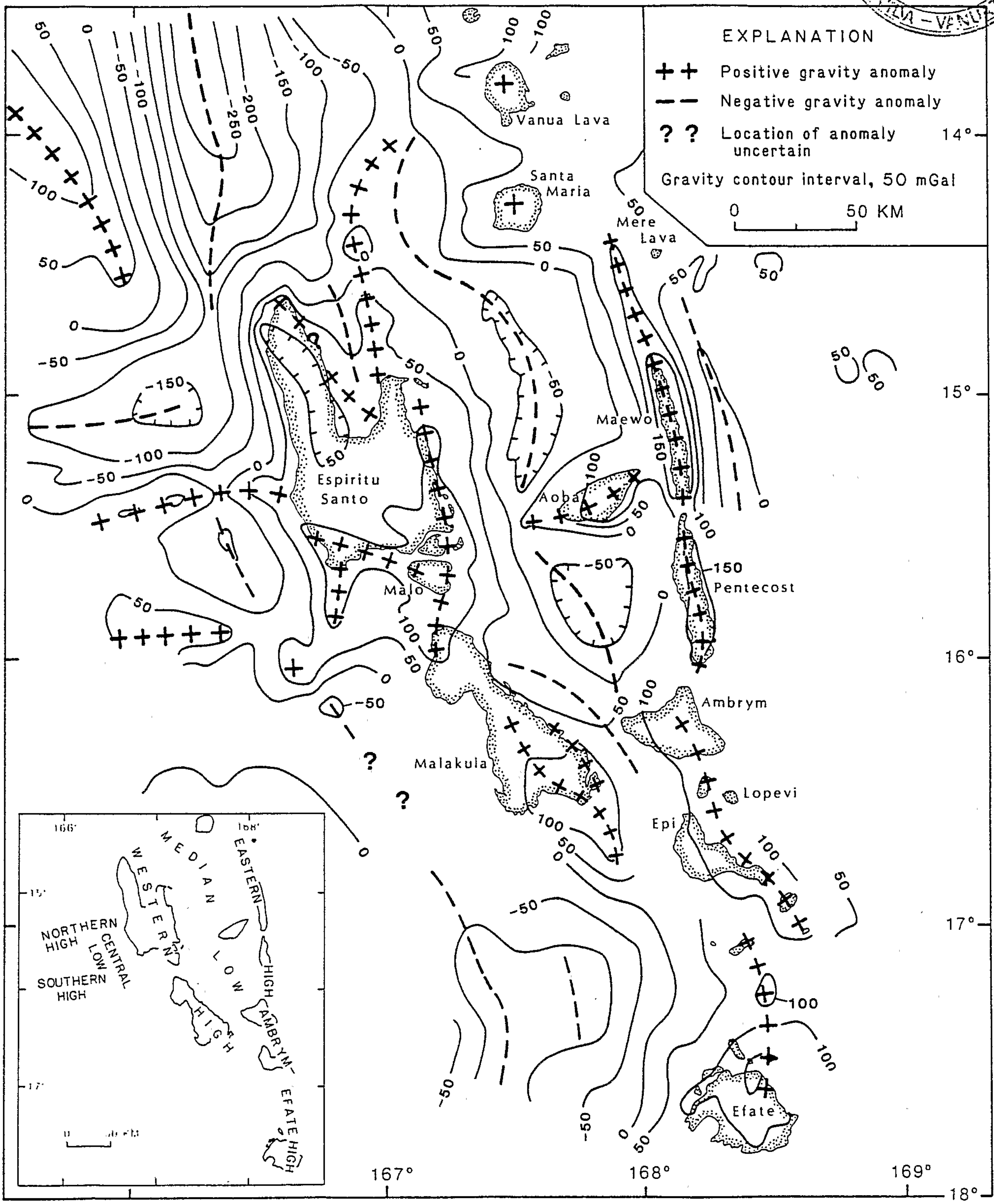

Figure 4. Main trends of the gravity field. Simplified from Figure 3.

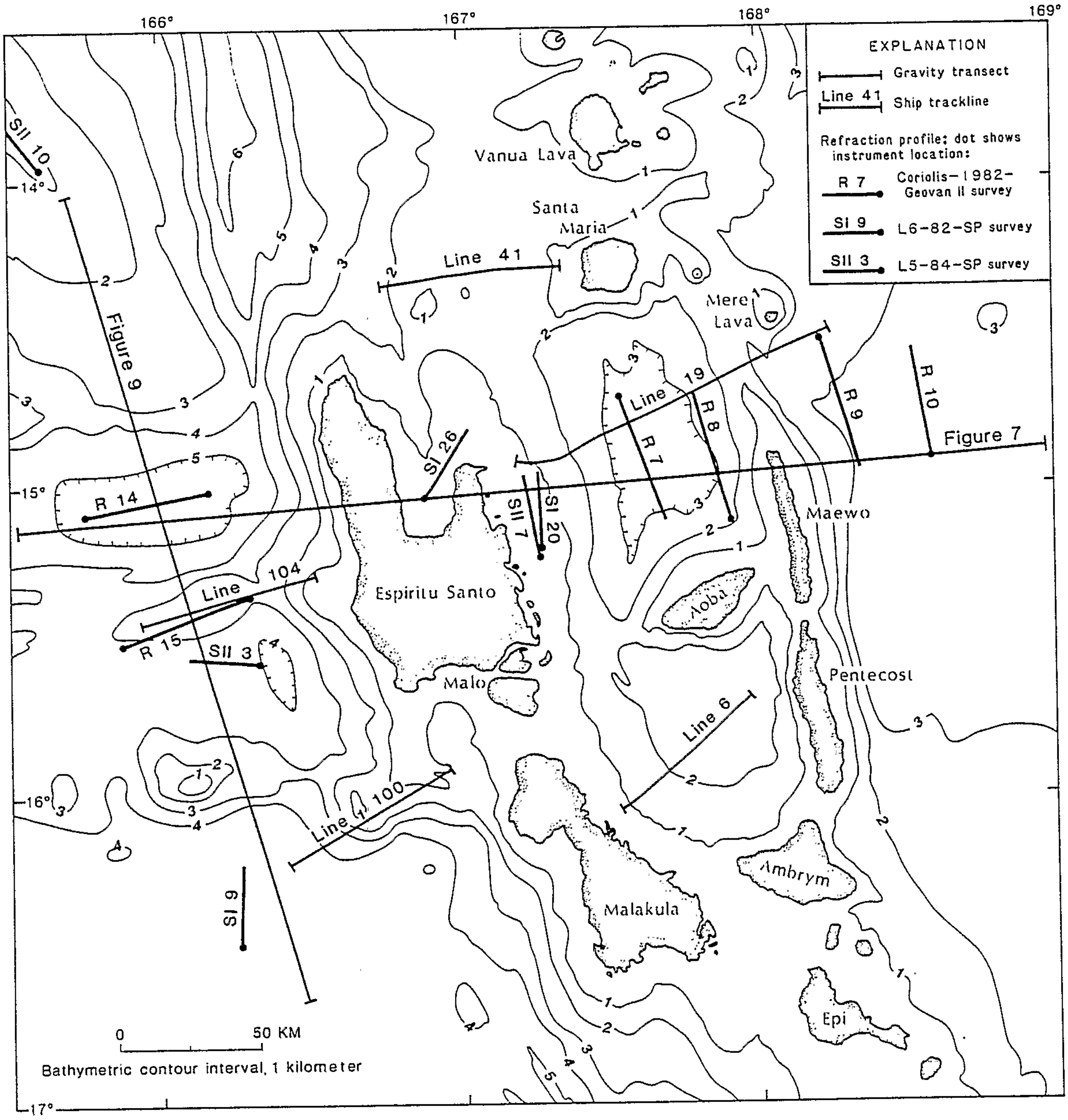

Figure 5. Trackline map of selected bathymetric, magnetic, gravity, and seismic-refraction profiles.

Wong, this volume) and on the downgoing plate from south to north and from west to east. We also investigate crustal structure of the central New Hebrides Arc and the d'Entrecasteaux Zone by using a two-dimensional gravity-modeling technique. Densities used in gravity modeling are deduced from seismic-refraction experiments (Figure 5; Pontoise, 1984; Holmes, this volume), utilizing the velocity-density relation of Ludwig, Nafe, and Drake (1970).

The Arc

Gravity anomalies over the arc platform in Vanuatu can be separated into four groups: the Ambrym-Efate high, the western high (Santo-Malakula Islands), the median low (North and South Aoba basins), and the eastern high (Maewo and Pentecost Islands) (Figure 4). The western high is generally more complex than the other three features.

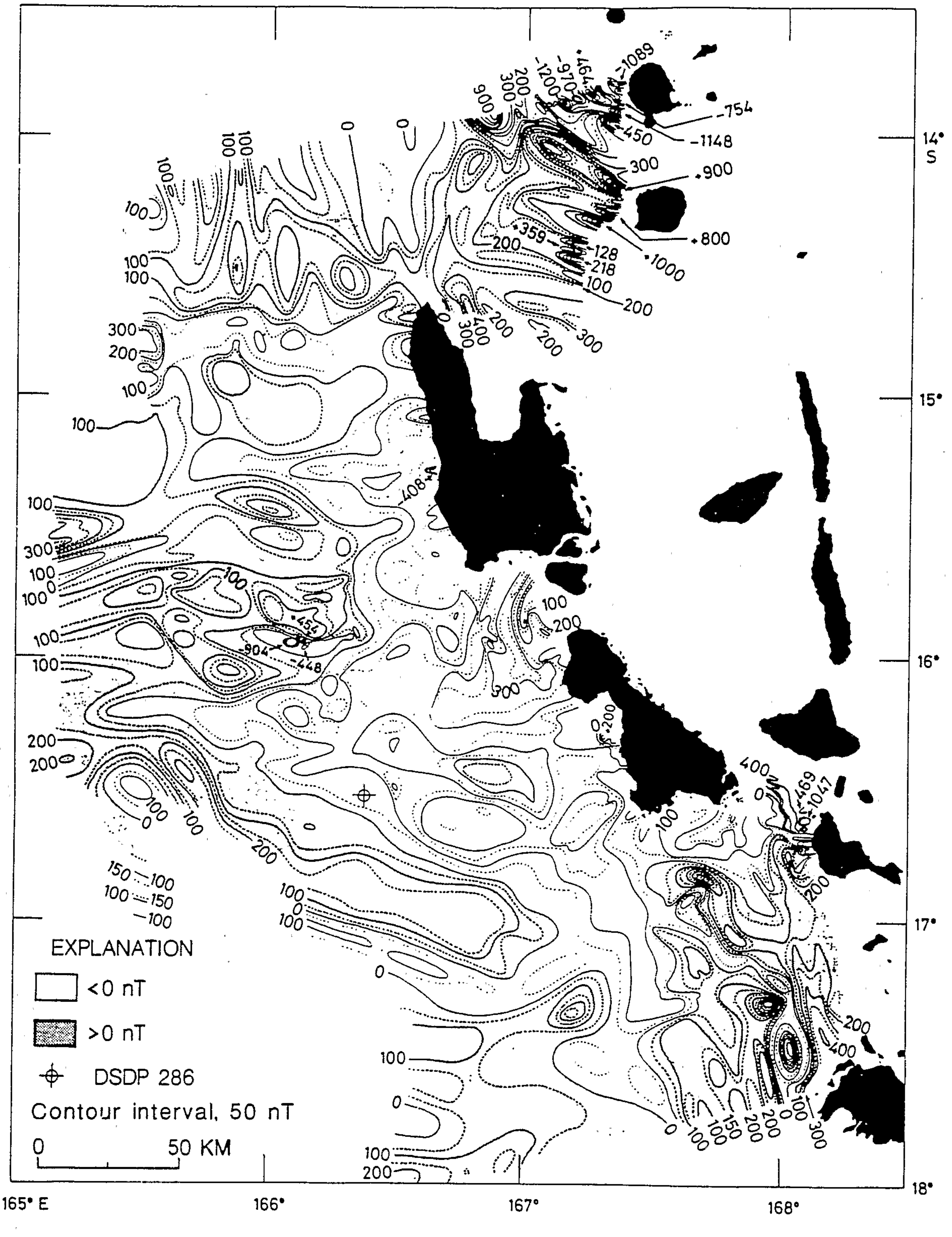

Figure 6. Offshore magnetic anomalies of the d'Entrecasteaux Zone and central New Hebrides Arc (from Collot, Daniel, and Burne, 1985), calculated from total magnetic field less the IGRF 1975.

Ambrym-Efate High

The gravity high that lies between Efate and Ambrym Islands is composed of two segments that are displaced at the latitude (17°S) of the Shepherd Islands (Figure 3b). On Efate, a major Bouguer high (+150 mGal) trends approximately north-south; it is associated with a 300-nT peak-to-peak magnetic anomaly that trends mainly east-west (Malahoff, 1970). According to Malahoff (1970), the volcanic plug, which is the source of the volcanoes in northern Efate, could be the source of these gravity anomalies.

The offset of the Ambrym-Efate gravity high at the Shepherd Islands is associated with an east-west-trending magnetic anomaly (Malahoff, 1970) that emphasizes a major transverse fracture. Other east-west-trending crustal fractures have been interpreted from magnetic anomalies (Malahoff, 1970), and, as shown from offshore structure (Greene et al, this volume), the Central Basin region of the arc appears to be dissected by such fractures. Furthermore, Aoba volcano has apparently developed along one of those fractures.

The northern segment of the gravity high, which closely overlies the line of active volcanoes between the Shepherd Islands and Ambrym, has a mean value of +120 mGal (Figure 3b). High-amplitude magnetic anomalies are measured over the following volcanoes in this area: Tongoa, Lopevi, Ambrym, and the submarine cones off northeast Epi (Malahoff, 1970). Malahoff described and interpreted the gravity and magnetic anomalies on Ambrym as the result of two major volcanic plugs; the southeastern one is presently inactive.

The Western High

The sinuous western gravity high (Figure 4) extends from offshore of the southern part of Malakula Island, northward along the central crest of Malakula and Espiritu Santo Islands, thence along the east edge of Cape Queiros, and offshore to the latitude of the Banks Islands (14°S). In addition to the overall north-south trend, several short gravity alignments trend oblique to the main anomaly. A gravity high of +120 mGal that extends offshore to the south of Malakula Island (Figure 4) is associated with a +300-nT magnetic anomaly (Figure 6) that was interpreted by Malahoff (1970) as a volcanic center.

A +110-mGal gravity high that trends north-south over the southwestern peninsula of Espiritu Santo and its submarine extension (Figure 4) is associated with a 300-nT magnetic gradient (Figure 6; Collot, Daniel, and Burne, 1985). This gravity high is truncated abruptly at its north end by a N60°W-trending gravity high of +100 to +120 mGal (Figure 4). This west-northwest orientation, which contrasts with the general gravity trends over Espiritu Santo Island, prevails across the southwest quarter of the island, where the highest topography and the oldest volcanic rocks (early Miocene; Macfarlane et al, this volume) of the island occur. A relative gravity low of +50 mGal observed over the Cumberland Peninsula (northwestern part of Espiritu Santo Island, Figure 4) correlates with a topographically high region consisting of middle Miocene volcanic rocks (Macfarlane et al, this volume). The transition between this north-south-trending gravity low and the N60°W-trending gravity high is a moderate gradient across the latitude of Wousi Bank, where a major east-west-trending wrench fault is recognized (Taylor et al, 1980).

Two interpretations may account for the observed data of the western high: either the densities of the surface to immediate-depth rocks vary from north to south, or subduction of the d'Entrecasteaux Zone under the south half of Espiritu Santo Island greatly influences the gravity field. These two interpretations are discussed below.

The rocks of the western part of Espiritu Santo Island are mostly volcaniclastic breccia and sandstone interbedded with basaltic pillow lavas or algal limestone. However, andesite, microdiorite, gabbro, and basalt intrusions are more numerous in the southwestern region than elsewhere on the island (Macfarlane et al, this volume). These intrusions do not seem to be a major influence on the N60°W-trending gravity high because one large intrusion lies along a conspicuous fault and crops out in a north-south direction. Andesite and diorite sampled on the island show an average bulk density of 2.68 g/cm^3 (Malahoff, 1970). We use 2.7 g/cm^3 as an estimate of the mean density of the core of the island, and 2.6 g/cm^3 for the shallow crust, which consists mainly of volcaniclastic rocks.

Our gravity model across the Cumberland Peninsula (Figure 7) suggests that the north-south-trending gravity low in the northwestern part of Espiritu Santo Island is due to the presence of a relatively thick and low-density root under the Cumberland Peninsula. In contrast, the N60°W-trending gravity high south of the profile of the gravity model may reflect the influence of the subducted North d'Entrecasteaux Ridge (Figure 4). Seismic-refraction data (Pontoise, 1984) indicate a 6-km/s velocity for

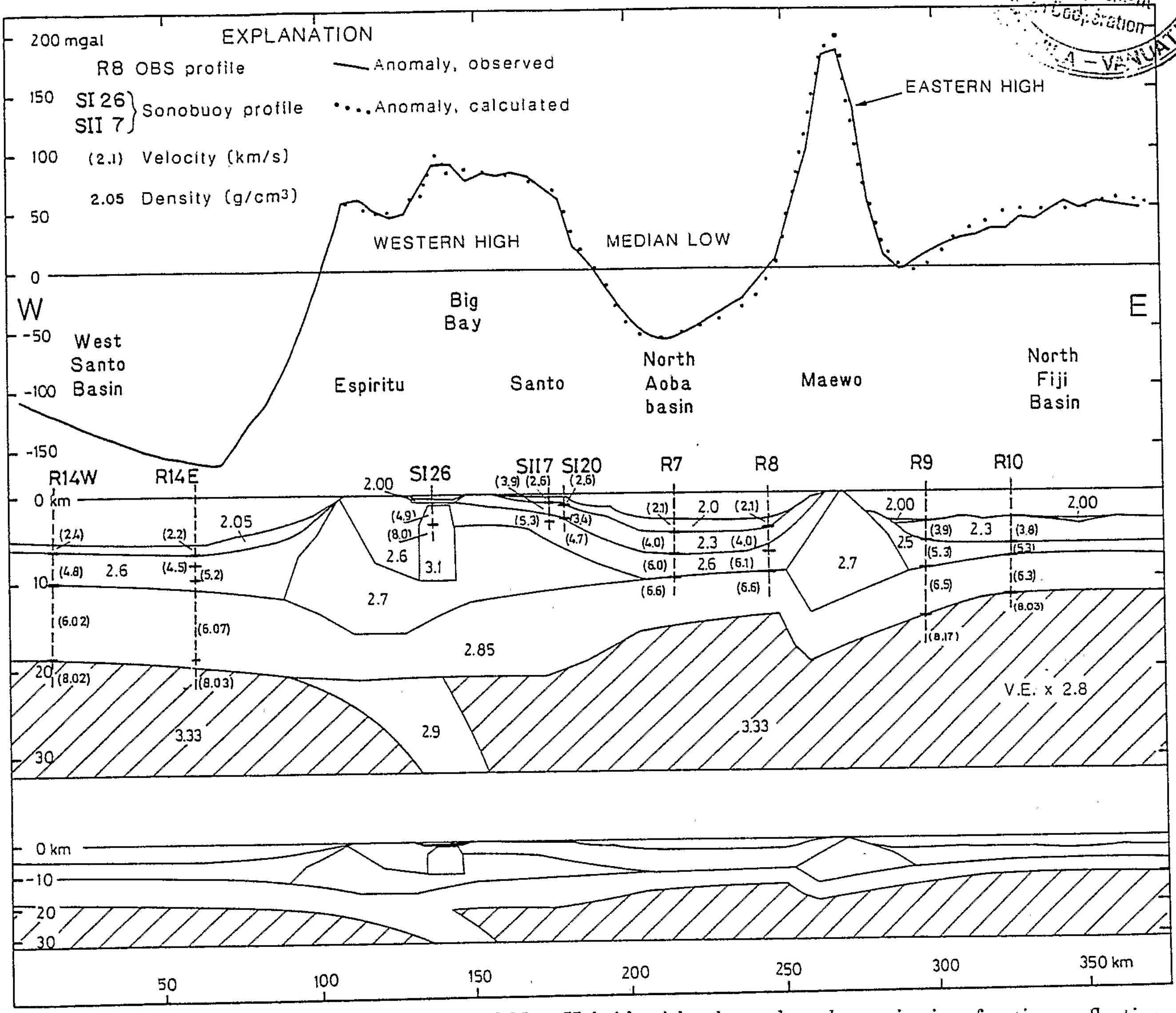

Figure 7. Crustal structures across the Central New Hebrides island arc, based on seismic-refraction, reflection, and gravity data. OBS (ocean-bottom seismograph) profiles from Pontoise (1984); sonobuoy profiles from Holmes (this volume). Two-dimensional calculated gravity anomaly is not shown in the West Santo Basin because of strong influence of the third dimension. An unexaggerated cross section is shown at the bottom of the figure. See Figure 5 for location of cross section.

the shallow basement of North d'Entrecasteaux Ridge. This velocity suggests a density of 2.8 to 2.9 g/cm^3 for the core of the ridge; this density is substantially higher than the average density of rocks exposed on Espiritu Santo Island. Therefore, in the southwestern part of this island, rocks from the d'Entrecasteaux Zone may partly replace the low-density root of the island. This replacement may account for not only the magnitude of the gravity high in the southwestern part of Espiritu Santo Island but also the similar gravity trend between North d'Entrecasteaux Ridge and the southwestern part of the island.

The gravity high along the eastern part of Espiritu Santo Island extends from the northern part of Malakula Island, across Malo Island, and along the east coast of Espiritu Santo Island to the latitude of Cape Queiros (14.5°S). The maximum gravity values of +130 to +140 mGal are observed near Malo Island. Along this high, emerged land areas consist of lower to middle Miocene volcaniclastic rocks covered by Quaternary raised reefs (Macfarlane et al,

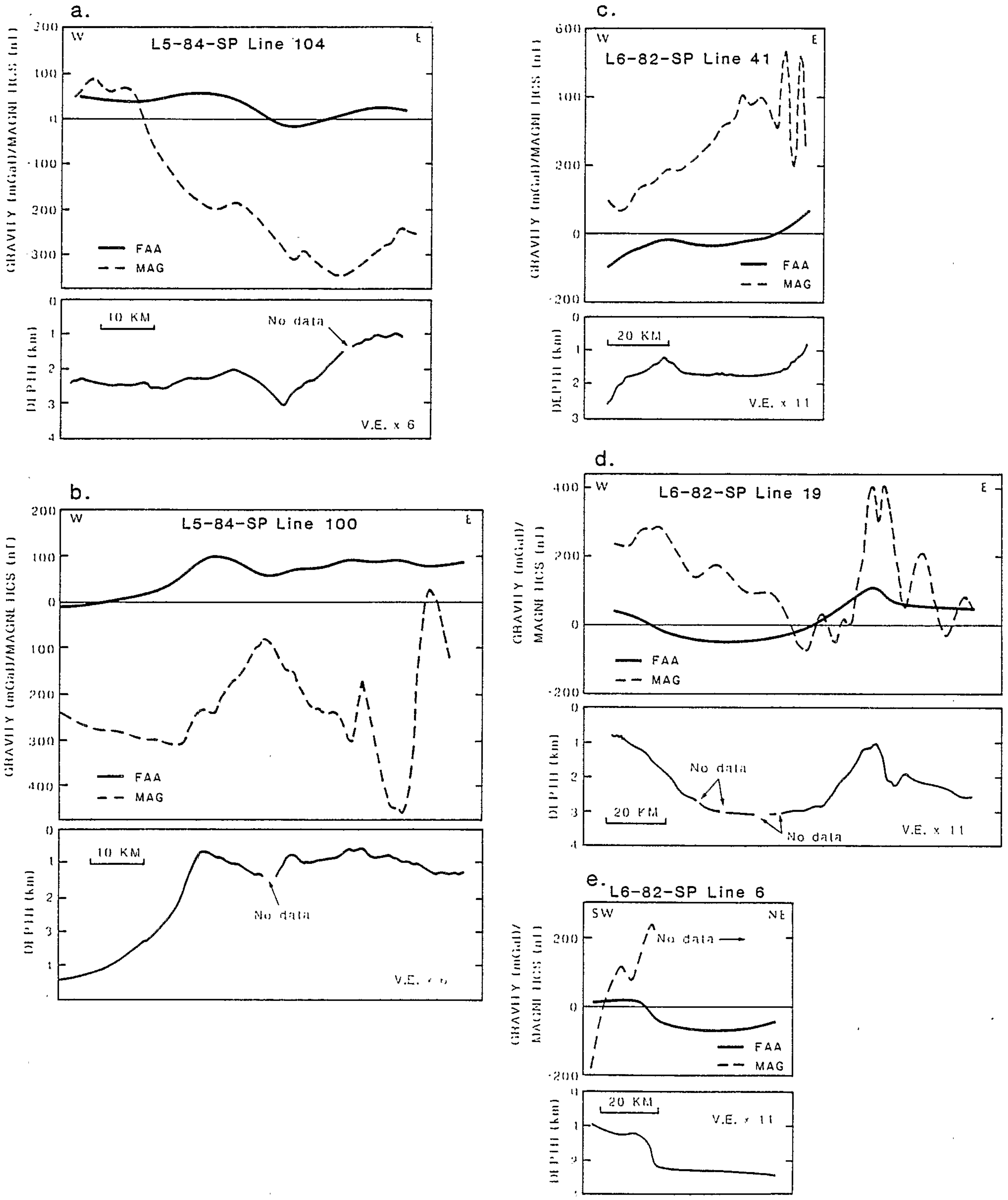

Figure 8. Bathymetric, magnetic, and gravity profiles **a.** along North d'Entrecasteaux Ridge, **b.** across Bougainville Guyot, **c.** across the Banks basin, **d.** across the East Santo and North Aoba basins, and **e.** across the Malakula and South Aoba basins. Magnetic anomalies were calculated by interpolating between the DGRF 1980 and IGRF 1985 values. See Figure 5 for location of tracklines.

this volume).

A complex pattern of gravity highs extends northward over Big Bay in the northern part of Espiritu Santo Island. A major northwest-trending gravity high of +90 mGal that crosses this bay may be connected to a +90-mGal anomaly observed above the north tip of the Cumberland Peninsula (Figure 4). This northwest-trending gravity anomaly coincides with a -200-nT magnetic anomaly (Figure 30 of Malahoff, 1970), as well as with a submarine oblique fault reported by Greene and Johnson (this volume). A body with a 3.1-g/cm^3 density (Figure 7) is required to match the observed anomaly. This requirement suggests that dense volcanic or ultramafic rocks may be buried along the oblique fault of Big Bay. Other magnetic anomalies reported by Malahoff (1970) along Espiritu Santo Island were interpreted to be possibly related to Miocene volcanic centers.

A second gravity high over the northern part of Espiritu Santo Island extends northward from Cape Queiros to approximately lat 14°S; its magnitude decreases northward from +100 to +10 mGal. West of the Banks Islands, this gravity high outlines the west boundary of the sedimentary North Aoba or Banks basin (Figures 1, 4, 8c; Katz, this volume; Fisher, Falvey, and Smith, this volume; Greene and Johnson, this volume). The junction between the eastern Espiritu Santo, Big Bay, and northern Cape Queiros highs remains undefined, because few data are available in this zone.

The Median Low

The median low, which extends from between Malakula and Ambrym Islands northward to the Banks Islands (lat 14°S), is more than 90 km long (Figure 3, 4). This low is sinuous and consists of several arcuate segments that are connected to form one continuous feature with a general north-south trend. In the south, a relatively short (30 km long) gravity low swings westward from the gap that separates Malakula and Ambrym Islands and parallels the northeast coast of Malakula Island. Free-air anomalies as low as -60 mGal were recorded over the intra-arc North and South Aoba basins.

The southern part of the median low (Figure 4) lies in the South Aoba basin where it reflects primarily the topography and sedimentary fill (Figure 8e). Seismic-refraction data suggest that both the North and South Aoba basins contain as much as 5 km of low-velocity rocks (Pontoise, 1984; Holmes, this volume). The minimum gravity values, which are displaced southwestward with respect to the morphology of the basin, appear to coincide with the maximum sediment thicknesses (Holmes, this volume; Fisher, Falvey, and Smith, this volume). The North Aoba basin shows a negative anomaly that is asymmetric transverse to the arc (Figure 7); the minimum gravity value is displaced toward Espiritu Santo Island with respect to the basin's physiography but centered with respect to the thickest sediment (Figure 3, 7). The gravity model across the North Aoba basin (Figure 7) indicates a 12-km-thick crust, which thickens toward the southwest. This crust is thin in comparison with the 25-km-thick crust of the southern New Hebrides island arc (Pontoise, Latham, and Ibrahim, 1982). If the upper crust of the North and South Aoba basins is made up of 4 to 5 km of sedimentary fill, the deep crust, which is characterized by velocities of 6.0 and 6.6 km/s, is likely to be oceanic igneous rock because anomalously low velocities characterize layer 3 of the oceanic crust near this island arc (Pontoise, Latham, and Ibrahim, 1982; Pontoise, 1984). Therefore, the North Aoba basin crust may have originated either as a trapped piece of oceanic crust or from crustal thinning by extension. The development of transverse fracture zones in response to the arc/ridge collision and of the large Ambrym and Aoba volcanoes may have been facilitated by the thinness of the crust. Both the South and North Aoba basins have the same -60-mGal gravity low, but at significantly different water depths, 2.4 and 3.1 km, respectively. This difference suggests that the crusts of the basins differ in either thickness, density, or mechanism of compensation.

A secondary gravity low of -10 mGal, observed over the Malakula basin (Figure 1, 3b, 4), suggests that the buried ridge, which separates this basin from the South Aoba basin, is composed of rocks that are denser than the basin fill (Fisher, Falvey, and Smith, this volume; Greene and Johnson, this volume). Seismic-refraction data suggest a maximum thickness of about 2 km for the sedimentary fill in the Malakula basin (Holmes, this volume).

The East Santo basin (Fisher, Falvey, and Smith; Greene and Johnson, this volume; Figure 8) is not apparent on the gravity map (Figure 1,3a), although seismic-refraction data suggest about 1.5 to 2 km of sediment thickness in this basin (Fisher, Falvey, and Smith, this volume).

The western part of the Banks basin of Katz (1981; Figure 1.3a), which may be associated with the extension of the North Aoba basin (Greene and Johnson, this volume; Katz, this volume; Fisher, Falvey, and Smith, this volume), appears to be well delineated by the -20-mGal contour on the gravity map (Figure 3a) and has a minimum magnitude of -30 mGal (Figure 8c), probably related to the estimated 3 km of sedimentary fill in the basin (Holmes, this volume; Fisher, Falvey, and Smith, this volume).

The Eastern High

The linear eastern high extends along the horst that underlies the Eastern Belt of islands from southernmost Pentecost to the latitude of Mere Lava (14°25′S)(Figure 3). The highest gravity values measured over the New Hebrides Arc occur over the Eastern Belt (Malahoff, 1970): +190 mGal on Maewo Island and +150 mGal on Pentecost Island. This anomaly has been interpreted to be due to an ultrabasic intrusion that crops out in the southern part of Pentecost Island (Macfarlane et al, this volume). In the northern part of Maewo, gravity modeling suggests rocks with an average density of 2.7 g/cm^3, which matches the density of the Miocene volcaniclastic series observed on the island. However, this series may include highly serpentinized periodotites, such as those cropping out on Pentecost Island to the south. On the basis of the gravity model, the crust beneath Maewo Island is as thick as 19 km—about 7 km thicker than the crust of the North Aoba basin.

A gravity low of 0 mGal was measured at the west edge of the North Fiji Basin off the eastern part of Maewo Island. This low seems to correlate with a slight topographic depression of unknown origin that parallels the Eastern Belt over the North Fiji Basin. The North Fiji Basin has a +30- to +40-mGal average gravity anomaly, with a few highs reaching +60 mGal.

Near the east coast of Maewo Island, refraction lines R9 and R10 (Figures 5,7) suggest an arcward downbending of North Fiji Basin oceanic crust. Our gravity model (Figure 7) shows an asymmetric crustal root beneath Maewo Island that supports the concept of a westward deepening of North Fiji Basin oceanic crust. This westward-deepening oceanic crust, in combination with the high uplift rate of the Eastern Belt islands during Quaternary time (Mallick and Neef, 1974), the recent folding of North Aoba basin sediment along Maewo Island (Katz and Daniel, 1981; Collot, Daniel and Burne, 1985, Figure 12), and the occurrence of shallow thrust earthquakes with compressive northeast-trending axes (Collot, Daniel, and Burne, 1985), suggest that the Eastern Belt is being thrust over North Fiji Basin oceanic crust.

The Downgoing Plate

The downgoing plate shows two different groups of gravity anomalies: low-gravity-field variations occur south of the d'Entrecasteaux Zone, whereas high gravity-field variations occur over the d'Entrecasteaux Zone and the West Torres Massif to the north.

South of the d'Entrecasteaux Zone

Northwest of Efate Island, a gravity low of -140 mGal has been measured over a forearc basin that underlies 4,200 m of water depth. The adjacent South New Hebrides Trench causes only a -120- to -130-mGal low associated with 6,500 m of water (Figure 3b). Except for some high-frequency, 800-nT peak-to-peak magnetic anomalies below the steep flank of the arc, this forearc area has a relief of 300 nT peak to peak (Figure 6). Both types of potential-field data suggest that an accumulation of low-density material lies in this physiographically depressed area and that the island-arc rocks, which constitute the east flank of this basin, are intruded by volcanic rocks.

A small northwest-trending gravity low of -50 mGal was measured over the plate boundary just south of Bougainville Guyot. This low may connect to the gravity low observed farther south over the trench.

Most of the North Loyalty Basin has a relatively high gravity anomaly (+30 mGal) associated with 4,800- to 5,000-m water depth. However, south and west of Bougainville Guyot, a broad gravity low of -20 mGal extends westward along the South d'Entrecasteaux Chain into the North Loyalty Basin. This low may result from lithospheric flexure in response to crustal loading by the volcanic South d'Entrecasteaux Chain and from resulting sediment accumulation.

Magnetic anomalies over the North Loyalty Basin, which trend N70°W, are related to Eocene reversals of magnetic-field polarity (Figure 6; Weissel, Watts, and Lapouille, 1982; Collot, Daniel, and Burne, 1985). The gravity model (Figure 9) shows that the crust of the North Loyalty Basin is about 10 km thick and is depressed near the South d'Entrecasteaux Chain. This estimate agrees with the 10- to 12-km thickness reported by Pontoise, Latham, and Ibrahim (1982) farther south along the trench.

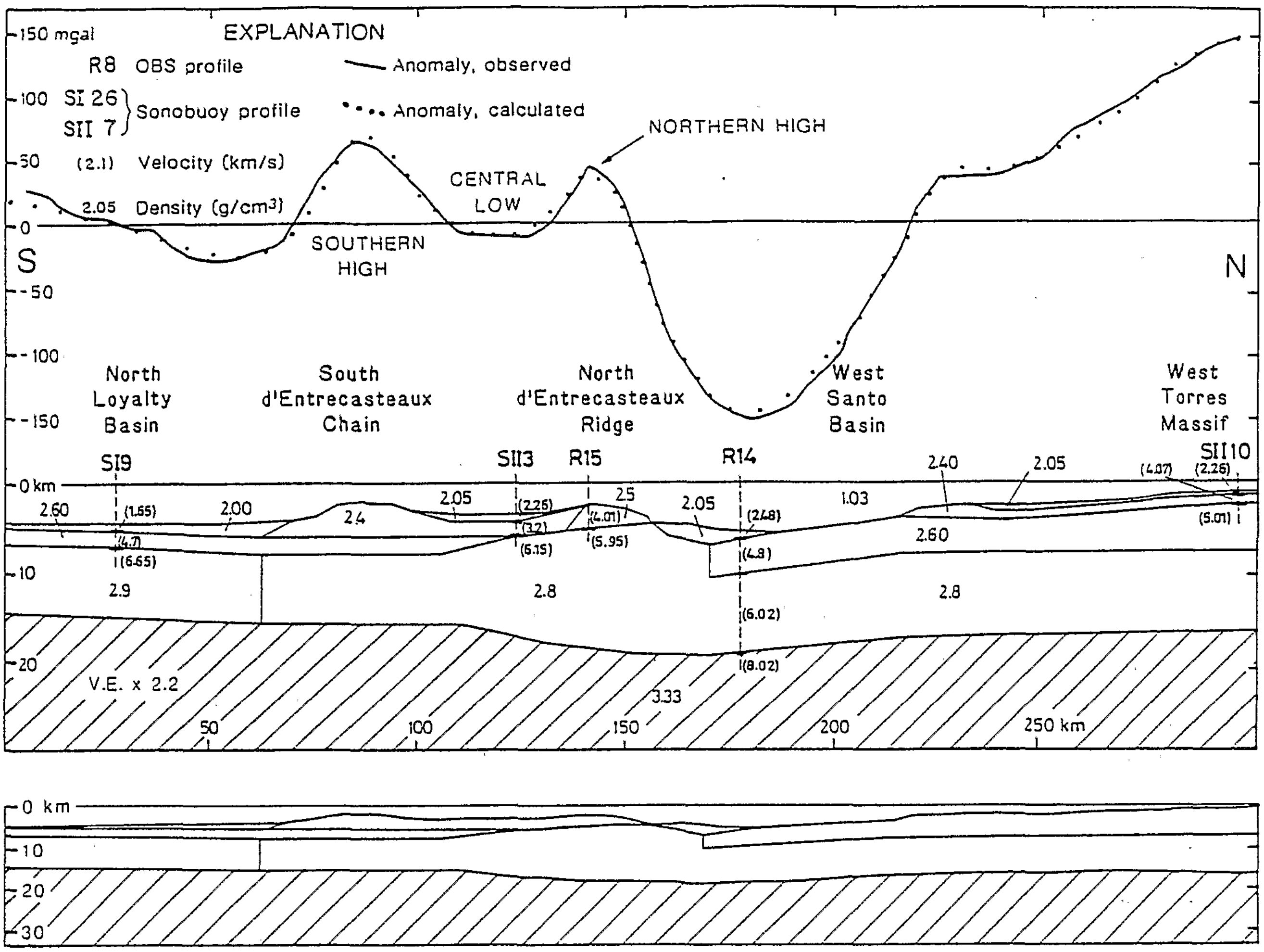

Figure 9. Crustal structures across the d'Entrecasteaux Zone, based on seismic-refraction, reflection, and gravity data. OBS profiles from Pontoise (1984); sonobuoy profiles from Holmes (this volume). An unexaggerated cross section is shown at the bottom of the figure. See Figure 5 for location of cross section.

The d'Entrecasteaux Zone

Gravity anomalies over the eastern d'Entrecasteaux Zone, which trend east-west, consist of a southern gravity high, a broad central low, and a northern high (Figure 4).

The southern high is dominated by a +50- to +100-mGal anomaly extending east-westward over Sabine Bank. High-frequency magnetic anomalies (Figure 6) show 1,300-nT peak-to-peak variations above the summit of Sabine Bank, whereas only moderate-frequency, 200-nT positive anomalies occur above the rest of the South d'Entrecasteaux Chain. The high gravity and magnetic anomalies, as well as the conical shape of Sabine Bank, are consistent with a volcanic origin for this ridge. An isolated +90-mGal gravity high is observed over Bougainville Guyot northwest of Malakula Island. Because this feature lies under 1.0 km of water, its relatively high gravity value may be related to volcanic rocks, although its magnetic signature is weak (Figure 8b; Fisher, Collot and Smith, 1986).

The broad central low observed over the Central d'Entrecasteaux Basin is asymmetric, with a steep gradient over the west flank of the western part of Espiritu Santo Island and a -50-mGal value above the plate-contact zone. This low is similar to the one observed south of Bougainville Guyot in about the same water depth (4,000-4,300 m). The magnetic field shows only low-relief variation and generally decreases from about +100 nT in the middle of the basin to -150 nT above the west slope of

Espiritu Santo Island.

The northern gravity high shows +50-mGal values over North d'Entrecasteaux Ridge, which lies beneath 2,500 m of water (Figure 8a). This gravity high connects to the east with the +60- to +70-mGal gravity high observed above the shallow Wousi Bank. Magnetic anomalies of 300 to 400 nT peak to peak lie along the south flank of North d'Entrecasteaux Ridge at long 165°10′ and 166°E (Figure 6). This anomaly may indicate an extension of the faulted oceanic basement that lies to the west (Maillet et al, 1983). A linear negative anomaly with a minimum value of −200 nT extends along the north flank of North d'Entrecasteaux Ridge, crosses the plate boundary, and ends at Wousi Bank. This negative magnetic anomaly, which coincides geographically with the faulted boundary between North d'Entrecasteaux Ridge and the West Santo Basin, suggests that the ridge extends into the subduction zone, far beneath the inner trench wall.

The gravity model (Figure 9) indicates no significant crustal root beneath the d'Entrecasteaux Zone. The oceanic crust of the North Loyalty Basin may extend part way beneath the d'Entrecasteaux Zone, but from seismic-refraction data, North d'Entrecasteaux Ridge may include a piece of the crust of the West Santo Basin, as discussed below. Seismic-refraction velocities, basement morphology, and sediment characteristics (Pontoise, 1984; Burne, Collot, and Daniel, this volume) indicate that the crusts of the North Loyalty and West Santo Basins have different oceanic origins. The identical seismic-refraction velocities (6.0 km) measured for the basements of North d'Entrecasteaux Ridge and the West Santo Basin suggest that the rocks forming these basements may have the same origin. However, the high-velocity basement of North d'Entrecasteaux Ridge is considerably shallower than that of the surrounding oceanic basins. This depth difference, together with the midoceanic-ridge basalt (MORB) dredged along the north scarp of North d'Entrecasteaux Ridge (Maillet et al, 1983), suggests that oceanic crust has been uplifted to form the ridge. The crustal thickening beneath North d'Entrecasteaux Ridge suggests that the West Santo Basin may have underthrust and uplifted the north edge of the d'Entrecasteaux Zone. Therefore, seismic-refraction, gravity, and magnetic data cannot confirm whether the crust of the North Loyalty Basin extends as far northward as North d'Entrecasteaux Ridge, but this ridge may encompass an underthrust fragment of the West Santo Basin and its basement.

North of the d'Entrecasteaux Zone

The West Santo Basin underlies water 5,400 m deep, and the basin rocks cause an east-west-trending gravity low of −180 mGal that correlates with a broad low-amplitude positive magnetic anomaly bounded to the north and south by negative anomalies (Figure 6). Both the positive and negative magnetic anomalies extend eastward beyond the plate boundary, across the island-arc slope.

The gravity low over the West Santo Basin, which extends along the north flank of North d'Entrecasteaux Ridge, partly reflects the 2 to 3 km of sediment filling a possible half-graben or relict trench. This large gravity low contrasts with the −20- to −30-mGal low observed just south of Sabine Bank in the North Loyalty Basin (Figure 1,3b). Seismic-refraction data from Pontoise (1984) reveal that the West Santo Basin has a 13-km-thick oceanic crust covered by a sedimentary wedge. Our gravity data support this interpretation and show that this crust deepens in a north-south direction. This thickening emphasizes that the West Santo Basin may be the site of an old subduction zone (Burne, Collot, and Daniel, this volume). Near the presently active plate boundary, along the New Hebrides Arc, bending of the oceanic plate, in combination with deposition of low-density material, may account for the large gravity low.

A gravity high of about +130 mGal trends north-northwest over the West Torres Massif (Figure 4). This high includes values larger than +100 mGal measured over water depths between 1,000 and 1,500 m. The steep-sided south flank of the West Torres Massif is truncated by a negative magnetic anomaly that trends east-west (Figure 6). This anomaly can be correlated either with the faulted and intruded south margin of the massif or with the oceanic crust of the West Santo Basin. The flank is also aligned with the Santa Maria fracture zone described by Greene et al (this volume). Magnetic anomalies observed over the West Torres Massif generally trend north-south, in contrast to the generally east-west trends observed over the West Santo Basin and the d'Entrecasteaux Zone. Seismic-refraction data from one sonobuoy (Figure 5) collected on top of the West Torres Massif indicate that a stratum with a 5-km/s velocity is close to the seafloor. At this site, our gravity model indicates a 16-km-thick crust. The northern part of the gravity model does not account for the complex bathymetry, which evidently violates the two-dimensional assumption used in our model.

Gravity values as low as −270 mGal were measured above the 6,500-m-deep North New Hebrides

Trench north of Espiritu Santo Island. The steepest gravity gradients are observed just south of lat 13°30'S and at the toe of the West Torres Massif. In this region, low-amplitude magnetic anomalies clearly trend north-south above both the outer and inner walls of the trench (Figure 6). These anomalies are sharply truncated by east-west-trending magnetic anomalies over the forearc region. We interpret the limit between the two crossing magnetic trends as the boundary between the igneous intruded volcanic arc to the east and the margin of the West Torres Massif extending beneath the forearc region to the west.

CONCLUSIONS

Gravity, magnetic, and seismic-refraction data reveal the complex crustal structure involved in the collision process along the central New Hebrides island arc. The Western Belt of this island arc includes different volcanic segments, volcanic centers, and transverse or oblique features. The North Aoba basin has a thin (12-13 km) crust with oceanic affinities. The North and South Aoba basins have similar gravity anomalies but at different depths, suggesting differences in crustal composition or thickness. The Western and Eastern Belts all show crust of about 20-km thickness that may reflect Oligocene and Miocene arc volcanism and (or) Pliocene to Quaternary collision of the d'Entrecasteaux Zone. The northern part of Espiritu Santo Island, a mountainous area, exhibits a relative gravity low, which we interpret as related to a low-density crustal root. This gravity low contrasts with the transverse gravity high of the southern part of Espiritu Santo Island, directly adjacent to the d'Entrecasteaux Zone.

The colliding d'Entrecasteaux Zone is not a deep-rooted feature. No significant differences in crustal thickness distinguish the d'Entrecasteaux Zone from the surrounding oceanic crust. Thus, the uplift of Espiritu Santo Island in the collision zone cannot be accounted for by the subduction beneath this island of a thick buoyant crustal body. In contrast, the rocks in the upper crust of the d'Entrecasteaux Zone vary in physical properties relative to the nearby oceanic plate. The South d'Entrecasteaux Chain seems to have an oceanic crust on which such volcanoes as the Sabine Bank are superimposed. North d'Entrecasteaux Ridge has a more complex structure, with a thick, shallow high-velocity crust that may have resulted from underthrusting and stacking of the West Santo Basin crust. Therefore, we believe that the variations in topography, velocity, and density of the uppermost 5 km of the crust of the d'Entrecasteaux Zone with respect to the adjacent basins may be responsible for such collision effects as the unique attitude of the accretionary wedge in the collision zone, the uplift of the forearc, and the tilt of the North Aoba basin.

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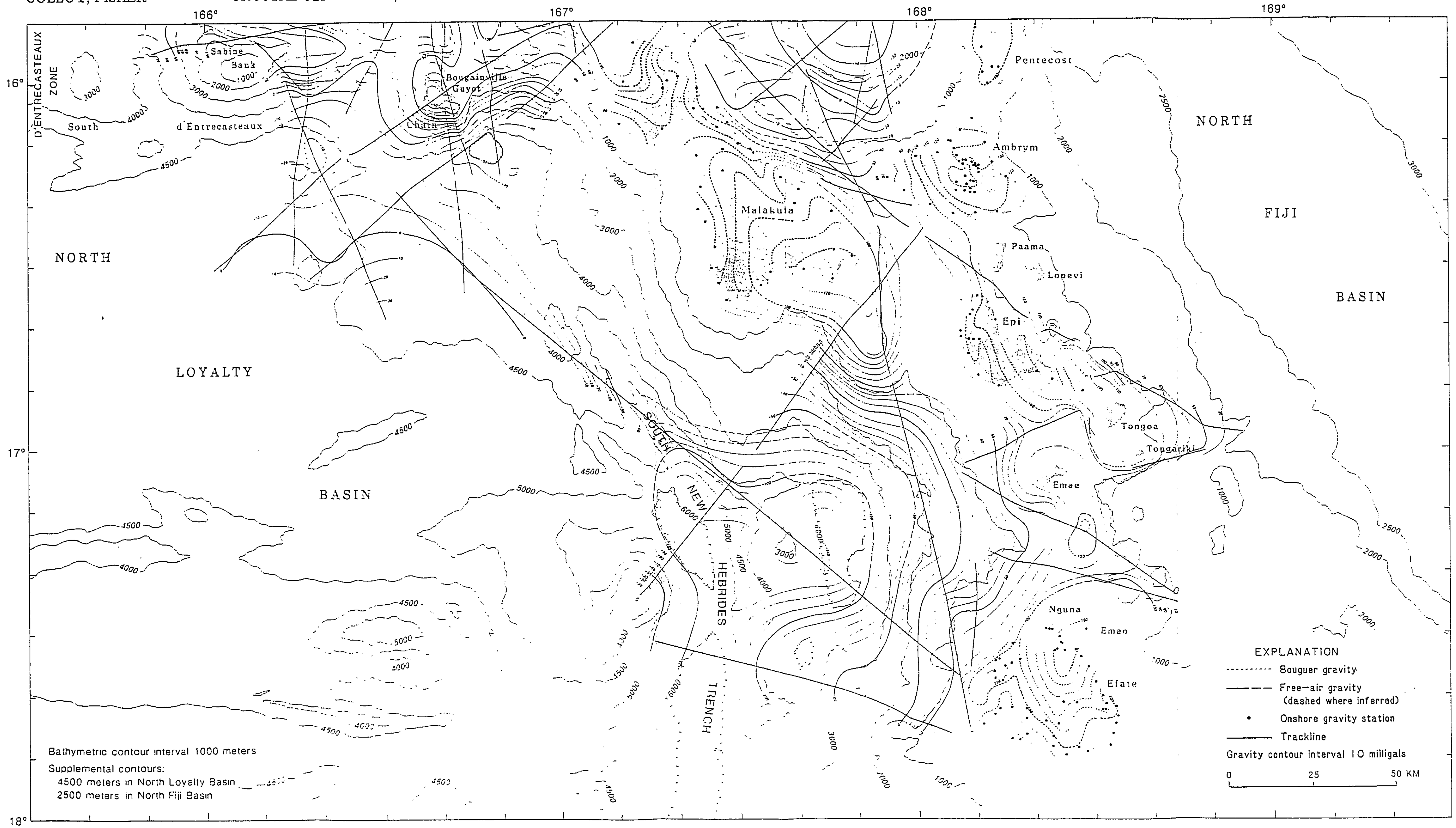

Figure 3b. Gravity map of the central New Hebrides island arc (from lat 15°50′S to lat 18°00′S) showing simple Bouguer anomalies on land from Malahoff (1970) and free-air anomalies at sea. Bathymetry after Chase and Seekins (this volume).

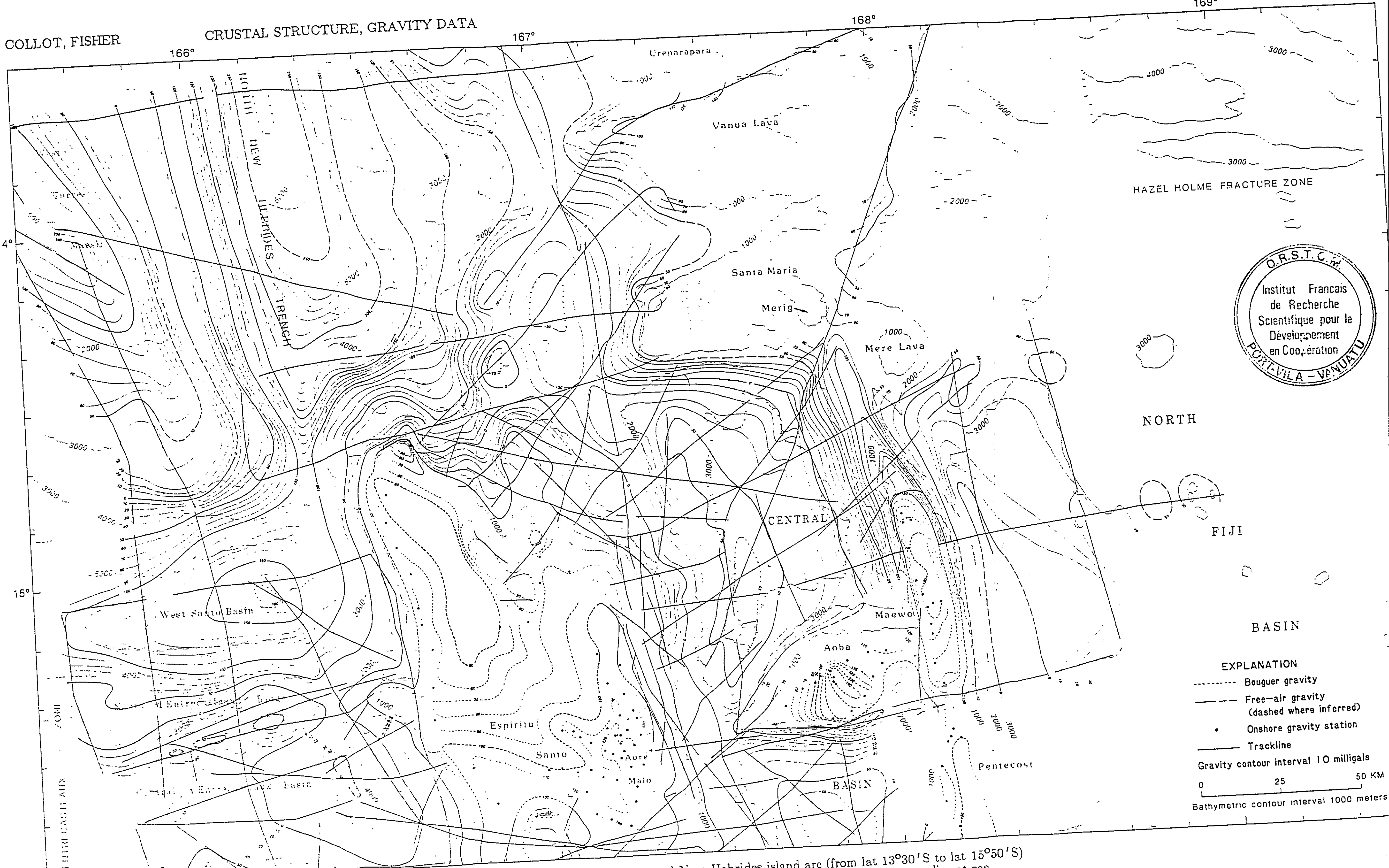

Figure 3a. Gravity map of the central New Hebrides island arc (from lat 13°30′S to lat 15°50′S) showing simple Bouguer anomalies on land from Malahoff (1970) and free-air anomalies at sea. Bathymetry after Chase and Seekins (this volume).