INTERNATIONAL SYMPOSIUM
ON GEODYNAMICS IN SOUTH-WEST PACIFIC
NOUMEA (NEW CALEDONIA) 27 AUGUST-2 SEPTEMBER 1976
EDITIONS TECHNIP, PARIS 1977, pp. 135-144

CRUSTAL STRUCTURE BETWEEN NEW CALEDONIA AND THE NEW HEBRIDES

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INTRODUCTION

A lot of gravity data in surface, made on marine profiles, in the Southwest Pacific under French influence, have been communicated by Foreign research institution (such as Woods Hole Oceanographic Institution) and by Oil Companies (Mobil Oil, Gulf Oil Companies).

Spreading all over the New Hebrides, the Loyalty Islands and New Caledonia areas those profiles present a great interest with respect to the structural observation in that area.

Gravity measurements, despite their inaccuracy, are a method of deep investigation of the earth's crust.

Thus it has seemed interesting to find out a method based on a computed interpretation of gravity profiles and therefore to apply it in the observation of a set of profiles given by the Gulf Oil NC2 - NC1 - NH17 representing the area included between New Caledonia and the New Hebrides. Those profiles are enlarged across New Caledonia with the help of gravity measurements previously made in field (Crenn 1953).

SUGGESTED METHOD :

This method involves the computation of the gravitational attraction produced by a geologically reasonable structure and the modification of density and geometry parameters, until obtaining the best coïncidence between the observed anomaly and the computed anomaly. The derived model is not the only one, as far. The problem of foundamental inacurracy is not solved. The suggested approach is a synthesis of the actually knowledge of all the profiles studied here.

Those approximately linear structures are assumed as infinitely long. The mathematical interpretation of anomalies connected with those structures may be given by the two dimensional criteria (Nettleton,1940).

The method of computed interpretations is based on analytical expressions of the vertical component of a gravitational attraction of any two dimensional structure approximated closely by a polygon (Talwani, Worzel, Landisman, 1959).

This computation can be used at any given point of the surface, without any limitations to the size or shape of the body. Its accuracy depends only of how closely the polygon fits with the body. This accuracy can be increased by increasing the number of sides of the polygon (see annex).

DATA AND HYPOTHESIS MADE IN THE CONSTRUCTION OF A STRUCTURAL APPROACH

Three profiles (see fig. 1) surveyed by the Gulf Oil Company form a continuous line, beginning at 169° E following the 20° S, to end at 20° 29' 2 S and 165° 06' 8 E. They were enlarged in using the observed gravity measurements made North oh New Caledonia (Crenn, 1953) to 21° S and 164° E (see fig.1).

They successively cross :

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- The New Hebrides *frontal arc*.
- The New Hebrides trench.
- The North Loyalty Plateau.
- The Loyalty Chain (North of Astrolabe).
- The Loyalty Basin.
- New Caledonia.

The crossed structures are approximately perpendicular to the gravity profile. This yields to a slight inaccuracy in the interpretation, which besides bring out interesting informations.

1. Observed free air anomaly (see fig.4)

At the level of New Caledonia, it represents a depression (high of + 85 mgals) enclosed by two maxima (high of + 116 mgals and + 120 mgals) immediately followed by the maximum of the Loyalty Chain (high of + 87 mgals).

The minimum of this profile (high of - 267 mgals) shifted 40 km to the East with respect to the New Hebrides Trench axis which depth is 6800 m there, follows a shallow anomaly bulge (high of + 36 mgals) at the level of the North Loyalty plateau. At the level of the frontal arc, the anomaly increases again (high of + 66 mgals).

A good knowledge of the surface gravity field is not sufficient to determine the repartition of the deep-seated masses; supplementary elements such as :

- density of the media
- geometry of some structures

observed or computed are necessary to obtain a realistic model.

This knowledge yet obtained in previous works, through seismology, bathymetry, seismic refraction and reflexion, contributes to reduce the number of reasonable models.

2. *Data and hypothesis*

The isostatic compensation traduces a physical mecanism : the Archimede's principle. This compensation is the result of an actual hydrostatic equilibrium between the crust and the rigid upper mantle. With respect to Airy's hypothesis, the compensation depth has been fixed at 32 km. This hipothesis involves a certain homogeneity to the masses beneath 32 km with a low influence upon the short period values of the observed field in surface. One can note that the Moho surface under New Caledonia is very irregular with variations of amplitude of 10 to 15 km. The lithosphere basement (60 to 70 km is depth) might yet reflect the Moho irregularities, this phenomenon is not well known. If it represents ondulations they would be only of long wavelengths and low amplitude. As more accurate informations are lacking, the structures are assumed as symetrical and the material as homogeneous; consequently, a very shallow influence dur to the existing masses beneath 32 km of depth. (see fig. 2).

The problem, meanwhile, appears very different with respect to the Benioff's plan as the lithosphere underthrusts in oblique slope down to 700 km; it includes the crust with a density d = 3,3, the whole inserated in the asthenosphere with a lightly lower density, made be d = 3,2.

Consequently, we have to deal with a completely dissymetric structure, heterogeneous in density; nevertheless such a structure with such a density contrast at so great a depth, may just have a regional effect of very long wavelength and low amplitude (Watt and Cocheran, 1973).

As a consequence of the above reasons, the compensation depth is maintened standardly at 32 km.

During the Nova survey, seismic refraction profile were made in the Southern area of the Loyalty basin. Quite far from the observed station, they have nevertheless given interesting informations about the velocity propagation, about the number and depth of the different layers with respect to the part of the profile connected with the Loyalty basin (see fig. 1). On the other hand, the relation : velocity of propagation, densities of the crossed layers is known (Talwani and al, 1959, Nafe, Drake, 1963). Those data are summarized in the following table I :

The mean density (average density of the eart's crust) assumed is d = 2,84. For each layer we obtain the following contrasts :

$\Delta\rho w = -1.81$ $\Delta\rho 1 = -0.84$ $\Delta\rho 2 = -0.44$ $\Delta\rho 3 = -.24$

$\Delta\rho 4 = -0.14$ $\Delta\rho 5 = 0.26$ $\Delta\rho 6 = 0.43$

We will determine 7 polygons (see fig. 4).

Because of the lack of geophysical information, we have taken in account, for a first outline of the model, the maximum depth for each of the layers in the Loyalty Basin (the Moho is fixed at 20 km).

On the other hand, the method used by Rose, Wollard, Malahoff (1968) in calm area, gives informations on the Moho depth.

at the km 225 under 3.8 km of water the FAA = 31 mgals we get the Moho at - 15,8 km

at the km 275 under 4,250 km of water the FAA = 10 mgals we get the Moho at - 14,7 km.

The detailed observation of the seismic reflection records communicated by the Gulf Oil allowed the location with a good accuracy of the sedimentarian basins with a density = 2.0, and the bathymetry all along the profile. The polygons I and II are then exactly determined (see fig. 4).

The western extremity of the profile crosses New Caledonia. This area is in its larger part, formed with ante senonian metamorphic grauwackes and senonian sedimentary formations. West to the great longitudinal flexure-fault, some peridotite lenses are resting on eocene and oligocene basalts. For the whole area, we have computed a density of 2,75.

The altitudes are those given by the New Caledonia maps with a 1/100 000/Scale.

-The observation of the propagation of the Rayleigh waves (Dubois, 1969) locates the Moho at 20 ± 2 km below the New Caledinia west coast, as below the Loyalty Islands, and at 35 ± 4 km below the New Caledonian central chain.

-The study of the New Hebrides arch seismicity (thesis : Pascal, 1974) gives with a great accuracy for Tanna island area, the australian plate shape and inclination angle. A dip, of 50 % has been kept on the first 30 km connected with our model.

The known elements may be summarized as following table II:

RESULTS

We had to make several computations on IBM to find out a good general fitting of the observed anomaly with the computed ones. Nevertheless a divergence high up to 9 mgals is observed between the two curves. As they are derived from anomalies of very short periods and low amplitude, no attempt was made to reduce those divergences due certainly to surface effects not involved in the present study.

The heterogeneity of the projected gravity profile, derived in joining together the different parts of the profiles, yields to consider three consecutive zones, avoiding any connection between them :

- New Caledonia
- The Loyalty Islands
- The New Hebrides Trench.

To obtain a better position of the structural elements we assume the graduations of the profile from the km - 100 to the km 500.

NEW CALEDONIA

New Caledonia presents a very complex structure in depth, which cannot be determined because of the few known elements about it.

The structural scheme given by gravity measurements, suggests a great synclinal fold, neatly dissymetrical, downgoing to - 31 km in depth, with an uplift to - 7 km of a material of density = 3,1, which is the crust. A relation can be made between the uplifted material with a density d = 3,1 and the existence on the island, of peridotite and covering serpentines massifs, whose basements underthrust Eastward with an angle varying within 10 and reaching on the East coast 45 to 50 degrees. (J.H. Guillon, ORSTOM, 1975).

On the other hand, many authors consider New Caledonia as a fossil subduction zone, active in the Eocene, whose underthrusting inclination of the plate would be East and the Loyalty Islands would be the volcanic arc witness. Some of these authors Geze (1963), Dubois and al, (1974), Daniel and al,(1976) locate this subduction zone on the western side of New Caledonia, others Lapouille and Dugas (1975) on the Eastern side. At first sight, one or the other of the synclinal side suggested by gravity measurements, may be assimilated to a plate underthrusting to East.

The dissymetry of the synclinal may be assimilated to the result of a flexure due to the blocking of the slight root under New Caledonia. The blocking having occurred at the level of the subduction zone. In this hypothesis none of both sides of the synclinal would agree with a particular plate and the whole structure would be on the underthrusting plate. The deeper part of the Western plate having been "digested" into the Asthenosphere after the rupture.

This assymetry suggests the presence of a deep fault on the eastern coast of New Caledonia : a great fault having affected the underthrusting plate at the very moment of the blocking of the structures. The peridotites having setled by means of this fault. Using the velocity dispersion of Rayleigh waves. Dubois and al, (1973) have shown off a lag in the seismic body waves from East ; undoubtedly this phenomenon may be connected with the existence of the slight root supporting New Caledonia. Apparently it does not exist any relation between this lag and the dissymetry of the structure. Maybe, a seismic survey made on the eastern coast of New Caledonia would give by the way of comparison further informations in agreement with the gravity profile.

LOYALTY

The Loyalty set involves from West to East

- a sedimentary basin
- the Loyalty Chain
- the North Loyalty plateau.

The sedimentary basin, whose two upper layers have been computed by seismic reflection is delimited by a fault system of subvertical throw on the west border. After Daniel and al (under press) the surface layers bevel themselves on the volcanic chain west of the basin. The whole basin appears to be symetrical at this scale. The layers of unhomogeneous densities are subhorizontal there. One can observe a thinning of the crust and an increase of the Moho up to the level - 16,8 km at the km 50. The first calculation on IBM 370-145 was made with - 20 km for the Moho depth, after the results obtained by Shor and al 1971.

The Loyalty chain presents in its submarine morphology a bulge lightly accentuated upwards (the profile crosses the northern extremity of the chain) and an important enrooting that may lower the Moho to the level - 24 km. The layers IV and V of the densities d = 2,7 and d = 3,7 increase in thickness (layer V included between the levels - 9,6 km and -24 km).

On the Northern Loyalty plateau at the km 275, the superficial layers are subhorizontal, the depth of the Moho decreases to - 12 km. The crust becomes typically oceanic with a thickness varying between 7 and 8 km. It is an evidence that if we assume a greater density beneath Moho, the crustal thickness would increase but in a low proportion; d = 3,32 and d = 3,20 being the extreme density values generally accepted and having no element to go beyond those limitations, it is found convenient to assume an average density d = 3,27.

THE NEW HEBRIDES TRENCH

Between the trench and the frontal arc, that is to say in the imbricated zone of the plates, we can see two characteristic breaks in the slope. (see I and II, fig. 3).

The Acoustic wave penetration on the first shelf included between the trench and the point I is practically inexistant. This zone is over lapped with a very shallow sedimentary layer of density d = 2,0.

Beneath the trench itself the sediments are up to 1.500 m thick.

From the Eastern side of the trench, andesites were dragged out (Luyendick and al 1973). Those magmatic rocks are certainly melted with different volcanic sedimentary formations so that we may assume for the whole, an average density of d = 2,4.

The soft tectonized sediments being practically inexisting in this zone, we are in presence of a prism of "non accretionary" pattern. Its basement is located at about - 10 km.

In conformity with Pascal's thesis the australo-indian plate underthrusting drops with a slope of about 50 % ; during the underthrusting it tends to thinning itself by successive bevellings of the layers of density d = 2,6 and d = 2,7. As for the Pacific plate, it presents a lightly double root increasing in thickness to the level - 32 km.

CONCLUSION

Although schematic, the results of this study allow :

For New Caledonia :

- the determination with a greater accuracy of the root form as a dissymetric synclinal and the determination of the crustal thickness to the level 31 km.

- to bring into evidence the upgoing of material with a density d = 3,1 beneath the Eastern lagoon, which may be connected with the enrooting of the surface peridotites.

For the Loyalty Islands :

- to bring into evidence a crust thickness the Moho at 16,8 km beneath the Loyalty basin.

- to bring into evidence a deep enrooting of the chain with a crustal thickness of 22 to 23 km.

- to confirm the existence of a thin oceanic crust beneath the North Loyalty plateau (8 km).

For the New Hebrides Trench :

- to characterize the prism of a "non accretionary" pattern.

- to state precisely the depth of the imbricated zone and the schematic shapes of the Australo-Indian and Pacific plates in that area.

- to confirm the slope of the underthrusting plate suggested by Pascal.

The offshore drillings of the IPOD project will be hightly necessary to a further knowledge of that aera and will, particularly, allow to identify with accuracy the material constituting the imbricated zone, and its origin.

APPENDIX

High speed digital computing

Imagine a polygonal section ABCD in a X-O-Z plane; let A be the origin of these axes.

The suggested structure is infinitely long for Y axis. The angle is computed positively from X to Z. Each apex of the polygon is given by its coordinates A (X_i, Z_i), B $(X_i + Z_i + 1)$..

$\rho 1$ is the density of the body

$\rho 2$ the density of the surrounding media.

The analytical expression of the vertical component of the gravitational attraction at the level of the point H is equal to :

$$A_Z = 2 G \oint 3 d\theta$$

The line integral being taken along the periphery of the polygon.

G = the universal constant of gravitation

ρ = density contrast between ρ_1 and ρ_2

the expression of the integral along the BC side is :

$$Z_i = \int_{BC} z d\theta = \int_B^C \frac{a_i \, tg\,\theta \, tg\,\varphi_i}{Ay \, \varphi_i - tg\,\theta} d\theta$$

the solution of the integral is given by :

$$Z_1 = a_i \sin\varphi_i \cos\varphi_i \left(\theta_i - \theta_i + 1 + tg\,\varphi_i . \log e \frac{\cos\theta_i \,(tg\theta_i - tg\,\varphi_i)}{\cos\theta_i + 1 \,(tg\theta_i + 1 - tg\,\varphi_i)}\right)$$

and the value of the integral taken along the periphery of the polygon :

$$Az = 2 G \varphi \sum_{i=1}^{n} Z_i$$

to punch on cards the program, the analytical expression of Z_i is transformed into a function of : Z_1, Z_2, X_1, X_2 ;

$$Z_i = \left(\frac{X_2 + Z_1 - X_1 + X_2}{(X_2 - Z_1)^2 + (X_1 - X_2)^2}\right)\left((X_1 - X_2)\right.$$
$$\left. - \text{THETD} - (Z_2 - Z_1)^* \text{ ALOG } \frac{(X_2^2 + Z_2^2)}{(X_1^2 - Z_1^2)}\right)$$

with THETD = OMEGA $\pm 2\pi$

and OMEGA = ATANZ (Z_1, X_1) - ATANZ (Z_2, X_2)

with X_1 and $X_2 \neq 0$

The imput data are :

N = number of polygons
KTØT = number of points of the profile
DELX = path in surface
G = universal constant of gravitation
JTØT = number of apexes of each polygon
EXX = x - axis) of each apex
ZEE = y - axis) of each apex
DEN = density contrast of each polygon
FA (K) = observed Free Air Anomaly;

An out-put table gives for each point of surface : the position of the point, its computed Free Air Anomalies which would be equal to zero in the best computation.

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TABLE I

Layer	S2 km	S1 km	Velocity km/s	Density
Sea-water	0 à 2,2	0 à 2,09	1,5	1,03
I	2,2 à 3,2	2,9 à 3,38	2,15	2,0
II	3,22 à 5,42	3,38 à 5,18	3,5	2,4
III	5,42 à 9,02	5,18 à 7,18	5,2	2,65
IV	9,02 à 14,62	7,18 à 9,98	5,9	2,75
V	14,62 à 20,12	9,98 à 13,98	6,9	3,1
Beneath Moho	20,12	13,98	8,2	3,27

TABLE II

	Density			Geometry		
	New Caledonia	NC2-NC1	H.H. Trench	New Caledonia	NC2-NC1	N.H. Trench
Sea water		known	known		known	known
I		known	known		known	known
II		known	supposed		partly known	supposed
III		known	supposed		partly known	supposed
IV	known	known	supposed	supposed	partly known	supposed
V	supposed	known	supposed	partly known	partly known	partly known
VI	supposed	known	supposed	30 ± 5 km	20 ± 4 km	partly known

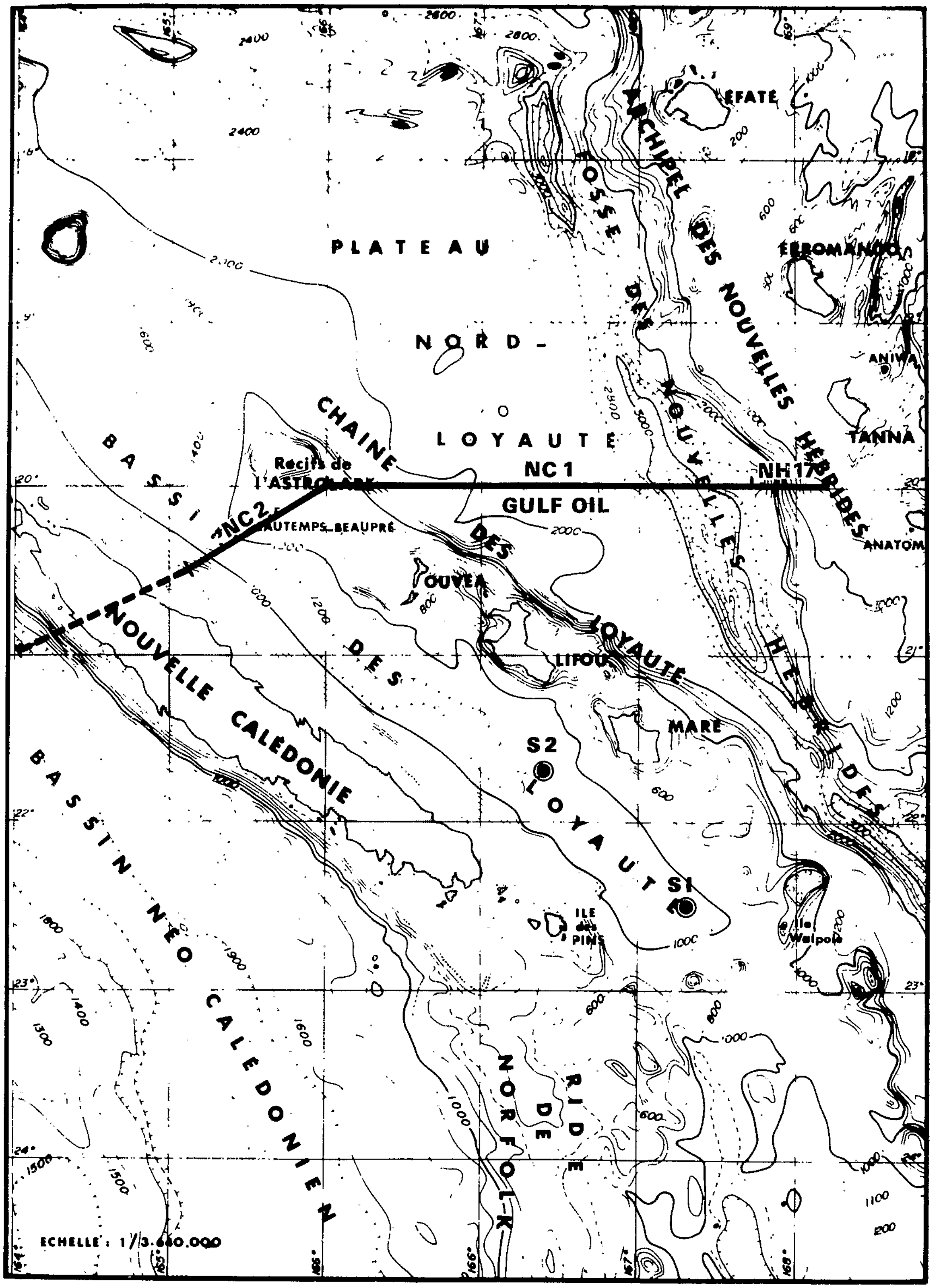

PLATEAU
NORD-
LOYAUTE
FOSSE DES NOUVELLES HEBRIDES
ARCHIPEL DES NOUVELLES HEBRIDES
EFATE
ERROMANGO
ANIWA
TANNA
ANATOM
CHAINE DES LOYAUTE
Recifs de l'ASTROLABE
NC1
NH17
GULF OIL
NC2
BEAUTEMPS-BEAUPRÉ
OUVEA
LIFOU
MARE
BASSIN DES LOYAUTE
S2
S1
NOUVELLE CALÉDONIE
BASSIN NÉO CALÉDONIEN
ILE des PINS
Ile Walpole
RIDE DE NORFOLK
ECHELLE : 1/3.660.000

FIGURE 1

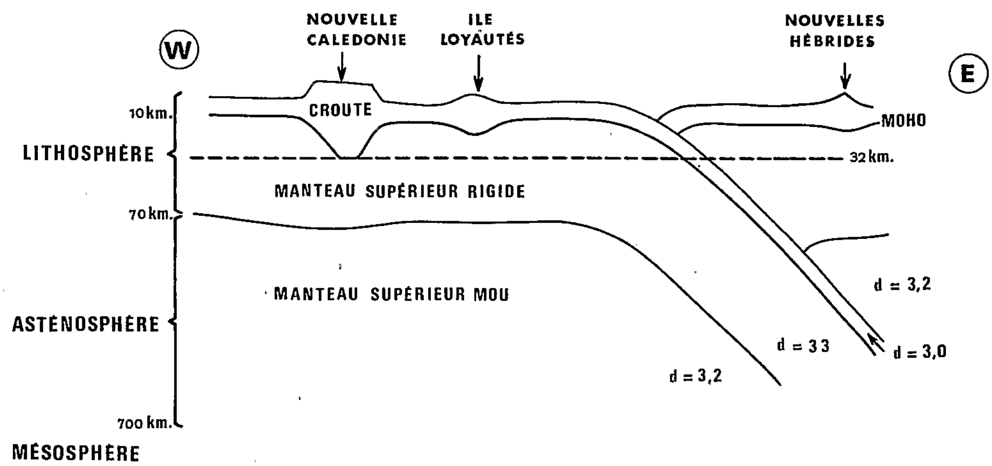


FIGURE 2

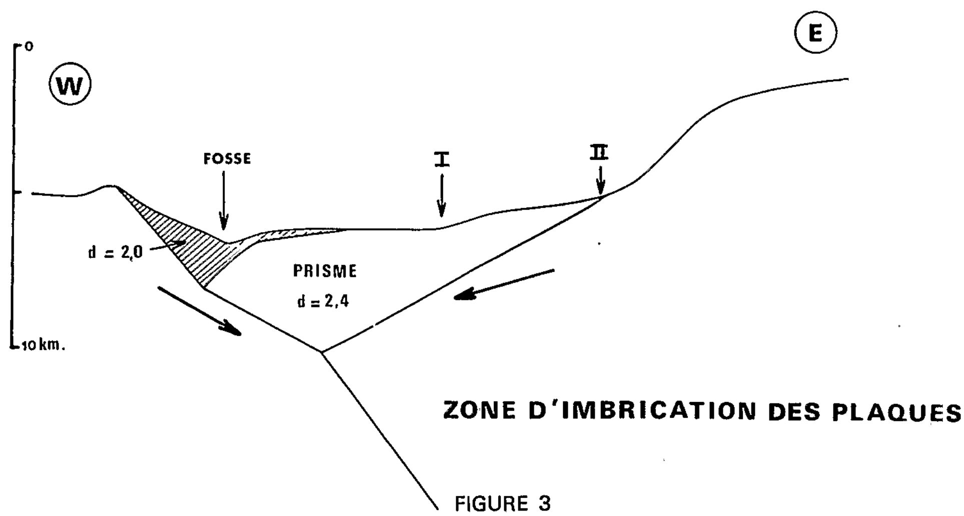
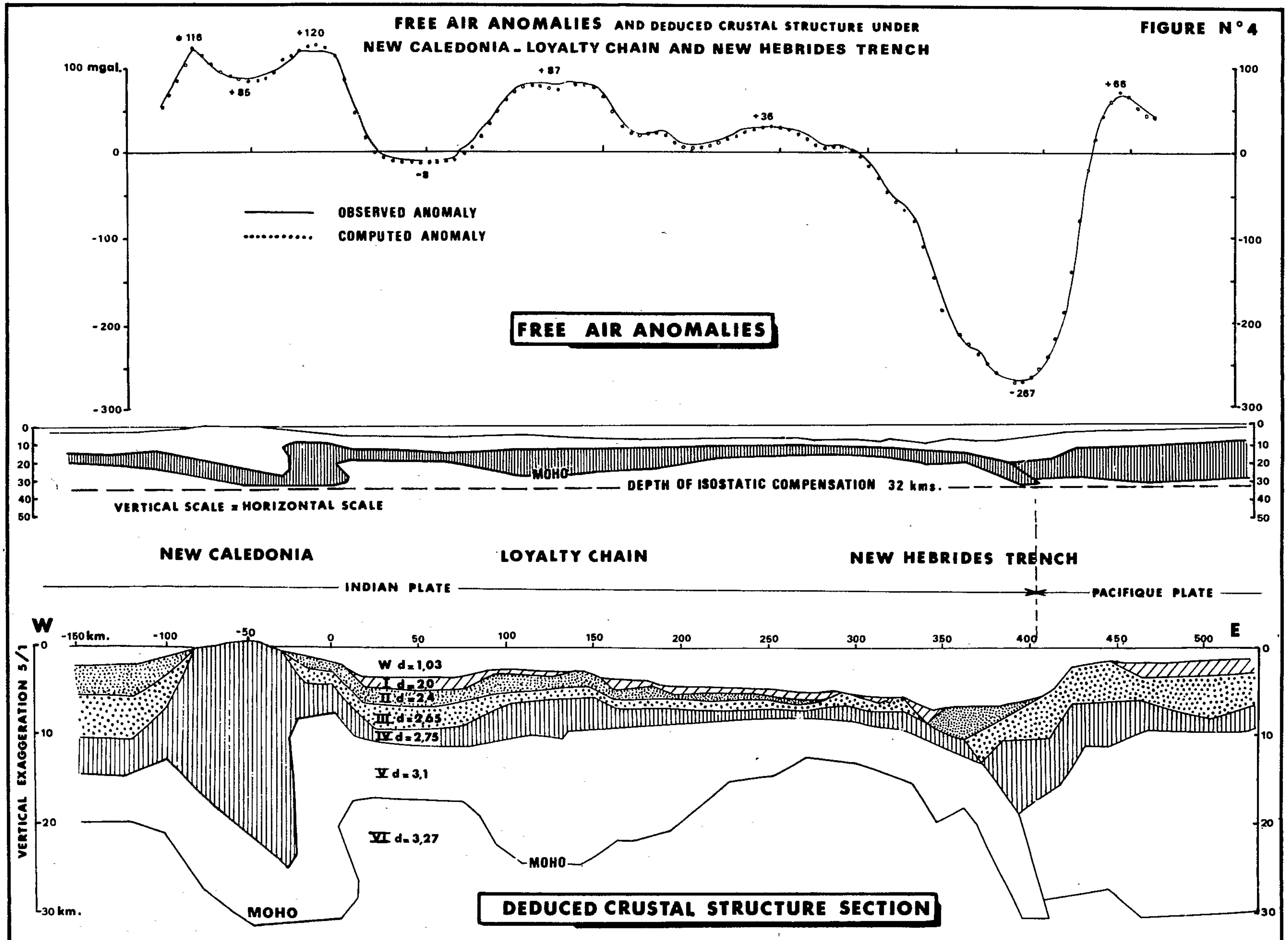


FIGURE 3


FREE AIR ANOMALIES AND DEDUCED CRUSTAL STRUCTURE UNDER NEW CALEDONIA - LOYALTY CHAIN AND NEW HEBRIDES TRENCH
FIGURE N°4
100 mgal.
+116
+120
+85
-8
+87
+36
-267
+66
OBSERVED ANOMALY
COMPUTED ANOMALY
FREE AIR ANOMALIES
MOHO
DEPTH OF ISOSTATIC COMPENSATION 32 kms.
VERTICAL SCALE = HORIZONTAL SCALE
NEW CALEDONIA
LOYALTY CHAIN
NEW HEBRIDES TRENCH
INDIAN PLATE
PACIFIQUE PLATE
W
E
-150 km.
VERTICAL EXAGGERATION 5/1
W d=1,03
I d=2,0
II d=2,4
III d=2,65
IV d=2,75
V d=3,1
VI d=3,27
MOHO
30 km.
DEDUCED CRUSTAL STRUCTURE SECTION

[redacted]

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Symposium International

GEODYNAMICS IN SOUTH-WEST PACIFIC

GÉODYNAMIQUE DU SUD-OUEST PACIFIQUE

NOUMEA – NOUVELLE-CALÉDONIE

27 AOÛT-2 SEPTEMBRE 1976

Sous le patronage de

Office de la Recherche Scientifique et Technique Outre-Mer
Bureau de Recherches Géologiques et Minières
Institut Français du Pétrole
Inter-Union Commission on Geodynamics.

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