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GRAVITY MEASUREMENTS IN LOYALTY ARCHIPELAGO, SOUTHERN NEW CALEDONIA AND THE ISLE OF PINES

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J.Y. COLLOT and F. MISSEGUE [1]

INTRODUCTION

This note is the presentation of the results of gravimetric surveys, made by ORSTOM in the Loyalty Archipelago in 1975, in Southern New Caledonia and the Isle of Pines in 1976. The purpose of these geophysical surveys besides a systematic gravimetric coverage is an attempt to settle the effect of the lithospheric bulge in connection with the subduction of the Australo-Indian plate, at the level of the New Hebrides trench.

The free air anomaly and the Bouger anomaly are plotted from 10 to 10 milligals from the anomaly values given at each observed station.

The FAA(a) produced by the lithospheric bulge is computed in subtracting, from the observed FAA, the FAA theoretically produced by the Loyalty Chain.

The FAA theoretically produced by the bulge of an oceanic crust of the same pattern as the Northern plateau of the Loyalty will be then computed.

The comparison between those two methods will be developed afterwards.

I - GRAVITY MAPS

In all, some 500 measurements stations were worked out from a Worden gravity meter. The whole measure stations are connected to the international gravity base of Noumea-IFO by Muckenfuss at G = 978882.00 mgals, after the Potsdam system, still in work there in order to maintain an homogeneity to the ORSTOM system all over the World.

Precision of the results. Three standard gravity bases have been created to check regularly the adjustment and the drift of the gravity meter.

- Noumea Magenta Airport G=978869.15 mgals
- Noumea Ouen Toro Observatory G=978853.99 mgals
- Noumea Mont Coffin G=978863.95 mgals.

The determination of the main insular gravity stations may be subjected to an error reckoned to ± 0.5 mgals, the accuracy of the gravity measurements between two close stations is about ± 0.1 mgals.

The altitudes of the stations were determined by barometrical levelling with very frequent checking on the different points of topographic levelling. The optimum error in the estimation of the altitude of a station may affect the gravity measurement of ± 0.2 mgals.

The location of the gravity stations are based on IGN maps (Scale: 1/50,000) with an accuracy high of ± 50 meters ; which gives an error of ± 0.025 mgals in the computation of the theorical gravity on the standard ellipsoïd.

The maximum of error in absolute value that may affect the final results is aboit ± 0.3 mgals.

(a) Hereafter for brevity the Free Air Anomaly is referred to as FAA.

(1) Office de la Recherche Scientifique et Technique Outre-Mer, B.P. A5, Noumea Cedex, New Caledonia

Theoretical Gravity. The theoretical gravity on the standard ellipsoid G_o is computed after the Potsdam system:

$$G_o = 978049.00\ (1 + 0.0052884\ \sin^2 L - 0.0000059\ \sin^2 2L)$$

Free Air Anomaly. The FAA is plotted from 10 to 10 mgals, referring to the values computed at each station (maps 1-2-3-4).

Bouguer Anomaly. The Bouguer anomaly has been computed for all the stations, with the following densities : - d = 2.1, 2.2, 2.35, 2.5, 2.67, 2.75, 2.85.
The term T (isostatic correction) was not taken in consideration, the surrounding bathymetry beeing too much inacurrate.
The anomalies are drawn up from 10 to 10 mgals.
For the Loyalty Islands the structures of whose are ancient uplifted coral massifs, with a density included within 1.9 and 2.2, the Bouguer anomaly is drawn up for a density d = 2.1 (see maps 5-6-7).
For the Southern New Caledonia and the Isle of Pines the geologic formation is ultrabasic rocks (peridotites,gabbros), the Bouguer anomaly is represented with a density d = 2.67 (see map 8).
The Bouguer anomaly (see maps 5-6-7) brings out the topography of the volcanic substratum of the Loyalty Islands with :

- in Ouvea, two maximum high of + 155 mgals which agree with the emerged lands.
- in Lifou, a maximum high of + 180 mgals in the North, high of + 170 mgals in the center and high of + 170 mgals in the South East of the island.
- in Mare, a maximum high of + 170 mgals in the center of the island, South of the line Rawa-Peorawa.

II - AN ATTEMPT TO BRING OUT THE GRAVIMETRIC EFFECT OF THE LITHOSPHERIC BULGE.

The uplift of the Loyalty Islands which has begun at the quaternary age, and is going on nowadays, seems due to the presence of a lithospheric bulge of the Australo-Indian plate before its underthrusting beneath the Pacific plate at the level of the New Hebrides trench. (Dubois et al 1973, 1974, 1975).

During the migration of the plate, the Loyalty atolls progressively reached the zone of bulge influence and as a consequence, they have emerged gradually.

Such a bulge was studied through bathymetric profiles (Hanks 1971) and uplifted atolls (Dubois and al 1974, 1975) in different zones of subduction.

This bulge is not easily disclosed on the bathymetric profiles made in the Loyalty - New Hebrides area, the morphology of the Loyalty Chain presenting large irregularities in the field of its general morphology. This bulge might be shown on gravimetric profiles.
Let us try to dissociate the FAA due to the presence of the Loyalty Chain from the FAA due to the lithospheric bulge, through the observed FAA on a synthetical profile of the latter.

Synthetical presentation of the regional FAA
The drawing up of a synthetical profile of the FAA seemed to be necessary the gravimetric coverage being reduced to that of the islands is not sufficient and does not allow any accurate estimation on regional FAA maps.
Let us now plot the FAA values observed at each measurement station, on a plan perpendicular to the New Hebrides trench axis, as a function of their distance to the trench (see fig. 1). Thus, we obtain three clusters of points and using those points we can compute and draw the regression curve of degree 2 of this set. The resulting curve (see A fig. 1) shows the variation of the regional FAA as a function of its distance to the trench axis. The maximum of that curve is high of + 167 mgals and is located at 132.5 km from the trench axis.

FAA theoretically produced by the Loyalty Chain
To determine with accuracy the FAA produced by the Loyalty Chain is difficult to carry out some parameters being not well known :

- the morphology of the volcanic basement
- the densities and thicknesses of the geological layers superposing one another up to the Mohorovicic discontinuity plan.

Though, a scale of size of this anomaly can be determined synthetically.
In order to that, let us draw up three models representing schematically each of the Loyalty islands with respect to all the given parameters, i.e.

- some elements of neighbouring bathymetry
- topography
- the density of coral deposit.
- the densities and thicknesses of the deep-seated layers of the Loyalty basin located West of the Chain (Shor and al 1971).
- the depth of the Moho (Collot, Missegue 1976).

Each model has been plotted as a function of the very distance to the trench axis (see fig. 2) of each of the islands, on a plan perpendicular to the trench axis.

- for Ouvea, we obtain at 200 km from the trench axis, a maximum high of + 145 mgals.
- for Lifou, we obtain at 150 km from the trench axis, a maximum high of + 165 mgals.

- for Mare, we obtain at 105 km from the trench axis, a maximum high of + 159 mgals.

The compensation depth chosen in the calculation of the anomaly produced by those models is - 32 km.

Those three curves Ouvea-Lifou-Mare have been drawn on a plan perpendicular to the trench axis.

Their curve of refression of degree 2, has been computed and plotted (see B fig.3) this synthetical curve may be considered as representative of the variation of the FAA produced by the Loyalty Chain, as a function of its distance to the New Hebrides trench axis. The maximum high of + 154 mgals is located at 140 km from the trench axis.

FAA due to the lithospheric bulge. The regional FAA is equal to the addition of the anomaly produced by the Loyalty Chain plus the anomaly produced by the lithospheric bulge. We can easily deduce the latter.

FAA bulge = Regional FAA - Chain FAA
A B

The figure 3 shows that the regional FAA is represented by the curve A, the chain FAA by the curve B.

The curve C shows the difference between the curves A and B.

Its maximum high of + 14.0 mgals is located at 125 km from the trench axis. It represent the FAA variation induced by the lithospheric bulge, as a function of its distance to the trench axis.

FAA theoretically due to an oceanic crust bulge. Let us consider an oceanic sheet of the same pattern as the Northern Loyalty Plateau which schematic definitions are the following:

- thickness of the plate : 8000 meters
- thickness of the water (d1 = 1.03) above the plate : 2220 meters
- layer 1 from -2220 m to-4220 m of density d2 = 2.4
- layer 2 from -4220 m to -5220 m of density d3 = 2.65
- layer 3 from -5220 m to -6720 m of density d4 = 2.75
- layer 4 from -6720 m to -10220 m of density d5 = 3.1
- layer under Moho of density d6 = 3.27.

Which plate is sujected to a flexure.

The deflection of a this lithospheric sheet of uniform thickness and homogeneous rhelogical properties,where horizontal and vertical forces are applied upon its free edge, is given as a function of its distance to the free edge by a differential equation of order 4, in involving the parameters of the media, the solution of whose is the following :

$$\zeta_x = \left(\frac{2Pb\lambda}{\rho m - \rho w}\right) \exp. - \lambda x \cos x$$

The evolution of that equation (Hetenyi 1946, Hanks 1970, Lliboutry 1974) has been computed with an elastic sheet resting on a viscous medium. Between New Caledonia and the New Hebrides trench the maximum deflection amplitude is high of 150 meters at 119.4 km from the trench axis. Its wavelength is 238.7 km (Dubois 1975) When the sheet has been deflected according to those parameters, we get the model represented on the figure 4.

The layers are uniformly deflected. The flexure is extremely shallow and cannot involve a landslide at the level of the interfaces.

With respect to a horizontal plan each layer produces the intruding of a lens of its own material into the following upper layer (see fig.4).

The anomaly due to the sheet flexure itself, is given by adding the anomalies produced by each lens. The maximum of the anomaly high of + 12.77 mgals, is located at 125 km from the trench axis (see curve D fig. 4).

Comparison between the curves C and D.

Let us compare the curve C - showing the variation as a function of its distance to the trench axis, of the anomaly due to the lithospheric bulge deduced from the synthetical profile of the regional FAA with the curve D showing still as a function of its distance to the trench, the variation of the anomaly theoretically due to an oceanic plate bulge.

Both curves have their maximum at the same distance from the trench. In Ouvea, the curve D gets a deeper slope, which agrees with the observed anomaly, West of Ouvea, having a quite deep slope due to the vicinity of the Loyalty Basin. Then both curves are nearly parallel, with a sleight lag high of 4 mgals maximum.

If we take in consideration the few wellknown elements which can help gravimetry, this method appears as a good approximation of the FAA produced by the lithospheric bulge between New Caledonia and New Hebrides trench.

CONCLUSION

The models studied in this note for the determination of the anomaly theoretically due to the Loyalty Chain have no other purpose them taking in consideration the general lines of the Chain structure.

The lithospheric bulge in connection with the Australo-Indian plate subduction at the level of the New Hebrides trench seems to be confirmed and its influence on the observed free air anomaly is determined with a good accuracy if we compare the observed results with the theoretical ones.

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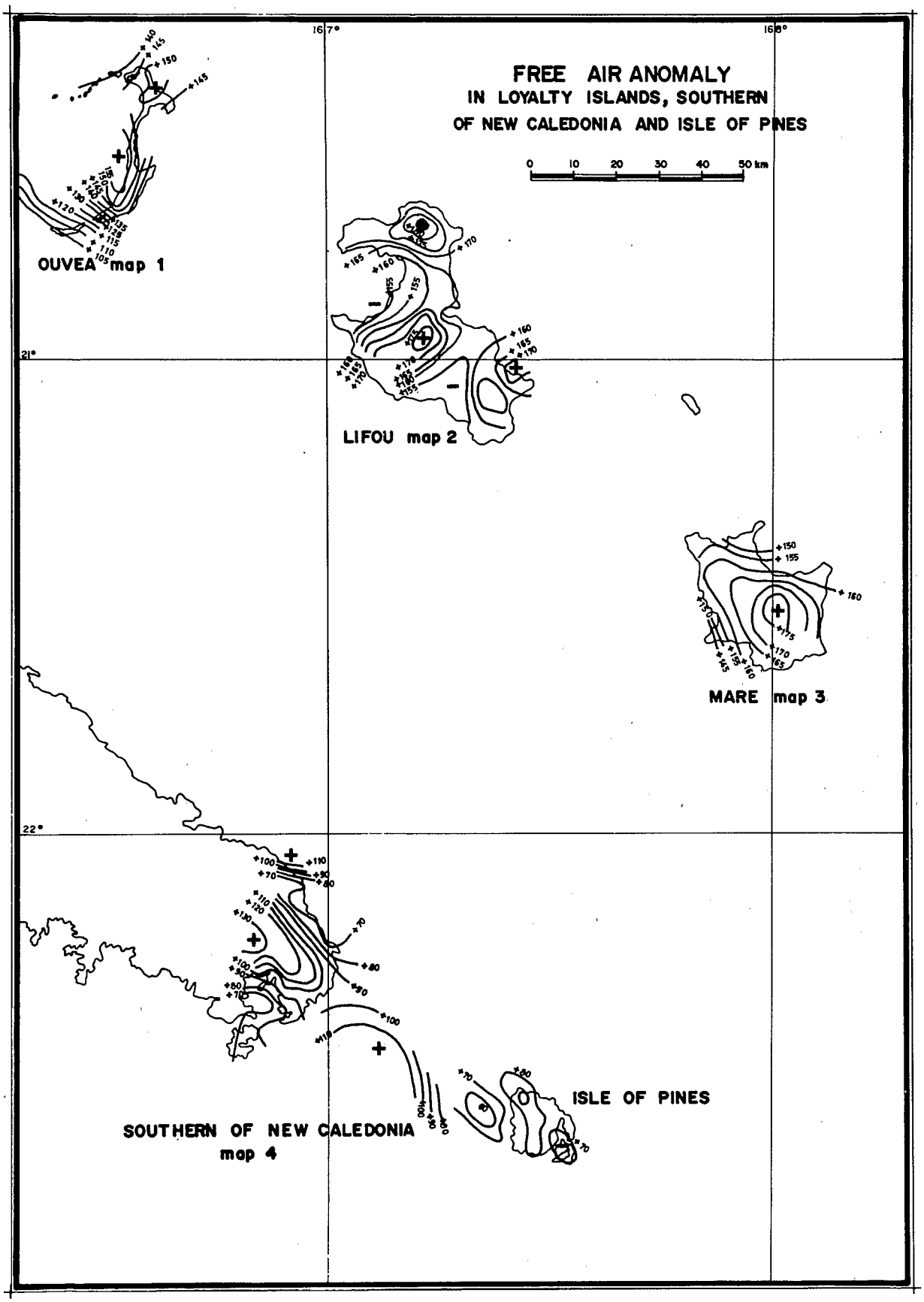
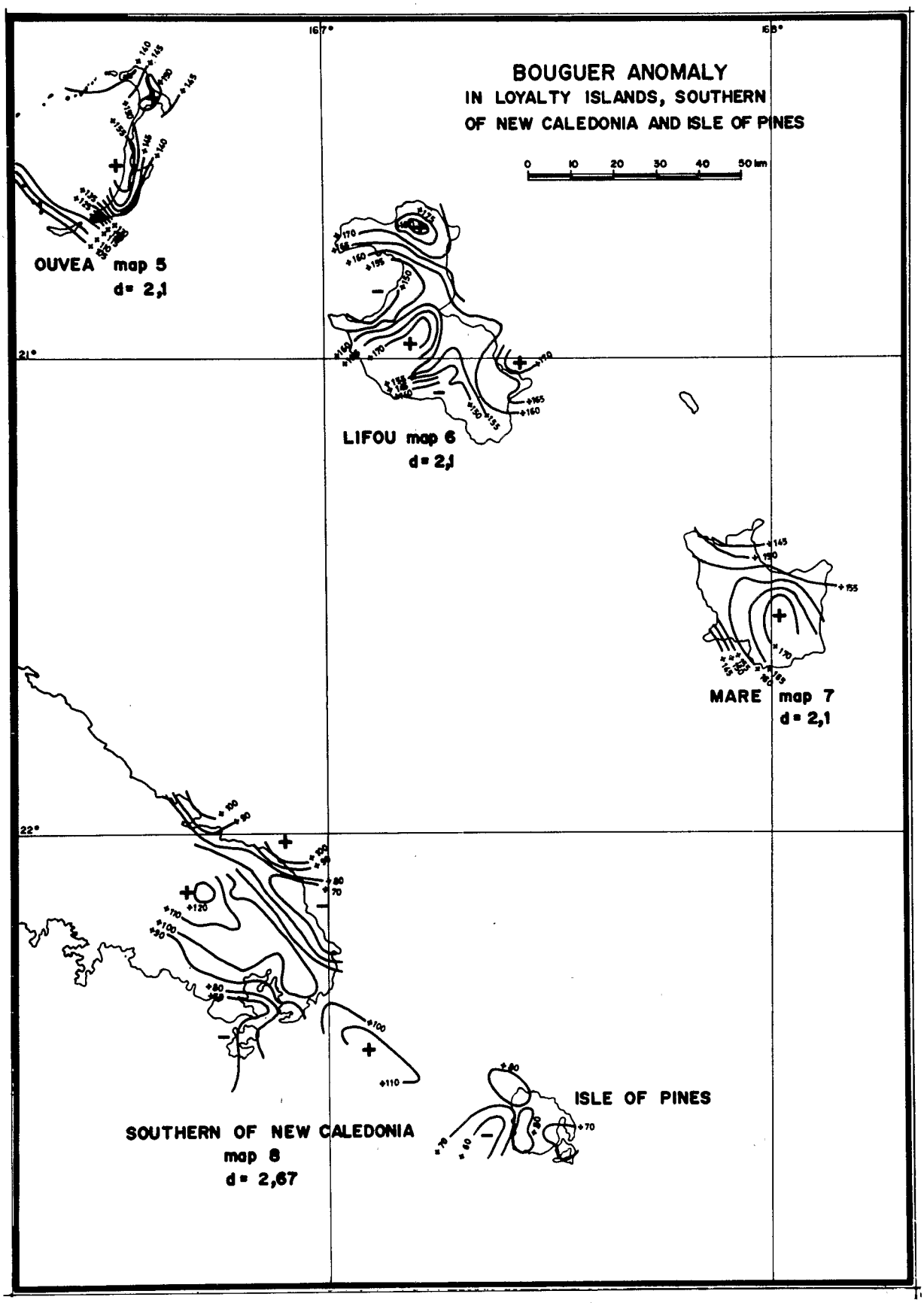
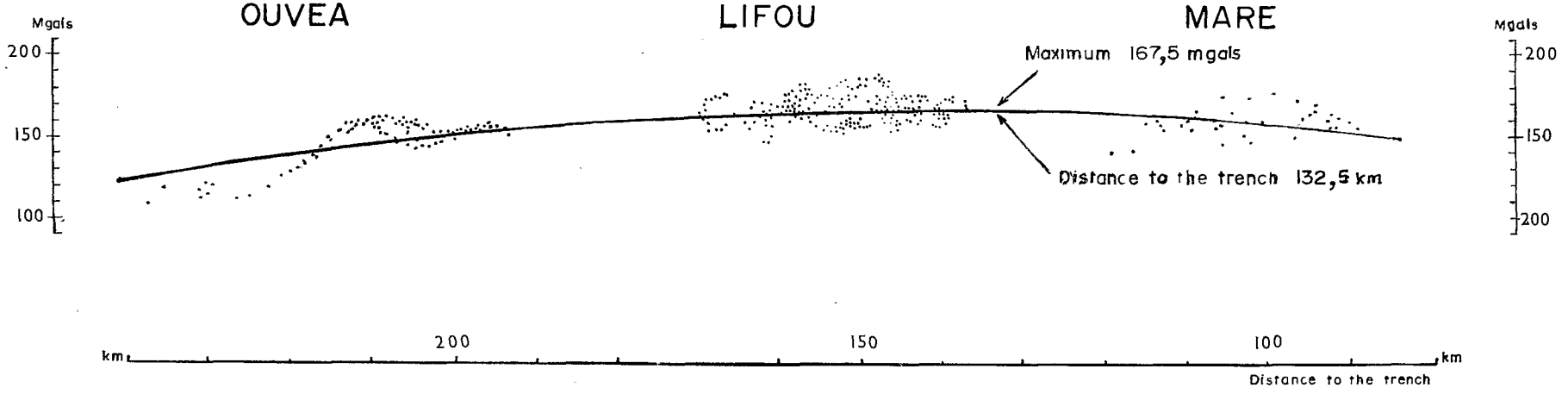

FREE AIR ANOMALY
IN LOYALTY ISLANDS, SOUTHERN
OF NEW CALEDONIA AND ISLE OF PINES
0 10 20 30 40 50 km
167°
168°
21°
22°
OUVEA map 1
LIFOU map 2
MARE map 3
SOUTHERN OF NEW CALEDONIA
map 4
ISLE OF PINES


BOUGUER ANOMALY
IN LOYALTY ISLANDS, SOUTHERN
OF NEW CALEDONIA AND ISLE OF PINES
0 10 20 30 40 50 km
167°
168°
21°
22°
OUVEA map 5
d = 2,1
LIFOU map 6
d = 2,1
MARE map 7
d = 2,1
SOUTHERN OF NEW CALEDONIA
map 8
d = 2,67
ISLE OF PINES

SYNTHETICAL REPRESENTATION
OF REGIONAL FREE AIR ANOMALY VARIATIONS

BETWEEN NEW CALEDONIA AND NEW HEBRIDES TRENCH

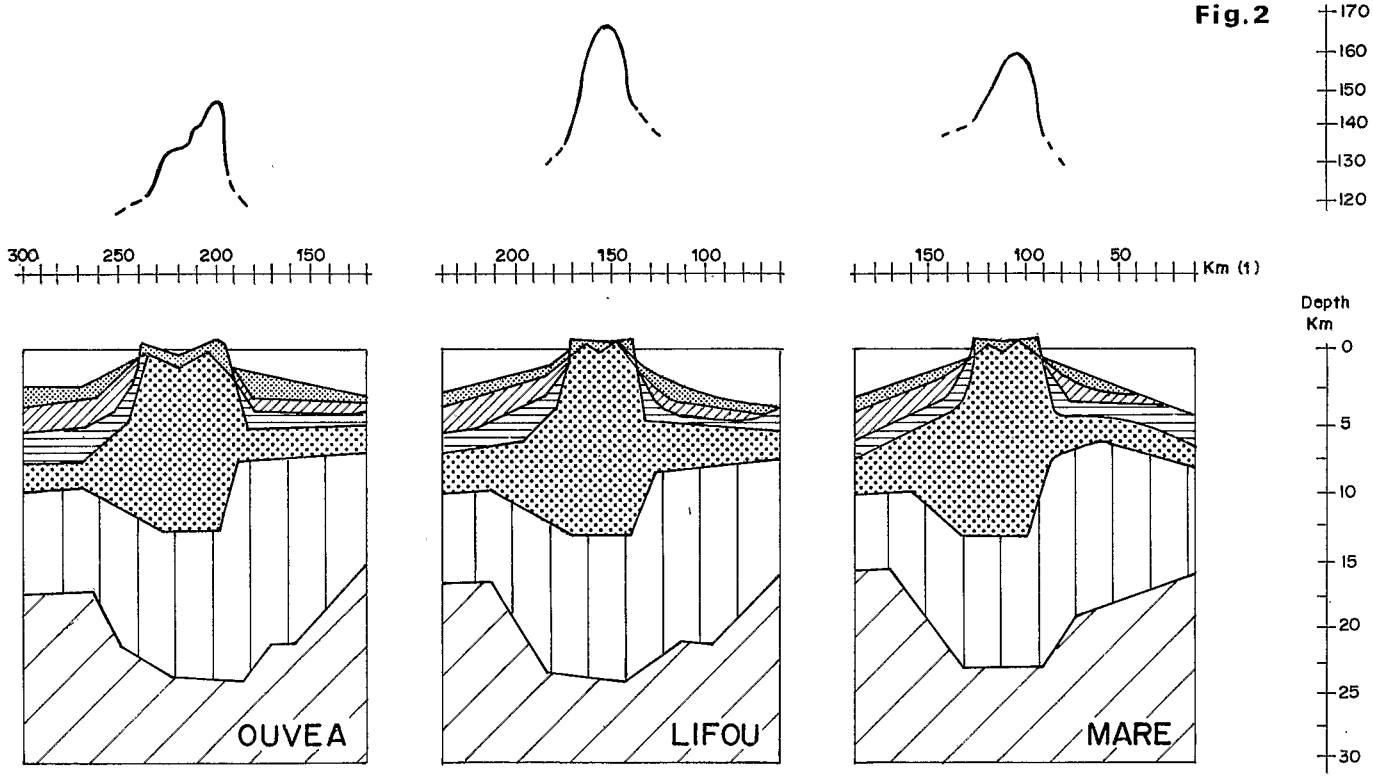
Fig. 1



Variations curve of regional free air anomaly is computed and drawned on a plane perpendicular to the New Hebrides trench axis from observed values on Loyalty Islands .

Let X-axis be the distance to the trench and Y-axis be the observed value of free air anomaly of each station.

Fig.2



d1 = 1.03 d5 = 2.75

d2 = 2.00 d6 = 3.10

d3 = 2.40 d7 = 3.27

d4 = 2.65

(1) Distance to the trench

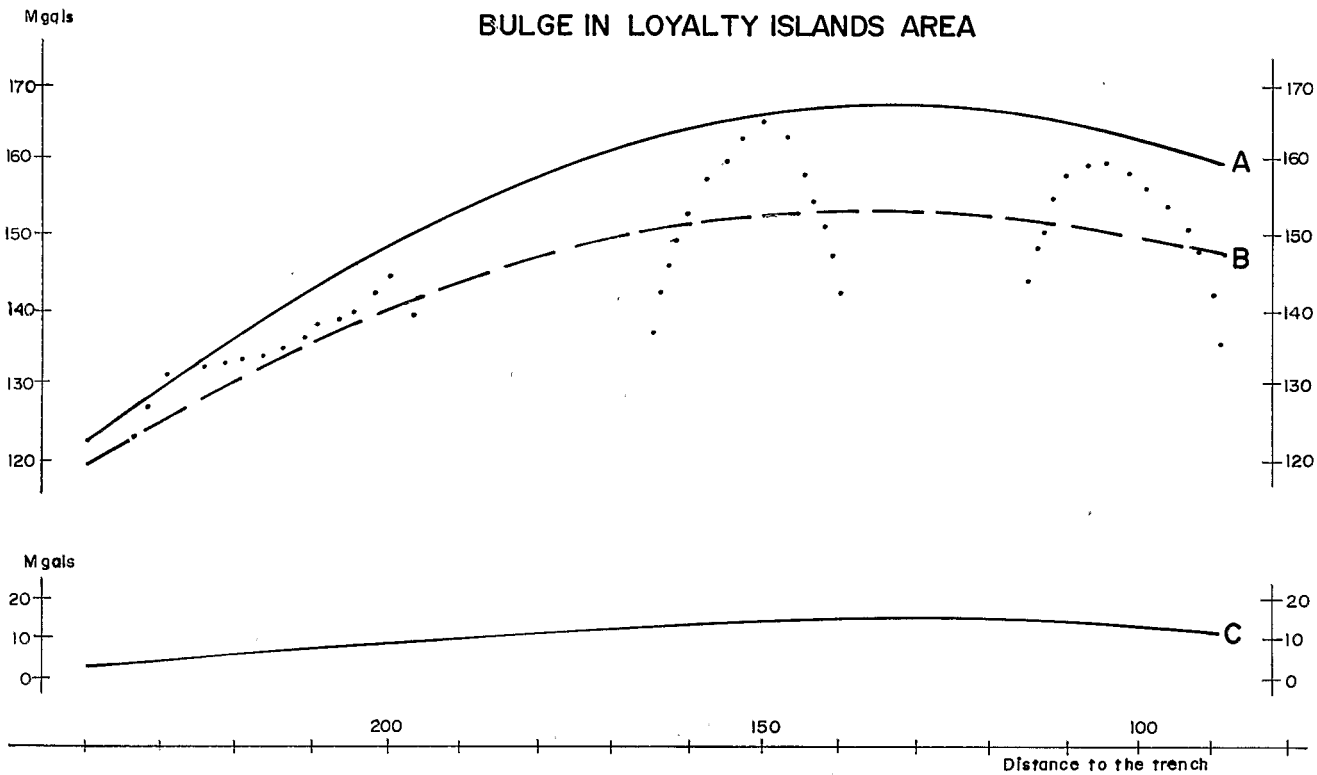
COMPUTED FREE AIR ANOMALY

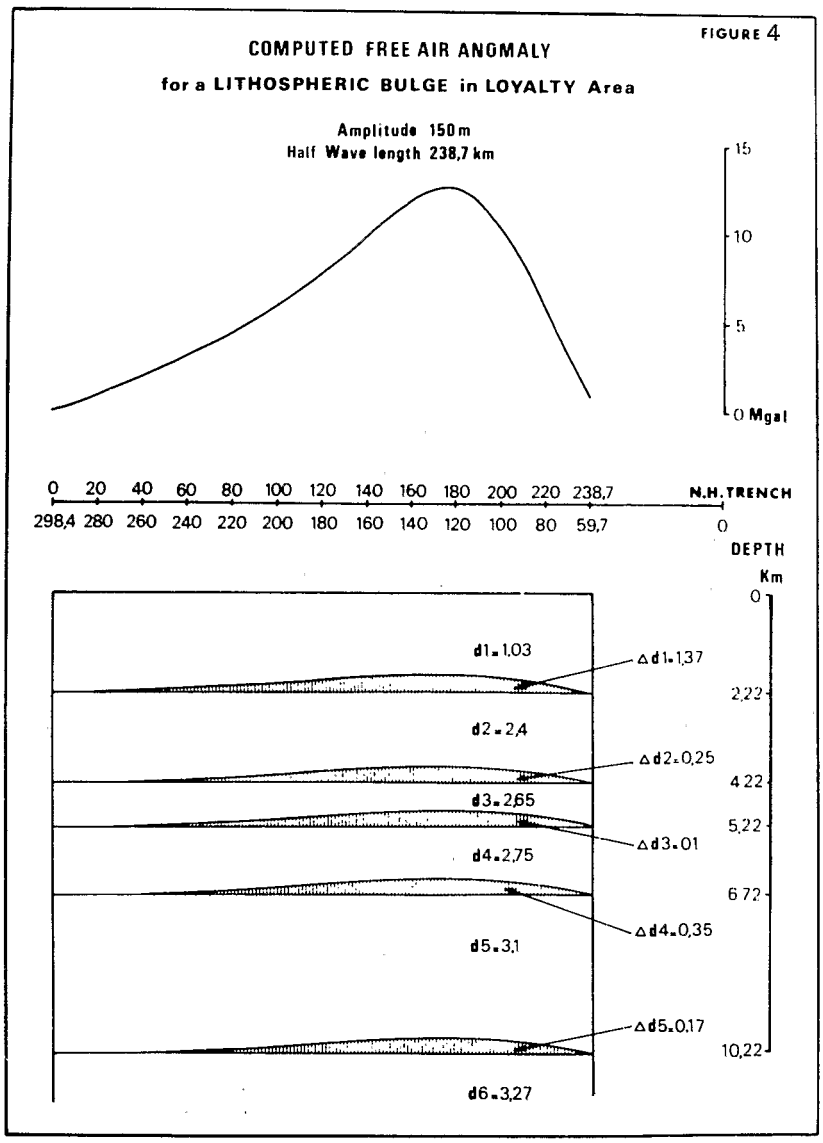
FOR TWO DIMENTIONAL BODIES WITH APPLICATION TO THE LOYALTY ISLANDS

DEPTH OF ISOSTATIC COMPENSATION IS - 32 km

DEDUCED FREE AIR ANOMALY GENERETED BY LITHOSPHERIC BULGE IN LOYALTY ISLANDS AREA

Fig. 3





COMPARISON OF DEDUCED FAA AND THEORETICAL FAA GENERETED BY THE BULGE

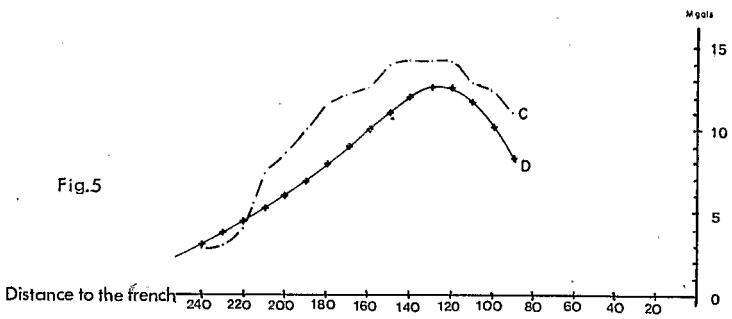
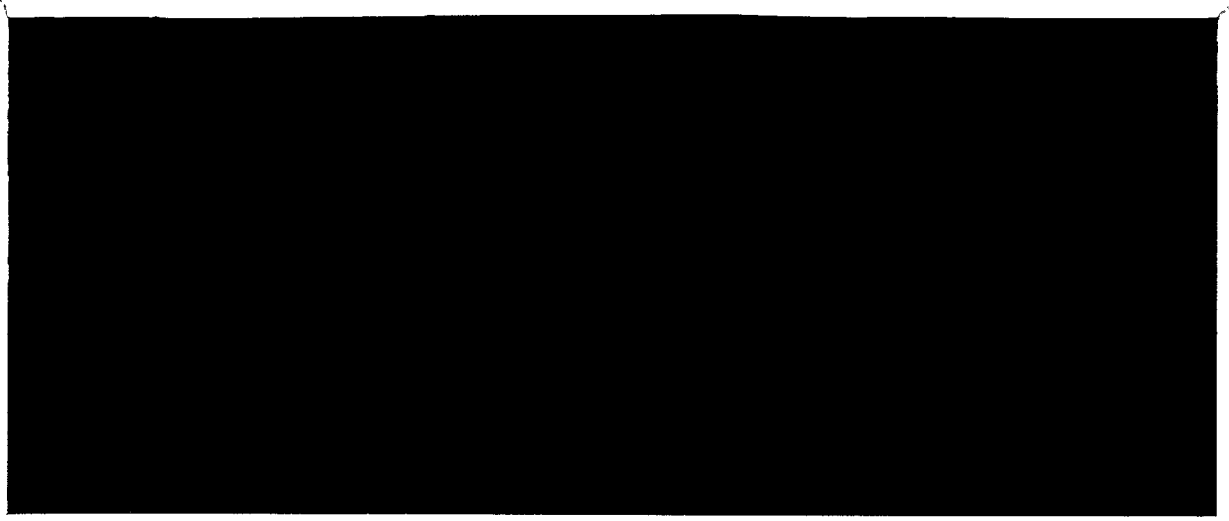


Fig.5



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