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GRAVITY, GEOID, ISOSTASY AND MOHO DEPTH IN THE ROSS SEA, ANTARCTICA.

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ABSTRACT

In the framework of several international research projects performed in Ross Sea (Antarctica) in the last years marine gravity data, high resolution reflection seismic lines and deep seismic sounding profiles have been acquired.

The gravity data set has been used to compute maps of Bouguer anomaly, isostatic anomaly, isostatic correction and local geoid undulations. Forward modelling of seismic and gravity data has been also used to compute the depths of the Crust-Mantle discontinuity.

INTRODUCTION

In the last years OGS (Osservatorio Geofisico Sperimentale) has acquired more than 7000 km of high resolution reflection seismic and gravity data along profiles in the Ross Sea (Antarctica), in the framework of international research programs; during the austral summer 1980/81 a large data set of multichannel seismic lines, gravity and magnetic profiles were acquired for the German research institution Bundesanstalt für Geowissenschaften und Rohstoffe (BGR) and the same seagravimeter was used by OGS and BGR so the two data sets are fully compatible. The BGR data set has been integrated and validated by using the OGS data (Gantar & Zanolla,1993). In 1991 IMGC (Istituto Metrologico Gustavo Colonnetti, Torino Italy) has established the first absolute gravity site in the Antarctica Continent at the Italian Base located at Terra Nova Bay (Cerutti at al., 1992). The marine gravity data set has been tied to the absolute site and used to compute a Free Air (Fig. 1) and Bouguer anomaly map (Coren et al., 1994). In both maps,

but particularly in the Free Air one, the main geological features affecting the Ross Sea area are clearly visible. Lineations with North- South direction are recognisable. From West to East they are: a) Victoria Land Basin (VLB); b) Terror Rift (TR); c) Northern Basin (NB); d) Central Trough (CT); e) Central High (CH)- Iseline Bank (IB); f) East Ross Basin (ERB).
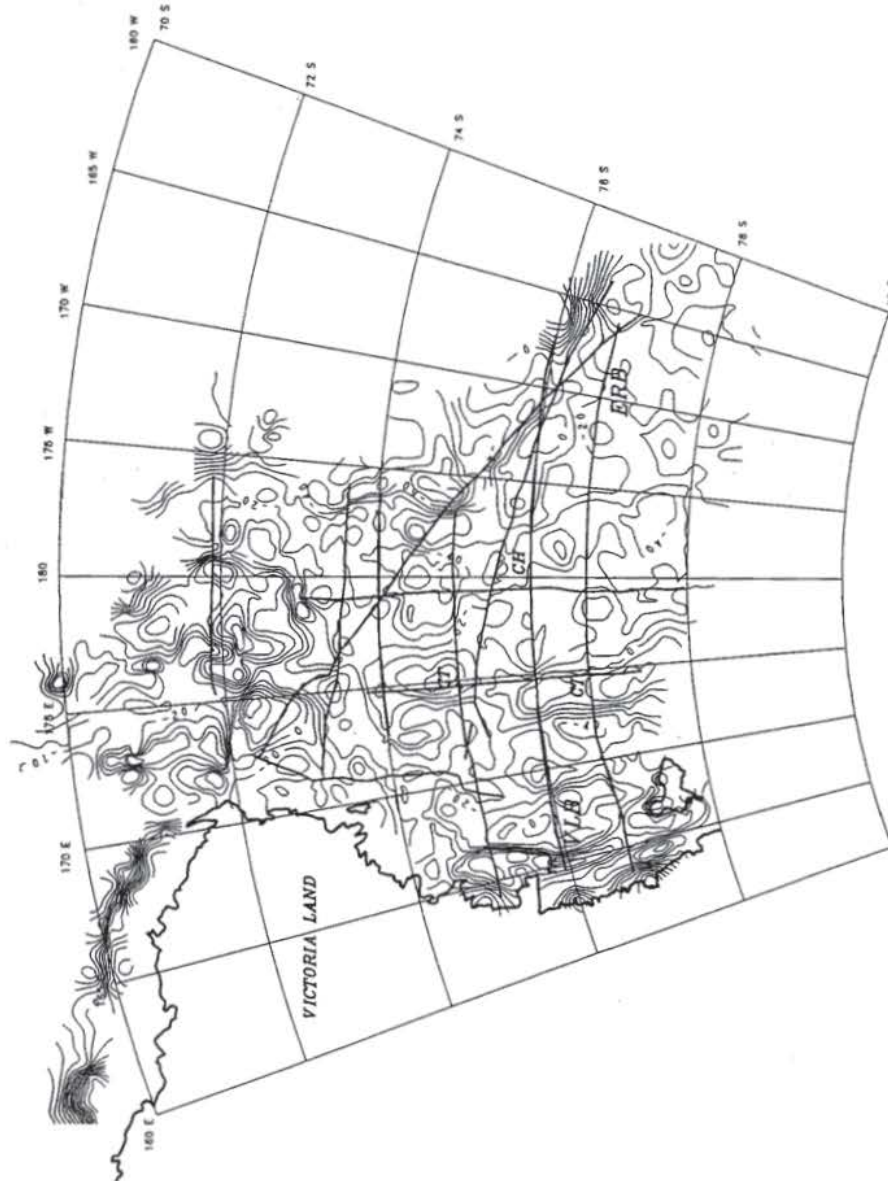

Fig. 1. Free Air anomaly map, (mgal). Reflection seismic survey lines are indicated. For other details see the text.

The marine gravity data set is of particular interest because the other available data are only Free Air anomalies computed from satellite (GEOSAT and ERS missions) which have of course a lower resolution.
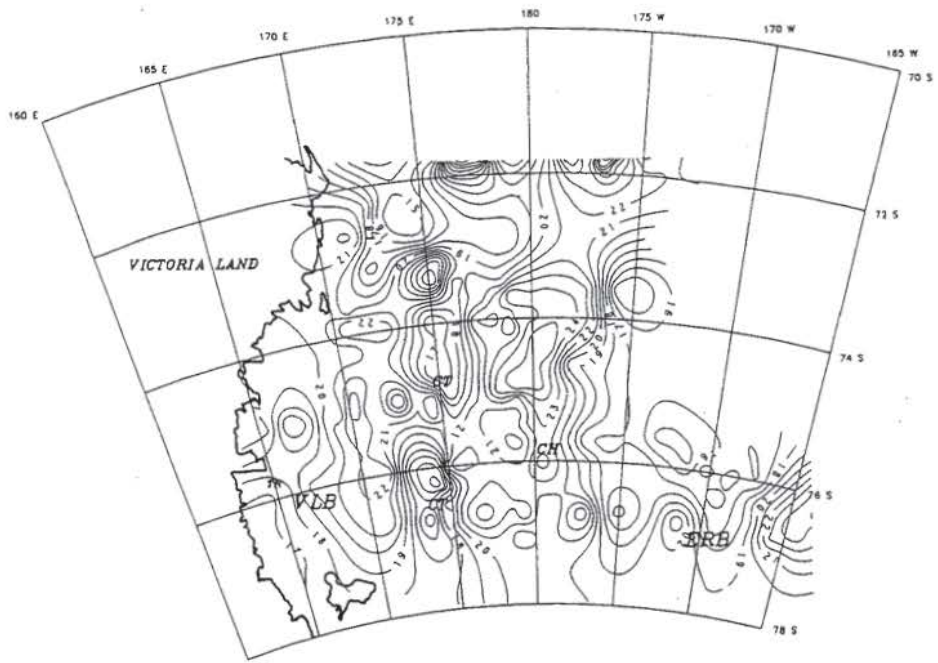
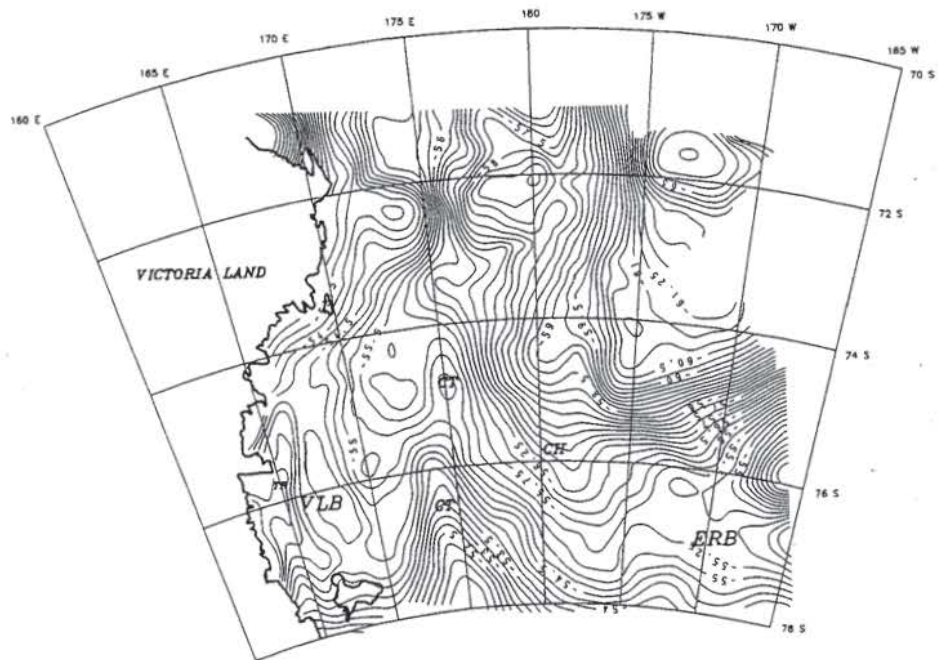Fig. 2. Moho depths map (m). Polar Stereographic Projection; k0 = 0.95 (at Pole); WGS84 geodetic reference.

Fig. 3. Local geoid undulations computed using the remove-restore technique, (m).

FORWARD GRAVITY MODEL

The geometry of the basement and crustal structures, inferred from the reflection seismic data, has been used to constrain the forward gravity models of the Crust-Mantle discontinuity (Coren et al., 1994). 2D models have been computed along the seismic lines to produce the map of the Moho depths of Fig. 2. The density values used for the model computation were: - sea water 1.03 g cm^{-3}; - first sedimentary body (sea floor) 2.50 g cm^{-3}; - second sedimentary body (top of the acoustic basement) 2.70 g cm^{-3}; - basement density 2.90 g cm^{-3}; - upper mantle density 3.40 g cm^{-3}. The map reflects the sedimentary basin morphology having a North- South direction, although other minor lineations can be traced in different directions: in the western Ross Sea, a general depression in the Moho is observed along a NW-SE direction.

This Moho depression crosses the northernmost sector of the Victoria Land Basin and projects trough Central Trough. A suite of W-SW to E-NE lineations is also observed. A dextral offset of Moho contours occurs across these lineations in the northern sector of the Ross Sea. These lineations curve from W-SW E-NE to E-W along 73.5°S and 73°S, in the N-E Ross sea nearly coincident with gravity trends observed by Davey (1994).

THE GEOID OF ROSS SEA

The availability of a relatively large data set of marine gravity tied to an absolute station has suggested the opportunity to compute the local geoid of Ross Sea. The geoid undulations shown in Fig. 3 have been performed using a remove-restore technique. Adopting the Stokes formula we compute the anomalous potential (the anomalous potential is defined as the difference between the potential on the geoid and the normal potential on the ellipsoid). This requires the complete gravity anomaly field over the Earth for the computation of the geoid undulations. We can only apply the expression in a limited region. However, in this case wavelength contribution of the gravity field will not be present in the results and we can provide them by a set of spherical harmonic coefficients obtained from the OSU91 geopothential model (Rapp et al., 1991). To compute even very short wavelengths, topographic heights are used, but their effects are small compared with the others. The true geoid undulation is obtained by restoring the contributions of the global geoid model (OSU91) N^{GM} and the contribution due to topography (N^h): $N = N^{GM} + N^{\Delta g} + N^h$; this expression includes the small wavelengths due to the gravity ($N^{\Delta g}$), the topographic terms (N^h), and the large wavelengths, from the global model term N^{GM}.

Several geological features are clearly affecting the geoid; from West to East it shows: a) the Victoria Land Basin (VLB), undulations from more then -55 m to about -54 m; b) the Terror Rift (TR), undulations between -55.25 m and -54.5m; c) the Central Trough (CT) characterised by two areas of relative maximum; d) the Central High (CH), with undulations from -55 to about -56.25; e) the East Ross Basin (ERB).
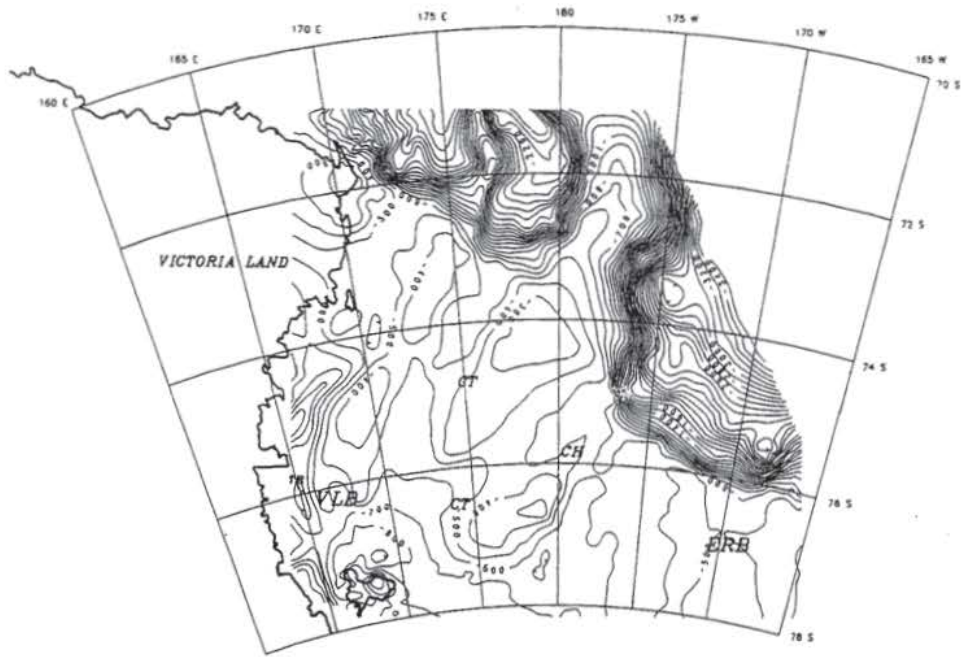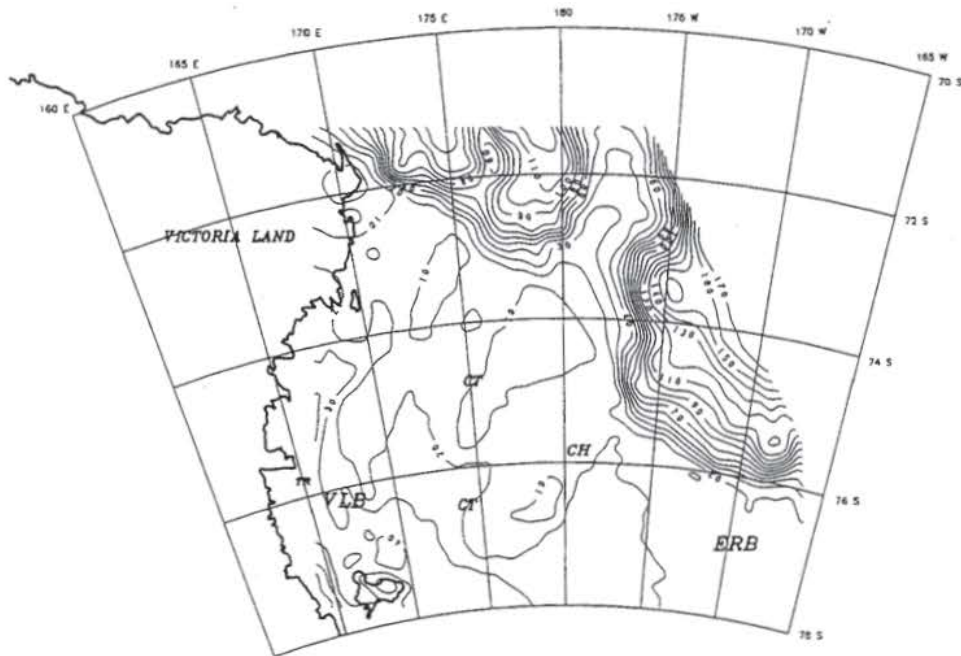
Fig. 4. Bathymetry map, (m).

Fig. 5. Isostatic correction map, (mgal).

Comparing the geiod undulations of OSU91 model (0°-360°) of Ross Sea (Rapp et al., 1991) and the geoid map computed for the Ross Sea, using the Stokes equation with the remove-restore technique the two models have relevant similarities in spite of the fact that OSU91 is mainly based on satellite altimetry data. As expected there is a bias between the two models at very low frequency. Our geoid model, entirely based on gravity data, could be useful to improve the geoid models of this area.

ISOSTATIC ANOMALIES

Assuming that the isostatic response of the lithosphere is isotropic, following the approach suggested by Dorman and Lewis (1970) we have computed the isostatic admittance as :

$$R(|k|) \cong \left\langle \text{Re} \left(\frac{BA}{H} \right) \right\rangle \tag{1}$$

where: $R(|k|)$ = isostatic response function;
$H(k)$ = Fourier Transform of the bathymetry;
$BA(k)$ = Fourier Transform of the Bouguer anomaly.

As input data we have used the Bouguer anomaly grid (Coren et al., 1994) and the bathymetry grid (Fig. 4), computed from the bathymetric data acquired along the seismic lines. The average included in eq. 1 has been computed over concentric rings, that is, of constant wave numbers.

We can consider the Bouguer anomaly as the sum of two contributions: the isostatic correction (IC), that is the portion of the field of the Bouguer anomaly correlated with the topography-bathymetry and the isostatic anomaly (IA).The isostatic correction (IC) and the isostatic anomaly "sensu latu"(IA) can be computed using eq. 2 and 3:

$$IC(k) = R(k) \cdot H(k) \tag{2}$$

$$IA(k) = BA(k) - IC(k) \tag{3}$$

As it could have been expected the isostatic correction (Fig.5) is relevant only over the East Ross Basin and on the Campbell Basin, where the bathymetry drops suddenly from 600 m to 3500 m. The central part of Ross Sea shows therefore relevant isostatic anomalies (Fig. 6), which have strong correlation with the main geological features of the area (TR, CR, CH, ERB). This could be a clear indication that the processes which have generated these features are non isostatic.

ISOSOSTATIC MOHO DEPTHS

Inverting the field of the isostatic correction it is possible to calculate the undulations of the Moho discontinuity correlated with the topographic load (Fig. 7). To work out the variations of the crustal thickness we have used the formula for the calculation of the
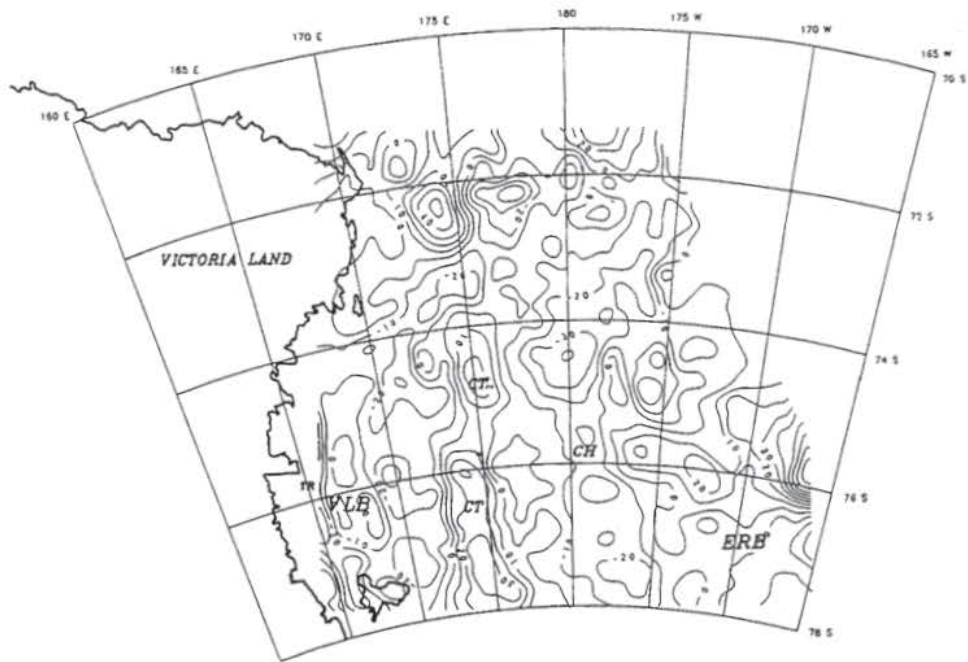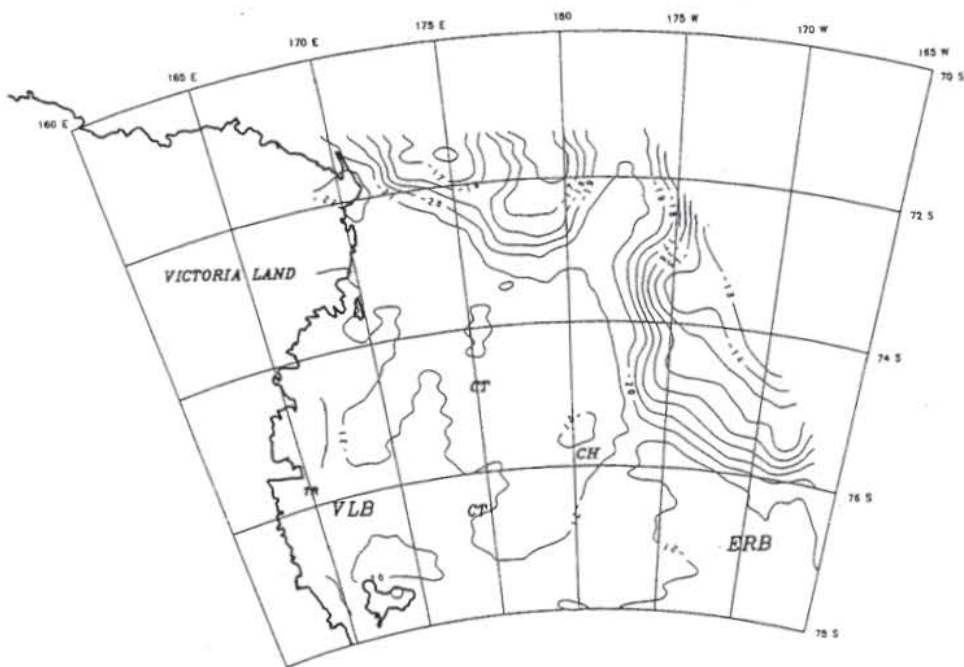
Fig. 6. Isostatic anomaly, (mgal).

Fig. 7. Isostatic Moho depth, (km).

gravity effect of a stratum with a waved interface (Parker, 1972). When w(x) <<d , it simplifies to a linear relation which can be given in the wave number domain as:

$$\Delta\Gamma(k) = 2\pi G\sigma \exp(-k\,d)\, W(k) \tag{4}$$

where W(k) is the Fourier transform of the undulation of the density contrast w(x), $\Delta\Gamma(k)$ is the Fourier transform of the measured anomaly of gravity, d the average depth of the undulation, σ the density contrast at the Moho discontinuity, G the gravitational constant.

By applying eq. 4 in the bidimensional notation to the data of the field of the isostatic correction, having fixed the average Moho depth by using seismic data, the undulations of the Moho correlated with the topographic load have been carried out and mapped. Starting from this map, adding the average Moho depth, a map of the Moho has been drawn using topographic and gravity data. As it could have been expected the isostatic Moho map shows a good agreement with the forward gravity models only in the area where the Bouguer anomaly map and the bathymetry are correlated.

CONCLUSION

The gravity data set upgraded with the new data acquired by OGS has been used to compute a forward gravity model of the Moho discontinuity, a local geoid, an isostatic correction map, an isostatic anomaly map and a isostatic Moho map.

The Moho shape follows mainly the reverse morphology of the sedimentary basin having north-south trend, although other minor lineations can be traced in different directions. In the western Ross Sea, a general depression in the Moho is observed along a NW-SE direction. This Depression crosses the northernmost sector of the Victoria Land Basin and the central Trough. A dextral shift of 25 km between the northern and southern axes of the Central Trough has been computed. A suite W-SW to E-NE lineations is also observed.

Of great interest is the comparison of the geoid map computed for the Ross Sea, using the Stokes equation with the remove-restore technique, with the OSU91 model. The computed geoid undulations show some differences, although it maintains the main trends. For example, the negative anomaly near 180°E-72°S can be also found in the OSU91 model but with a difference of about 2 metres. Even the trends of the anomalies delimited by 74°-76°S / 170°-172°E and 72°-74°S/170°-172°E are found in the Global Geoid Model. Globally we have an increase in the presence of the high frequency components but the general trends of the geoid undulations show good agreement with the global model OSU91.

The isostatic correction and isostatic anomaly maps provide same information about the process which have generated the main geological features of this area. The isostatic correction map shows a strong signal associated with the area of oceanic crust in which the bathymetry is correlated with the Bouguer anomaly. In the area of continental crust, where there aren't correlation, the isostatic correction contains poor informations. On the other

side the isostatic anomaly shows in this area anomalies correlated with the main geological features.

If several region with different isostatic response functions are combined into one study the statistical procedure employed to estimate the admittance may yield a pattern which is misleading if interpreted within the context of loading on the top alone. If several tectonic provinces are combined in a single study, the statistical procedure employed in obtaining a stable estimate of the transfer function places primary emphasis on the region with the greatest topographic relief. Isostatic anomalies are caused by masses, or loads, that are compensated in some different way than assumed in the model. The relationship between topography and gravity for these loads must be characterised by different transfer function. Isostatic anomalies indicate that two or more processes with different transfer functions are important within the study area, such as simultaneous surface and subsurface loading, or regional variations in flexural rigidity, or loading with one rigidity followed by erosional unloading another rigidity. The zone, where bathymetry and Bouguer anomaly are correlated, dominate the isostatic admittance, so that isostatic correction (generated applying the transfer function to the bathymetry) is more significative in this area.

The computation of the Moho undulations inverting the field of isostatic correction provide a map showing a good agreement with the forward Moho model in the area of oceanic crust. The inversion doesn't provide a good result in the zone of continental crust.

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