# A new gravity map of southern Chile and its preliminary interpretation

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## ABSTRACT

New onshore gravity data have been collected in Southern Chile in the region onshore of the Chile Margin Triple Junction. The aim of the project was to investigate the effects of ridge subduction on the continental margin. The resultant Bouguer anomaly map shows a regional decrease in Bouguer anomaly to the east, corresponding with thickening of the mantle wedge, a large circular low of about -60 mGal in the Bouguer Anomaly in the vicinity of Lago General Carrera and a linear trend at the western edge of the main Andean Chain along the Liquiñe -Ofqui Fault. Euler deconvolution has been used to determine the depth to the principal causative body which lies at subcrustal depths (*ca.* 65 km). The anomaly lies close to the predicted positions of subducted segments of the Chile Rise and the authors suggest that the anomaly is associated with the ridge subduction process.

*Key words: Triple junction, Bouguer anomaly, Slab window.*

## RESUMEN

**Un nuevo mapa de la gravedad en el sur de Chile y su interpretación preliminar.** Se han recolectado datos de gravedad en el sur de Chile en la región continental frente al Punto Triple Nazca-Sudamérica-Antártica. El objetivo de este proyecto fue investigar los efectos de la subducción de una dorsal bajo el margen continental. El mapa de anomalías de Bouguer muestra una disminución regional de ellas hacia el este,correspondiendo con un engrosamiento de la cuña mantélica, un gran bajo circular de *ca.* -60 mGal de la anomalía de Bouguer en la vecindad del lago General Carrera y una tendencia linear en el borde occidental de la cordillera Andina Principal a lo largo de la zona de Fallas Liquiñe-Ofqui. Se utilizó la desconvolución de Euler para determinar la profundidad del cuerpo causativo principal, el que yace a profundidades subcorticales (*ca.* 65 km). La anomalía yace cerca de la posición predicha para los segmentos subducidos de la Dorsal de Chile y los autores sugieren que la anomalía está, por lo tanto, relacionda con el proceso de subducción de dorsales.

*Palabras claves: Punto Triple, Anomalía de Bouguer, Ventana astenosférica.*

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## INTRODUCTION

Ridge subduction is predicted to have occurred along much of the Pacific margin over the past 200 my (Atwater, 1970) although the Chile Triple Junction (CTJ) (Fig. 1) is the only current example in the world of an active oceanic ridge subducting beneath a continent. A similar situation is occurring as the Explorer Ridge approaches the Queen Charlotte plate. However, here unlike the Chile Rise, the ridge is resisting subduction by reorganisation and fragmentation of the plates on either side (Riddihough, 1984). Studies of such geological situations will reveal much about the relative importance of the processes of plate creation and destruction in the context of the driving forces of plate tectonics.

Marine geophysical investigations have been carried out in the Chile Triple Junction region over the past two decades (Herron *et al.*, 1981; Cande and Leslie, 1986; Behrmann *et al.*, 1992, 1994, Tebbens *et al.*, 1989). These studies have allowed the prediction of the current positions and kinematics of the Nazca, Antarctic and South American plates and the segments and transforms of the Chile Rise as they are subducted beneath the South American continent (Fig. 2). There is no evidence of reorganisation of the plates before subduction as seen by magnetic, gravimetric or bathymetric surveys (Herron *et al.*, 1981, Cande and Leslie 1986, Behrmann *et al.*, 1992). Murdie *et al.* (1993) showed that seismicity near the CTJ is anomalous. No solutions for earthquake fault mechanisms are compressional, all relate to oblique-normal faults. These data are used (*op. cit.*) to suggest that Nazca-Antarctic plate separation continues at the site of the subducted Tres Montes ridge and that extension is transferred into the overlying forearc. Studies of the Taitao Ophiolite (Nelson *et al.*, 1993) and the tectonics of the Liquiñe-Ofqui Fault and the Golfo de Penas basin (Forsythe and Nelson, 1985; Nelson *et al.*, 1994) suggested that continued ridge related extension after ridge subduction contributed to the tectonics of this region. Evidence for the renewed subduction of the Antarctic Plate to the south of the CTJ is provided by the arc volcanism and subduction related seismicity of the extreme south of South America (Kilan, 1996).

Although plate separation may continue once a ridge has entered a subduction zone mantle melting must be modified. Magmas formed at oceanic ridges melt by decompression as the asthenosphere rises towards the surface along its adiabat (McKenzie and Bickle, 1988; Planck and Langmuir, 1992). At some stage during ridge subduction, this adiabatic decompression and associated melting below the ridge must cease due to the increased pressure. If the plates continue separating at the same rate and ocean ridge magmatism ceases, the locus of separation will be filled by upwelling asthenospheric material (Uyeda and Mirashiro 1974; Marshak and Karig, 1977; Dickinson and Snyder, 1979; Jachens and Griscom, 1983; Thorkelson and Taylor, 1989; Severinghaus and Atwater, 1990) and is now termed a slab window. Figure 2 shows the predicted positions of subducted spreading centres and maximum slab windows delimited by the boundaries between lithosphere generated under the ocean and lithosphere/asthenosphere generated once the ridge has been subducted. The authors have predicted these positions assuming that the plates continue to separate at the site of the mid ocean ridge at the same rates as before subduction which are taken from Tebbens *et al.* (1989). However, processes such as thermal ablation and spherical shell strain have not been considered here and are likely to influence the width of the window (Thorkelson, 1996).

This paper reports the results and interpretations of gravity surveys over the predicted locations of subducted ridge and transform segments which can aid the determination of the locations and nature of the subducted ridge independent of the predictions from marine magnetic data. This will allow changes in tectonic and magmatic processes associated with ridge-subduction to be evaluated.

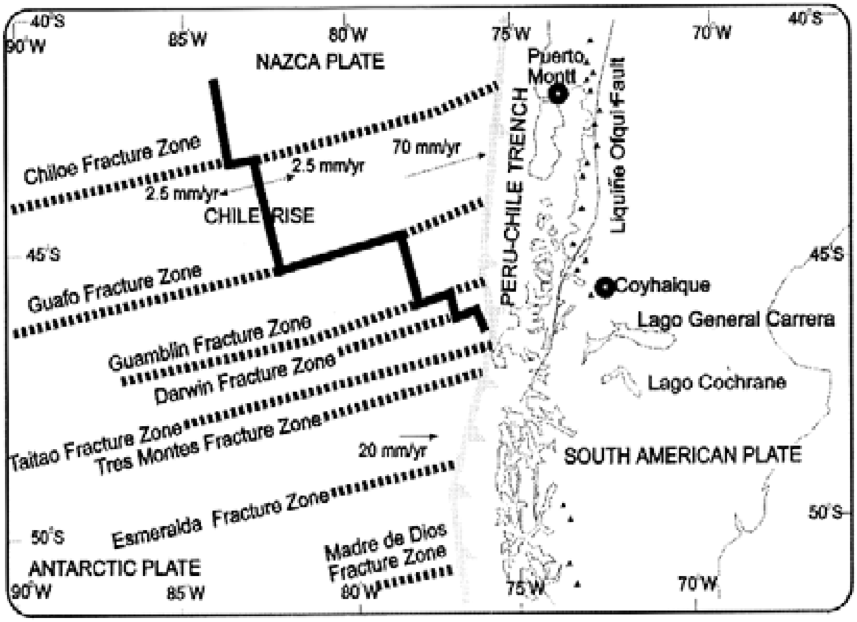


FIG. 1. The tectonic location of the Chile Margin Triple Junction. The Peru-Chile Trench is denoted by the heavy grey line with triangles. The active ridge segments and transform faults of the Chile Rise are given by the solid heavy black line and the associates fracture zones given by the heavy black dotted lines. The arrows indicate the relative direction and velocity of plate motions.

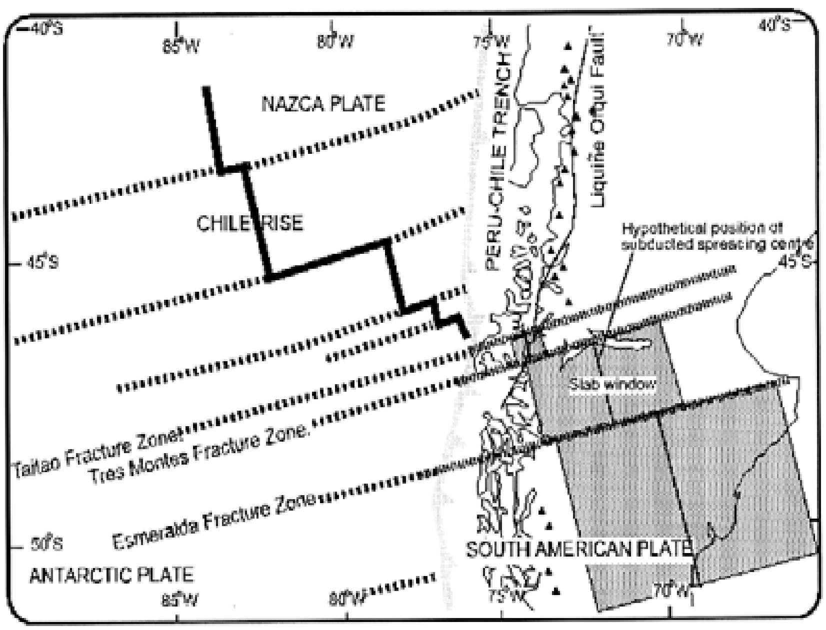


FIG. 2. Predicted positions of the slab windows generated by the continuing separation of the ridge segments of the Chile Rise after subduction into the Peru-Chile Trench. The finely dotted lines show the predicted extension of the transform faults and fracture zones into the trench.

## PREVIOUS GRAVITY DATA

Offshore data clearly show the positions of the major fracture zones which are marked by lows in the order of -30 mGal and are apparent in SEASAT images (Haxby, 1987) and GEOSAT (Sandwell and Smith 1997) data. Ridge segments of the Chile Rise are not as well resolved as the fracture zones although Cande *et al.* (1987) showed that the Chile Rise has an associated Free Air low mimicking the shape of the rift valley which continues up to the low of the forearc. A small high marks the positions of the elevated flanks with a low over the ridge axis (Haxby, 1987). The free air low of the ridge axis decreases in amplitude towards the trench in correlation with the elevated bathymetry (Herron *et al.*, 1981). There is no low under the extrapolated position of the ridge axis below the forearc. Free air anomalies show large lows in the order of -70 mGal in the region of the Peru-Chile trench. The low south of the triple junction is much broader and more negative by about 30 mGal than that to the north. This is due to the thicker sediment fill north of the trench and the shallower subduction angle in the south (Herron *et al.*, 1981; Hayes, 1966). Marine gravity surveys have established that the prominent low associated with the Peru-Chile trench diminishes as the triple junction is approached from either side. Other offshore data, collected by Forsythe and Nelson (1985), show a negative Bouguer gravity anomaly (-20 mGal) centred over the Golfo de Penas superimposed on a regional westwards increase in Bouguer anomaly. The local negative anomaly reflects the thick sedimentary accumulation whilst the regional gradient indicates extremely thin or locally dense crust along the margin. The Bouguer anomaly gradient also reflects the uplift of the basin to the north and west (Forsythe and Nelson, 1985).

Prior to this study there has been very little on-shore work in Region XI of Southern Chile due to the severe logistical problems of working in the Taitao Peninsula and North Patagonia. For example, there are no seismic reflection or refraction surveys to help constrain the crustal structure, nor are there enough recorded earthquakes to determine the dip of the slab here. About 30 gravity data points within Southern Argentina help constrain the regional gradient, which can be estimated to decrease eastward at a rate of 0.8 mGal/km.

## ESTABLISHMENT OF BASE STATION

The field area lies between latitudes 45°S and 47°S. The nearest gravity base station is at Puerto Montt, ISGN'71 ref no. DOD 0493-3. A permanent gravity base station in the field area was set up in Coihaique in January 1991. Flights were made between Puerto Montt and Coihaique, latitude (45°30'S) using a Lacoste-Romberg gravity meter no. G-568. A further 20 base stations were set up from the Coyhaique base station.

## GRAVITY SURVEYS

A total of 914 readings were collected covering an area of 150 km by 200 km (Fig. 3a). A variety of transport was used to conduct the surveys as the terrain presented severe logistical problems. Surveys around Coyhaique were carried out with Lacoste-Romberg meter G816 along roads. Outside the populated areas, as surveys required periods of time away from electricity sources and manual transportation of the gravimeter, a Worden gravity meter was used. As this was a regional survey with a range of gravity over 200 mGal, the drift of 2.5 mgals over ten days was not significant in comparison with other variables. A linear drift over this time was assumed.

MAGELLAN G.P.S. receivers were used to determine locations. These gave accuracies of ± 20 m in the horizontal plane, but were unreliable for accurately determining altitude. Where possible, simultaneous leapfrog barometry was used to determine site altitudes. Otherwise sites were chosen so that the measurements were made at spot heights marked on Chilean 1:50,000 topographic maps. A detailed analysis of the total cumulative error involved in the acquisition of gravity data using leapfrog barometry is given in Gerdes (1982) during a survey of the Red Sea Hills and coastal plain. He estimated the maximum height error to be *ca.* 5 m for his terrain and atmospheric conditions. Murdie (1994) estimated the maximum height error to be 10 m for this survey in more extreme terrain and with less stable atmospheric conditions. Using his methodology, the authors estimate that the total error in the Bouguer anomaly would be about 4 mGal per data point due to surveying limitations. This is the actual error in the Free-Air anomaly. An additional uncertainty is introduced by an imperfect knowledge of density for the reduction to Bouguer anomaly and terrain correction, which is discussed in the following section.

## BOUGUER ANOMALY MAPS

The Bouguer anomaly was calculated using an average rock density of $2.67 \times 10^3$ kgm$^{-3}$. Terrain corrections were made out to Hammer zone M. Data points with extreme terrain corrections were removed from the data and for the remaining stations the mean correction is 7.3 mGal, with a standard deviation of 5.9 mGal. The authors' data were combined with the offshore Free Air from the U.S. Defence Mapping Agency data to produce the Bouguer anomaly map shown in figure 3a. The offshore portion of the map has been described previously. Onshore, the map shows a general westward increase in Bouguer anomaly from -80 mGal to about 60mgal. Superimposed on the general north-south trend of the map which reflects the general cordilleran structure, is a prominent negative Bouguer anomaly which extends eastward to a minimum low of ~130 mGal over Lago General Carrera between the main Andean volcanic arc and the Argentinean border. The Bouguer low is best constrained on its northeast, southeast and southwest margins and is most poorly constrained on the northwest margin, corresponding to the most remote terrain.

A topographic map of the region is given in figure 3b, which shows a clear topographic break corresponding to the Liquiñe-Ofqui Fault. The highest relief corresponds to the Patagonian batholith south of 46°30'S which forms a broad north-south feature. These peaks, the San Valentin range, exceed 3,000 m and are covered by the North Patagonian Icecap. The Jeinemeni mountains at *ca.* 2,000 m are another area of significant topography, lying south of Lago General Carrera on the international frontier with Argentina.

A summary of the geology and topography of this region is given by Forsythe and Prior (1992). A geological map (simplified from Niemeyer *et al.*, 1984) is shown in figure 4. The dominant feature is the Patagonian batholith. To the east, there are Mesozoic and Tertiary volcanic, volcaniclastic rocks and minor interbedded sediments and the remnants of Tertiary siliciclastic basins. To the west and southeast lies Palaeozoic basement, which unconformably underlies the Mesozoic and Tertiary rocks. A major dextral strike-slip crustal fault, the Liquiñe-Ofqui Fault, cuts through the western part of the Patagonian Batholith.

## DEPTH ESTIMATES

One of the most important parameters to estimate is the depth of the sources of the Bouguer anomaly signal.

As a first approximation, the mean depth (z) to a statistical ensemble of bodies giving rise to the gravity anomalies can be calculated from the radially

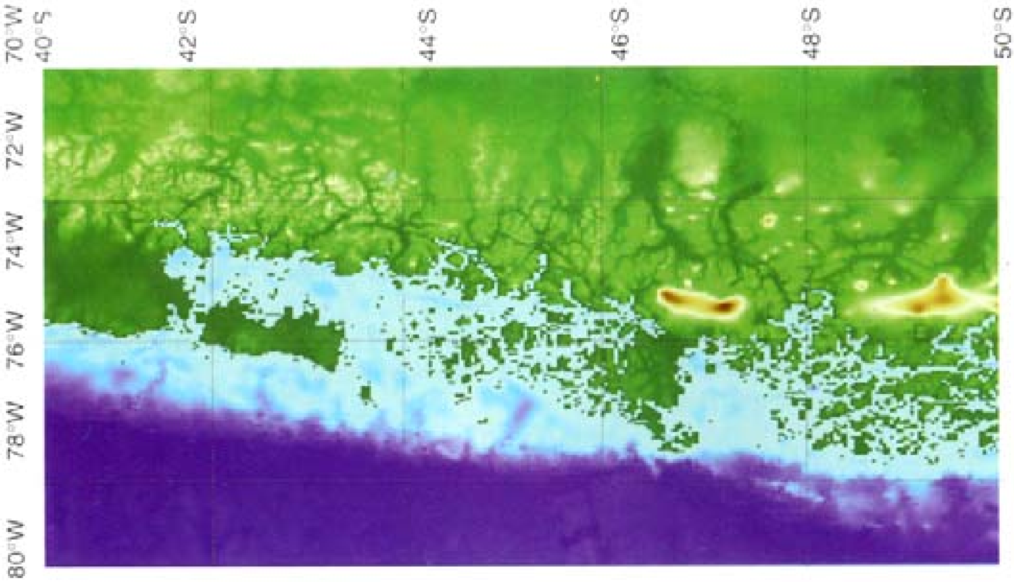


FIG. 3b. Topographic map over the same region as figure 3a.

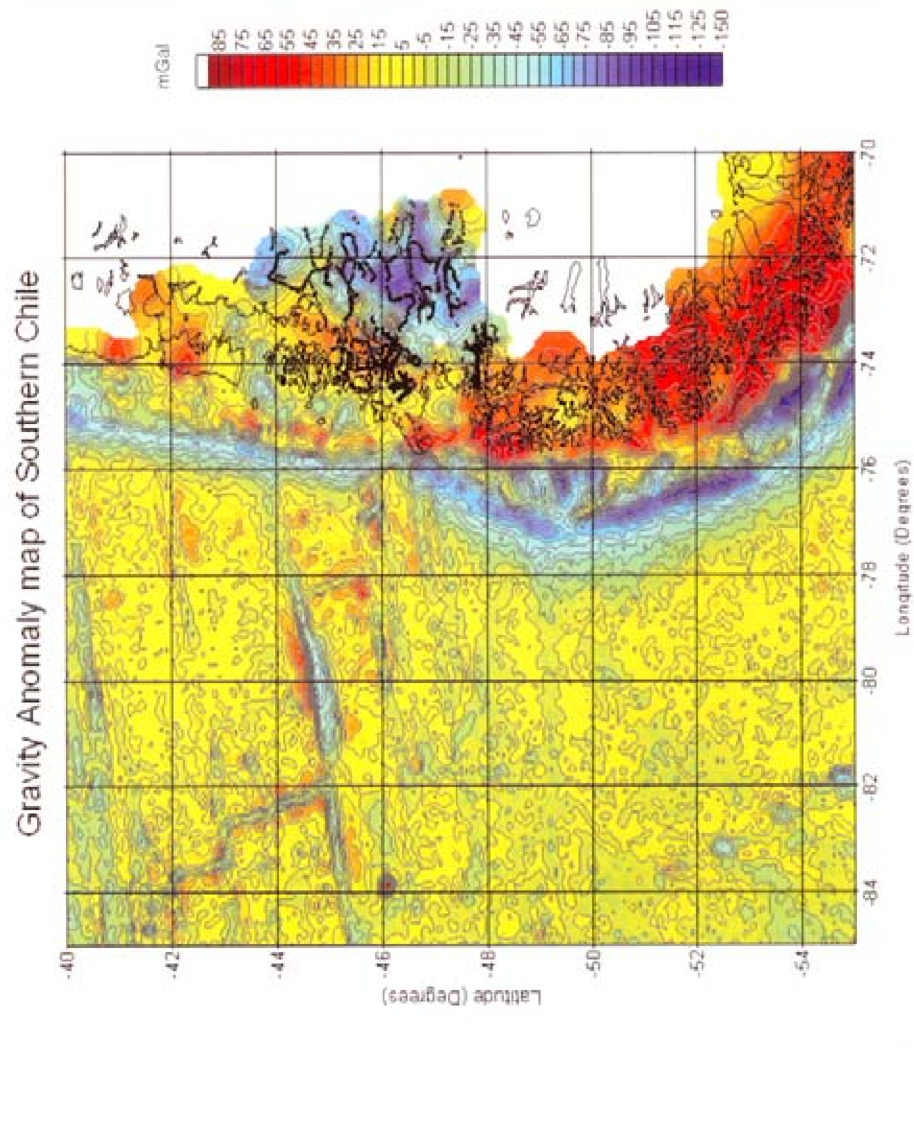


FIG. 3a. Interpolated Bouguer anomaly of gravity data collected on land. Circles show the positions of the readings which contribute to the Bouguer Anomaly.

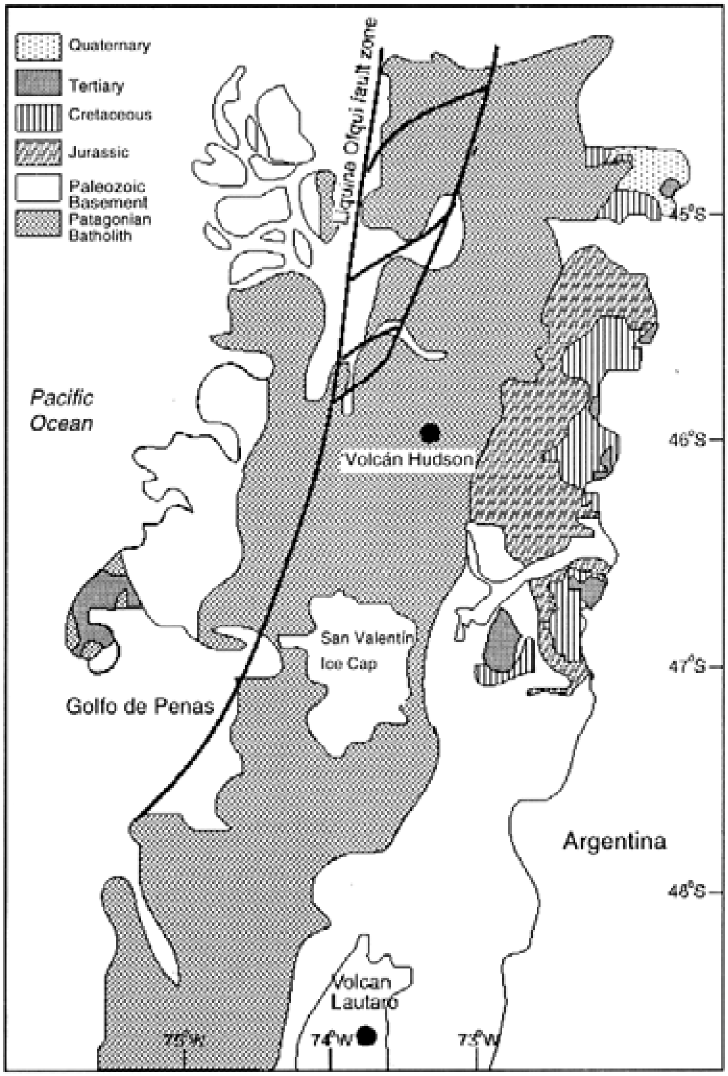


FIG. 4. A simplified map of the geology of the considered segment of the Patagonian Andes, after Niemeyer *et al.*, 1984.

averaged power spectrum (Blakely, 1995). A plot of the log of the gravity power spectrum against wavenumber should be approximately a straight line with a slope of -2z. The slope of the log (gravity power) is due largely to the attenuation of high frequency in the relief by upward continuation (Blakely *op. cit.*). Hence for each contributing mass ensemble, there will be a linear segment on the graph, which defines the mean depth to that ensemble of bodies.

The radially averaged power spectrum for all of the gravity data collected is shown in figure 5. Three slopes can be seen in the data. The shallowest of the three slopes indicates a mean depth to a density contrast at 6 km. The intermediate of the three slopes indicates a mean depth to a density contrast at 14 km and the steepest of the three gradients gives a mean depth to a density contrast at 66 km.

A second independent method for estimating the depths and location of the corners of the causative body is Euler Deconvolution (Thompson, 1982, Reid *et al.*, 1990). This gives estimates at particular positions of the depth to the causative bodies whereas the power spectral method gives a statistical estimate for the whole map.

The two-dimensional form of Euler 's Equation was solved for depth and position. The structural

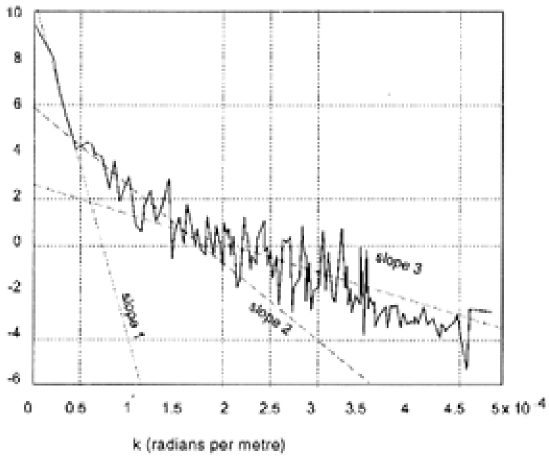


FIG. 5. The radially averaged power spectrum of the Bouguer gravity data with the interpreted slopes.

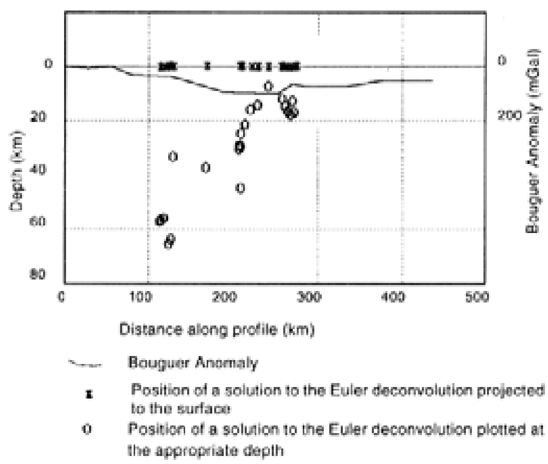


FIG. 6a. A sample profile (47°S, 73°30'W- 46°S,71°W) taken from the Bouguer data showing possible solutions to the Euler equations marked by a circle.

index (n=2) used was that for a tabular body. Several profiles were taken across the map and values for depth z at various locations across the map were located. These points indicate the depth of the corner or top surface of a body. The output shows possible solutions for the equation for a moving window through the data. Only solutions that were possible for many windows were counted as real as

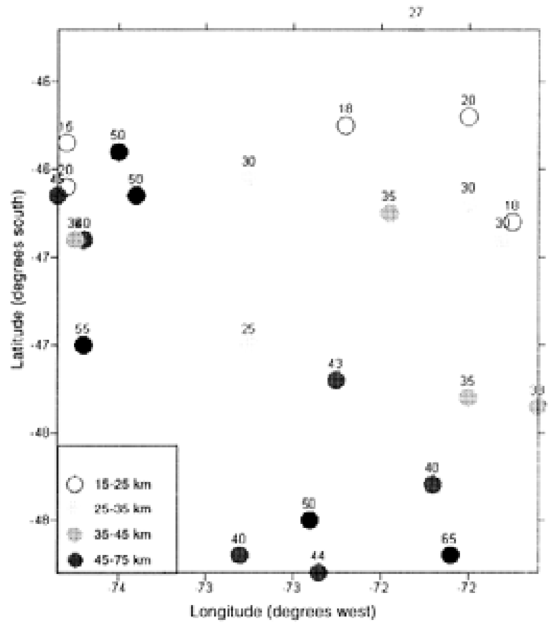


FIG. 6b. A map of the solutions to the Euler equation. Circles show depth to the corner of the causative body.

shown by many circles (one circle = one solution) coinciding (Fig. 6a). A summary map was made of depth to the corners of the anomaly (Fig. 6b). Several families of solutions were obtained. The map was low-pass filtered to remove high-frequency noise before this inversion which explains why no shallow solutions, corresponding to the 6 km deep segment shown in the power spectral method were obtained from this analysis. One set corresponds to mid-crustal depths of 15 to 20 km, agreeing well with the intermediate depth from the power spectral method estimate at 14 km. The second, at 35 to 50 km is likely to be associated with the Moho density contrast, although independent estimates of crustal thickness are not available for this region at present. This set, while well represented here, is not prominent in the radially averaged power spectrum which may be due to the fact the area of the spectrum in which this segment would lie is extremely short and the authors may not be adequately discriminating the number of causative ensembles. The deepest set at 65-70 km is found over the largest negative Bouguer anomaly, agreeing well with the deepest ensemble identified from the power spectral method.

## POSSIBLE SOURCES OF THE BOUGUER LOW

### CRUSTAL ANOMALIES

A Mesozoic-Tertiary basin system outcrops at the site of the Bouguer low. This basin extends considerably further north, south (Fig. 4) and east into Argentina. The basin fill is dominated by Mesozoic rhyolitic and andesitic tuffs, rhyolitic to basaltic lavas and volcaniclastic sediments (Niemeyer *et al.*, 1984; Flint *et al.*, 1994). The surrounding geology comprises the Patagonian Batholith and Palaeozoic basement. The range of densities of the rocks in the basin is similar to the batholith (typical granites 2.52-2.75 g/cm$^3$) and the Palaeozoic basement. The Mesozoic-Tertiary basin system does not present enough density contrast and has a shape entirely inappropriate for explaining the observed Bouguer gravity low.

The Bouguer low could be explained by a hidden granitic body at mid-crustal levels, although it is not clear why there should be such a large body with a lower density than the Patagonian Batholith or the Palaeozoic/ Mesozoic volcanic rocks. One way to make that body lighter is to suppose that it is still molten. This explanation is unlikely as there are no surface thermal manifestations; the most recent acid/intermediate volcanics in the region ended in the mid-Miocene (Niemeyer *et al.*, 1984) at the latest.

Although some component of the gravity anomaly is clearly derived from mid-crustal depths, as evidenced by the power spectral analysis, this is a minor component in terms of the power contained in the signal. Both basins and acid igneous bodies can be excluded as potential sources of the main negative Bouguer anomaly. Additionally there is no apparent correlation between surface geology and the extent of the Bouguer low.

### ANOMALIES AT THE BASE OF THE CRUST

The general north-south trending Bouguer low can be associated with a crustal root as seen future north in the Andes (Götze *et al.*, 1990, 1991). This still leaves the excess low north of Lago General Carrera. An area of anomalously thick crust, a crustal root, could account for the anomaly. Simple calculations of the amount of Moho topography to generate a density model, which fits the observed gravity profile, show that a Moho perturbation of at least 10 to 15 km is required. Such a crustal root requires either a compensative topography or to be supported by the flexural strength of the crust. For Airy isostasy, with normal crust and mantle densities, the region of the low would need to be elevated 1800-2700 m above the surrounding region. There is no topographic anomaly (Fig. 3b) corresponding to the deepest Bouguer low and there is no reason to suppose that the region is significantly out of isostatic equilibrium. Unfortunately, there are neither refraction seismic nor teleseismic data to constrain the Moho topography.

### NORMAL SUBDUCTION ZONES

In a normal subduction zone density variations at depth may be generated in the slab through metamorphic changes and in the mantle wedge through the melting process accompanying dehydration of the underlying slab. It seems reasonable that these processes will operate in the same way at all points along a slab that is continuous along strike and that any density variations they generate should form lineaments parallel to the trench.

The gravity survey of Götze *et al.* (1990, 1991), above the subducting Nazca plate in northern Chile between 20° and 26°S shows that the gravity anomaly rises from the negative (Free Air) values over the trench to a peak (Bouguer) over the coast and then falls again to a broad Bouguer low over the Andean Cordillera, between 250 km and 500 km from the margin. The broad Bouguer low in the western Cordillera also trends parallel to the margin, but contains sub-rounded smaller anomalies that do not show the Andean trend. The broad low corresponds to the thickest Andean crust and correspondingly high topography (Götze *et al.*, 1990, 1991, 1993). The variations within the low are related to intrusive bodies within the upper part of the thickened crust. Similar observations of minor anomalies superimposed on margin-parallel trends are seen in Peru (Haederle, 1987; Bussell and Wilson (1985) and in a series of transects across the Chilean Andes at 30-35°S (Introcaso *et al.*, 1992).

In these data sets all the strong anomalies which may be associated with the normal processes of subduction are lineated parallel to the margin in marked contrast to the authors' observed Bouguer low (Fig. 3a). Deviations from margin parallel trends tend to be less intense than our observed Bouguer low and all relate to near surface igneous variations within significantly thickened crust. However, such intrusions are not seen in this study area and there is very little evidence for large scale crustal thickening. It would suggest that the Bouguer low seen in this study is a result of other processes, which are not active in the Northern and Central Andes.

## RIDGE SUBDUCTION

The principal tectonic feature in the study area, which disrupts the trend of the subduction zone, is the presence of the Chile Rise at various depths within the subduction zone. Earthquake data from 400-1200 km to the north of the CTJ (Pflaker and Savage, 1970; Stauder, 1973; Barazangi and Isaaks, 1976; Fuenzalida *et al.*, 1992; Kanamori and Stewart, 1979; Jordan *et al.*, 1983) suggested that here subduction of the Nazca plate is shallow (25-40°). The shallowest estimate of subduction angle, in the region of the triple junction, is about 15° (Bangs *et al.*, 1992) from seismic reflection data acquired in the forearc. However, given that very young hot oceanic lithosphere is being subducted at the triple junction, subduction angles are likely to be very shallow (Isaaks and Molnar, 1971). If plate separation continues at the full rate, as ridge segments are subducted, then the predicted position of the Tres Montes and Esmeralda ridge segments would be as shown in figure 2. If the authors assume a subduction angle of 15° and that the subducting slab remains intact, the Tres Montes Ridge would lie at a depth of 35 km and the Esmeralda ridge segment would now lie at a depth of about 70 km. This is in agreement with the deepest sources determined from both power spectral estimates and Euler deconvolution.

The good agreement between the source depth of Bouguer low and the predicted depths of the Tres Montes and Esmeralda ridges does not completely address the problem of the Bouguer anomaly. A significant problem with trying to subduct very young oceanic lithosphere is that the low density of the oceanic lithosphere means that it is too light and buoyant to subduct easily (Cloos, 1993). Presumably, the Nazca Plate is being pulled into the subduction zone ahead of the Chile Rise by the mass of the rest of the plate. However, thermo-mechanical modelling by Van den Beukel (1990) predicts that when the Chile Rise enters the trench, the strength of the young slab, weakened by heating due to friction and heat conduction, is diminished enough that the opposing forces of slab pull and the buoyancy of the young slab cause the slab to rupture. Hence the locus of plate separation should jump down-dip from the Chile Rise into the Nazca plate. Van den Beukel (1990) estimates that the age of the slab at the break point will be between 1.8 Ma and 3.2 Ma. The north-south extent of the anomaly is approximately 40 km. The length of the Tres Montes ridge segment was 50 km, so the tearing of the slab is likely to have been along the subducted Tres Montes and Esmarelda fracture zones, following the mechanism suggested by Van den Beukel (1990). The Bouguer low may now be indicating the location of the new gap in the slab down-dip, from the Tres Montes Ridge which may explain why the Bouguer low does not fall exactly on the predicted positions of the ridge segments.

## SLAB DEPTH COMPOSITIONAL ANOMALIES OF THE SLAB

If the authors consider a gap in the slab at depths of about 70 km, the asthenosphere which fills any gap will not have undergone partial melting and will, therefore, be undepleted. Undepleted mantle has a higher density than the oceanic lithosphere created from the partial melting (Oxburgh and Parmentier, 1977) which means that a positive Bouguer anomaly will result. Hence the negative anomaly cannot be simply explained by density variations associated with the opening of a slab window.

## MANTLE THERMAL ANOMALIES

One way to introduce a Bouguer low is to introduce a thermal anomaly in the mantle. The thermal anomaly associated with the Phoenix ridge as it interacted with the Antarctic Peninsula is thought to have been the source of the small volume of alkali basalts now found there (Hole 1988, 1990; Hole and Larter, 1993). In Chile, the Miocene- Pliocene flood basalts (Ramos and Kay 1992; Charrier *et al.*, 1979) of the Chile/Argentinean border are much larger in volume than would be expected from a simple ridge subduction. However, they have been correlated spatially and temporally with the passage of slab windows (Ramos and Kay 1992; Gorring *et al.*, 1997). The geochemistry of them indicates that normal temperature mantle cannot explain the observed geochemistry and that a thermal anomaly located at slab-depth is needed (Ramos and Kay, 1992; Cheadle and Petford, 1993 ). A 'weak plume' or small-scale convection current (Davies, 1988) has been suggested for the anomalous geochemistry found in these basalts (Gorring *et al.*, 1997). In the region of the Cocos-Nazca slab window beneath Central America, it is postulated that anomalously hot asthenosphere has been entrained into the slab window from the region of the Galápagos plume. This is used to explain the occurrence of adakites above the slab window (Johnston and Thorkelson, 1997).

Material in small scale convection currents is thought to be only a small amount hotter than the upper mantle by about 50°C (Davies 1988) and the maximum is thought to be about 300°C which would give rise to the emplacement of komatiites. This would give a density contrast of between $0.01 \times 10^3$ to $0.03 \times 10^3$ kgm$^{-3}$, which is too small to generate all of the observed Bouguer anomaly. Additionally temperature variations within the mantle of 300°C would certainly have an expression as surface volcanism. Small amounts of material have been found near the north-west arm of Lago General Carrera. These have been interpreted, from their asthenospheric signature as being a product of the subduction of the most recent segments of the Chile Rise (Demant *et al.*, 1998). Additionally, high heat-flow values of about 100 mWm$^{-2}$ have been recorded in this region (Murdie *et al.*, 1999).

Modelling of the flow of the asthenosphere through a slab window generally indicates that the average viscosity of the sub-slab asthenosphere is too low to allow it to upwell forcibly into the supra-slab mantle in the asthenospheric wedge. It is only if there is a mantle temperature excess of about 300°C above normal, that upwelling actually occurs (Daniel, 1996). The chemistry of the Murta basalts (Demant *et al.*, 1998) would indicate that anomalous upwelling is occurring.

## ISOSTATIC ANOMALIES AND DYNAMICALLY COMPENSATED MODELS

Isostatic profiles were generated where the isostatic component was calculated from the observed gravity minus the gravity anomaly due to the crustal root. The amplitude of the observed anomaly in the region of the collected data, agreed well with the predicted, although the wavelength of the modelled anomaly was much larger than the observed. The fit was even closer when slab break off as postulated by Van den Beukel (1990) was considered. Changes in the model such as incorporating conductive cooling by or an anomalously hot asthenospheric wedge, dynamic down drag caused by stresses in the crust, post glacial rebound and altering the depth of the phase changes in the mantle showed that the general shape of the gravity anomaly over the southern end of South America can be modelled by a simple subduction scenario. The result of viscous fluid modelling (Daniel, 1996) suggests that subducted slabs are partly compensated by the down-drag of the upper plate which, hence, may be held below isostatic equilibrium. Thus the general shape of the Bouguer anomaly across southern South America can be accounted for by the combination of the isostatic, slab and dynamic contributions, but the prominent Bouguer low over the area of this survey could not be modelled exactly using these parameters.

## DISCUSSION

The location of the Bouguer low above the region of predicted slab break off suggests a causal relationship between the postulated slab window and Bouguer anomaly. The general shape of the anomaly can be explained by isostatic and dynamic effects (Daniel 1996). However, the excess Bouguer anomaly which has been discussed extensively in this paper is still not explained. The wavelength is too small to be due to a large perturbation in the Moho. However, smaller Moho anomalies would be supported flexurally. It is possible that localised underplating has increased the thickness of the Moho. The source of the material for the underplating would be from material liberated form the anomalously hot asthenosphere which lies within the slab window. Thus the combination of a thermal anomaly and underplating could generate such a low in the Bouguer gravity.

If the subduction of the Tres Montes ridge and the subsequent break in the slab should give such an anomaly, then previously subducted ridge segments should give similar anomalies. Certainly basalts with anomalous chemical signatures have been related to the passage of older windows (Gorring *et al.*, 1997). Viscous fluid modelling suggests that the effect of the slab window is much reduced after about 6 my which would explain the lack of further, deeper anomalies in the gravity (Daniel, 1996).

These are suggestions as to the cause behind the observed gravity. As there are no other geophysical data currently available to constrain these poorly estimated parameters, this is the explanation which the authors currently favour. However, once further observations are acquired, it is hoped that better explanations can be generated. It appears that no single explanation can give the complete answer as to why there is this large Bouguer low in the region of the Chile Triple Junction. It is larger in size and magnitude than local anomalies seen within the trench parallel trends further north along the Andean Margin. The proximity of the anomaly to the subducting Chile Rise would suggest that the complicated tectonics have given rise to the anomalous gravity. It is probable that several factors have combined to give the observed gravity. It appears that the Bouguer anomaly is generated by a density difference at subcrustal depths. Without better constraints, it is possible that there could be a small deflection in the Moho which will contribute to the gravity signal. There may also be a contribution to the gravity from the relocation of the gap between the leading and trailing plates as the Bouguer anomaly lies in the place predicted by Van den Beukel (1990) where the slab would split. It is probable that there is some thermal induced density differences as petrological studies of the plateau basalts suggest that one exists under this region of South America. However, it is not clear why the anomaly should be so localised as there should be similar anomalies associated with previously subducted segments. Further geophysical investigations of slab structure, such as magnetotelluric or large-scale seismic profiling and detailed seismic tomography will be required to resolve these uncertainties.

## CONCLUSIONS

In an area close to Chile Triple Junction, 21 new gravity base stations have been established and 914 gravity readings have been collected over an area of 150 km by 200 km. The Bouguer anomaly map produced from these data shows;

- a regional decrease in Bouguer anomaly to the east, corresponding to thickening of the mantle wedge;
- a sharp lineament in the Bouguer anomaly correspondent with the Liquiñe-Ofqui Fault and;
- a 60 mGal residual Bouguer low north of Lago General Carrera. The Bouguer low cannot be explained by the crustal geology, neither does it correspond to a topographic anomaly. It is unlike Bouguer anomaly patterns generated above subduction zones elsewhere along the Andean margin. The locus of the anomaly suggests that the Nazca Plate is fragmenting after subduction and the site of plate separation moves down dip in the slab. A thermal anomaly from a weak plume at the site of the slab window at the new locus of plate separation, as well as a change in Moho topography best explains the observed anomaly.

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