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21. Gravity Transect across the Transantarctic Mountains South of the Drygalski Ice Tongue

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Summary: During GANOVEX VI new gravity data were collected along an east-west profile in North Victoria Land south of the Drygalski Ice Tongue, extending 150 km across the Transantarctic Mountains, and comprising 21 data points. Thirty five additional data points were collected over a small area near Brimstone Peak, near the western end of the regional profile. The survey south of the Drygalski has been connected to northern gravity data (GANOVEX V) by a survey line of 12 points. All data have been terrain corrected, and are further constrained by satellite elevation (GPS) and radar ice-thickness measurements.

A pronounced regional Bouguer gravity gradient decreasing to the west by approximately 3 mgal/km is superimposed over a coast-parallel belt of granitoid basement rock. West of this belt the local gravity fields become more variable. Over Beta Peak (Ferrar dolerite) a 50 mgal spike is observed. Within this area, the Ferrar sills are exposed at the surface. West of Brimstone Peak (Ferrar/Kirkpatrick sequences), a smooth regional gradient appears to reassert itself.

We interpret the initial gradient east (oceanward) of the break-in-slope to be representative of the crust/mantle boundary within the study area. We interpret the initial break-in-slope and the apparent flattening of the regional gradient to be an effect of the N-S trending zone of dense Ferrar sills and associated deep crustal fractionate replacing less dense basement. We attribute the variability of the local field to be the product of sub-glacial density contrasts that cannot be removed.

The regional gravity gradient of the profile is steeper than that observed to the north (Mt. Melbourne quadrangle) and shallower than that reported to the south (McMurdo Sound). The absolute values of the coastal points of origin south of the Drygalski and within the Mt. Melbourne quadrangle differ by 60 to 100 mgal. In addition, topographic relief within the regional transect area is subdued relative to the Transantarctic Mountains to the north and south. We speculate that the root structure of the Transantarctic Mountains undergoes a change somewhere between the Mt. Melbourne quadrangle and the region south of the Drygalski Ice Tongue.

INTRODUCTION

During the 1990-1991 Antarctic field season, the sixth German Antarctic North Victoria-Land-Expedition (GANOVEX VI) and the United States Antarctic Program (USAP) conducted joint geophysical studies in the Transantarctic Mountains. Gravity surveys were performed in three different areas. The surveys north and west of Mt. Melbourne and in the Yule Bay / Rennick Glacier region are described in REITMAYR (this vol.); this paper reports on the southernmost area SW of Terra Nova Bay.

One goal was to measure the regional gravity gradient along a transect perpendicular to the Transantarctic Mountains range front, in an area lying between the steep South Victoria Land gradients observed by SMITHSON (1972), BEHRENDT et al. (1991), and ROBINSON (1964), and the shallower North Victoria Land slopes reported by REDFIELD et al. (in press) and DÜRBAUM et al. (1989). Additional data were collected along the coast, directly connecting the survey to existing gravity measurements within the Mt. Melbourne quadrangle.

The completed regional transect comprises 21 data points, spanning approximately 150 km. It extends from the coast to a point past Brimstone Peak on the Polar Plateau. Map coverage was provided by the Mt. Joyce and Relief Inlet Quadrangles of the United States Geological Survey 1 : 250,000 Antarctic Reconnaissance Series (Fig. 1). The regional transect passes through an area measured in detail from a field camp, as part of a local survey conducted near Brimstone Peak. The Brimstone Peak survey consists of 36 data points, distributed within a 10 km by 36 km rectangular area. Twelve points were obtained along the North Victoria Land coast between the Gondwana Station at Terra Nova Bay and the start of the regional profile near the Nordenskjöld Ice Tongue. These last data provide a direct link with the data collected in 1988-1989 during GANOVEX V.

As described below, the gravity data have been reasonably well constrained by radar echosounding ice thickness measurements and have been terrain corrected. Though large uncertainties continue to exist, we believe their effects to be much less than the regional gradient we are seeking.

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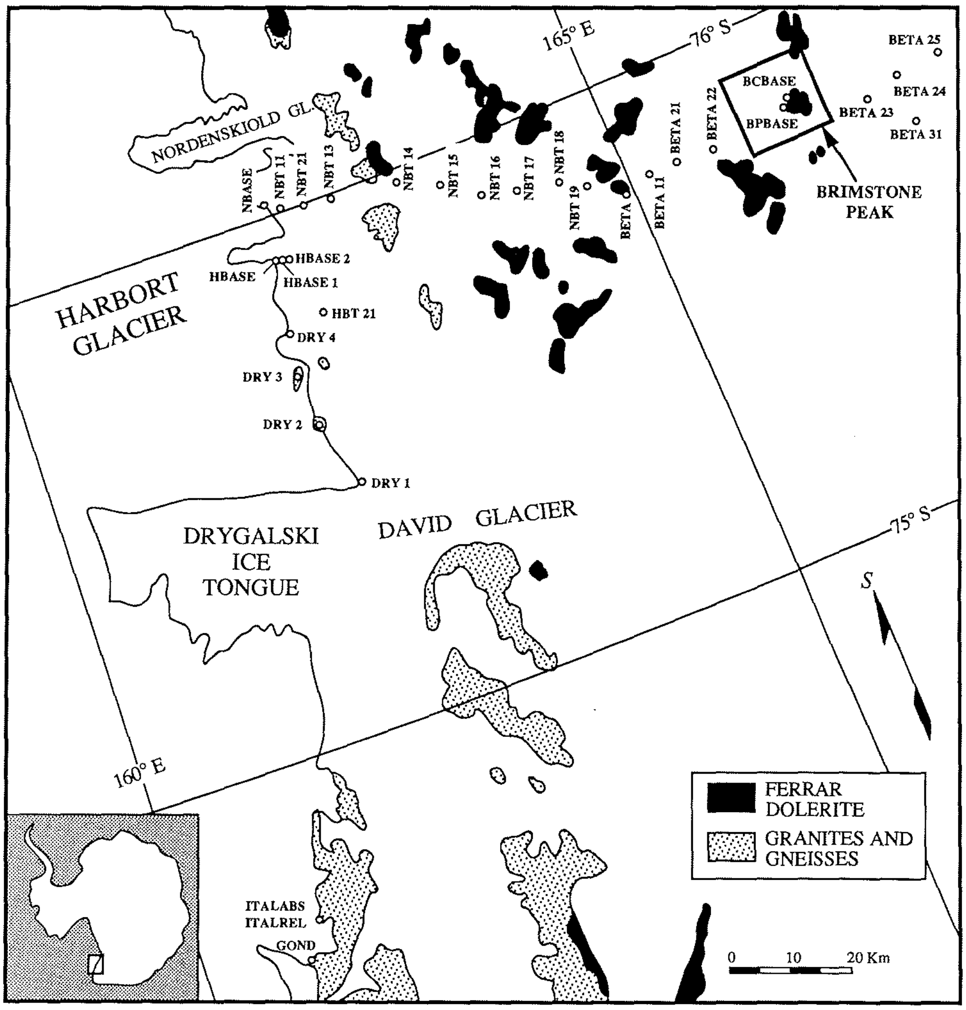


Fig. 1: Location map showing data points of the regional profile, coastal profile, and the area of the Brimstone Peak gravimetric survey.

Abb. 1: Lagekarte mit dem regionalen gravimetrischen Profil, dem Küstenprofil und dem Meßgebiet im Inland am Brimstone Peak.

REGIONAL GEOLOGY

Within the Mt. Joyce and Relief Inlet quadrangles the dominant rock types exposed through the glacial cover are the mafic Ferrar Dolerite intrusions or Kirkpatrick Basalt extrusive equivalents, and the felsic Granite Harbour Intrusives suite. The contact between the two rock types is obscured, but in an overall sense runs north-south, parallel to the coastline, between longitudes 161° and 162° E.

Granitoid outcrops occur in nunataks along a coast-parallel belt approximately 40 km wide. Where exposed, the basement complex appears to be massive and relatively homogenous. KLEINSCHMIDT & MATZER (pers. comm. 1991) observed no major shear zones within the area; structural complexities appear to be limited to events of local importance.

Inboard of the felsic belt, exposures are primarily volcanic sills and lavas of the Ferrar group with minor occur-

Station	South Decimal Latitude	East Decimal Longitude	Station Elevation m a.s.l.	Ice Thickness m	Ice Thickness Corr.	Terrain Corr. 2.67g/cm³	Complete Bouguer Anomaly
NBASE	76.031	162.710	112	0	0	10	- 48
NBT11	76.029	162.636	218	260	19	0	- 57
NBT12	76.006	162.411	382	270	20	0	- 81
NBT13	75.990	162.198	439	150	11	0	- 110
NBT14	75.957	161.777	767	215	16	0	- 144
NBT15	75.936	161.428	1089	145	11	0	- 161
NBT16	75.894	161.121	1208	205	15	0	- 164
NBT17	75.877	160.817	1334	210	16	0	- 169
NBT18	75.859	160.548	1374	270	20	0	- 181
NBT19	75.844	160.310	1410	225	17	0	- 134
BETA	75.841	160.128	1569	0	0	10	- 119
BETA11	75.823	159.869	1383	235	17	0	- 170
BETA21	75.810	159.639	1397	190	14	0	- 170
BETA22	75.786	159.271	1434	460	34	0	- 130
BETA23	75.738	158.078	1728	185	14	0	- 182
BETA31	75.653	157.796	1709	500	37	0	- 184
BETA24	75.749	157.778	1777	240	18	0	- 183
BETA25	75.727	157.423	1706	260	19	0	- 207
HBT21	75.833	162.583	485	0	0	5	- 86
BPBASE	75.805	158.624	1556	0	0	20	- 129
BCBASE	75.821	158.576	1522	137	10	10	- 135
Coastal Transect Data							
GOND	74.634	164.224	22	0	8	2	21
ITALYABS	74.693	164.099	114	0	6	2	30
ITALYREL	74.694	164.099	86	0	6	2	30
HBT11	75.000	162.000	1007	0	0	5	- 109
DRY1	75.434	162.586	165	0	0	25	- 44
DRY2	75.563	162.971	93	0	0	10	- 13
DRY3	75.683	162.833	114	0	0	10	- 32
DRY4	75.774	162.682	189	0	0	5	- 57
HBASE	75.948	162.961	47	0	0	5	- 58
HBASE1	75.948	162.960	96	60	4	5	- 59
HBASE2	75.948	162.959	109	80	6	5	- 59
NBASE	76.031	162.710	112	0	0	10	- 48
Brimstone Peak Data							
BCBASE	75.821	158.576	1522	137	10	10	- 135
BCT11	75.791	158.920	1595	507	38	0	- 153
BCT12	75.794	158.900	1591	530	39	0	- 142
BCT13	75.797	158.860	1578	835	62	0	- 121
BCT14	75.800	158.800	1574	770	57	0	- 126
BCT15	75.803	158.760	1571	820	61	0	- 120
BCT16	75.808	158.720	1567	608	45	1	- 130
BCT17	75.812	158.700	1568	373	28	1	- 136
BCT18	75.815	158.620	1544	195	14	3	- 140
BCT19	75.818	158.600	1535	190	14	5	- 138
BCT21	75.791	158.638	1526	200	15	1	- 157
BCT22	75.779	158.748	1587	200	15	0	- 155
BCT31	75.757	158.741	1580	347	26	0	- 149
BCT32	75.767	158.561	1565	150	11	0	- 136
BCT33	75.763	158.439	1667	515	38	0	- 128
BCT34	75.774	158.268	1711	800	59	0	- 141
BCT35	75.786	158.099	1725	549	41	0	- 137
BCT36	75.812	157.947	1777	323	24	0	- 143
BCT41	75.766	158.561	1539	150	11	0	- 141
BCT42	75.824	158.999	1601	507	38	0	- 173
BCT51	75.767	158.561	1558	150	11	0	- 137
BCT52	75.762	158.561	1614	90	7	0	- 133
BCT53	75.772	158.561	1570	150	11	0	- 131
BCT54	75.776	158.561	1541	160	12	0	- 133
BCT55	75.780	158.561	1526	130	10	0	- 134
BCT56	75.785	158.561	1512	120	9	0	- 137
BCT57	75.767	158.552	1622	169	13	0	- 131
BCT58	75.767	158.542	1651	225	17	0	- 130
BCT59	75.767	158.533	1656	255	19	0	- 132
BCT510	75.767	158.542	1675	300	22	0	- 134
BCT511	75.767	158.570	1553	125	9	0	- 133
BCT512	75.767	158.579	1533	135	10	0	- 130
BCT513	75.767	158.588	1518	135	10	0	- 132
BCT61	75.744	158.595	1657	250	19	0	- 138

Table 1: Station data for the entire survey, including coordinates and description of BPBASE.
Site Description of BPBASE for re-occupation: The NE flank of Brimstone Peak is fringed by a talus bench, underlain by glacial ice. From the margins of the bench, dividing the East Face neatly in two, extends an arm displaying bedrock, some 20-50 m above the surrounding glacier. Just west of the summit of this arm, along its ridgecrest, is a boulder of notable, though certainly not outstanding size, capped by a half a meter cairn and a ring of stones surrounding the fossil location of the base plate. It is believed that the ridge and boulder crest are geologically stable, for at least the near future - say some twenty years or so.

Tabelle 1: Meßpunkt-Daten für das gesamte Untersuchungsgebiet einschließlich Koordinaten und Beschreibung des Basispunkts (BP Base) am Brimstone Peak.
Beschreibung des BP-Basispunkts für mögliche weitere Messungen: Die NE Flanke von Brimstone Peak ist an der Basis von einem auf dem Gletschereis liegenden Schuttmantel umgeben. Von den Rändern dieses Schuttmantels springt etwa in der Mitte der Ostflanke des Berges eine Rippe anstehenden Gesteins nach Westen vor, die das Eis um etwa 20-50 m überragt. Direkt westlich vom höchten Punkt dieser Rippe befindet sich ein großer Block, auf dem ein Steinmal von 50 cm Höhe errichet wurde. Die Basis des Blocks enthält eine Fossil Lokalität, um die ein Steinring ausgelegt wurde. Es wird davon ausgegangen, daß die Rippe und der Block für eine gewisse Zeit, in der Größenordnung von ca. 20 Jahren, stabil genug sind, um als Basispunkt zu dienen.

rences of the Beacon Supergroup clastic rocks. Outcrops occur at widely scattered nunataks and mountains. The constituent flows and intrusions have suffered very little tilting and faulting (WÖRNER pers. comm. 1991).

The topography of the study area as a whole is relatively subdued. A series of ice-covered benches rise from the coast to the Polar Plateau, which begins west of Brimstone Peak. Existing ice-thickness measurements imply that the benches are capped by relatively thin neves, except where cut by the deep drainage glaciers (DELISLE & SIEVERS pers. comm.). Extreme relief is not generally present, except at the base of the larger nunataks and mountains. These conditions make the Mt. Joyce quadrangle a good field area for Transantarctic Mountain gravity measurements.

METHODS

Previous gravity studies in the Transantarctic Mountains include ROBINSON (1964), SMITHON et al. (1971), BEHRENDT et al. (1991), DÜRBAUM et al. (1989), and REDFIELD et al. (in press). The problems posed by vast glaciers and poor topographic control are well recognized, and in response different solutions have been applied (DÜRBAUM et al. 1989, REDFIELD et al., in press). Our general approach is described below.

During the first half of GANOVEX VI ground traverses were conducted out of the Brimstone Peak field camp. Gravity sites were generally approached by skidoo and Nansen sledge. In the second half of the expedition, a regional profile was measured with helicopter support, to a point approximately 150 km inland on the polar plateau. The two surveys were tied together by common secondary base stations, and coupled to the absolute gravity measurement made by Italian colleagues during the 1990-1991 season. Lastly, a north-south coastal profile was measured, connecting the data of the Mt. Melbourne quadrangle (REDFIELD et al. in press, DÜRBAUM et al. 1989, REITMAYR this vol.) to the regional profile south of the Drygalski Ice Tongue.

Gravity measurements of the 1991 Mt. Joyce quadrangle survey were made under three general sets of conditions: (i) During the local survey at Brimstone Peak, comprehensive radar ice-measurement coverage was available. Terrain and ice corrections could be made with fewer uncertainties than elsewhere. (ii) During the regional survey flown from the coast, data points were sited on flat ice fields, free of local terrain effects. Ice thickness measurements were made at each landing site. The soundings obtained enabled the construction of a simple infinite slab ice model, which represents the greatest component affecting the gravimeter. (iii) Selected rock outcroppings characterized by subdued, limited topographics were measured for use as base stations. Additional nunataks were measured as part of the coastal profile. Using the correction methods described in REDFIELD et al. (in press), they were incorporated into the regional profile.

GEODECTIC AND ELEVATION CONTROL

The commercial development of the Global Positioning Satellite System (GPS) has solved some (though not all) of the difficulties associated with geodetic work in the Antarctic. We were convinced that the GPS two receiver long baseline method has improved elevation control beyond that that could be expected by traditional altimetry, and therefore employed the GPS system throughout this survey.

All secondary gravity base station were anchored to the WGS-84 reference ellipsoid by GPS, and subsequently corrected to sea level. Field data were collected for one half hour, and compared to simultaneous base station measurements made by either Italian colleagues at the Stazione Baia Terra Nova or by one of us at the Gondwana Station (both stations host known geodetic reference points). Most gravity station elevations were determined directly, by half hour GPS measurements. Twenty seven stations were measured by Thommen precision altimeter, barometrically corrected and tied to a nearby GPS point. Twenty one of these sites were within the Brimstone Peak survey area (Fig. 2a). These altimeter measurements were made during skidoo traverses across relatively flat ice; thus the altimeter hysteresis has not been exaggerated by extreme pressure elevation changes. The remaining six sites occur at low elevation, very close to the coast, where barometric control could be established (Figs. 3 and 4).

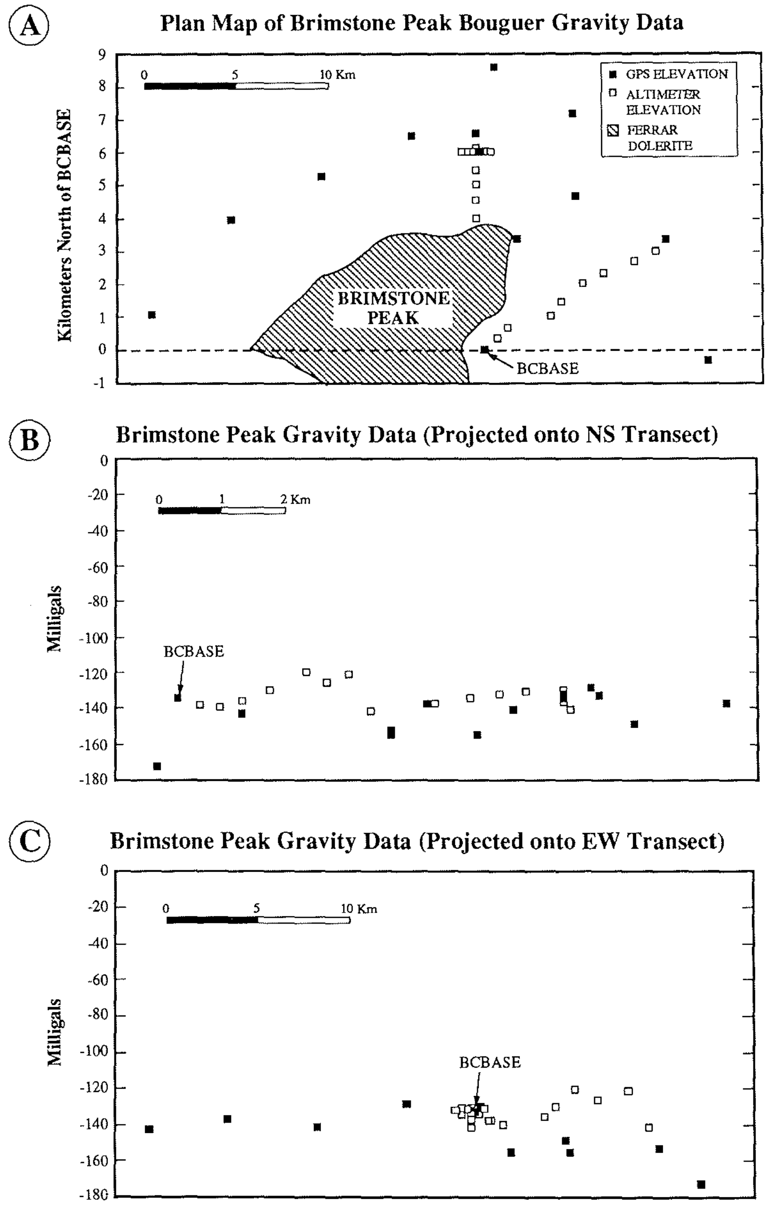


Fig. 2: Map showing Brimstone Peak local gravity survey (A) and gravity profiles of the gravity data projected onto NS and EW lines (B) and (C). Open symbols denote altimeter sites.

Abb. 2: Meßgebiete am Brimstone Peak mit lokalem Meßgebiet (A) sowie den gravimetrischen Profilen (B) und (C) auf N-S und E-W Linien projeziert. Offene Symbole kennzeichnen Altimeter-Meßpunkte.

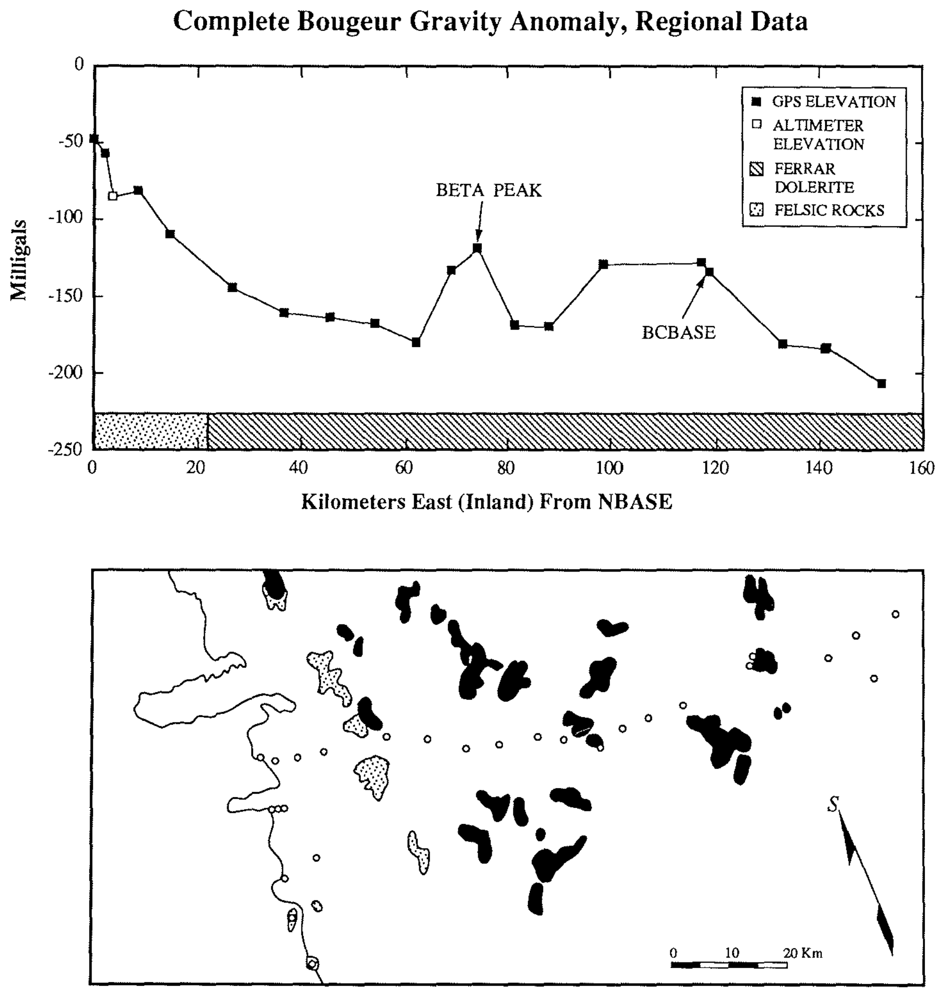


Fig. 3: Regional gravity data profile and map view. Open symbols denote altimeter sites.

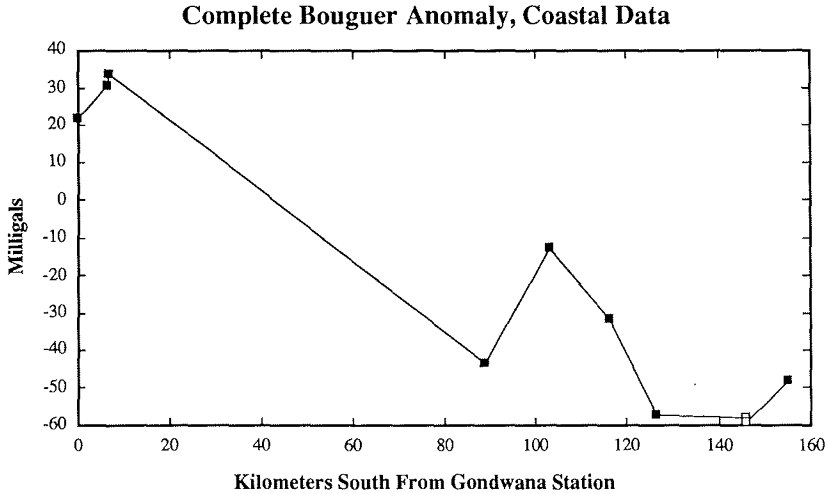
Abb. 3: Regionales gravimetrisches Profil und zugehöriger Kartenausschnitt. Offene Symbole kennzeichnen Altimeter-Meßpunkte.

RESULTS

Brimstone Peak Data

For the 1990-1991 Mt. Joyce quadrangle survey, field logistics were shared with a radar echo-sounding geophysical group that mapped sub-ice topography near Brimstone Peak. Radar penetration of both the blue ice fields and the non-ablating glaciers was excellent (DELISLE & SIEVERS pers. comm.). The group found that sub-ice topographies surrounding Brimstone Peak tend to be rugged, a factor reflected in the sharp fluctuations of the observed gravity field.

The Brimstone data are shown in Figures 2a, 2b, and 2c. The field is complex, and does not permit easy interpretation. Examination of the projected cross sections (Figure 2b, 2c) shows spikes up to 50 milligals. The sources of these anomalies lie under broad expanses of ice and cannot easily be determined. Two dimensional models



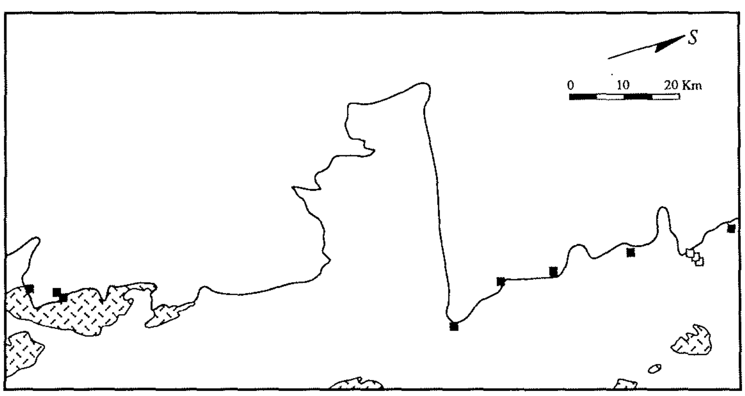


Fig. 4: Coastal gravity data profile map view. Open symbols denote altimeter sites.

Abb. 4: Gravimetrisches Küstenprofil. Offene Symbole kennzeichnen Altimeter-Meßpunkte.

suggest that much of the erratic nature might be accounted for by lateral variability in the ice thickness itself. Sufficiently sophisticated three dimensional modeling programs might resolve this, but are not available to us at this time.

The base station for each loop, BCBASE, is underlain by active glacier ice and cannot be expected to provide a repeatable value for future surveys. To that purpose a bedrock station, BPBASE, was established two kilometers to the north. Coordinates and a site description for BPBASE are included in Table 1.

Regional Data

Radar penetration and reception along the regional profile was variable, and difficult measuring conditions were often encountered. However, when viewed in context of the magnitude of the gravity gradient, the resultant errors in the ice corrections are probably quite small. A simple slab difference caused by 100 m of ice (0.90 gm/cm^3) instead of rock (2.67 gm/cm^3) results in a „missing" 7.4 mgals. Under a regional gradient of 3 mgal/km, a station spacing of greater than 2.5 km would lie outside this error. Most stations of the regional profile (Fig. 3) are between 5 and 10 km, implying that a great ice thickness error would be necessary to completely „hide" the plunging regional gradient.

The regional profile shows a pronounced break-in-slope between kilometers 35 and 40 (longitudes 161° 00' and 162° 00' E). Seaward of this break the gradient is approximated by 3 mgal/km. Landward, local complexities impart variability up to 50 mgal. No consistent slope is noted. The three westernmost data points suggest the possibility that the landward gradient is re-established beneath the Polar Plateau, and that the gravity anomalies continue to decrease in value.

Coastal Transect

Due in part to the total attenuation of radar at an ice/water interface, all measurement points along the coastal transect were sited on rock outcroppings. Additionally, long wavelength tidal oscillations render the Nansen Ice Sheet unsuitable for measuring. The station spacings are therefore dependent upon natural features, and are correspondingly uneven.

A rising trend towards the north comprises the dominant feature of the profile (Fig. 4). Low Bouguer gravity values (-30 mgal to -60 mgal) characterize the coast of the southern portion of the Relief Inlet quadrangle. As the Drygalski Ice Tongue is approached from the south, gravity values dip into a poorly defined trough, and then climb sharply to positive values at Inexpressible Island and the Gondwana Station. Though the absolute shape and amplitude of the anomaly cannot be constrained, it seems fairly clear that it stems from a deep seated origin located at some point between the David Glacier (Drygalski) and Priestley Glacier drainages. The coastal transect suggests that a substantial mass difference exists between the coastal areas of the Mt. Melbourne quadrangle and those south of the Drygalski Ice Tongue.

DISCUSSION

The observed break-in-slope of the regional profile is coincidental with the inferred sub-ice lithologic boundary between the granitoid basement complex and the supracrustal mafic rocks. The sharp change of the regional gradient might be due to considerable thicknesses of dense mafic rock capping the crustal sequences, „pulling" the regional gradient upwards. This is the simplest explanation,and is our favoured one.

Well to the south of the Drygalski Ice Tongue, near McMurdo Sound, SMITHSON (1972) measured gravity gradients between 4 mgal/km and 7 mgal/km. To the north, near the Gondwana Station, REDFIELD et al. (in press) described a much shallower gradient, less than 2 mgal/km. The 3 mgal/km gradient observed in the Mt. Joyce quadrangle profile is intermediate in slope between these data, fitting a transitional pattern along the Transantarctic Mountains rangefront.

The enormous difference in Bouguer gravity revealed by the coastal data represents a substantial mass contrast that cannot be explained by the simple juxtaposition of rocks of the upper crust. (A sample density contrast calculation requires over 500 m of nonexistent, 3.2 gm/cm^3 mafic rock replacing the existent 2.67 gm/cm^3 granitoids). A possible interpretation is that the depth to the Moho might be less in the north than to the south, thus emplacing denser rock at higher levels under the Mt. Melbourne quadrangle. This is mildly supported by the work of O'CONNELL & STEPP (in press), who described a shallow, west dipping reflector underneath the Northern Foothills. A difference in depth to mantle between the two areas might imply that a different state of isostatic equilibrium (or disequilibrium) exists, in turn implying a difference in the uplift histories.

As a final and independent observation, it is worth noting that the topographic crest of the Transantarctic Mountains also displays a remarkable contrast. Within the Mt. Joyce quadrangle the crest is low, rarely rising above 2000 m, and is located well inland. Considerable thickness of Ferrar Dolerite and even the Kirkpatrick lavas (WÖRNER pers. comm. 1991) imply a much later uplift history. Within the Mt. Melbourne quadrangle the rangecrest approaches 3000 m and is considerably closer to the coast. Also, the Ferrar caps the highest reaches of the Eisenhower Range, and represents the basal section above the Kukri Peneplain. Coupled with the different natures of the Bouguer gravity fields, it seems plausible that the two areas have had different uplift histories.

CONCLUSIONS

Regional Bouguer data collected in a traverse across the Transantarctic Mountains south of the Drygalski Ice Tongue has quantified the gradient, which is observed to be intermediate between those of North Victoria Land and South Victoria Land. A coastal transect connecting the Drygalski area survey with the Mt. Melbourne area shows a 60 mgal to 100 mgal jump over a short distance. The jump occurs over the David Glacier (Drygalski Ice Tongue) and Priestley Glacier drainages, both major physiographic features.

No geologic evidence exists for large, supra-crustal density contrasts that could explain the mass differences. We suggest that the gravity field variations stem from deep features at the crust/mantle boundary, on in the lower crust. We infer that the Drygalski area and the Mt. Melbourne area are characterized by different root structures. And we speculate that the uplift histories of the the two areas may well be significantly different.

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