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A RECONNAISSANCE GRAVITY SURVEY OF THE SKELETON COAST

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ABSTRACT

A reconnaissance gravity survey of the Skeleton Coast in SWA/Namibia has provided a significant contribution to existing Bouguer anomaly data. A traverse along the coast from Torra Bay to the Kunene River mouth, with stations spaced at 10 to 20 km intervals, was supplemented with additional traverses up the Hoanib River, from Mile 108 to the Brandberg and south of the Brandberg.

A Bouguer anomaly map and a profile along the coast have been produced using computer techniques. Most significantly, the results indicate the presence of hitherto unknown regions of positive Bouguer anomalies at Möwe Bay and Cape Fria.

1. INTRODUCTION

The Department of Surveying at the University of Cape Town has been taking gravity measurements in southern Africa since 1978. The main thrust of these measurements has been to develop a test area in the south-western Cape Province for the evaluation of gravity prediction techniques, and for the determination of a detailed model of the geoid for this region. Such a geoid model is required for the purpose of relating two-dimensional classical survey networks to three-dimensional satellite-based networks. To this end, most of the observations have been made in the southwestern Cape. These observations are essentially complete, and we have now reached a stage where the geoid modelling techniques can be extended to the whole of southern Africa. Indeed, a preliminary gravimetric geoid for this region has recently been computed (van Gysen, 1985). This geoid model makes use of a regular grid of mean gravity anomalies which in turn are computed from the available point gravity data using the techniques described in Merry (1983).

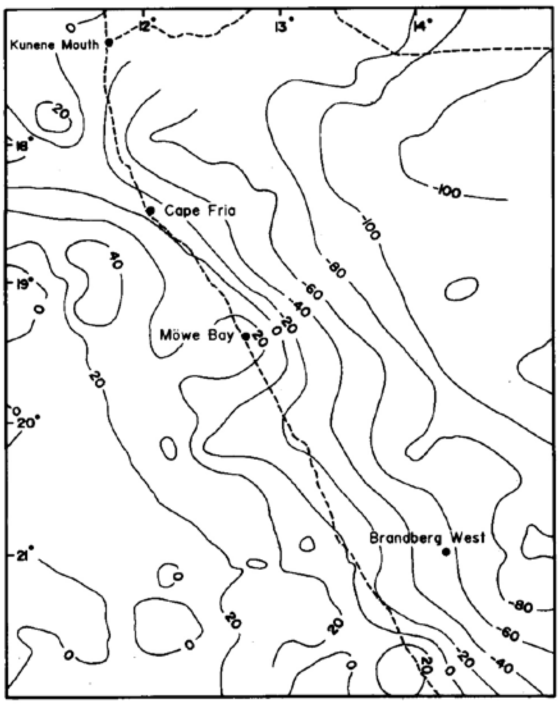

Fig. 1: Pre-1985 Bouguer gravity data for north-western Namibia. The solid circles indicate observation points, and the contour interval is 20 mgal.

A number of large gaps exist in this point gravity data coverage. One of the largest of these gaps occurs in northwestern Namibia, along the Skeleton Coast, between Torra Bay and the mouth of the Kunene River (Fig. 1). This figure shows the available data; all the land data are from the regional gravity survey of Namibia, carried out in the 1960's (Kleywegt, 1967).

As a change of strategy, we decided to continue carrying out gravity surveys at a reduced rate, filling in, at a rather coarse spacing, those areas which would have an impact on our long-term goal of computing a precise geoid for South Africa. The Skeleton Coast was the first area selected for this type of survey and field observations were undertaken in July 1985. This survey consisted principally of a traverse along the coast from Torra Bay to the Kunene, with station spacings varying from 10 km to 20 km. In addition, a 50 km spur was measured along the Hoanib River valley. At the end of the field trip a traverse from the coast to the Brandberg West Mine was observed, as was a shorter, more detailed, profile immediately south of the Brandberg. This latter survey was done in support of an investigation of a graben structure being carried out by the Geological Survey of SWA/Namibia.

2. INSTRUMENTATION

2.1 Gravity Meters

Two gravity meters were used throughout the survey, as a precaution against instrument failure. Fortunately, neither instrument failed, and the redundant data could be used in checking for gross errors and in improving the overall quality of the results.

The instruments used were a Worden Master, no. 1255, and LaCoste and Romberg model G no. G-757. The Worden meter belongs to the University of Cape Town and is of the a static type in which the spring ele-

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ment is made of fused silica. This element is enclosed within a vacuum flask and its temperature is thermostatically controlled using a heating element powered by a rechargeable Ni-Cd battery. The nominal operating temperature is 90° F. Small deviations from this temperature (as did occur) can be tolerated, as the instrument is also equipped with a temperature compensation mechanism. The meter has two reading dials - a so-called geodetic dial and a small dial. The geodetic dial provides a greater range of gravity, but provides less precise results than the small dial. For this survey only the small dial was used. This has a limited range (214,5 mgal) and has a resolution of 0,01 mgal. The dial can be reset to allow a greater range to be covered in steps of 200 mgal or less, and this procedure was used a number of times on this survey.

The LaCoste and Romberg meter, which is owned by the Geological Survey of SWA/Namibia, employs a 'zero-length' metallic spring element, and is also temperature controlled. The operating temperature of 51,3°C must be maintained throughout the survey, as this instrument is less tolerant of temperature fluctuations. The resolution of the meter is 0,01 mgal and its range is in excess of 7000 mgals, giving it global coverage without any need for resetting.

In order to ensure that both meters operated continuously at the correct temperatures throughout the two-week field trip, four rechargeable batteries were used with each instrument. A portable Honda petrol generator was used to provide the 220V, 50Hz, current required to recharge the batteries. As a backup, one of the vehicles was modified to provide 12V direct current to the LaCoste and Ramberg meter from the vehicle battery. The Worden, which uses 6V batteries, was supplied with a battery charger which could operate off a 12V vehicle battery.

2.2 Positioning Equipment

One of the features of a gravity survey is that the positions and heights of each gravity point must be known or determined, in order to calculate gravity anomalies. The positions are required to a fairly low degree of accuracy (usually to within a few hundred metres), but the height determination requires more accuracy, as these should be known to within a few metres. Where possible, existing survey marks would be used as gravity stations. On the Skeleton Coast very few such marks exist, and the survey was planned on the basis that positions and heights would need to be determined at the same time as the gravity measurements were made. The choice of a route along the coast was deliberate, as it offered an opportunity to obtain heights with very little effort - gravity measurements could be made on the beach, with a visual estimate of height.

A number of different approaches were used in the determination of position. Very few permanently marked survey points exist in this region. Before leaving Windhoek it proved possible to gain access to private records of a survey carried out on the Skeleton Coast some ten years previously (Visser, pers. comm., 1985). These data were invaluable, and almost 30% of our gravity measurements were made at points from this survey.

Another positioning system available consisted of scaling the positions and heights off 1:50000 topographic maps. In some parts (especially the northern part of the coast) identification of the gravity station on the map was impossible. In these areas the approximate position on the map was plotted using distances travelled from identifiable features. These distances were measured by reading the odometers of both vehicles, averaging these values and reducing the derived value by 10% (to allow for wheelspin in loose sand). No Further calibration of either odometer was attempted.

The loan of a Magnavox Terrain Navigator had been negotiated with the suppliers. This system employs the TRANSIT navigation system (Danchik, 1984), together with dead reckoning based upon the vehicle odometer. For various reasons this instrument could not be used as originally intended, and its eventual role was that of a backup positioning system at the overnight stops.

3. GRAVITY BASE STATIONS

The immediate area of the Skeleton Coast is completely devoid of gravity base stations. The base station established in Swakopmund in 1949 (Hales and

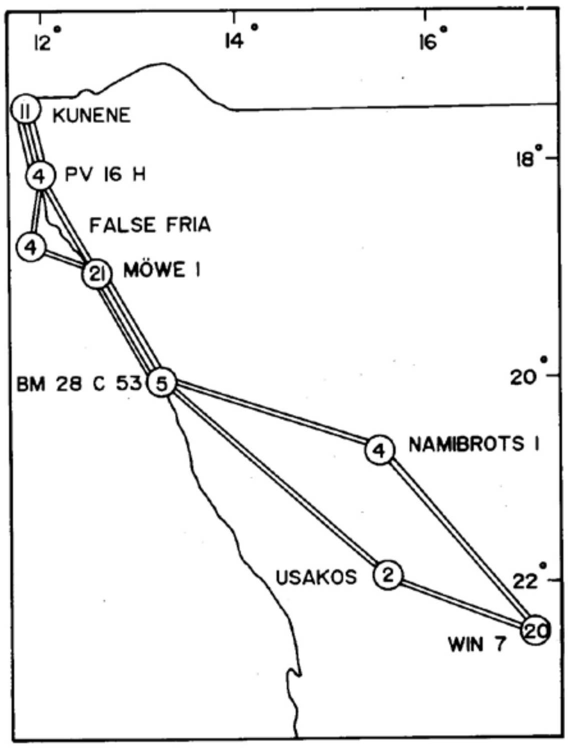

Fig. 2: Sub-base station network. The lines between points indicate the number of ties between stations. The figures in circles indicate the total number of gravimeter readings made at each point.

Gough, 1950) is unlikely to be still in existence, and, in any event, is of a low accuracy. The gravity stations of the regional survey of Namibia were not permanently marked and are not recoverable (Kleywegt, pers. comm., 1985). The nearest base station of acceptable accuracy is that at the Geological Survey of SWA/Namibia in Windhoek. This station, identified as WIN 7, was tied to base stations in Pretoria during 1980 (Venter, 1980). This station was used as a basis for all the gravity measurements undertaken for this survey. The value of gravity at this station in the IGSN71 system is given below:

WIN 7 : 978 302,89 ± 0,05 mgals

As part of this survey a number of temporary sub-bases were introduced, as a means of strengthening the results and isolating errors (Fig. 2). No additional field trips were made to establish these stations, and most of these subbases consist of points that were observed more than once.

This situation would occur, for example, at overnight stops and at points that were observed on the return journey down the coast. In all, a total of seven such points, plus WIN 7 (which was treated as a fixed station), were involved in a least squares adjustment of the data relevant to them.

A number of separate adjustments were carried out, initially treating the Worden and the LaCoste and Romberg data separately. Prior to processing these adjustments, the observations were converted from dial units to milligals using the calibration factors described in the next section, and corrections for the effect of the earth tides were applied. A preliminary analysis of the LaCoste and Romberg results showed that a significant change in the drift rate had occurred part way through the survey. The inclusion of a solution for two drift rates for this instrument substantially improved the consistency of these results. Surprisingly, the Worden results showed greater internal consistency (with a single drift rate) than those of the LaCoste and Romberg. Consequently, when the two sets of data were combined in a single adjustment, the Worden data were assigned greater weight. The results of this final adjustment are shown in Table 1. These values were treated as fixed in the subsequent determination of gravity values at intermediate points.

TABLE 1: Sub-base station gravity values
Note that the associated standard errors give the uncertainty of the gravity values with respect to the IGSN71 system, and include the effect of the 0,05 mgal uncertainty in the value for WIN7.

Usakos	978 484,73 ± 0,14 mgals
BM28C53	978627,62 ± 0,10 mgals
Möwe 1	978 601,64 ± 0,08 mgals
False Fria	978 553,74 ± 0,11 mgals
PW16H	978 518,49 ± 0,11 mgals
Kunene 1	978 463,00 ± 0,08 mgals
Namibrots 1	978 512,16 ± 0,11 mgals

Of these points, Kunene 1 and Namibrots 1 are unmarked and are not recoverable, and Usakos and Möwe 1 are not marked but can be recovered using the locally sketches shown in Figs. 3a and 3b. BM28C53, False

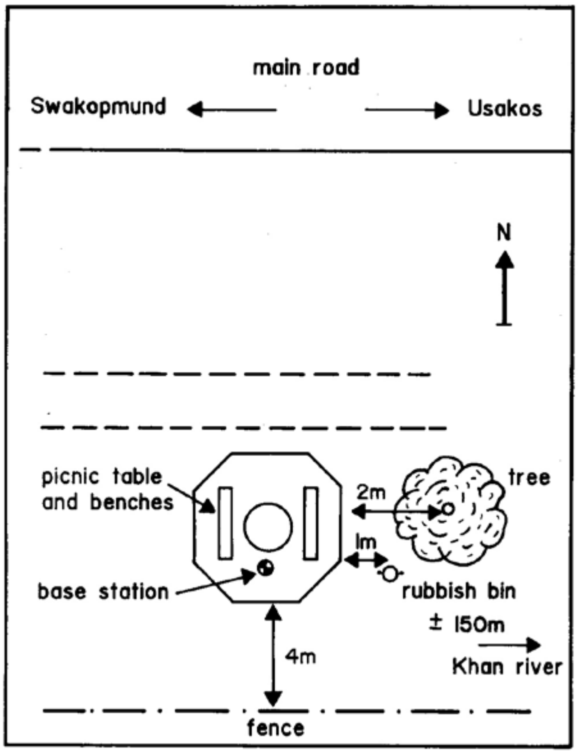

Fig. 3a: Locality sketch for Usakos

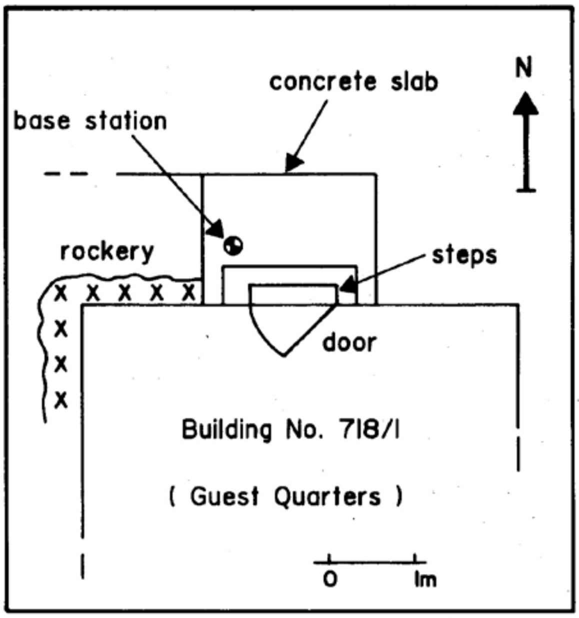

Fig. 3b: Locality sketch for Möwe 1

Fria, and PV16H are permanently marked by concreted survey points.

4. GRAVITY METER CALIBRATION

The first calibration of the LaCoste and Romberg gravity meter no. G-757 took place approximately one week after the completion of the Skeleton Coast survey. This calibration involved flying the LaCoste and Romberg meter between bases in Windhoek and Cape Town. The Windhoek base is WIN7, described earlier, and the Cape Town base is UCTNEW, located at the University of Cape Town. The measurements took place over a period of six days - two in Windhoek, two in Cape Town, followed by two in Windhoek. The 32 observations were corrected for the effects of the earth tides and used in a least squares adjustment in which a single drift rate and the calibration factor were determined. The computer calibration factor is:

$$1{,}000\ 778 \pm 0{,}000\ 016$$

The Worden gravity meter, no. 1255, on the other hand, has been calibrated on a number of occasions. The most recent of these was in October 1984 (van Gysen and Merry, 1984). This value was determined using the Table Mountain calibration line (van Gysen and Merry, 1983). This calibration line has a range of 185 mgal, which is compatible with the limited range of the Worden (215 mgal). The value deter-mined in this 1984 calibration has been used in processing all observations made for this survey:

$$0{,}097\ 275 \pm 0{,}000\ 011$$

5. GRAVITY MEASUREMENTS

A total of 69 gravity measurements were made during this survey. Of these, 42 were made on the Skeleton Coast within 500m of the sea, and another two were made slightly Further inland in the same region. Seven measurements were made in the Hoanib River valley, extending 50 km inland. A Further nine measurements were made between the coast at Ugabmond and the Brandberg West Mine, and another nine just south of the Brandberg. Observations were made with both instruments at all sites, near simultaneously. Three readings were taken on each instrument, in rapid succession, together with a note of the time, the temperature, and (where appropriate) the vehicle odometer reading. Where possible, overnight stops were chosen to coincide with gravity stations and repeat observations were made in the evening and in the morning. In addition, on the return trip down the coast, repeat observations were made at selected identifiable points. These points were included in the sub-base network described in section 3.

Each observation consists of the mean of the three readings, and was converted to units of milligals using the appropriate calibration factor, and was corrected for the effects of earth tides and linear drifts. The drift was calculated between sub-bases, which were held fixed at the values listed in section 3. The Worden and the LaCoste and Romberg observations were processed separately, and the two results for each station meaned to produce a final result. This procedure allowed a global estimate for the precision to be obtained - 0,14 mgal. This value includes the uncertainty in the gravity values at the sub-bases. The greatest individual discrepancies between the Worden and the LaCoste and Romberg results (up to 0,34 mgal) occurred at the points Kunene 2 and Kunene B, which were observed during a sandstorm.

6. MEASUREMENTS OF POSITION AND HEIGHT

Where possible, points of known position and height were used as gravity stations. Where this was not possible, points that could be clearly identified on 1 :50 000 topographic maps were used. For these points the positions and heights were scaled off the maps. In many instances no suitable identifiable features could be found. In these cases, which all occurred at the beach, the height was found by visual estimation (most of these points fell within the intertidal zone). The positions of these points were determined by using odometer readings from identifiable features, plotting these distances on the map, and scaling off the resultant position. The distribution of the various types of points is as follows:
Survey beacons: 23
Levelling benchmarks: 2
Scaling from maps: 32
Odometer plus scaling: 12

Further details on each type are given in the following:

(a) Survey Beacons: One trigonometrical beacon, near the Kunene mouth, was occupied. All other beacons used were survey beacons established as part of ground control surveys for aerial mapping. In all cases gravity measurements were made at ground level - all heights shown in Table 2 are ground level heights. The accuracy of the surveyed positions is estimated to be of the order of a few metres, while that of the heights is estimated to be 0,5m. Two of the stations used were unheighted and heights had to be estimated from the 1:50 000 maps. The precision estimates for these heights have been set accordingly.

(b) Levelling Benchmarks: Two precise levelling benchmarks were used as gravity stations. The precision of the heights is estimated to be better than 0,1 m. Positions for these two points were scaled from the 1 :50 000 maps and are estimated to be good to two seconds of arc (approximately 60m).

(c) Scaled Points: All the inland points (in the Hoanib valley, on the Brandberg West road, and south of the Brandberg) are of this type. Several other points near or at the coast which are located on identifiable features (such as rock outcrops) also fall within this category. The estimated accuracy of these positions varies from two to three seconds, depending upon the reliability of identification of the feature. Height accuracies are estimated to vary from 2m to 3m, depending upon the contour interval (10m to 20m).

(c) Odometer Points: These points occurred in the northern part of the park, where no other means of positioning was available. Position accuracies were estimated to lie between 5 and 10 seconds (150m to 300m). As these points were all at or near sea level, heights could be estimated reliably to 0,5m or 1,0m.

All positions were originally provided or scaled in the SWA/Namibia plane coordinate system. These were converted to latitudes and longitudes referred to the Bessel ellipsoid and the Namibian datum. This is a non-geocentric datum, and conversion to a geocentric datum may result in changes in both coordinates of several seconds of arc. All heights, except those of the odometer points, which are referred to sea level, are referred to the South African Land Levelling datum, which corresponds closely (to within 0,2m) to mean sea level.

7. RESULTS

The data shown in Table 2 represent the results of this survey. All gravity values refer to the International Gravity Standardisation Net 1971 - IGSN71 (Morelli, 1974). The station names preceded by the letters BM indicate bench-marks, and those preceded by the letter PV were surveyed as part of the ground control survey mentioned earlier. With two exceptions the remaining points have been scaled from maps, by direct identification or by use of odometer readings. These two types can be distinguished by the precision estimate associated with their heights - 0,5m to Im for odometer points, 2 m to 3 m for the others. The two exceptions are Kunene B, which is a trigonometrical beacon, and False Fria, which is a lower order survey beacon.

A number of checks were carried out on these data. Bouguer gravity anomalies were computed and listed and the list scanned visually for abnormal values. After this step, a computer generated Bouguer anomaly map was produced at a scale of 1:2 500 000. This map was overlaid on a topographic map of the same scale and the positions of all points checked for gross errors. The Bouguer anomaly map was also used to isolate any height or gravity errors not detected earlier - the errors manifest themselves as sharp peaks or valleys in the contour representation. No errors were found using these checks, but it may still be possible that small errors exist in the final values.

The Bouguer gravity anomalies were calculated using a simple Bouguer plate reduction, with a density of 2,67 gm/cm^3:

$$\Delta g = g - T + 0{,}1967\ h$$

Where Δg is the Bouguer anomaly, g is the observed gravity, T is the normal gravity on the ellipsoid, and h is the height, in metres. The normal gravity T is computed using the Geodetic Reference System 1980 (Moritz, 1980).

Fig. 4 is a contour representation of the Bouguer anomalies for the data observed on this survey. The contour interval is 20mgal. Fig. 5 is a contour representation of the Bouguer anomalies in this region using all available data. This figure should be compared to Fig. 1, which excludes the data obtained during this survey. It is apparent that our observations contribute significantly to the determination of the overall shape of the Bouguer anomaly field in northwestern Namibia. In particular the two regions of positive Bouguer anomalies on the coast at Möwe Bay and Cape Fria are not represented on the existing Bouguer anomaly maps of this region. These two highs are clearly seen in Fig. 6, which shows the Bouguer anomaly profile from Torra Bay to the Kunene River mouth. The interpretation of these two features will have to await a more detailed investigation.

8. ACKNOWLEDGEMENTS

Funding for this survey was provided by the South African Foundation for Research Development and by the SWA/Namibian Committee for Research Priorities. The assistance of Dr. R. Miller in obtaining the CRP funds is gratefully acknowledged. The Magnavox Terrain Navigator was provided on loan by the Magnavox Advance Products Company, of Torance, California. Mr P. Visser, of the Surveyor General's Office in Windhoek, kindly made available his records of surveys undertaken by him on the Skeleton Coast.

The Department of Nature Conservation of SWA/ Namibia granted special permission to enter the Skeleton Coast Park, in which the major part of this survey took place. The Chief Conservator of this park, Mr R. Loutit, and the two conservators at Möwe Bay, Messrs S. Braine and P. Tarr, provided much needed assistance and advice.

9. REFERENCES

Danchik, R.J. 1984. The Navy navigation system (TRANSIT). *John Hopkins APL Technical Digest*, **5**(4), 323-329.

Hales, A.L. and Gouch, D.I. 1950. *Measurements of gravity in southern Africa*. Government printer, Pretoria, 486 pp.

Kleywegt, R.J. 1967. *The Gravity Survey of South West*

TABLE 2: Observed Gravity Data (IGSN71 system)

NAME	LATITUDE	LONGITUDE	POSN ACC SEC	M HEIGHT	HT. ACC	GRAVITY MGALS	GRAV ACC
BM28C53	-20 19 4	13 14 40	2	13.5	.1	978627.62	.09
TORRA1	-20 16 25	13 13 13	2	13.0	3.0	978620.74	.14
PV25H	-20 11 58	13 11 36	1	30.0	3.0	978613.20	.14
UNIAB1	-20 7 17	13 6 54	2	5.0	3.0	978620.74	.14
PV100H2	-20 2 1	13 3 9	1	30.5	.5	978623.58	.14
PVMYN	-19 59 26	13 2 28	1	57.0	.5	978612.74	.14
PVS1	-19 56 27	13 0 26	1	18.6	.5	978622.69	.14
PVS3	-19 51 15	12 57 46	1	18.8	.5	978621.00	.14
PVS5	-19 47 26	12 56 39	1	49.5	.5	978613.62	.14
PVS7	-19 43 41	12 53 54	1	25.9	.5	978617.72	.14
PVS10	-19 38 31	12 51 37	1	20.5	.5	978613.82	.14
PVS12	-19 34 40	12 49 1	1	21.6	.5	978615.50	.14
PVS13	-19 32 0	12 47 42	1	16.9	.5	978618.44	.14
PVS15	-19 26 45	12 44 49	1	23.0	.5	978609.87	.14
MÖWE1	-19 22 18	12 42 35	3	15.0	3.0	978601.64	.07
PVS17	-19 21 42	12 42 39	1	39.1	.5	978595.31	.14
MÖWE2	-19 16 38	12 40 14	5	.5	.5	978586.84	.14
HOARUSIB1	-19 12 18	12 37 40	5	.5	.5	978580.72	.14
HOARUSIB2	-19 5 4	12 34 14	2	.5	.5	978574.70	.14
PVS26	-19 1 41	12 30 33	1	13.5	.5	978569.06	.14
PVS27	-18 59 54	12 28 45	1	19.2	.5	978567.56	.14
KHORASEB	-18 57 22	12 28 15	2	2.0	1.0	978560.78	.14
ROCKYPT.1	-18 52 19	12 25 15	3	1.0	.5	978546.96	.14
PV11/26/76	-18 49 55	12 23 30	1	2.9	.5	978546.92	.14
ROCKYPT.2	-18 47 32	12 21 43	10	1.0	.5	978546.07	.14
PV10/43/60	-18 44 29	12 19 48	1	2.9	.5	978542.94	.14
SECHOMIB1	-18 41 36	12 16 27	5	1.0	.5	978540.15	.14
PV9/58/58	-18 38 35	12 12 48	1	1.4	.5	978542.84	.14
1812CA1	-18 35 12	12 8 27	5	1.0	.5	978545.60	.14
FALSEFRIA	-18 28 48	12 1 33	1	10.0	2.0	978553.74	.10
CAPEFRIA1	-18 25 57	12 0 13	3	1.0	.5	978545.58	.14
PV16H	-18 17 44	11 57 32	1	9.2	.5	978518.49	.10
BRAKPAN1	-18 12 16	11 55 3	10	.0	.5	978510.10	.14
BRAKPAN2	-18 3 44	11 49 50	10	.5	.5	978506.18	.14
1711DD1	-17 53 40	11 48 12	10	.5	.5	978492.94	.14
1711DA1	-17 42 20	11 45 41	10	.5	.5	978485.26	.14
1711DA2	-17 31 50	11 44 30	10	1.0	.5	978478.74	.14
KUNENE1	-17 18 3	11 45 25	10	3.0	1.0	978463.00	.07
KUNENEB	-17 16 0	11 45 45	1	5.6	.5	978463.07	.14
KUENE2	-17 23 1	11 45 7	10	1.0	.5	978467.26	.14
OLDFRIA	-18 14 30	12 1 5	3	42.0	3.0	978490.74	.14
PV10/42/75	-18 45 28	12 23 37	2	129.3	2.0	978516.75	.14
MÖWE3	-19 23 35	12 44 35	2	42.0	3.0	978594.70	.14
PVS14	-19 29 28	12 46 38	1	35.7	.5	978611.98	.14
PVS16	-19 23 46	12 43 39	1	40.5	.5	978600.12	.14
HOANIB1	-19 27 2	12 49 24	2	75.0	3.0	978590.80	.14
HOANIB2	-19 23 58	12 53 28	2	155.0	2.0	978554.44	.14
HOANIB3	-19 24 2	12 57 14	2	180.0	2.0	978541.39	.14
AMSPOORT1	-19 23 19	13 2 39	2	243.0	2.0	978516.78	.14
AMSPOORT2	-19 21 54	13 7 3	2	245.0	5.0	978503.78	.14
AMSPOORT3	-19 20 45	13 9 44	2	263.0	3.0	978489.40	.14
BM28B6	-21 26 38	13 49 26	2	16.4	.1	978697.64	.17
UGAB1	-21 25 13	13 53 52	2	88.0	3.0	978677.68	.17
UGAB2	-21 22 57	13 55 45	2	120.0	3.0	978662.38	.14
MESSUM1	-21 18 8	14 2 27	2	318.0	3.0	978605.32	.14
BRANDBERG1	-21 14 3	14 3 36	2	420.0	3.0	978575.14	.14
BRANDBERG2	-21 11 11	14 5 20	2	450.0	5.0	978558.04	14
BRANDBERG3	-21 5 31	14 8 38	2	435.0	3.0	978548.69	.14
BRANDBERG4	-21 2 32	14 10 28	2	375.0	3.0	978558.34	.14
BRANDBERG5	-21 4 21	14 14 26	2	465.0	3.0	978545.94	.14
NAMIBROTS1	-21 17 56	14 34 42	2	688.0	3.0	978512.16	.10
NAMIBROTS2	-21 18 39	14 33 43	2	670.0	3.0	978517.56	.14
NAMIBROTS3	-21 18 1	14 32 35	2	678.0	3.0	978519.28	.14
NAMIBROTS4	-21 17 40	14 31 9	2	662.0	2.0	978522.43	.14
NAMIBROTS5	-21 17 40	14 38 29	2	765.0	3.0	978498.92	.14
NAMIBROTS6	-21 18 19	14 39 40	2	761.0	2.0	978489.11	.14
NAMIBROTS7	-21 18 33	14 42 26	2	820.0	3.0	978471.40	.14
NAMIBROTS8	-21 18 57	14 43 27	2	835.0	3.0	978468.09	.14
SEBATA1	-21 19 44	14 47 59	2	835.0	3.0	978467.20	.14

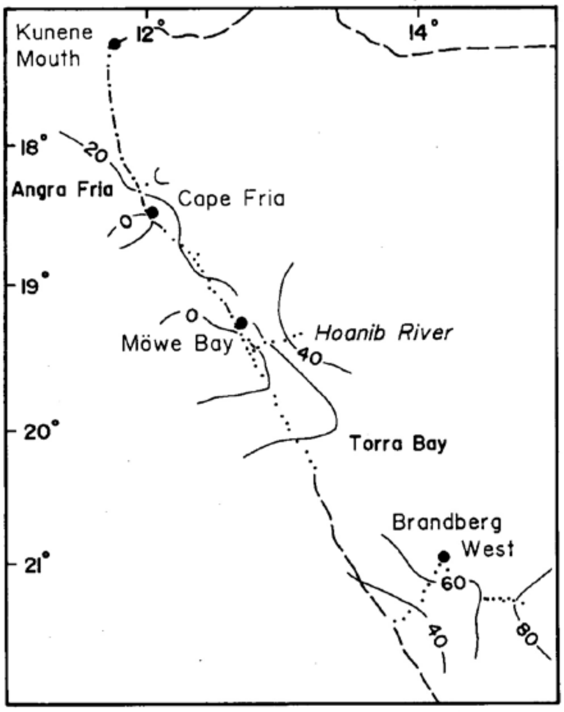

Fig. 4: Bouguer gravity data determined on this survey. The solid circles indicate observation points, and the contour interval is 20 mgal.

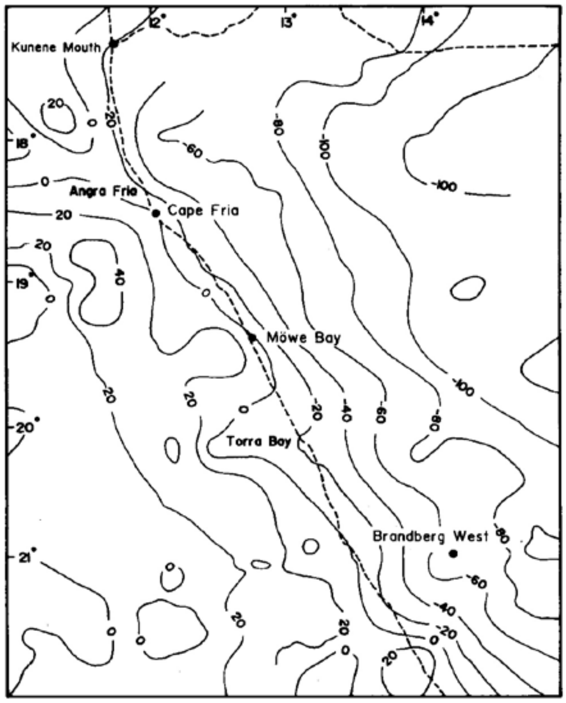

Fig. 5: Combined Bouguer anomalies for northwestern Namibia. The solid circles indicate observation points, and the contour interval is 20mgal.

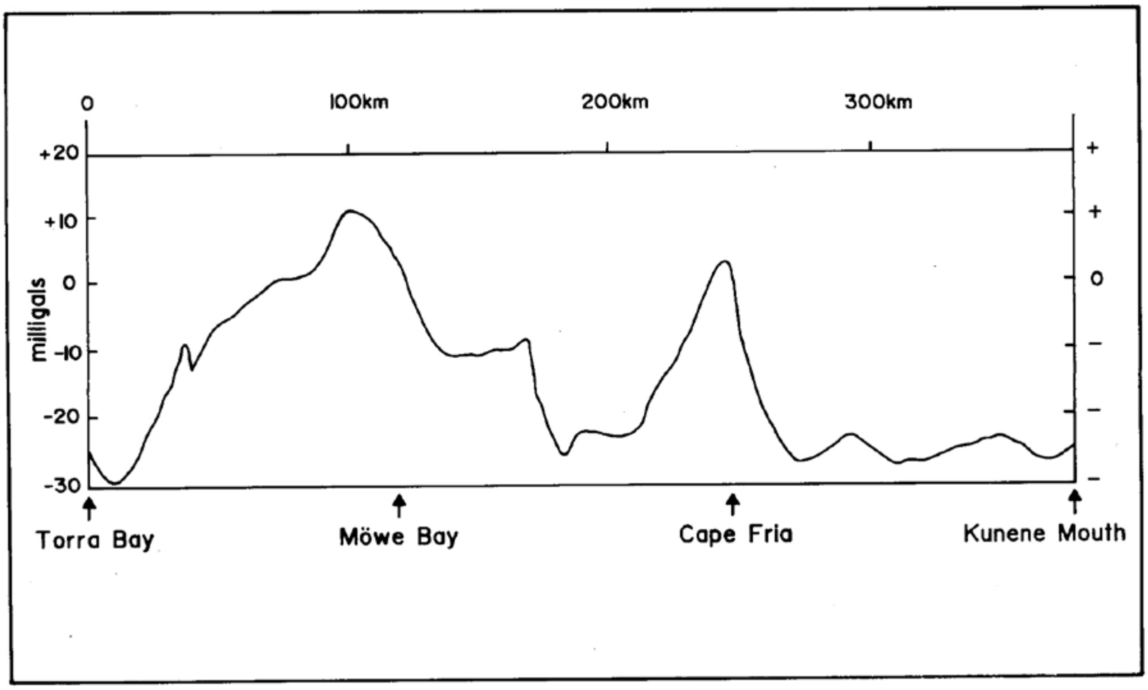

Fig. 6: Bouguer anomaly profile along the Skeleton Coast.

Africa. PhD thesis (unpubl.), University of Natal, Pietermaritzburg, 98 pp.

Merry, C.L. 1983. A 1/4° by 1/4° gravity field for southern Africa. *Proc. Int. Symp. on Improved Gravity Field Estimations on a Global Basis, Hamburg*, **1**, 532-551.

Morelli, C. 1974. The International Gravity Standardisation Net 1971 (IGSN71). *Spec. Publn. International Association of Geodesy*, **4**, 194 pp.

Moritz, H. 1980. Geodetic Reference System 1980. *Bulletin Geodesique*, **54**(3), 395-405.

Van Gysen, H. and Merry, C.L. 1983. *Calibration of gravity meters: 1983*. University of Cape Town, Department of Surveying, Internal Report no. G-11, 18 pp.

Van Gysen, H. and Merry, C.L. 1984. *Reconnaissance gravity survey of degree square 3219*. University of Cape Town, Department of Surveying, Internal Report no. G-14, 17 pp.

Van Gysen, H. 1985 A preliminary gravimetric geoid for southern Africa. *Proc. 8th Conf. of southern African Surveyors, Durban*, 20 pp.

Venter, C.P. 1980. *Bepaling van die absolute waardes van gravitasiebasisse in Windhoek, Namibia*. Geological Survey of South Africa, Report no. 1980-0187, 9 pp.