DEPARTMENT OF NATIONAL RESOURCES

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

Record 1977/30

TENNANT CREEK GRAVITY AND MAGNETIC SURVEY, NORTHERN TERRITORY, 1973

by

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SUMMARY

Between July and October 1973 the Bureau of Mineral Resources made a gravity and magnetic survey covering an area of about 1500 km^2 in a region 30 km west of Tennant Creek, Northern Territory. The survey was made to investigate two gravity anomalies found in previous surveys, and to investigate the relation between high-grade metamorphic rocks encountered in drilling in BMR Area No. 3 and Lower Proterozoic sediments of the Warramunga Group. A further objective was to devise field techniques suitable for semi-regional gravity surveys.

The two gravity anomalies investigated were the anomaly west of the Cabbage Gum West track (Anomaly A) and the anomaly over BMR Area No. 3 (Anomaly B). Anomaly A is attributed to a dense intrusive body at depth. Anomaly B is attributed to near-surface metamorphic rocks (intersected by drilling) which may be metamorphosed Warramunga Group sediments. An intrusive body could lie at depth.

The survey results have been used to determine the probable southern boundary of Warramunga Group sediments north of BMR Area No. 3 and to determine margins of the Cabbage Gum and Warrego Granites.

The technique adopted for the semi-regional survey was to navigate by compass and vehicle odometer and to level with microbarometers. Control was from a framework of accurately located and levelled traverses.

Drilling is recommended to investigate Anomaly A, to investigate the southern margin of the Warramunga Group sediments, and to investigate the northern margin of the metamorphic rocks in BMR Area No. 3.

1. INTRODUCTION

The Bureau of Mineral Resources (BMR) 1967 regional helicopter gravity survey detected a 20 mGal Bouguer anomaly 40 km southwest of Tennant Creek, N.T. (see BMR map E53/B2-14). In 1972 this anomaly was further investigated in a BMR gravity and magnetic survey carried out by Hone (1974). A station interval of 200 m was used along existing roads and tracks in an attempt to provide information on the structure and geology of the Tennant Creek field. An unexpected result of the 1972 survey was the discovery of a second Bouguer anomaly of about 10 mGal over BMR Area No. 3. This anomaly was not shown on the regional helicopter gravity survey results because of the wide station separation. In 1973 a survey was made to investigate these two anomalies in more detail using a semi-regional method which would improve the accuracy of the regional contour map which incorporated the 1972 work. It was also hoped to gain information that would help reveal the relation of the high-grade metamorphic rocks encountered in drilling of BMR Area No. 3 (Whittle, 1966) to Lower Proterozoic sediments of the Warramunga Group. A further objective in 1973 was to devise a suitable field technique which would yield an overall accuracy in the order of ± 0.5 mGals.

The field party consisted of two geophysicists, P. Bullock and F. Michail, and two field hands. Survey control was provided by a framework of lines accurately pegged and levelled by a Department of Services and Property survey team lead by J. Hyslop. Information concerning stations is given in Appendix. The field work was done in the period July to October 1973.

This project was carried out in co-operation with the Mines Branch of the Department of the Northern Territory. Geopeko Ltd and Australian Development N.L., held exploration licences over part of the survey area and their assistance in supplying drill hole data and information on the location of base lines which were incorporated in the survey is acknowledged.

2. GEOLOGY AND TOPOGRAPHY

A summary of the geology of the Tennant Creek field is given by Hone (1974). The geology of the Tennant Creek 1:250 000 Sheet area is described by Mendum & Tonkin (in prep.).

The area of the 1973 survey is shown in Plate 1; it is mostly covered by aeolian deposits, and geological outcrop is limited to superficial travertine and laterite. The area is of low relief, but is so rough that it can be driven over only at very low speed. The vegetation consists mostly of spinifex and low scrub; some areas are covered with dense mulga.

Little geological information is presently available over the area of the survey except that from a few company and BMR drill holes over magnetic anomalies; most of these holes do not sample the country rock.

3. SURVEY METHODS

Conventional methods of surveying were used to locate and level accurately a framework of traverses. This framework was then used to provide a control for further traverses which were positioned by navigating with a Brunton compass and levelled with microbarometers.

Experiments using helium-filled meteorological balloons as navigational aids were unsuccessful because the lightest breeze prevented the balloons from rising above tree height. Attempts at directing a vehicle along traverse by using two-way radio communication proved unsatisfactory. The method finally adopted was to use a Brunton compass to take a bearing and to select an on-line landmark such as a tree that was as far away as possible. The landmark was then approached in a straight line while marking the traverse by attaching PVC tape to trees. Where thick tree cover reduced the line of sight it was quickest for a person to use the compass while walking and at the same time define a straight line by tying tape to trees. Using this method an error of less than 1° could be obtained even on thickly wooded lines. Station positions were then determined using a Halda odometer fitted to a Land Rover. An error of less than 200 m in 10 km was achieved even on lines through thick tree cover where vehicles could not follow a straight course.

Barometric levelling was done using three pairs of Mechanism microbarometers. Two vehicles were used so that two loops could be read at the same time. In most cases a base station was chosen at the centre of a 10 km line and the five stations at each side could then be read within one and a half hours. This method and the data reduction technique were suggested by F. Michail. Before reading the loops, all barometers were read at one-minute intervals alongside the base station barometers for a period of five to ten minutes. This routine was repeated on return to the base station. This procedure showed whether or not the barometers behaved consistently. As a further check, several stations were also reread on the return to the base station. Closure errors in elevation were usually found to lie within ± 1.5 m.

Gravity and vertical magnetic intensity were read using a Worden gravimeter and an Askania torsion magnetometer. The method in which readings are tied to fixed base stations was used at first, but later a leap-frog or moving base station method was adopted and loops were adjusted for misclosure. It was found that the latter method was more rapid and provided satisfactory instrument drift control.

The methods used in the gravity survey were adopted after consideration of the required accuracy in position and elevation. Since an overall accuracy to within ± 0.5 mGals in the observed gravity values was sufficient, station latitude and elevation were required to about ± 200 m and ±1.5 m respectively. It followed that use of the conventional surveying methods of chaining and levelling which are slow and expensive could be minimised and used only on an outer framework of lines as a control for determing the closure errors on other lines where the approximate methods described were used. The error in the magnetometer survey was about ± 10 nT. Greater accuracy than this was not required because superficial sources created variations in field strength of this order over horizontal distances of only a few metres in many parts of the survey area.

4. RESULTS

The gravity results were incorporated with the previous gravity data using the BMR Regional Gravity Section computer program, and a revised Bouguer contour map of the area was obtained at 1:250 000 scale (Plate 2). The gravity surface was constructed by mathematically fitting a smooth surface to the gravity station network. Hence the reliability of the Bouguer contours varies in relation both to station density and to the accuracy at the individual stations. Bouguer contours over areas remote from Hone's 1972 traverses and the 1973 network are based solely on the BMR 1967 regional helicopter gravity survey network; gravity data accuracy is ± 0.3 mGal, and the accuracy of the Bouguer contours between stations is probably about half the difference of Bouguer values at adjacent stations. However the large anomaly at 19° 30' S, 134° 15' E is regarded as doubtful and due to an error in one of the helicopter gravity stations. The accuracy of the gravity data of the 1972 and 1973 survey stations is ± 0.03 and ± 0.5 mGals respectively. Bouguer contours within the 1972/73 network, but remote from the survey lines are less accurate.

The main features of the gravity map are the large Bouguer anomaly west of the Cabbage Gum West (CGW) track (Anomaly A) and the anomaly over BMR Area No. 3 (Anomaly B). These two anomalies are larger than any which have been detected so far over the Tennant Creek field and they account for most of the gravity expression over the area of the 1973 survey.

The magnetic results are shown as profiles, which are superimposed on the traverse location map in Plate 3. Field strength is plotted along each traverse at a scale of 250 nT to 1 cm with increasing values to the north or west. The magnetic data could not be contoured meaningfully because the wavelengths of the magnetic anomalies were much shorter than the traverse spacing. The magnetic results however do show anomalies which are consistent with the airborne total intensity contour map (Plate 1).

5. INTERPRETATION

Interpretation was commenced with a study of the 1972 profiles which passed over areas with geological control. It was hoped that a model could be obtained which would relate the gravity and magnetic results to a geological subsurface simulation that is consistent with the surface geological map of Mendum & Tonkin (in prep.). Such a model could then assist in explaining the data from the present survey, where surface geology is mostly unknown.

1972 gravity profiles (Stuart Highway and Nobles Nob

Geological subsurface simulation of the Stuart Highway traverse was done using a Hewlett Packard 9100B calculator and a program for calculating a gravity profile across a two-dimensional body having arbitrary four-sided cross-section and infinite strike. Rectangular blocks of depth 0 to 10 km representing granites of low density and sediments of higher density were used and a good fit with the geology was obtained. The observed and theoretical profiles are shown as continuous and broken lines respectively in Plate 4. The simulated section and implied density contrasts are shown beneath the profiles. The positive regional gradient towards the south was obtained by postulating a large dense block at the southern end of the traverse. It was later realized that this gradient is more likely to be caused by a decrease in depth of basement. Such an assumption would also be consistent with the magnetic results and is discussed later. Simulation of the Nobles Nob traverse was attempted by using blocks of the same density contrast as had been used on the Stuart Highway traverse and by placing their boundaries in accordance with the surface geological map. It was found that the observed profile could not be simulated by such a model because the gravity response over the southern 14 km of the traverse, which is almost entirely over granites, is greater than that over the outcropping Warramunga Group sediments to the north. In order to match the theoretical and observed profiles it was necessary to assume that the granite forms only a thin sill which overlies a denser rock, possibly Warramunga Group sediments (see Plate 4). Also a regional gradient such as that which has previously been mentioned would be consistent with the observed profile and would help to explain the higher gravity values to the south.

<u>1972 magnetic profiles (Stuart Highway, Nobles Nob, and Cabbage Gum)</u>

The vertical magnetic field profiles along the Cabbage Gum North and South tracks (CGN and CGS), Stuart Highway and Nobles Nob traverses (Plate 5) show certain similarities. To the south all three traverses show a smooth gradient which is considerably greater than that attributable to the Earth's main magnetic field. The steeper gradient may result from the basement becoming shallower south of the Tennant Creek field. The geological map shows this region, which lies roughly south of the Nobles Nob-Mount Samuel line, mainly as granites with only minor outcrops of Warramunga Group roof pendants.

On the Stuart Highway traverse an anomaly between 7.0S and 8.0N coincides with the area mapped as Warramunga Group sediments. The magnetic profile can be simulated by superimposing the anomaly due to a rectangular block on the above mentioned gradient. A block with its upper surface at 0.15 km, a depth extent of 10 km, and a susceptibility contrast of 0.0006 cgs units is required (see Plate 5). The Nobles Nob traverse shows a similarly shaped anomaly which extends north to 12N, the Quartz Hill-Rocky Range Fault. To the south there is a correlation at 4S between the magnetic results and the southern margin of the Warramunga Group sediments.

The airborne total magnetic intensity map (Plate 1) shows pronounced west-northwest trending anomalies which can be used to map the southern margin of the Warramunga Group sediments; these anomalies imply that the southern margin occurs at about 27N on the CGN traverse. At this point on the CGN traverse there is a sudden increase in field strength. In BMR Area No. 3 the magnetic features on the CGN traverse (11N to 17N) are of similar character but more intense than those over the Warramunga Group sediments encountered on the Stuart Highway and Nobles Nob traverses. It is possible that the rocks in this area are a roof pendant of the metamorphic equivalent of the Warramunga Group sediments.

Interpretation of the 1973 survey data

The main problems considered were:-

(1) Interpretation of the large Bouguer anomaly west of the Cabbage Gum West track (Anomaly A) and the Bouguer anomaly over BMR Area No. 3 (Anomaly B).

(2) Interpretation over the area of the survey in terms of an extension of the known geology of the Tennant Creek area.

Methods

The data were interpreted using a simulation technique with bodies extending to a depth of 10 km; however the bodies relating to Anomalies A and B were treated as three-dimensional.

The influence of Anomaly A extends over most of the survey area and so a causative body was found which would account for as much of the total gravity relief in the area as possible. Further bodies were then introduced to simulate north-south and east-west profiles.

Anomaly A

Anomaly A (Plate 2) is elongated about an approximately east-west axis so the first stage of the interpretation was to consider a two-dimensional body, and several sections at right angles to this axis were simulated.

The simplest body found which produced an anomaly of the required shape has an asymmetrical wedge-shaped cross-section. If the top of the body is at ground surface a density contrast of + 0.23 g/cm^3 is required. If the depth to the top of the body is increased to 1.2 km a density contrast of + 0.5 g/cm^3 is required, and the cross-sectional area is reduced by about half. The first model corresponds to a source consisting of near-surface metamorphic rocks similar to the interpreted source of Anomaly B, about 9 km to the north (see next section). However the amplitude of Anomaly A is much larger than that of Anomaly B and the density of a near-surface source for Anomaly A would have to be much larger than for Anomaly B, and so it is considered that the anomalies have different sources. The model used to interpret Anomaly A is the one at 1.2 km depth which would correspond to a source consisting of basic intrusive rocks at depth.

Interpretation of Anomaly A was extended to three dimensions by considering an along-strike east-west profile running close to the CGW track (Plate 6). A Fortran program for calculating the gravity effect of a three-dimensional body of arbitrary shape, GRAV3D (Spies, 1975), was used. This program uses a method which sums the contributions of horizontal polygonal laminae which approximate the body. Adjustments were made to the along-strike section until the profile was simulated.

A two-dimensional block with negative density contrast was inserted near the eastern end of the profile. Drill hole results from this area are reported by Crohn (1961). Fresh granite was intersected at an average depth of about 50 m and was overlain by decomposed granite in most holes. Warramunga Group rocks were also intersected in some places suggesting the occurrence of roof pendants within the granite. A two-dimensional block was used in modelling although there is a distinct gradient to the south of this area.

Using GRAV3D an across-strike north-south profile was generated in a position which would pass over the centre of Anomaly B (Plate 7). Modelling was done using a fixed, common, gravity datum. At the northern end of this profile a block with negative density contrast was required. Granites are postulated in this area.

Interpretative sections are presented in Plates 6 7 & 8, where the observed profiles are represented by continuous lines and the theoretical profiles by broken lines. Anomaly A is attributed to a dense intrusive body at depth. It is considered unlikely that basement uplift would be responsible for a localized feature of such comparatively small scale.

The magnetic anomalies in the area of Anomaly A (Plates 1 and 3) are considerably less in amplitude than the anomalies from the near-surface metamorphic rocks in BMR Area No. 3 near anomaly B; they may be due to metamorphic rocks at depth, basic intrusive rocks at depth, or the magnetite-bearing Warramunga Group sedimentary rocks which are the source of many of the anomalies in the Tennant Creek Area.

Anomaly B

Drilling in BMR Area No. 3 has encountered near-surface metamorphic rocks with an average density greater than that of the Warramunga Group sediments. It was thus assumed that a body extending to the surface is required to simulate this anomaly. Interpretation was done by curve fitting to the residual anomaly after the gravitational field of Anomaly A had been removed. An approximate model was obtained by using a program for calculating the response of a vertical cylinder (Cull, 1971). The best fit was a semi-infinite vertical cylinder of radius 2.5 km and density contrast + 0.13 g/cm^3 with its upper surface at ground level.

Anomaly B is slightly elongated about an east-west axis as is Anomaly A (see Plate 2). An east-west section was simulated using GRAV3D (Plate 8). The best fit resulted from a body of approximately circular horizontal cross-section at the ground surface but assuming an increasingly larger approximately ellipsoidal cross-section as depth increases to 2 km. Such a body would require a density contrast of + 0.11 g/cm^3.

A smaller anomaly (Anomaly C) is evident about 15 km west of Anomaly B. A model in which Anomalies B and C result from a single body produced too large a gravity expression. Anomaly C was therefore simulated using a rectangular block with a convex upper surface at a depth of 2 km and the same density contrast as the block used for Anomaly B.

A two-dimensional block 3 km wide was used to simulate a gravity low on the west flank of Anomaly C. This low may relate to a southern tongue of the Warrego Granite which according to the gravity contour map (Plate 2) appears to extend about as far south as 11S on the 1973 survey grid.

Bouguer values decrease slowly to the east of Anomaly B. Granites are postulated in this region on the Stuart Highway; however it is difficult to fix their western margin from the Bouguer contours.

A vertical magnetic field contour map of BMR Area No. 3 (O'Connor & Daly, 1962) and the airborne total magnetic intensity map (Plate 1) both show an arcuate series of sharp anomalies due to near-surface sources. The CGN gravity profile shows a gravity high over the area and there appears to be a correlation of small superimposed gravity peaks with the magnetic results (Hone, 1974). Drilling results suggest that the magnetic anomalies might be simulated by upright cylinders or spheres, but it is impossible to find a solution in which magnetic and gravity expressions are provided by the same bodies because the magnetic anomalies are mainly confined to only the northeast sector of the gravity anomaly revealed by the 1973 survey.

The most plausible interpretation of Anomaly B is that it is caused by near-surface rocks which could be metamorphic equivalents of the Warramunga Group sediments and which produce the magnetic anomalies in BMR Area No. 3. However gravity anomalies of similar magnitude to Anomaly B do not appear over the Tennant Creek field; an intrusive body could lie at greater depth beneath the area. Anomaly C could also result from a deeper intrusive body, and the weak magnetic anomalies in the vicinity of Anomaly C could similarly represent the effects of metamorphism. The possibility remains that these anomalies are caused directly by Warramunga Group rocks or their metamorphic equivalents.

Cabbage Gum Granite

From the gravity data, the western margin of the Cabbage Gum Granite is interpreted to lie in the vicinity of CGW 19.0 (Plate 2). The increase in Bouguer values south of the Cabbage Gum West track suggests that either the southern margin of the Cabbage Gum Granite lies about three or four kilometres south of the CGW track or that the granite overlies a southeastern extension of the causative body of Anomaly A.

The east-west interpretive section through Anomaly B (Plate 8) suggests that the Cabbage Gum Granite does not occur close to the eastern flank of Anomaly B. Such a conclusion is tentative being dependent upon the accuracy with which the residual field of Anomaly A is removed in this region.

Warrego Granite

The gravity data indicate that the Warrego Granite extends southwards in the region west of line 27W at least as far as the east-west section through Anomalies B and C. The boundary in the southeast appears to be just north of Anomaly B. It is possible that the Warrego Granite joins the Cabbage Gum Granite but it is difficult to draw positive conclusions from the data available.

6. CONCLUSIONS AND RECOMMENDATIONS

Lacking geological control, interpretation of Anomaly A remains ambiguous. A model has been postulated with a density contrast of + 0.5 g/cm^3 and a depth of 1.2 km; however a less dense body could reach the surface. A gravity survey using ¼-km station spacing would define the peak of the anomaly in more detail. A drill hole would determine if the anoamly is due to a near-surface source or not. The best location on the basis of the work done in 1973 is a vertical hole sited at 17.4 S/1.0W. This position is shown in Plate 2.

Diamond-drilling in 1974-75 by the Mines Branch, Department of Northern Australia, has shown the presence of metamorphic rocks underlying the magnetic anomalies on the edge of Anomaly B. A vertical hole 213.5 m deep has been drilled near the peak (see Plate 2 for position). From the surface to 32.9 m this hole intersected mudstone, possibly Cambrian. From 32.9 m to the end of the hole, metamorphic rocks, mainly schist, were intersected.

The main conclusions that have been drawn from the gravity, magnetic, and geological data are:

1. Gravity data on the Stuart Highway and Nobles Nob traverses can be explained by a model using two-dimensional blocks to represent Warramunga Group sediments and granite. However it is necessary to assume that some mapped granite south of the Nobles Nob area forms only a thin sill overlying denser rock which could be Warramunga Group sediments.
2. The southern margin of the Warramunga Group sediments north of BMR Area No. 3 probably occurs near CGN 27.0.
3. Anomaly A appears to be caused by a dense intrusive rock at depth.
4. Anomaly B is caused by near-surface rocks which may be metamorphosed Warramunga Group sediments. An intrusive body could lie at greater depth. A minor anomaly 15 km west of Anomaly B is attributed to an intrusive body at depth.
5. The Cabbage Gum Granite extends west to about CGW 19.0 and south for about 4 km south of the CGW track.

6. The Warrego Granite probably extends to 11 km south on line 27W. The southeastern boundary is near the northern margin of Anomaly B.

The survey methods were satisfactory although slower than had been expected. They would not necessarily be suitable in other kinds of terrain.

The northern extent of the metamorphic rocks in BMR Area No. 3 and the nature of the rock unit to the north could be investigated by drill holes near the edge of the postulated causative body.

The location of the southern margin of the Warramunga Group sediments on the CGN traverse could be investigated by drilling at CGN 27.0 and, according to the rock type encountered, further holes could be sited at intervals of 1 km either to the north or south along the CGN traverse until the position of the margin is established.

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APPENDIX

GRAVITY STATION DATA

Station identification was based on a co-ordinate system over most of the area with an origin at CGN 23.0. Stations around a fenced paddock were mostly placed at 1 km intervals and were numbered F1 to F66. Stations along two base lines between Cabbage Gum North and the Stuart Highway were read at available pegs which had been placed at 400 feet intervals by Australian Development N.L. Details of the accurately surveyed lines and their ties to the Cabbage Gum tracks are listed below. The lines are identified in Plate 3.

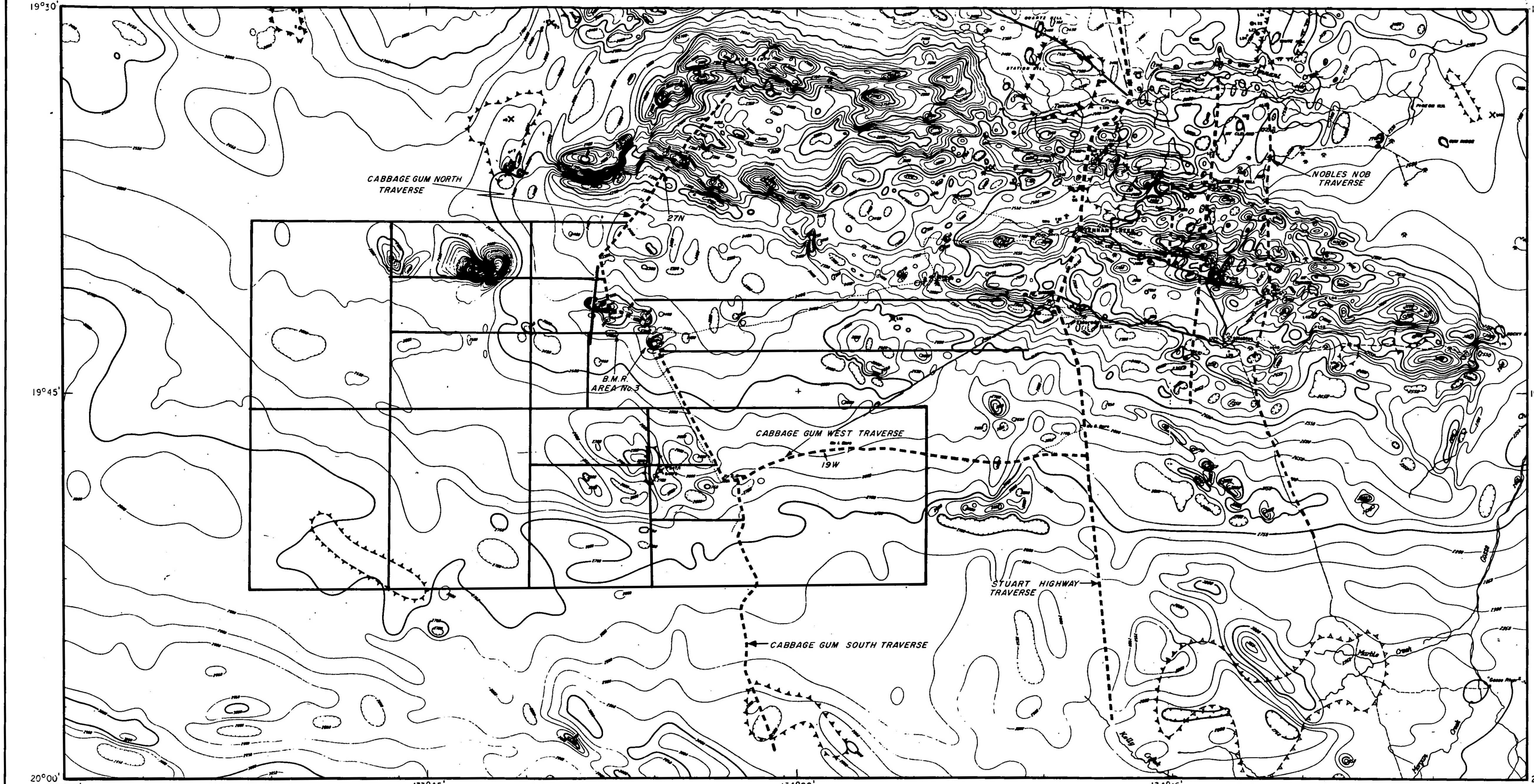
Accurately surveyed stations

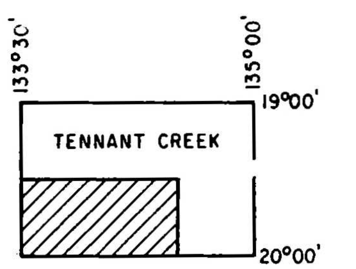
LINE OS , OW - 27 W
LINE 13.4S, 1.27E (F4) - 7W
LINE 26.5S, 1.70E (F17) - 27W
LINE 7W, OS - 13.4S
LINE 17W, OS - 26.5S
LINE 27W, OS - 26.5S (station intervals measured by odometer).
F1 - F25 (Fence west of CGN/S).

Ties to 1972 work

STN OS, OW	-	CGN	23.0	
STN F1	-	CGN	6.0	(approx.)
STN F25	-	CGS	8.2	(approx.)
LINE 4S	-	CGN	18.0	
LINE 5.5S	-	CGN	16.4	
LINE 8S	-	CGN	12.0	
LINE 9.5S	-	CGN	10.5	
LINE F8	-	CGN	1.4	
LINE F12	-	CGS	3.0	

The gravity base used in 1973 was CGN 7.0





REFERENCE TO AUSTRALIA 1:250 000 STANDARD MAP SERIES

KILOMETRES

5 0 5 10 15

CONTOUR INTERVAL 50 nT

TENNANT CREEK 1973
LOCALITY MAP AND AEROMAGNETIC CONTOURS

Record No. 1977/30

Traverses 1971-72

Traverses 1973

Mine

Road or track

Aerodrome

Bore

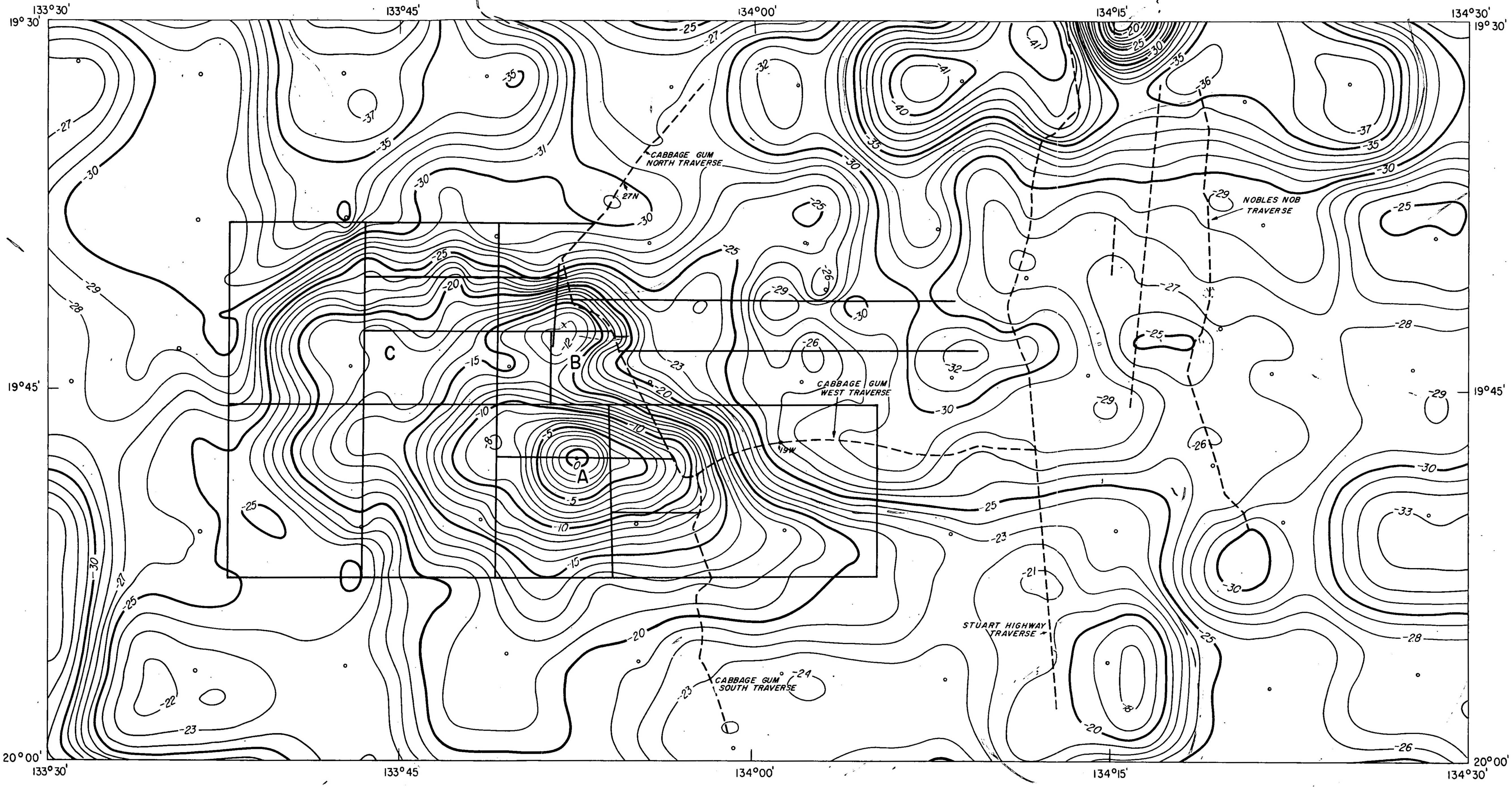
2000 Magnetic contours

Magnetic low

Radiometric high

Radiometric anomalies

E53/B7-176



TENNANT CREEK 1973

BOUGUER GRAVITY CONTOURS

— — — Traverses 1971–72

——— Traverses 1973 (see Plate 3 for 1973 traverse and station numbers)

∘ Gravity station, Helicopter Survey

× Drill hole

• Recommended drill hole

KILOMETRES

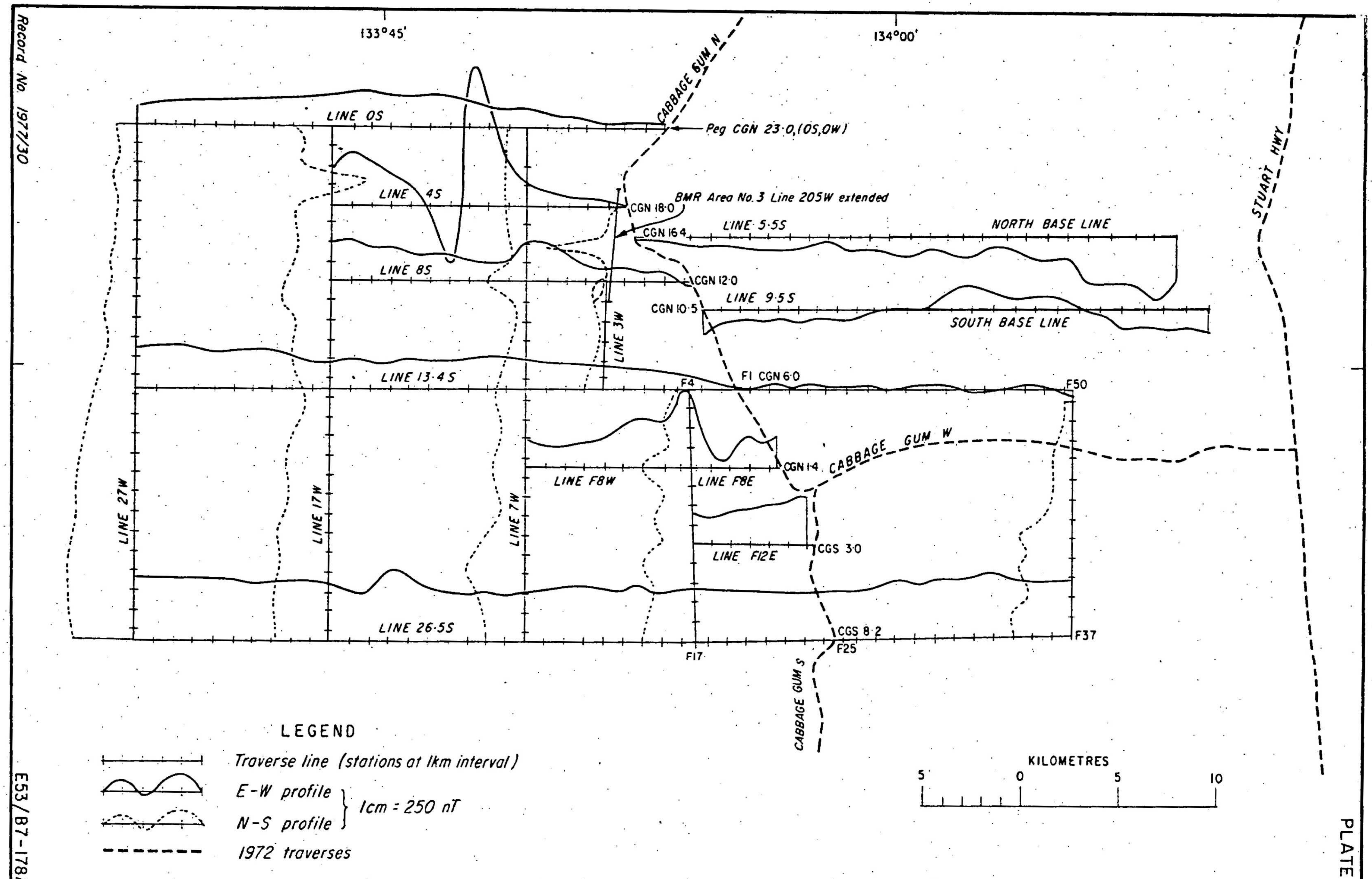
5 0 5 10 15 20

For the calculation of Bouguer anomalies $2{\cdot}67 g/cm^3$ has been adopted as an average rock density.

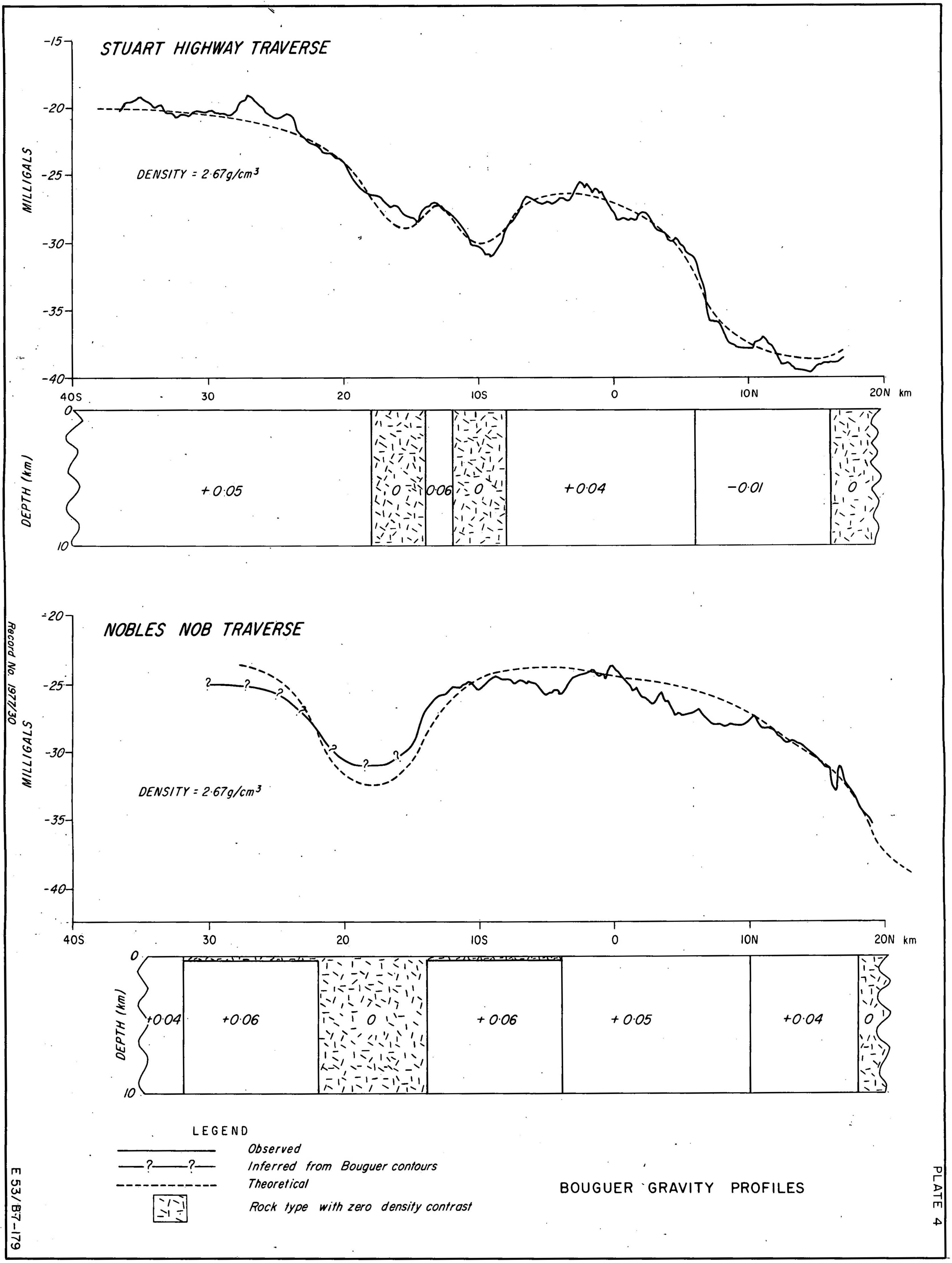
Contour interval — 1 milligal

Record No 1977/30

E53/B7-177



VERTICAL MAGNETIC FIELD PROFILES

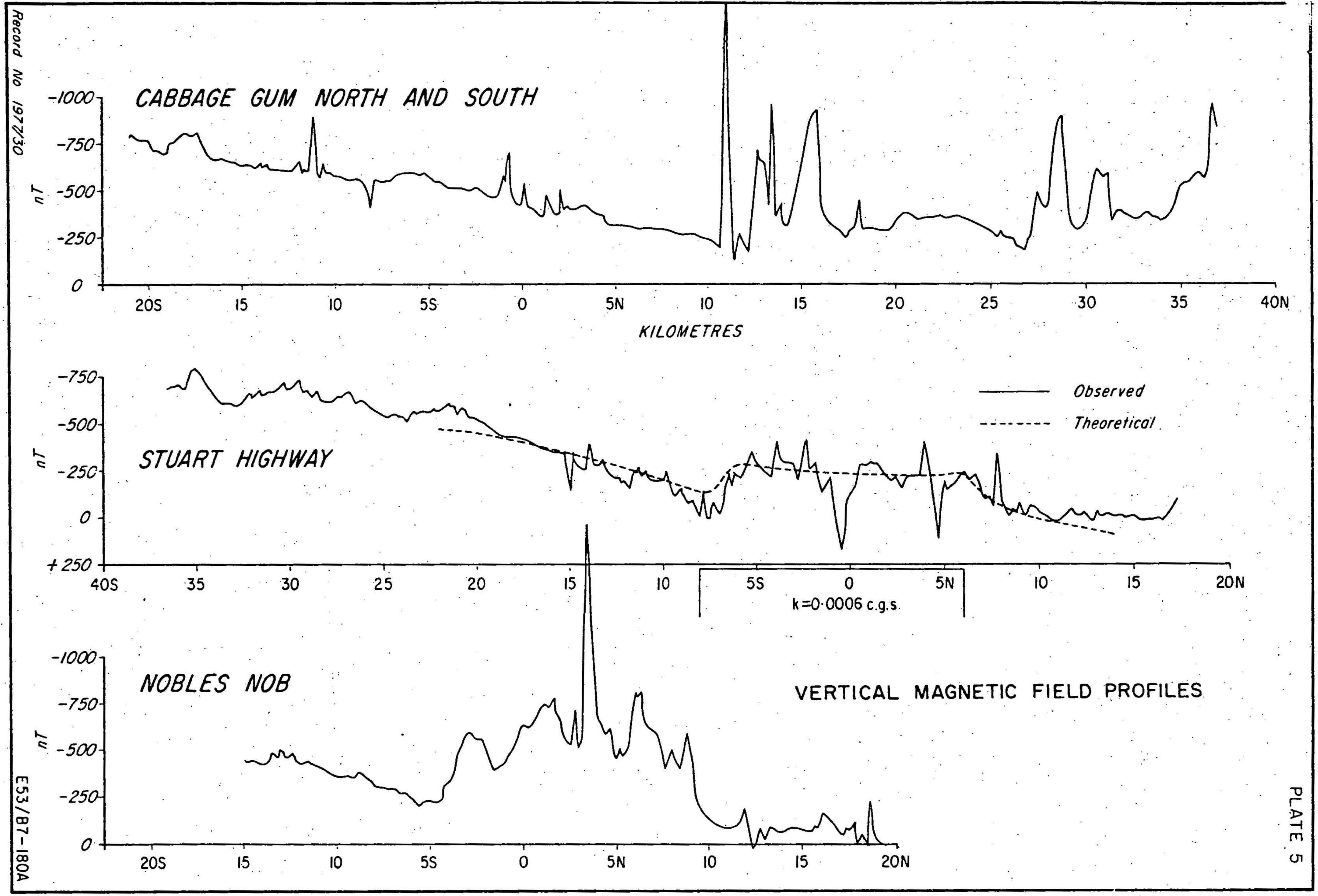


BOUGUER GRAVITY PROFILES

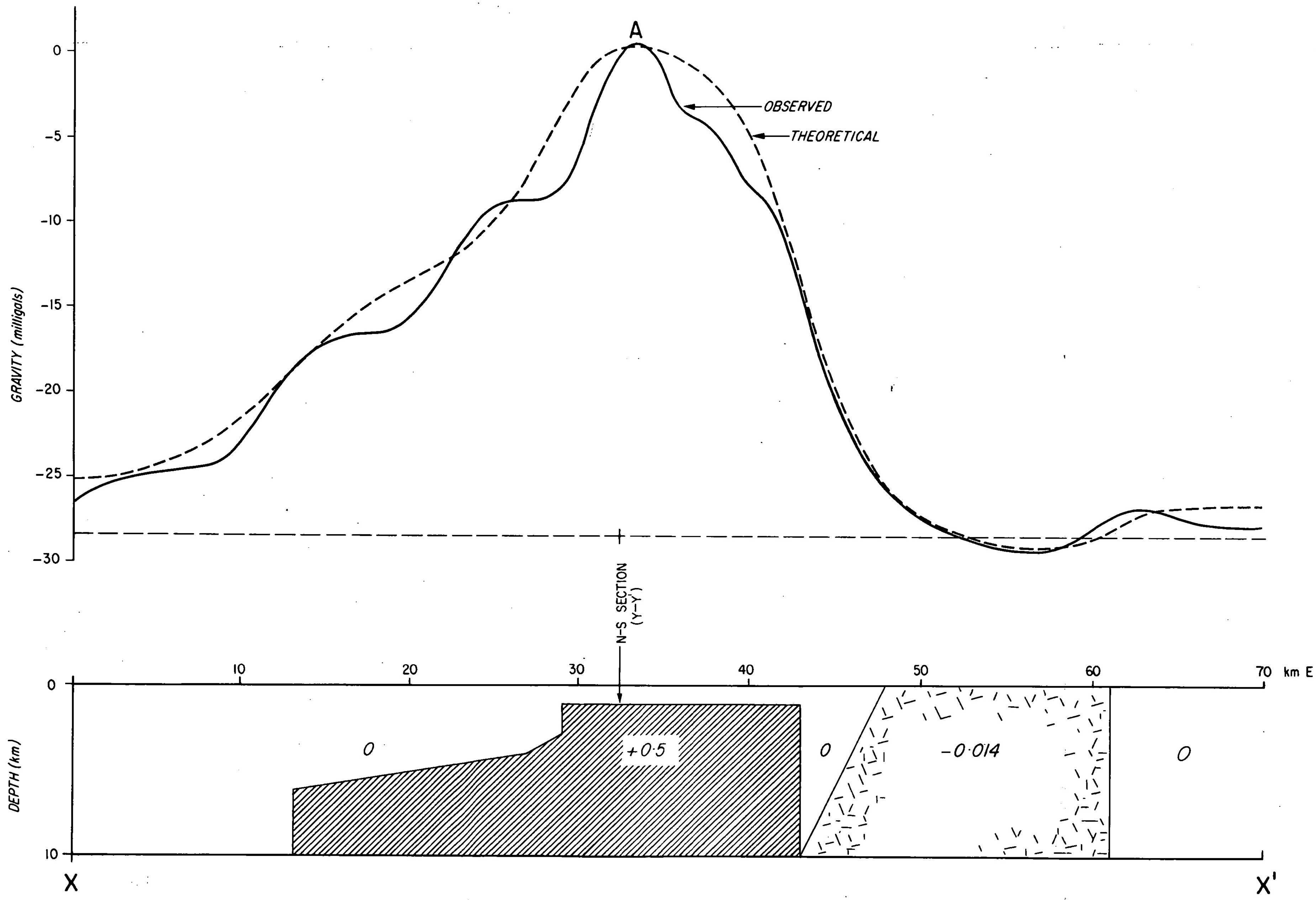
PLATE 4

Record No. 1977/30

E 53/B7-179

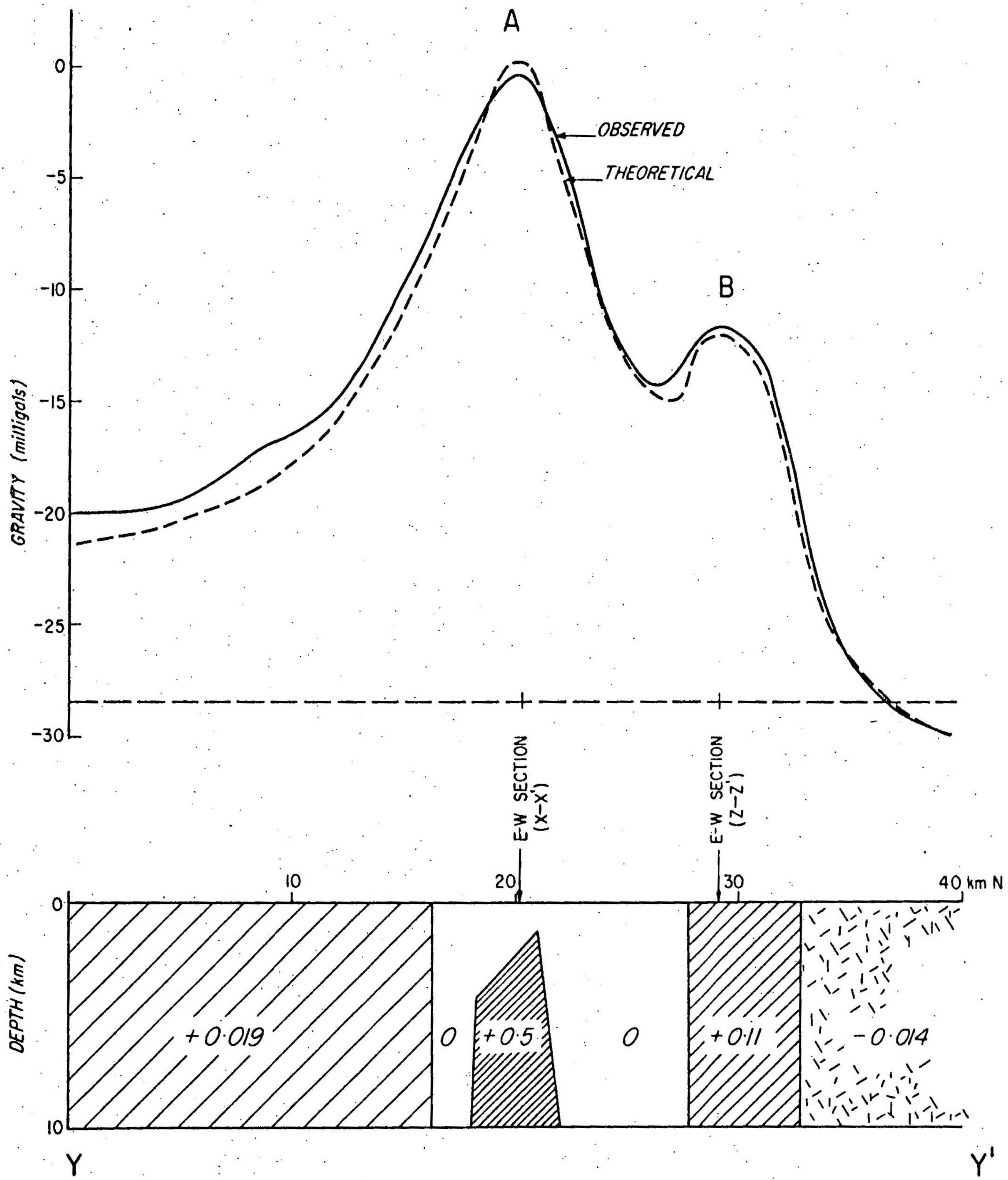


VERTICAL MAGNETIC FIELD PROFILES



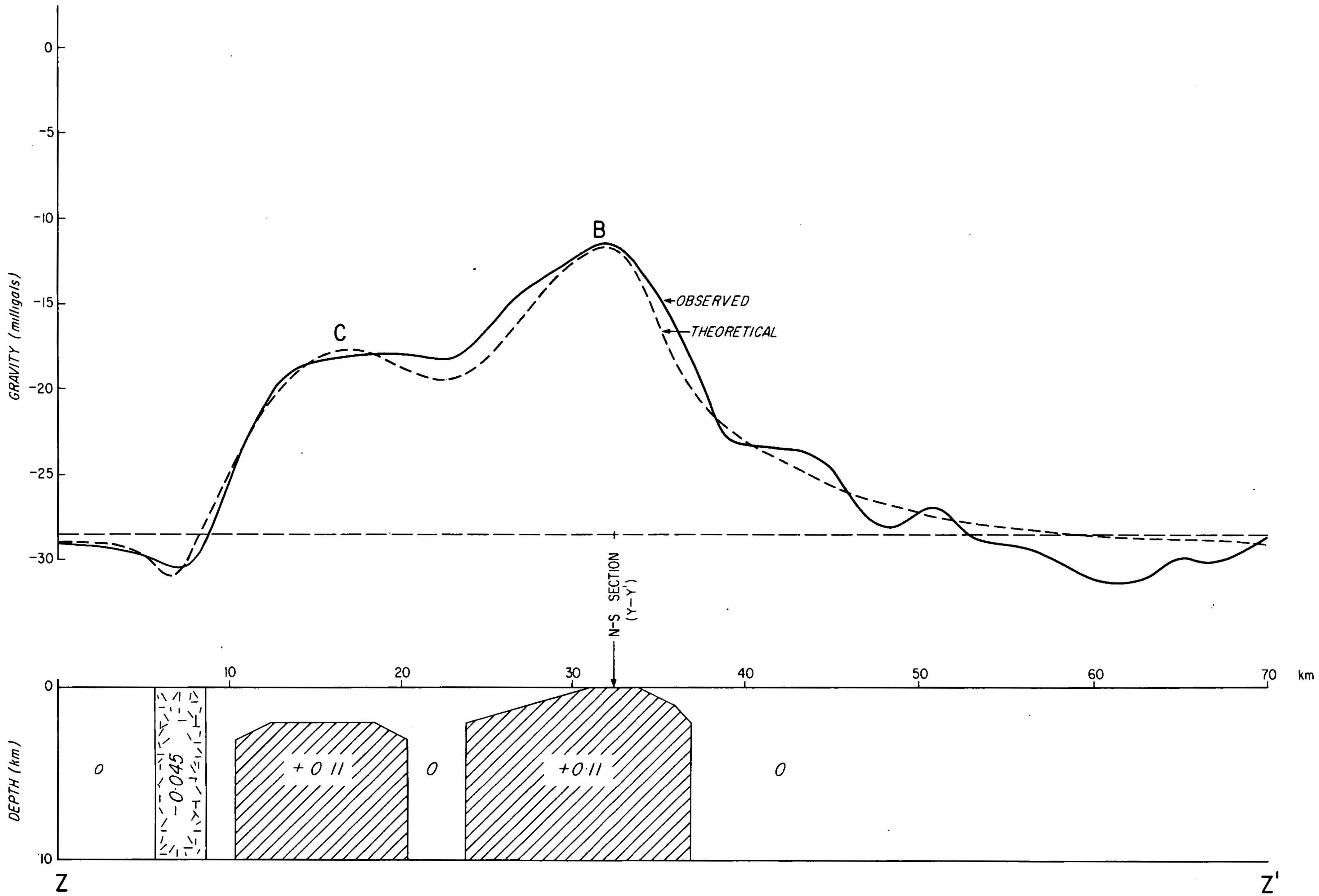
THEORETICAL AND OBSERVED BOUGUER GRAVITY
SECTION X-X'

PLATE 7



THEORETICAL AND OBSERVED BOUGUER GRAVITY
SECTION Y-Y'

E 53/B7-186 A



THEORETICAL AND OBSERVED BOUGUER GRAVITY

SECTION Z-Z'