Gravity investigations of the permo-triassic deposits of furness and South West Cumberland

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GRAVITY INVESTIGATIONS OF THE

PERMO-TRIASSIC DEPOSITS OF

FURNESS AND SOUTH WEST CUMBERLAND

by

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CONTENTS

SUMMARY

A detailed gravity survey was carried out by G. G. Knott and the writer on the coastal strip of New Red Sandstone of south-west Cumberland and Furness.

An account of the field work is given together with the necessary reductions of the instrument readings from which the Bouguer anomaly map was constructed. From this map the interpretation was performed using the methods described.

Two negative gravity anomalies were found, one over the New Red Sandstone deposits and the other over the Eskdale Granite. Interpretation was based only upon the former. Here the 16mgal. anomaly was attributed to the low density New Red Sandstone in relation to the adjacent denser Lower Palaeozoic rocks. Calculations aided by the use of an electronic computer showed that the New Red Sandstone basin possibly reaches a depth of 3,400 feet, while an even greater basin depth is required if there is underlying Carboniferous or Old Red Sandstone. The depths calculated conform with the known geology. The writer suggests that deposition of the New Red Sandstone occurred in an isolated basin with infilling contemporaneous with crustal downwarp.

It is further suggested that later faulting in the northern part of the area is the major cause of the westerly thickening but in the south crustal downwarp causes the thickening.

CHAPTER I INTRODUCTION, STRATIGRAPHY AND STRUCTURE

1.1. Introduction

The following thesis describes a gravity survey carried out by the writer, assisted by G. G. Knott, during September 1962 of the coastal strip of New Red Sandstone in south-west Cumberland and Furness. Previous geophysical work in the region had been done by Dr. M. H. P. Bott of the University of Durham as part of an overall gravity survey of north west England. The survey described following was to provide a more detailed gravity map of part of that larger area in order that a more critical interpretation could be performed, and also that the results gained would contribute towards similar surveys upon New Red Sandstone deposits in other regions bordering the Irish Sea, as well as with work being done on the Irish Sea itself.

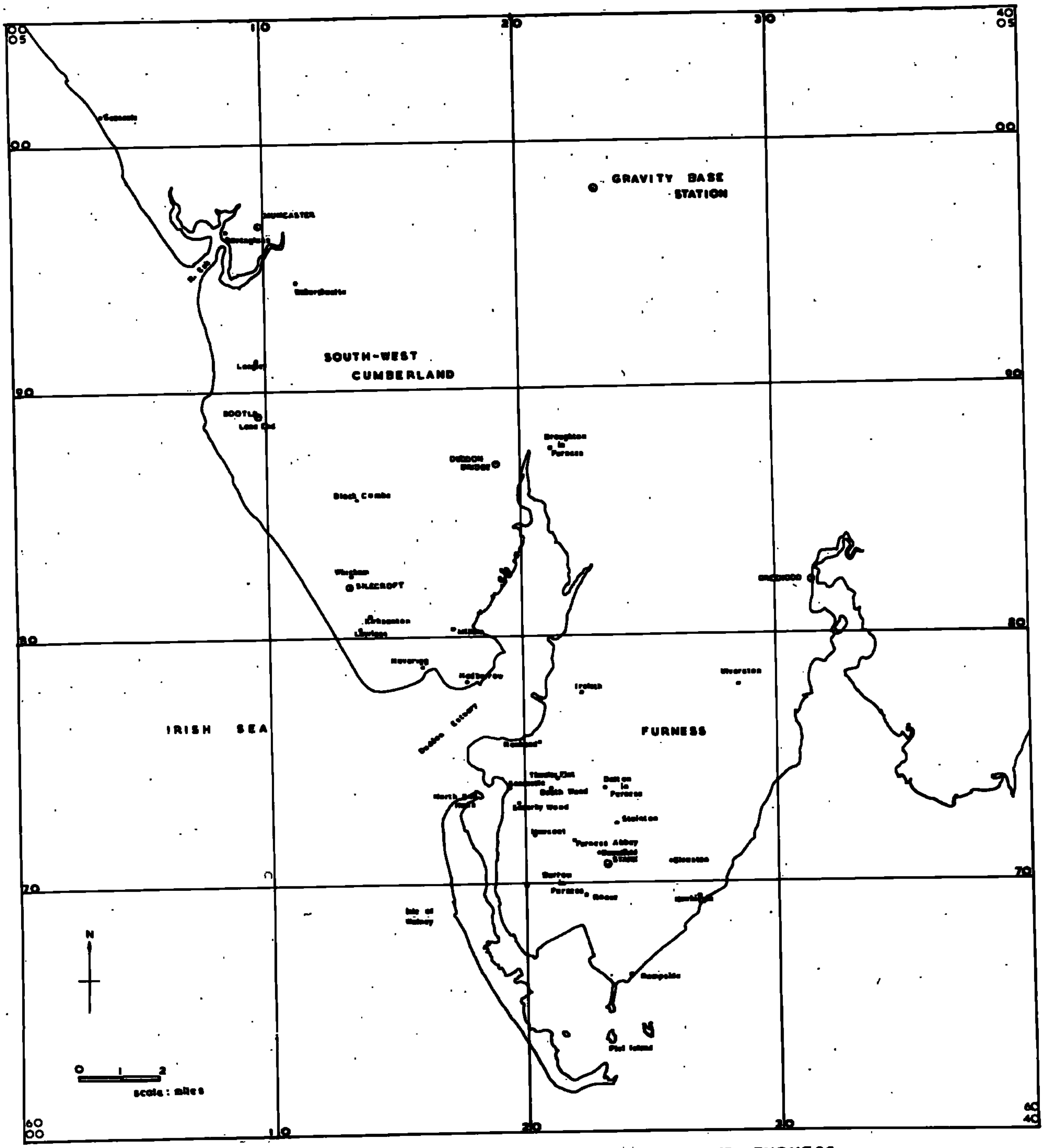


FIGURE 1. LOCALITY MAP OF SOUTH-WEST CUMBERLAND AND FURNESS

1.2. Stratigraphy and structure

The area surveyed forms the south-west border of the English Lake District and thus has much in common with the overall geological history of the latter.

The distribution of the following geological formations (solid) within the area are shown on the map, Fig. 2.

Superficial deposits		Approximate thickness in feet
Recent and post-Glacial		
peat, alluvium, blown-sand, gravels		
Glacial		
Boulder Clay		0 - 120
Solid		
Permo-Triassic (New Red Sandstone)		
	Kirklington Sandstone	0 - 2,000
	St. Bees Sandstone	up to 2,178
	St. Bees Shale	0 - 615
	Magnesian Limestone	0 - 65
	unconformity	
Carboniferous		
	Yoredales	up to 1,098
	Carboniferous Limestone	1,190+
	Basement Beds	up to 626
	unconformity	
Silurian		
	Coniston Grits and Flags	6,000+
	Stockdale Shales	about 250
	unconformity	

Ordovician

Coniston Limestone	150 - 1,300
Borrowdale Volcanic Series	0 - 20,000
Skiddaw Slates	about 4,000

Intrusive

Eskdale Granite

Haematite deposits

(a) Lower Palaeozoic rocks

North of the Duddon Estuary and up to the River Esk the rocks consist essentially of Skiddaw Slates, Borrowdale Volcanics and the Eskdale Granite forming an inner mountainous tract of country separated from the sea by a relatively narrow lowland strip of drift covered New Red Sandstone. The Skiddaw Slates (Smith, 1912) which form a roughly triangular inlier (Fig.2) within the Borrowdale Volcanics consist of blue-grey slates showing evidence of great compression with cleavage planes dipping north west with roughly coincident quartz veins. Softer shales of the same age form the south east side of Black Combe (height 1,969 feet), the highest hill in the area, and are possibly separated from the blue-grey slates by a thrust dipping north west. The Borrowdale Volcanic rocks are chiefly andesitic lavas and ashes, occasionally vesicular, together with some rhyolites. Both Skiddaw Slates and Borrowdale Volcanics have numerous small intrusions and have both suffered intense earth movements making structural relationships extremely difficult to determine. A marked unconformity (Mitchell, 1955-6) exists between the Borrowdale

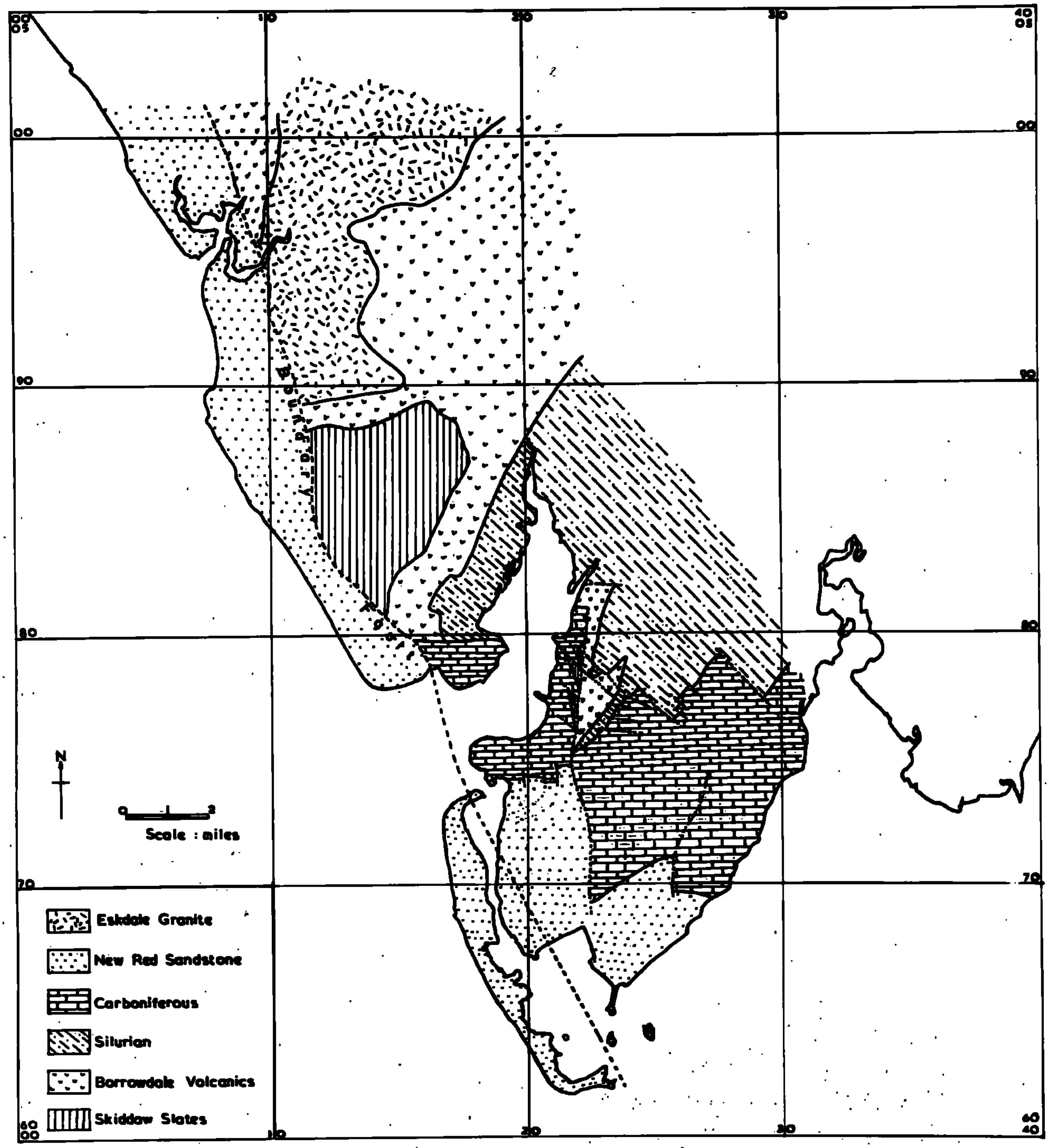


FIGURE 2. GEOLOGICAL SKETCH MAP OF SOUTH-WEST CUMBERLAND AND FURNESS.

Volcanic rocks and the overlying Coniston Limestone. As the Coniston limestone is traced south west towards Millom it transgresses over and rests progressively on lower and lower beds of the volcanic rocks. Over much of the area the two groups strike at right angles with the Borrowdale Volcanic rocks dipping east or north east. This structural relationship between the Borrowdale Volcanics and the Coniston Limestone implies that before deposition of the latter, i.e. pre-Caradocian, there was a period of crustal movement in the south west of the Lake District.

The overlying Silurian ~~rocks of~~ grits, flags and shales are the most extensive of the Lower Palaeozoic formations in the area south of the River Duddon and present a far less rugged topography. Their earliest representative the Stockdale Shales follow closely the outcrop of the Coniston Limestone, but later earth movements have considerably disturbed the outcrop of the shales (Mitchell, 1955-6).

No Devonian strata is present, the period being one of intense earth movements with pressures direct along south-south-east and north-north-west lines resulting in folds trending north east-south west, examples of which are to be found east of the Duddon Estuary where the Silurian and older rocks have been folded into two major anticlines. The earth movements caused later sediments to rest with great angular unconformity upon the older rocks.

(b) The Eskdale Granite

The Eskdale Granite (Trotter et al, 1937, Gosforth Memoir) outcrops two miles north of Black Combe with its metamorphic aureole (Smith, 1912) affecting both the Borrowdale Volcanics into which it is intruded (Fig.2) and the Skiddaw Slates to the south. The granite averages about two miles in width at its southern extremity but northwards over the River Esk its outcrop extends laterally. On its eastern side the granite forms high ground but westwards it descends towards the coastal plain where its intrusive relationships are masked by the downfaulted New Red Sandstone and later drift covering. Two main types of granite have been recognized and are referred to in the Gosforth Memoir (Trotter, et al, 1937) as normal granite and granodiorite. The Survey regard the Eskdale Granite as a stock though it may have local transgressions. Although the dating of the granite is problematical stratigraphical and structural relations suggest the intrusion to be connected with Devonian earth movements (Simpson, 1934, Mitchell, 1955-6). Potassium-argon dating (Miller, 1962) yields the age of the Eskdale granite as 383 $\pm$ 2 million years which supports the proposed Devonian age.

(c) Carboniferous

The Carboniferous rocks occur predominantly in the Furness region though in and around Millom there is a faulted block of Carboniferous (Fig.2). The Basement Beds, which unconformably overlie the older rocks are represented by alternations of shales, conglomerates and limestones. Their thickness is variable reaching up to 626 feet beneath the mines at Hodbarrow (Kendall, 1925). Mitchell (1955-6) suggests the variations in the conglomerate thickness near Millom to be due to infilling of hollows in the pre-Carboniferous land surface. The overlying Carboniferous Limestone (Kendall, 1925) reaches over 870 feet thickness at Kirksanton in the northern block while a thickness greater than 1,190 feet has been recorded at Ronhead in Furness, both thicknesses being obtained from boreholes. The Limestone can be regarded as a single bed with only a few interbedded shales near the top and bottom. It has been quarried both for its limestone and for its rich haematite content which occurs either in sops or in mineralized fault fissures (Eastwood, et al, 1937) trending along two predominating directions, one east-west the other north west-south east. At Gleaston in Furness boring shows that the Yoredale succession of shales, limestone and sandstones reaches 1,098 feet thick (Kendall, 1925) while north eastwards at Sowerby Wood only 132 feet of Yoredales were found (Kendall, 1925). Although there is no single section through all of the Carboniferous strata it is evident that in and around Stainton in the Furness district one may expect the Carboniferous to exceed 2,000 feet. The Carboniferous rocks have undergone considerable faulting both during and since the Hercynian orogeny but estimation of the throw of many of the faults is not possible as the Carboniferous Limestone contains few marker horizons. The limestone outcropping south of Silecroft is believed by the Geological Survey (Trotter, et al, 1937) to form the southern limb of a Hercynian anticline whose axis possibly runs east-west and from which the Carboniferous rocks were denuded prior to Permo-Triassic deposition. Following the Hercynian earth movements there followeda period of denundation before the Permo-Triassic was deposited.

(d) Permo-Triassic

Evidence concerning the Permo-Triassic deposits has come essentially from boreholes as natural outcrops are few due to erosion susceptibility and cover of later drift deposits. Old quarries particularly at Hawcoat and Furness yield information concerning the St. Bees Sandstone and also provided suitable sampling localities. Nowhere however is the St. Bees Shale exposed. In the Furness district (Rose and Dunham, 1938) the Permo-Triassic is bounded to the north by the east west running Sandscale fault and on its east by the Yarlside fault system running south as far as Bowesfield. From here the boundary runs eastwards to Newbiggin. In the Furness district one of the earliest records is that of the Davy Street borehole in Barrow ("Furness Lore," 1900-6), when boring reached a depth of 2,950 feet revealing the following succession.

		Depth
	New Red Sandstone	98 feet
St. Bees Shales	marly gypsum	2,276 feet
	gypsum	2,610 feet
	grey gypsum	2,770 feet
	dark grey limestone	2,829 feet
	sandstone	2,833 feet
	shale	2,891 feet
	Carboniferous shale and sandstone.	2,924 feet

Two miles to the north east at Furness Abbey a borehole penetrated 1,950 feet of New Red Sandstone before reaching the underlying rocks. West-north-west of this latter locality at Sowerby Wood (Kendall, 1925) 500 feet of New Red Sandstone overlies 25 feet of Magnesian Limestone which in turn unconformably overlies the Yoredales. At Gleaston (Kendall, 1925) to the south east 590 feet of New Red Sandstone overlies 65 feet of Magnesian limestone which is underlain by the Yoredales.

The Geological Survey (Rose and Dunham, 1938) published the following general succession in the Furness district as obtained from borings and wells.

	thickness
red marl with rock salt and gypsum	1,260 feet +
grey and white sandstone	300 feet +
red gritty sandstone with thin white sandstone	2,500 feet +
red and grey shale with gypsum and anhydrite	0-660 feet
Magnesian Limestone	0- 65 feet

These values are subject to much variation within the area as suggested by the above and the following evidence. (Rose and Dunham, 1938). In the neighbourhood of Sandscale and Thwaite Flat the New Red Sandstone appears to rest directly upon the Carboniferous, while intervening at the nearby Bouth Wood is a 400 feet thick conglomerate containing a bed of Magnesian Limestone. Southwards from Sandscale the St. Bees Shale division thickens rapidly reaching a maximum at the Davy Street borehole.

Beneath the drift covered Walney Island borings have shown that the rocks consist almost wholly of marls and salt beds, the latter up to 175 feet thick. This series belongs to the Keuper and its presence is believed to be due to a major north north west-south south east fault running through North End Haws, Buccleugh Dock then between Piel Island and the southern end of Walney Island. This fault is probably a continuation of the Boundary Fault recognized north of the Duddon Estuary. In this northern area the only recorded exposure (Trotter, et al, 1937) of Permo-Triassic deposits is at Langley of 15 feet of red sandstone dipping west-south-west 20° and believed to be of the Kirklington type which is found at Seascale, four miles north west of Ravenglass. Boring at Lane End near Bootle (Trotter, et al, 1937) penetrated 2,249 feet of New Red Sandstone without reaching the base, nor did the bore at Haverigg (Kendall, 1925) which reached a thickness of 1,396 feet. The deep bore (Gregory, 1915) at Seascale (Fig.1), although out of the area of the gravity survey sheds light upon the New Red Sandstone succession and distribution within the area. The bore reached a depth of 3,200 feet and was still in the New Red Sandstone. Close examination of the core suggests that the strata penetrated down to 2,072 feet does not belong to the St. Bees Sandstone but to the Kirklington Sandstone of Keuper Age. The St. Bees Sandstone is characterised by alternations of red sandstone and shales and this was found below 2,072 feet but above this is a very thick sandstone 2,047 feet, separated only by a five feet shale band. Possible infilling of an ancient valley could result in a thickness of

3,200 feet for the St. Bees Sandstone, elsewhere estimated to have a maximum thickness of about 1,800 feet, but exposures at Seascale and microscopic examination, of the sediments do suggest the thick upper sandstone to belong to the Kirklington Sandstone of Keuper Age. This would give a much greater thickness of Keuper at Seascale than at Carlisle, 40 miles to the north east, but would be expected if one approached the centre of a depositional basin off the south west Cumberland coast. The Kirklington Sandstone at Seascale would represent part of the lower Keuper formations while the marls on Walney Island would be part of the upper Keuper.

(e) The Boundary Fault

Separating the New Red Sandstone from the Eskdale Granite, Skiddaw Slates and Borrowdale Volcanics is the north-north-west running Boundary Fault (Fig.2) whose westerly downthrow calculated from boring in the Gosforth district (Trotter, et al, 1937) is 700 feet decreasing in magnitude to the north. The presence and thickness of sandstone of the Kirklington type around Bootle in close proximity to the Eskdale Granite suggests a major fault of considerable downthrow which is believed to be a continuation of the same Boundary Fault. At Kirksanton, five miles south-south-east of Bootle, the Boundary Fault (Eastwood, et al, 1937) as seen in an old mine at Old Whicham separates the Carboniferous Limestone from the Skiddaw Slates while further south the fault has several smaller north-north-west branches, the most westerly of which runs down through Haverigg to form the western boundary of the Carboniferous against the New Red Sandstone. The possible continuation of the Boundary Fault across the Duddon estuary to the northern end of Walney Island with further extensions has been previously mentioned.

Possibly connected to the same movements which produced the Boundary Fault was the Tertiary doming of the Lake District as a whole, which resulted in the present peripheral outcrops of the ancient sediments due to their erosion from the higher ground.

(f) Pleistocene and Recent

The Glacial Epoch modified the topography to more or less its existing relief and deposited considerable thicknesses of drift, the greatest extent of which is to be found of sands and gravels between Roose, Rampside and Newbiggin and believed to be the result of deltaic activities (Rose and Dunham, 1938). On the coastal strip between the River Esk and the Duddon Estuary is a continuous stretch of mixed drift (Mackintosh, 1871) comprising of sands, gravels and boulder clays, the latter containing boulders of which 90% originated from the Eskdale Granite. On the cliffs north of Silecroft one finds stratified sands, clays and gravels attaining a thickness of 100-120 feet.

CHAPTER II THE GRAVITY SURVEY

Geological Survey in relation to Pendulum House, Cambridge, together with the results obtained on the run are as shown in Table I.

Gravity station	value of gravity (mgal)	A differences in gravity (mgal)	B differences in instrument reading (scale divisions after drift correction)	Calibration factor (A/B mgals/scale division)
Newcastle	241.51			
		15.87	191.1	.083040
Durham	225.64			
		44.06	528.8	.083321
Northallerton	181.58			
		31.72	381.6	.083124
York	149.86			
Newcastle-York		91.65	1101.5	.083205

Table I - Summary of data obtained in determination of the Calibration Factor of the gravimeter

Maximum drift of the instrument encountered on the run amounted to 1.3 scale divisions over a period of 1½ hours, the average drift was approximately 0.25 scale division per hour.

From the above results the calibration factor determined for the Frost gravimeter used in the survey was

.083205 ± 0.000116 mgals/scale division.

CHAPTER III DETERMINATION OF ROCK DENSITIES

3.1. Rock densities

The density values of the rocks were required for two purposes, the elevation correction and the interpretation of the gravity results from the Bouguer anomaly. Samples were chosen from different localities within the area to give a representative selection for each formation, then brought back to be measured in the laboratory. The results are shown in Table II. The values for standard error and standard deviation are given for average densities between localities, differences between densities of individual rock specimens within any one locality being usually smaller.

Formation	No. of localities	No. of specimens	Mean saturated density ± standard error of the mean (grm/cm^3)	Standard deviation (grm/cm^3)	Mean dry density ± standard error of the mean (grm/cm^3)	Standard deviation (grm/cm^3)
Borrowdale Volcanics and Skiddaw Slates.	4	27	2.772±0.033	0.058	2.761±0.033	0.058
Silurian	2	17	2.656±0.051	0.051	2.637±0.051	0.051
Carboniferous Lmst. series.	3	32	2.686±0.030	0.042	2.675±0.030	0.042
Eskdale Granite.	2	15	2.702±0.052	0.052	2.689±0.051	0.051
New Red Sandstone.	4	33	2.336±0.018	0.099	2.131±0.007	0.042

Table II Summary of sample density values.

It is of interest to notice the variation of densities between localities with the same rock formation where such variation is marked. This is especially so in the Borrowdale Volcanic series whose density range is indicative of the differing lava types. A further density contrast is that between the granite and denser granodiorite of the Eskdale Granite, this, together with the variation in the Ordovician rocks, is shown in Table III.

Formation	No. of localities	No. of specimens	Mean saturated density ±standard error of the mean (grm/cm^3)	Standard deviation (grm/cm^3)	Mean dry density ±standard error of the mean (grm/cm^3)	Standard deviation (grm/cm^3)
Borrowdale Volcanics.	1	7	2.826±0.015	0.037	2.818±0.106	0.260
do.	1	6	2.703±0.024	0.053	2.695±0.003	0.007
Skiddaw Slates.	1	6	2.775±0.026	0.058	2.760±0.030	0.067
do.	1	8	2.785±0.022	0.059	2.772±0.018	0.048
Eskdale Granite.						
granite.	1	8	2.696±0.047	0.125	2.681±0.002	0.005
granodiorite.	1	7	2.707±0.011	0.028	2.696±0.011	0.028

Table III Variation in rock densities within individual formations

In laboratory determinations of rock densities from samples three sources of error are introduced.

(i) Marked variation of lithology in any formation.

This is demonstrated by the Carboniferous with its alternations of shales, sandstones and limestones. The limestones were by far the dominant outcropping representative in the area giving for the Carboniferous a mean density of

2.686 grm/cm^3. In south west Scotland (McLean, 1961) and the Alston Block (Bott and Masson-Smith, 1957) a lower value of the order of 2.54 grm/cm^3 was used incorporating densities of sandstones, shales and limestones. If thicknesses of shales and sandstones comparable to those of the limestones are present in the area then it is evident that a greater density contrast to the Lower Palaeozoic rocks would be required in interpretation. A mean density of 2.656 grm/cm^3 for Silurian rocks is lower than those found for the same formation around Dumfries (Bott and Masson-Smith, 1960) and in the Clee Hills - Nuneaton area (Cook, Hospers and Parasnis, 1952) and again probably due to varying lithologies.

(ii) Compression with depth due to overburden.

This particularly effects younger sediments as in the New Red Sandstone at Barrow with a thickness exceeding 2,500 feet ("Furness Lore" 1901-6). It results in an increase in density with depth giving a corresponding reduced density contrast. The more satisfactory method of mean density determination of younger sediments by measurement of the vertical change in gravity down a mine shaft (Hammer, 1950) was not possible as mine shafts in the area penetrated only Carboniferous strata. Nettleton's (1939) method for near surface density determination by a gravity traverse over a topographic feature was hot possible as the New Red Sandstone gave very little relief.

(iii) Surface exposures provide samples with increased porosity due to weathering and give an estimate of saturated density slightly less than their true value.

Of the rock types present in the area it was found that the Eskdale Granite had suffered the most through weathering making fresh samples difficult to find.

Density values used in the elevation correction were

New Red Sandstone..	2.33 grm/cm^3
Eskdale Granite	2.65 grm/cm^3
Carboniferous.	2.60 grm/cm^3
Silurian.	2.72 grm/cm^3
Borrowdale Volcanics and Skiddaw Slates ..	2.77 grm/cm^3

Density contrasts between the major rock groups necessary for interpretation were obtained from Table II using mean saturated densities and are estimated as:-

Lower Palaeozoic and New Red Sandstone. ..	.44 grm/cm^3
Lower Palaeozoic and Carboniferous	.09 grm/cm^3
Carboniferous Limestone series and New Red Sandstone	.35 grm/cm^3

CHAPTER IV ERRORS OF THE GRAVITY SURVEY

Errors introduced, both systematic and random, can be broadly classified into those due to instrumental variations and those occurring in the correction of the results.

4.1. Errors in measured gravity

1. Errors in the setting up of the base stations using the values of gravity previously determined at Muncaster and Duddon Bridge resulted in a closing error of 0.13mgal.

2. The net drift of the instrument during the survey averaged 0.05mgal. per hour, drift being assumed linear over the maximum period of two hours taken for any one run. The day to day drift of the instrument was random and much greater than any long term drift of the instrument, the latter thus being neglected. The standard error of the value of gravity at any one station was obtained by reoccupying four of the stations and was found to be ± 0.15mgal.

3. An accurate calibration of the instrument was not completed until after the survey was finished and results tabulated. In using a slightly incorrect calibration factor in calculating the anomalies a systematic error of 0.0002mgal. per scale division resulted producing a maximum error at one station of 0.05mgal. At the majority of stations however, the error was considerably less than this value.

4. The possibility of misreading the instrument has been neglected as each reading was double-checked.

4.2. Errors in reduction of results

In obtaining the Bouguer anomaly of any station corrections are made for latitude, elevation and terrain, each introducing further errors.

1. An error in the station position of one second of latitude causes an error of ± 0.024mgal. Latitudes are correct to one second read from the six inch to one mile map, thus random latitude errors never exceeded ± .02mgal.

2. The combined elevation correction (Free air correction - Bouguer correction) causes a random error of ± 0.064mgal. per foot in error for a density value of 2.33 grm/cm^3. Bench marks give station heights to an accuracy of 0.5 feet and spot height to one foot, so the error caused by elevation of stations resulted in a maximum of ± 0.06mgal.

3. The above assumes the density value as correct but taking a density uncertainty as ± 0.10 grm/cm^3, the anomaly for the granite would be most effected as it has the greatest elevation, giving a value of about ± 0.60mgal. difference from that plotted. This is calculated from the Bouguer correction which is dependent upon density, an error of 0.1 grm/cm^3 producing a systematic error or ± 0.00128mgal. per foot. Standard errors for the other density values are likely to be much lower than this and also their rocks form much lower relief producing errors of less than ± 0.2mgal. Where the densities were in doubt due to drift covering the underlying geological boundaries the two adjacent density values were taken and the Bouguer anomaly calculated for each. The value of the anomaly which fitted best into the Bouguer anomaly map (Appendix IV) was plotted, the other value appearing in the brackets in the tabulated results (Appendix III) for the station concerned.

4. The terrain corrections were computed using a programme derived by Dr. M. H. P. Bott (1959) for the Pegasus computer,

King's College, Newcastle. Calculated in this way one may get discrepancies of up to 5% compared to the zone chart method of Hammer. Terrain corrections never exceeded 2.55 mgals. in the survey area, hence the computed values are correct to ± 0.13mgal. Average terrain corrections were of the order of about 0.7mgal. showing a computed error of less than ± 0.04 mgal.

4.3. Combined error

From the non-systematic errors discussed above it is considered that the maximum uncertainty likely to be encountered in the Bouguer anomaly of any station is ± 0.5mgal.

CHAPTER V THE GRAVITY ANOMALIES

5.1. Regional Field

The Bouguer anomaly can be resolved into two components, that due to the regional field and that due to near surface structures producing the local or residual field. The regional field usually has a deep origin and in the region studied its value and strike are assessed by studying the Bouguer anomaly over the outcropping Lower Palaeozoic rocks. An accurate determination of its value necessary for interpretation purposes cannot be guaranteed as its consistency is uncertain, thus the estimated value is possibly one or two milligals in error. The strike of the undisturbed Bouguer anomalies over the area studied is not immediately recognizable from the Bouguer anomaly map (Appendix IV) but by comparing the region studied to the Bouguer anomaly map of north west England (M. H. P. Bott, private communication) it is evident that the regional anomalies strike north west-south east. This is approximately the direction of the isogals seen on the Bouguer Anomaly map (Appendix IV) which fall over the outcropping Silurian rocks. However it is noticeable that this north west-south east strike of the steady regional field is greatly disturbed as the coast is approached, due to the influence of the local field producing what would otherwise appear to be a gravity high centred north east of Dalton-in-Furness and caused almost solely by the underlying geological structures. The regional field increases towards the Irish Sea by approximately one milligal per mile and by extrapolation across the area the local anomalies would appear to be superimposed upon regional values varying from between 22mgals. to 32mgals. An increase towards the Irish Sea was also found by Bott and Masson-Smith (1960) in their studies near Dumfries, and attributed to causes within the upper part of the crust.

5.2. Local field.

Superimposed upon the regional field is the local or residual field whose value is obtained by subtracting the estimated regional field from the total Bouguer anomaly. The local anomalies fall into two main groups:-

(i) Over the entire coastal strip of New Red Sandstone (Fig.2) lies a negative gravity anomaly with a minimum recorded Bouguer anomaly of 11.8mgals. (Appendix IV). The isogals in general trend north west-south east following the boundaries of the underlying New Red Sandstone deposits. In the vicinity of Silecroft a steep gravity gradient of up to 10mgals. per mile is observed. Although no readings were obtained in the Duddon Estuary it is assumed that the isogals may be continued over it to link up with similar values obtained over Walney Island and the Barrow-in-Furness region. The gravity low in this southern part increases westwards as does its counterpart north of the Duddon Estuary, but its gravity gradient is apparently less severe reaching a maximum of about 8mgals. per mile.

(ii) In the north of the area is a negative gravity anomaly resulting from the low density rocks of the Eskdale Granite (Fig.2.) However the anomaly caused by the granite mass encroaches upon that due to the adjacent coastal strip of New Red Sandstone resulting in a gravity low centred to the west of outcropping granite with a minimum recorded Bouguer value of -9.2mgals. (Appendix IV). The true minimum is probably lower than this as a detailed gravity survey of this area was not completed. The negative anomaly is roughly oval in shape with the major axis trending north north west-south south east and it has a steep gradient of gravity on its eastern and south-eastern edges of 10mgals. per mile and 14mgals. per mile respectively. Although the anomaly appears to be centred over New Red Sandstone deposits it is a combination of the anomaly due to the latter and that caused by the adjacent Granite and any interpretation of the anomaly due to the Eskdale Granite would first require the removal of the anomalous field due to the New Red Sandstone deposits.

It is on the first of the above anomalies that the interpretation was carried out. Gravity measurements taken in the Irish Sea (M. H. P. Bott, private communication) show that the anomaly due to the coastal strip of New Red Sandstone is closed on its western side before reaching the Isle of Man. Further, the steep gravity gradient observed on its eastern edge disappears to the west to average about one mgal. every two miles. The lowest recorded Bouguer value in the Irish Sea lies some thirteen miles from the coast.

CHAPTER VI INTERPRETATION

6.1. Ambiguity of gravity anomalies

For a given gravity anomaly there is no unique solution as an infinite number of mass distributions can give rise to a given anomaly. If certain assumptions are applied however it is possible to obtain a unique model from a gravity profile using a particular density contrast. Applying the converse by considering a model geologically possible within the survey area a unique gravity profile can be calculated. By a process of trial and error different geological models can be used until the theoretical anomaly approximates to the one observed. This process is a tedious one but has been greatly speeded up by computer methods which were utilized in the following interpretation.

6.2. General interpretation

The linearity and shape of the gravity anomaly suggests the cause as an underlying elongated basin of relatively low density sediments whose thickness increases westwards. The steepness and rate of change of the gradient particularly at the north part are indicative of a near surface body with a possibly faulted eastern margin (see (iv)). The abrupt north eastern margin of the anomaly correlates almost exactly with the north eastern boundary of the New Red Sandstone suggesting these rocks to be the major cause of the anomaly. Carboniferous rocks are however known to be present and must contribute to the anomaly. Drift deposits could contribute up to 2mgals. on the basis of their known thicknesses. Old Red Sandstone if present could also contribute slightly.

Certain general characteristics of the body causing the anomaly may be gained from the following data.

(i) The minimum possible thickness for a body causing an anomaly is given by the formula for the gravitational attraction of an infinite horizontal slab and is;

$$A = .01277\ \rho\ t \quad \left[A = 2\pi G \rho t \text{ c.g.s. units}\right]$$

Where A is the maximum residual anomaly change in milligals, t the thickness in feet, ρ the density contrast in grm/cm^3, and G is the gravitational constant.

The value of the residual anomaly was derived graphically by subtracting the minimum observed Bouguer anomaly from the extrapolated regional anomaly.

Taking the residual anomaly as 16.2mgals., ρ as 0.44 grm/cm^3 and substituting in the above formula a minimum thickness of 2,880 feet New Red Sandstone is required. Repeating for the Carboniferous, using a maximum density contrast of 0.2 grm/cm^3 a minimum thickness of 6,400 feet would be required. The calculated thicknesses are an underestimate as the New Red Sandstone and Carboniferous deposits do not form an infinite horizontal slab.

(ii) Bott and Smith (1958, Theorem 3 and 6) stated formulae for the estimates of the limiting depth of two dimensional and three dimensional gravitating bodies. These formulae were independent of density but Smith (1959 Theorem 3) published a more powerful formula incorporating the density contrast and second derivative notation stating:-

h(maximum depth to top of anomalous body) = $\frac{5.4\ G\rho}{A''_{max}}$ c.g.s. units

If the body is two dimensional this formula may be adapted (Smith, 1959) and improved (Bott, 1960 A) to give

$$h \leqslant \frac{2.60\ G\rho}{A''max}$$

Substituting in for $\rho = 0.44$ grm/cm^3 for New Red Sandstone and for A", the maximum rate of change of gradient (second derivative), a maximum depth of 862 feet is obtained. A Carboniferous contrast of $\rho = 0.2$ grm/cm^3 gives a maximum depth of 1,800 feet. Geological evidence from boreholes indicates that New Red Sandstone is penetrated from below the drift cover to over 2,000 feet thus covering the possible range of Carboniferous depths had the latter been the major factor causing the anomaly.

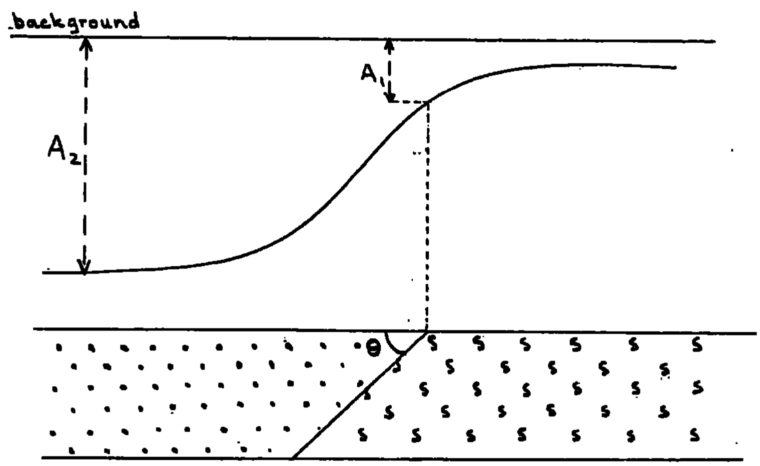
From the above lines of evidence it is fairly certain that the main cause of the anomaly is a sedimentary basin of New Red Sandstone deposits. Part of the anomaly may be due to underlying Carboniferous, Old Red Sandstone and the overlying but relatively thin drift deposits.

(iii) A second derivative or rate of change of the gradient of gravity method (Bott, 1962) for interpreting negative gravity anomalies was applied to the gravity profile taken along section AA'. The method involves taking the second derivative of gravity outwards from the centre of a region of negative gravity anomaly. If the source is a sedimentary basin the profile of the second vertical derivative shows two turning values, an outer maximum value(G" max)and an inner minimum value(G" min.). It is usually found for a sedimentary basin

G"max. > |G"min.|. The ratio $r = \frac{G'' \max}{G'' \min}$ allows distinction between inward sloping contacts as in a sedimentary basin to outward sloping contacts as produced by granite batholiths. For the former $r > 1$, the value of r increasingfrom $r = 1$ for a vertical contact to higher values as the angle of contact decreases towards the horizontal. The opposite relations hold for the second horizontal derivative. The slope of the angle of contact may suggest a faulted margin, normal faults dipping between 55 degrees to 75 degrees towards the downthrown side (Bott, 1962).

An approximate second ~~horizontal~~ derivative can be obtained directly from the gravity profile but this is inaccurate as it assumes that the gradient between two points is uniform and represented by a straight line. A more accurate method was used as described in Appendix II giving a second derivative profile shown in Fig.3. From this profile $r = 0.83$, contary to that expected for a sedimentary basin but probably due to there being too few gravity station values along the observed profile. (Fig. 3) ~~which demonstrates again the sedimentary origin of the anomaly and that it is clearly not caused by a granite~~.

(iv) A rough estimate of the angle of slope θ can be derived from the following:-



$$\frac{\text{Anomaly } A_1}{\text{Anomaly } A_2} = \frac{\theta}{\pi} \text{ radians}$$

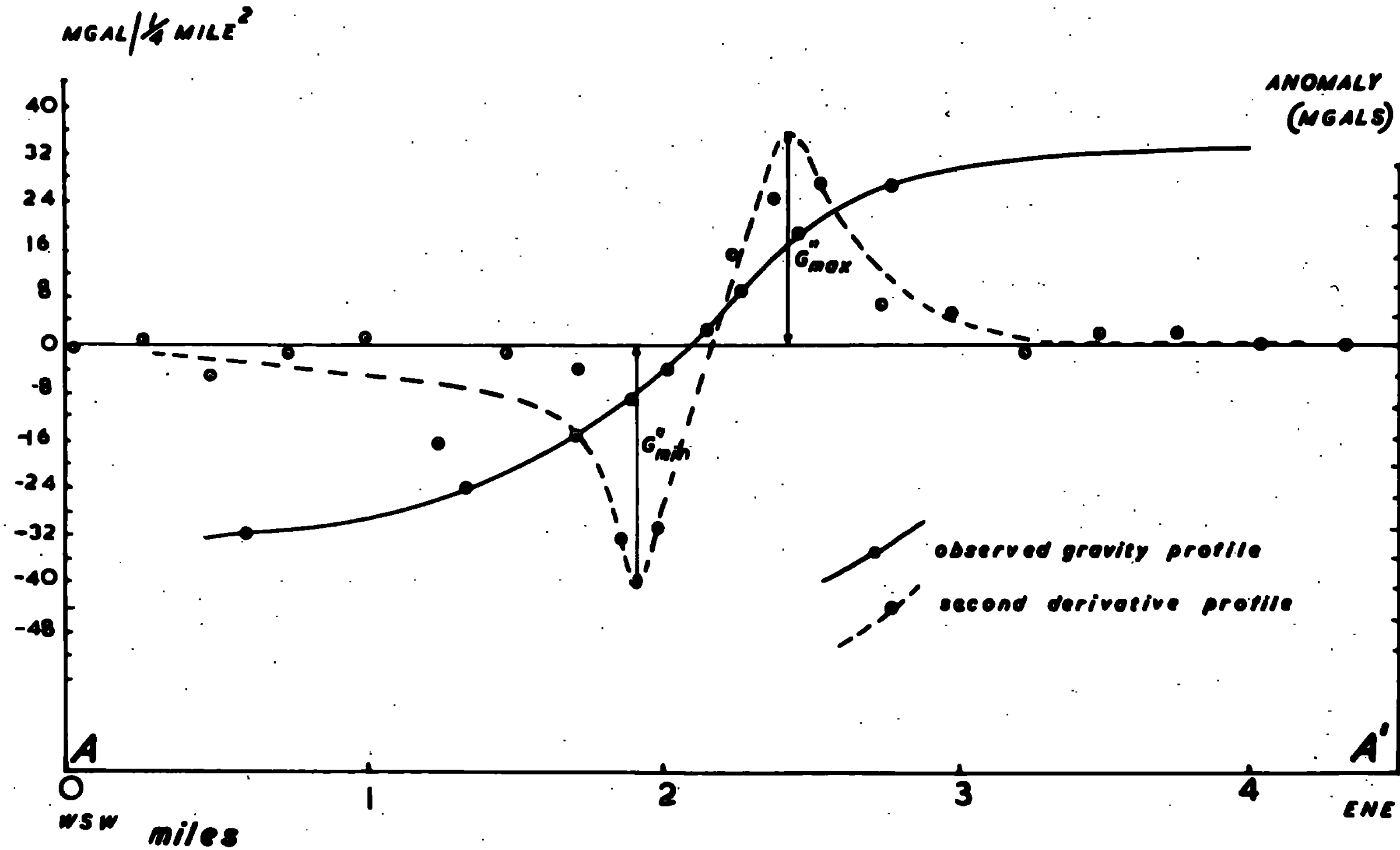


FIGURE 3. Gravity and second derivative profiles along the line AA'.

which gives, using profiles AA' and BB' (Appendix IV) angles of θ of approximately 20–25 degrees. The approximation does not distinguish whether or not the contact is the result of faulting.

(v) The gravity profile for line BB' (Fig.9) suggests that the thickening of the deposits takes place in two stages, the first on the mainland and the second, the major of the two, between the mainland and Walney Island. This latter thickening coincides with the proposed position of the Boundary Fault.

More detailed interpretation of the anomalies was performed using the computer methods.

6.3. Interpretation using computer methods

The succeeding interpretation is based upon the assumptions that the anomaly is mainly caused by New Red Sandstone and underlying sediments and also that the structure is a two dimensional one. These assumptions appear highly plausible considering the observations stated earlier in this chapter. It is further assumed that the thickening of the basin deposits stop at or near the coastline. Although this is perhaps not strictly valid it is strongly suggested from the gravity profiles drawn across line AA' (Fig.4) and line BB' (Fig.9) which show the gravity gradient approaching zero value in the west. Further support for this is obtained from gravity results recorded in the Irish Sea (M. H. P. Bott, private communication) where a seaward extension along the line of BB' shows the gradient of gravity reduced to approximately one milligal per two miles. This reduction in the gravity gradient indicates that maximum thickness is approached provided the density contrast has remained uniform.

Two computer methods were used to interpret the shape of the sedimentary basin, both programmed by Dr. M. H. P. Bott for use in the Ferranti Pegasus computer held by the University of Durham. These are:-

1) The method due to Bott (1960) obtains the shape of a two dimensional interface, of specified density contrast and specified depth at one position directly from the gravity anomaly it causes. The shape of the basin thus calculated is unique for a given gravity anomaly if one assumes that there is a single interface and the density contrast is known and uniform.

2) Talwani, Worzel and Landisman (1959) describe a computer method which calculates the vertical component of gravitational attraction of two-dimensional bodies, bounded in cross section by straight lines. It is based upon the formula for the gravitational attraction of a semi-infinite horizontal slab bounded by a sloping surface. Any polygonal shape representing a geological body may be built up using slabs of this type. The anomaly produced is obtained by adding the gravitational contributions of the slabs whose sloping interface forms the left boundary of the polygonal shape, and subtracting the contributions from the slabs forming the right boundary. This gives the gravity anomaly for the polygonal shape in question. A programme using this method is available at Durham.

Profiles across the Bouguer anomalies were drawn along the lines AA' and BB' and by means of the first of the above computer programmes the unique shape of the corresponding sedimentary basin was determined, after which the second of the above computer methods was applied.

a) Section AA'

Section AA' was drawn north of the Duddon Estuary on a line passing through Silecroft and at right angles to the isogals (Appendix IV). The results (using programme (1)) for this section are shown in Fig.4 which give the gravity profile plotted using different regional gradients over the area with the corresponding calculated anomalies. The depth of the basin in all three is greater than 2,000 feet with a maximum difference of 477 feet for the two extreme values of regional gradient variations. Using the same programme but with a constant Bouguer Anomaly profile the sedimentary basin shapes were determined for density contrasts between New Red Sandstone and Lower Palaeozic rocks of .34 grm/cm^3, .39 grm/cm^3 and .44 grm/cm^3. These shapes are illustrated in Fig.5. For the maximum error of 0.1 grm/cm^3 in density contrast a depth difference of 738 feet is encountered.

Using the second of the two programmes hypothetical basin shapes, based upon the known geology of the area were fed into the computer. The resulting calculated anomalies were compared with the observed and where agreement was unsatisfactory new shapes were introduced and the process repeated. The basin shapes, together with their anomalies, are shown in Figs.6, 7 and 8. Fig.6 shows the anomaly produced by a basin consisting of the probable maximum thicknesses, based on known geological evidence, of New Red Sandstone and Carboniferous likely within the area. The theoretical anomaly from this was greater than the observed by about 6mgals. thus the succeeding shapes were altered accordingly. A faulted contact was used in the models, the fault being positioned where the proposed Boundary Fault crossed the section AA'. Various angles of hade were used but the resulting profiles differed only slightly for different angles (Fig.7). From the anomalies calculated for hypothetical basin shapes it was found from Fig.8 that a basin with a maximum depth of 2,500 feet of New Red Sandstone and 700 feet of Carboniferous gave an anomaly ~~of 1.7mgals. in excess of~~ very similar to that observed. The depth of 2,500 feet was based upon the minimum of 2,249 feet of New Red Sandstone recorded at Lane End while the Carboniferous value was estimated from the thickness found at Kirksanton (870 feet) and Hodbarrow (626 feet). ~~To account for the 1.7mgals. difference between the calculated anomaly and that observed the thicknesses of the New Red Sandstone and Carboniferous may be altered accordingly provided they still conform to the known geology. Using the formula $A = .01277\rho t$ noted earlier in this chapter the succeeding estimates of the order of changes in thickness were calculated. Drift deposits on the coast near Silecroft reach a thickness of about 100 feet and would therefore contribute about 1mgal. leaving a further .7mgals. to be accounted for. For this either all of the 700 feet of Carboniferous (density contrast .09 grm/cm^3) can be removed leaving 2,500 feet of New Red Sandstone or the latter can be reduced by 100 feet and~~

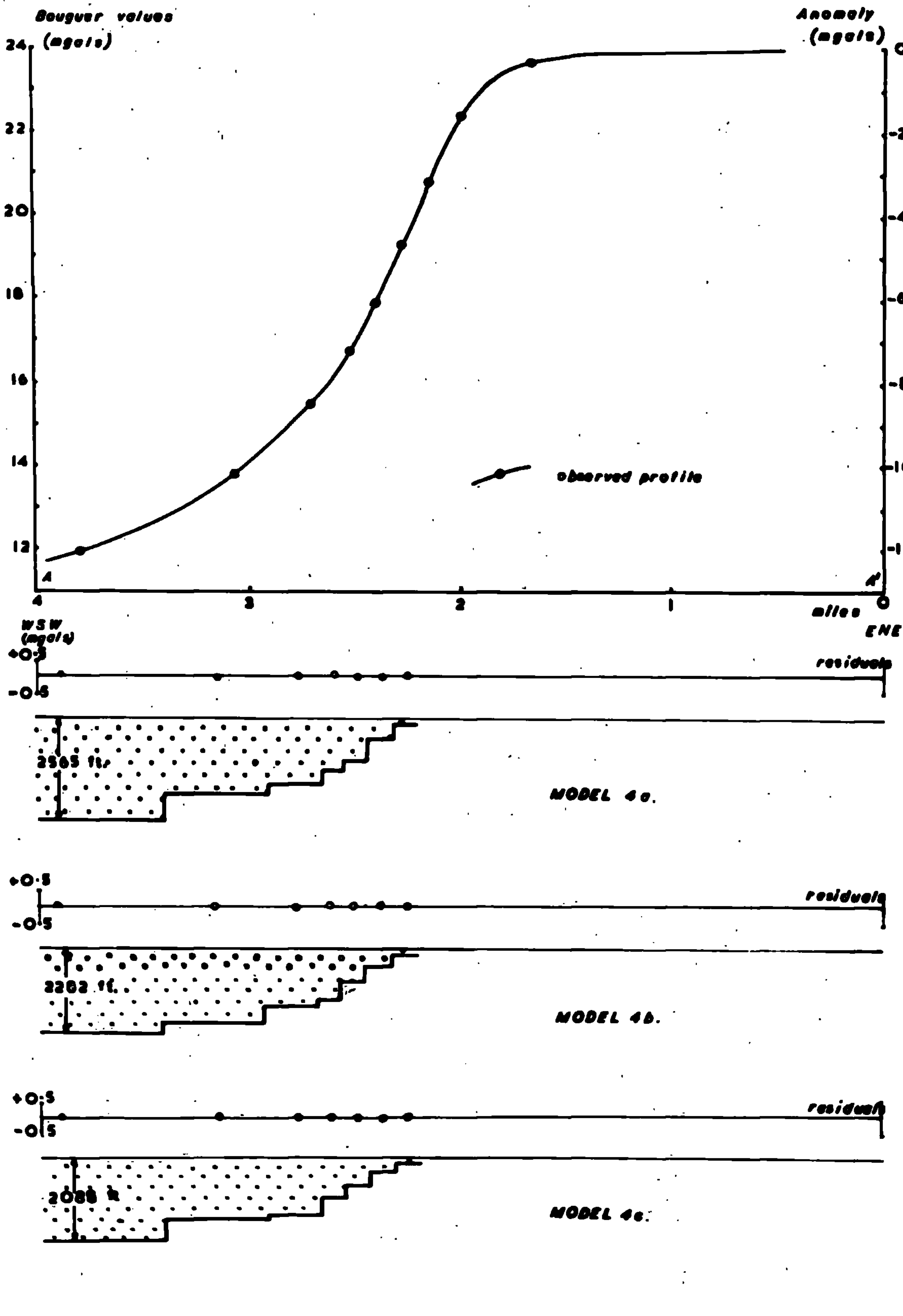


FIGURE 4. Interpreted shape of New Red Sandstone basin along section AA' using a uniform density contrast of -·44grm/cm.³
Model 4a. Regional value increasing to west by one milligal.
Model 4b. Regional value constant.
Model 4c. Regional value decreasing to west by one milligal.

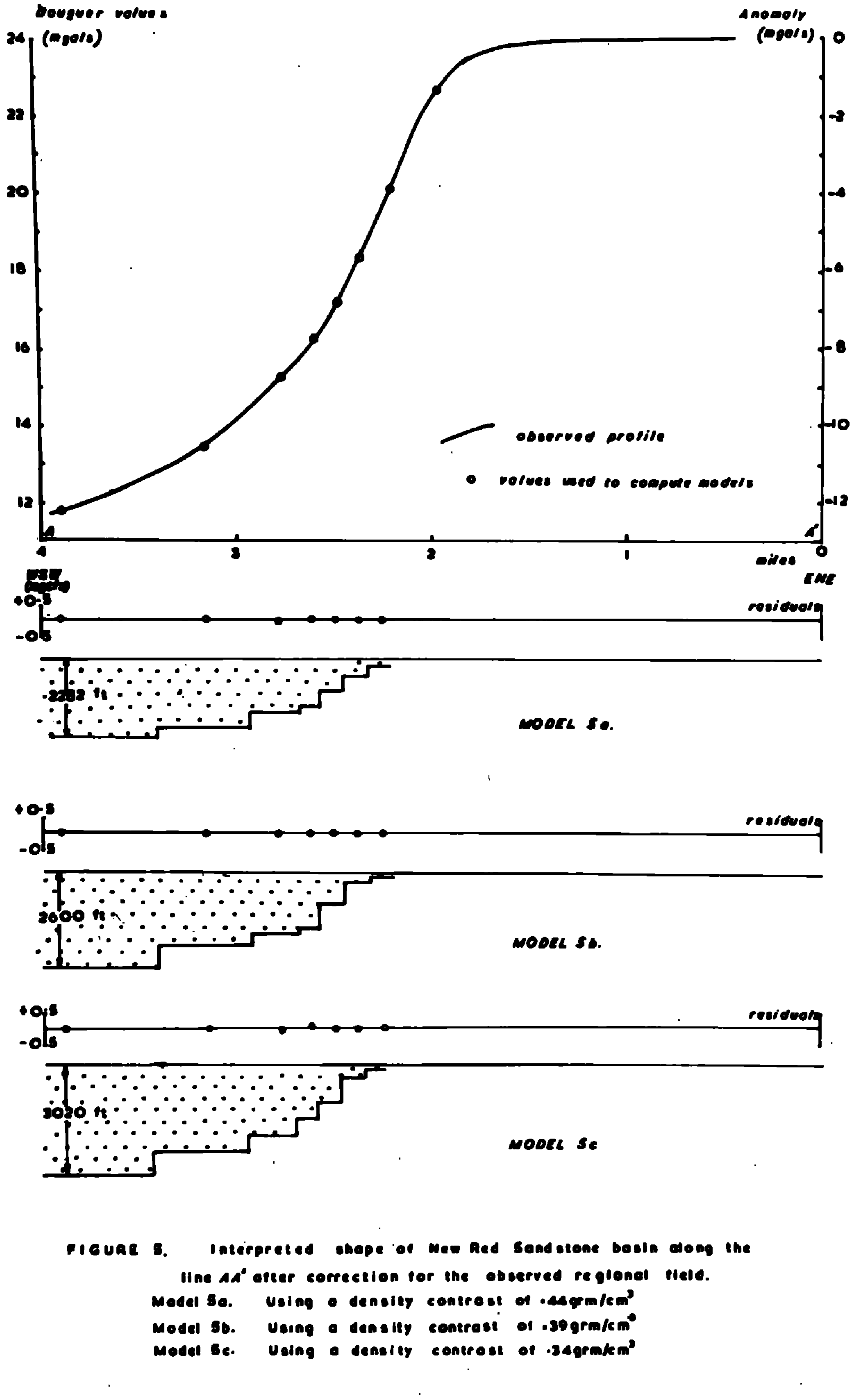


FIGURE 5. Interpreted shape of New Red Sandstone basin along the line AA' after correction for the observed regional field.
Model 5a. Using a density contrast of ·44grm/cm³
Model 5b. Using a density contrast of ·39grm/cm³
Model 5c. Using a density contrast of ·34grm/cm³

~~leave the Carboniferous. Alternatively one could reduce both the Carboniferous and New Red Sandstone provided their respective reductions when totalled did not exceed the .7mgals. error.~~ It appears therefore that providing the thickness of New Red Sandstone at Lane End is not a result of local thickening any Carboniferous present it not likely to exceed 700 feet thickness (density contrast .09 grm/cm^3), or be greater than 350 feet for a maximum density contrast of .2 grm/cm^3.

b) Section BB'

This section occurs south of the Duddon Estuary running north east-south west across the mainland and Walney Island. The procedure following was as for section AA' with the results illustrated in Figs.9, 10,11, 12, 13. One extra profile was calculated however for a polygonal shape(Fig.14)replacing the stepped basin shape of Fig.10 (model 10a), a polygonal shape being a more representative shape for a sedimentary basin providing there was no faulting of the basin floor. Comparison between the calculated anomaly and that observed shows the former to be the larger but this discrepency is to be expected as the polygonal shape was drawn so as to enclose all of the stepped basin.

In both sections AA' and BB' the respective calculated shapes of the basin are fairly constant for all assumptions of regional fields and densities, and only in the depths do differences occur caused by the use of the varying density contrasts and regional gradients.

* In Figs. 6, 7, 8, 11, 12, the calculated profile may justifiably be moved to the same level as the observed profile. This would then illustrate more fully the similarities between the two profiles particularly with reference to Fig. 8. when the observed and calculated profiles would almost coin

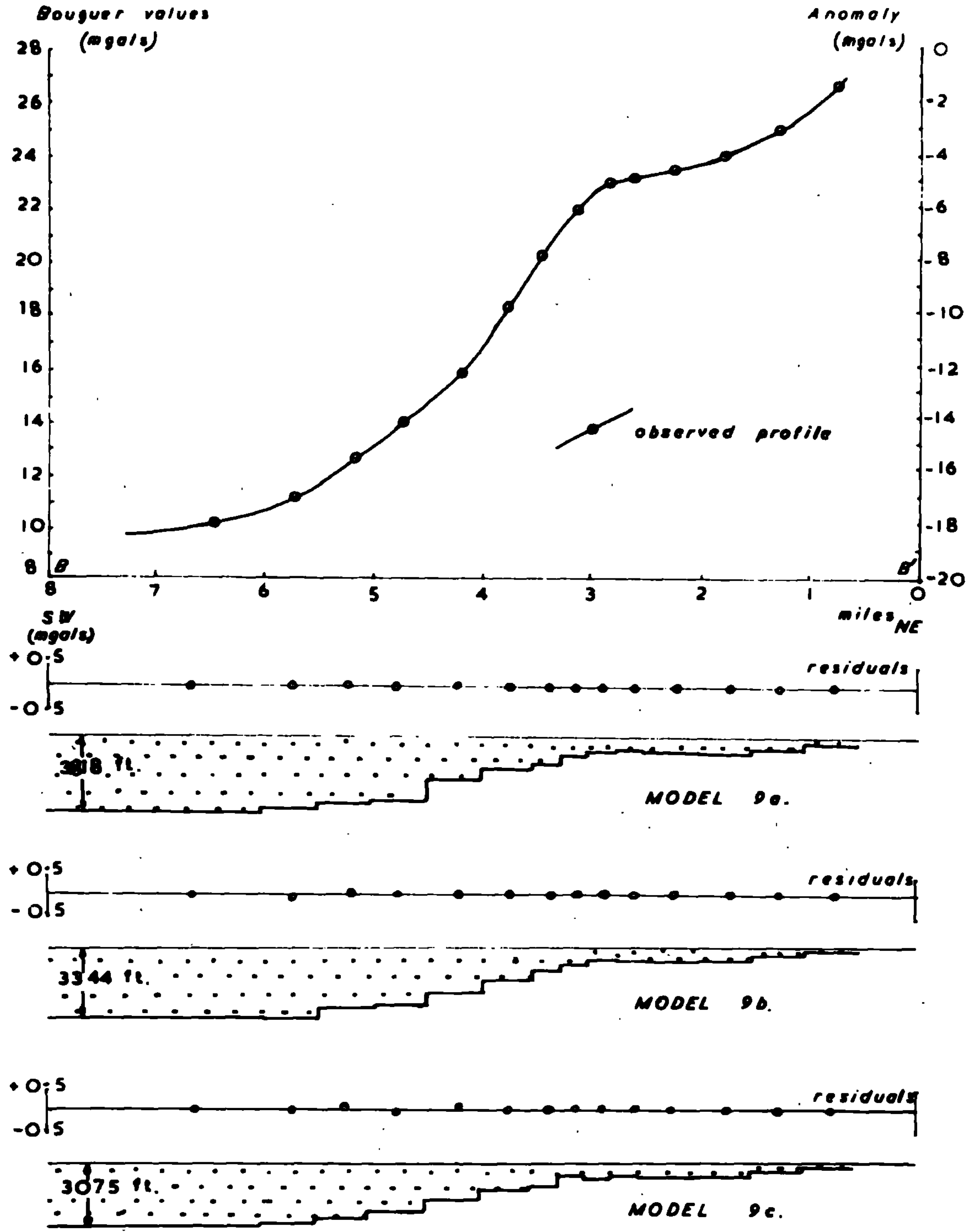


FIGURE 9. Interpreted shape of New Red Sandstone basin along line BB' using a uniform density contrast of ·44 grm/cm.^{3}

Model 9a. Regional value increasing to west by one milligal.

Model 9b. Regional value constant.

Model 9c. Regional value decreasing to west by one milligal.

6.4. Geological significance of the results

In the northern part of the area (characterised by section AA') the basin depths increase westwards towards the Irish Sea reaching a maximum thickness between the limits of 2,088 feet to 3,020 feet shown in Figs.4 and 5. The more likely value however obtained using the known density contrast and estimated regional gradient gives a thickness of the New Red Sandstone basin as approximately 2,400 feet,*which agrees with the boring evidence from Lane End and Haverigg where thicknesses of New Red Sandstone greater than 2,249 feet and 1,396 feet respectively were penetrated. The value of 2,400 feet has been calculated on the assumption that there is only one interface between New Red Sandstone and Lower Palaeozoic. If any Carboniferous rocks or Old Red Sandstone rocks are present the sedimentary basin will be deeper due to the reduced density contrast of these latter formations. Using the hypothetical models however it was deduced that if in fact any Carboniferous is present it is unlikely to exceed 700 feet in thickness, and in all probability its value may be substantially less than this as this estimate was calculated using a Carboniferous density contrast of .09 grm/cm^3, this latter calculation also allowed for the effect of the 100 feet drift covering near Silecroft.

Section 'BB', Figs.9 and 10, indicate that the order of thickness of the sedimentary basin is 3,400 feet beneath Walney Island, again a greater depth of the basin being required if Carboniferous or Old Red Sandstone are present. The interface in all cases of the calculated basin shape shows a gradual increase from its eastern edge to reach a value of around

* Greater thicknesses of sediments would be involved if (i) the sediments increase in density depth (ii) there is a higher regional gradient towards the Irish Sea than that estimated.

700 feet after one or two miles. This agrees with known geological evidence as an increase in thickness of the New Red Sandstone is observed from Thwaite Flat and the conglomerates of Bouth Wood south westwards to the deposits at Furness Abbey and Davy Street. After attaining the thickness of 700 feet the floor of the New Red Sandstone basin appears to remain relatively level for about two miles before a further thickening appears approximately between the mainland and Walney Island. This second thickening coincides almost exactly with the proposed position of the Boundary Fault. This two stage thickening is also evident from the profile across BB' (Fig.9) as previously mentioned. Disregarding the basin shapes and returning to the system of trial and error using suggested shapes a theoretical profile similar to that observed is obtained using a thickness of 3,000 feet of New Red Sandstone and 1,200 feet of Carboniferous (necessary due to the recorded 1,190 feet of Carboniferous at Ronhead).

Structurally the problem resolves itself into what is the cause of the rapid thickening, is it simple crustal downwarp or of a faulted nature. North of the Duddon Estuary the steep gravity gradient at the eastern contact of New Red Sandstone and Lower Palaeozoic suggests the boundary as a faulted one. The second derivative method applied to the section AA' indicates a normal interface as against a reversed one as found with granite batholiths. From the basin shapes calculated in Figs.4 and 5 it is noticeable that slightly to the west of the proposed Boundary Fault (Fig.2) there is a rapid westerly increase in thickness of the New Red Sandstone. A maximum increase of about a thousand feet over a quarter of a mile is attained and is suggestive of a fault or perhaps a series of closely spaced step faults downthrowing to the west. This would explain the presence of the Kirklington Sandstone at Lane End in close proximity to the Eskdale Granite and Lower Palaeozoic rocks.

A similar structure is interpreted south of the Duddon Estuary from the information gained using the section BB'. Again over the proposed extension of the Boundary Fault a further (though less severe than its northern counterpart) westerly increase in thickness of New Red Sandstone is observed. From the Bouguer Anomaly map (Appendix IV) the crowding of the isogals off the north west of Walney Island almost exactly coincident with the proposed position of the Boundary Fault also indicate this thickening. However it is noticeable from the same map that south eastwards from this crowding of isogals the gravity gradient gradually lessens eventually to show no immediate indication of rapid thickness changes. Faulting if present suggests itself as a series of step faults downthrowing to the west. This faulting which is the proposed extension of the Boundary Fault then appears to die out south eastwards soon after the line BB' is crossed, when normal crustal downwarp could account for thickness changes. Figs.9 and 10 suggest another thickening to occur in the vicinity of Bouth Wood (Fig.1). This thickening coincides with the north south running fault (Fig.2) of the Yarlside fault system (Page 7) and to this the westerly increase in thickness of New Red Sandstone is attributed.

The features of the basin suggested from the interpretation and also from the known geology indicate that the New Red Sandstone deposits probably formed in an isolated basin with its major axis running north west-south east lying slightly off and possibly parallel to the present coastline. The great thickness of the basin with its apparently isolated nature suggest that deposition was contemporaneous with crustal downwarp. There is no evidence to favour the idea that the deposit is purely a remnant of a once larger, uniform sheet. South of the Duddon Estuary the present eastern limit of the New Red Sandstone likely falls approximately over the original eastern edge, supported by the conglomerates of Bouth Wood and associated thickening of the St. Bees Shales southwards towards Barrow. To the north however no indication as to a possible original eastern margin of the basin can be seen due to the intensive faulting. The later Boundary Fault, is either a normal fault or a series of step faults downthrowing to the west, possibly formed along a line of weakness originally present during the crustal deformation which formed the New Red Sandstone sedimentary basin. However due to its apparent dying out south from line BB' the Boundary Fault suggests its formation to be associated with the larger Tertiary movements of the Lake District.

CHAPTER VII CONCLUSIONS

7.1. Conclusions

The conclusions reached from the interpretation of the gravity anomalies over Furness and south west Cumberland are:-

(i) A negative gravity anomaly runs parallel to the coastal strip of New Red Sandstone. The anomaly increases to the west with a maximum recorded residual value of 16.2mgals. and is attributed mainly to the low density sediments of the New Red Sandstone against the background of the denser Lower Palaeozoic rocks of the Lake District, but also partly due to the Carboniferous sediments and drift deposits.

(ii) Assuming that there are no deposits of Carboniferous and Old Red Sandstone beneath the New Red Sandstone then the maximum depth of the basin calculated using the observed density contrast of .44 grm/cm^3 reaches about 2,400 feet north of the Duddon Estuary and 3,400 feet to the south; these thicknesses agree with geological evidence obtained from borings. Should Carboniferous or Old Red Sandstone be present then the basin depth should be of a greater value. Although no Old Red Sandstone has been found in the area pockets could exist beneath the Carboniferous. Carboniferous rocks are however exposed in the area and the interpretation shows that across sections BB' and AA' thicknesses of 1,200 feet and 700 feet respectively of Carboniferous beneath the New Red Sandstone would be permissible. Such thickness however require a reduced thickness of New Red Sandstone of 100-200 feet but would still not conflict with known geological evidence.

(iii) It is suggested that due to the thicknesses of sediments involved deposition of the New Red Sandstone was accompanied by contemporareous downwarping of the basin.

(iv) The Boundary Fault appears more or less to follow the previously suggested strike southwards at least as far as the northern end of Walney Island. As far as this it possibly consists of either a normal fault or a series of step faults downthrowing to the west, and accounts for the higher beds of the Permo-Triassic deposits to be in close proximity to the Lower Palaeozoic rocks. Progressing southwards down Walney Island the Boundary Fault appears to be dying out leaving the main cause of thickening as probably due to crustal downwarp. Some thickening due to faulting is attributed to the Yarlside fault system but apart from this it appears likely that in south west Furness the New Red Sandstone thickens westwards without the aid of later faulting. The Boundary Fault probably formed during the Tertiary earth movements which affected the Lake District.

ACKNOWLEDGEMENTS

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APPENDICES

APPENDIX Ia

GRAVITY BASE STATION

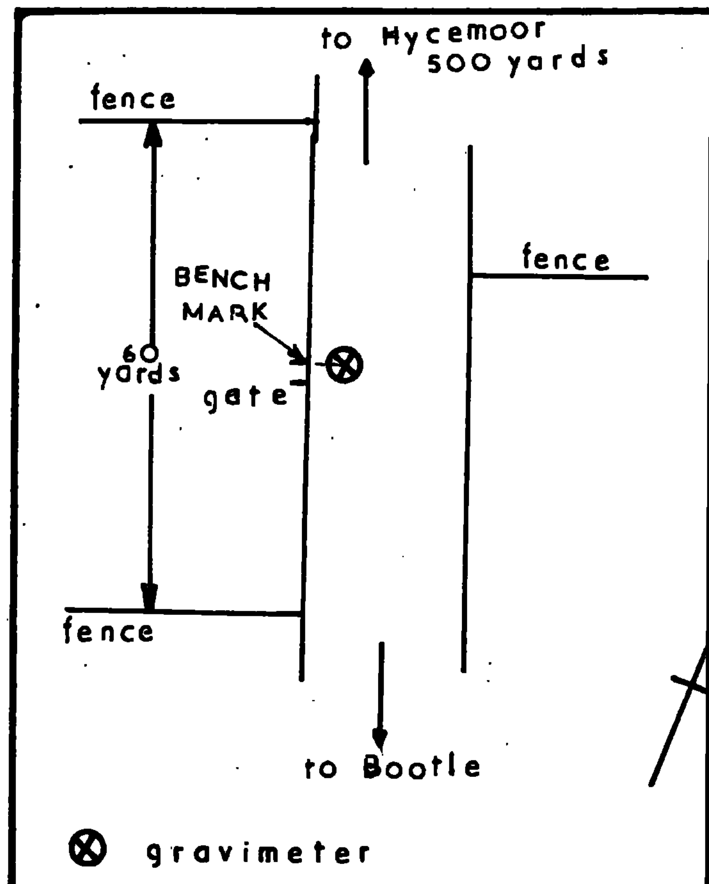
Town - BOOTLE   County - CUMBERLAND

1 inch map Sheet 88   6 inch map SD 08NE

DESCRIPTION

Situated on road to Hycemoor one mile north-west of Bootle. Bench mark on gate-post furthest from Bootle and on west side of road. Meter in line with this post and sited on road two feet from the verge.

GRAVITY	180.29mgals.
LATITUDE	54° 17' 16" N
LONGITUDE	3° 23' 15" W
ELEVATION	61.5 feet (Newlyn)
DATE	8.9.62
OBSERVER	R. G. B. Renner



APPENDIX Ib

GRAVITY BASE STATION

Town - SILECROFT   County - CUMBERLAND

1 inch map Sheet 88   6 inch map SD 18SW

DESCRIPTION

On east side of road midway between Silecroft railway station and junction with A.5093. Meter in line with and three feet from level crossing sign.

GRAVITY 204.45mgals.

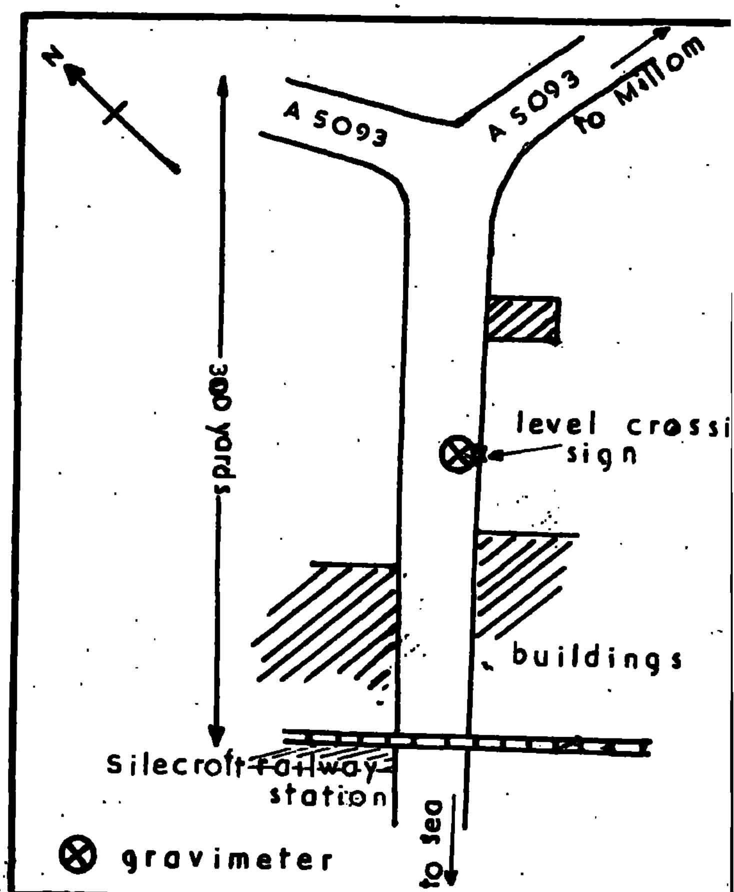
LATITUDE 54° 13' 36" N

LONGITUDE 3° 19' 55" W

ELEVATION 30.0 feet (Newlyn)

DATE 6.9.62

OBSERVER R. G. B. Renner



APPENDIX Ic

GRAVITY BASE STATION

Town - STANK County - LANCASHIRE

1 inch map Sheet 88 6 inch map SD 27SW

DESCRIPTION

On east side of road ¼ mile north of the village of Stank. Meter place on road in line with the bench mark which is on side of building.

GRAVITY 189.67mgals.

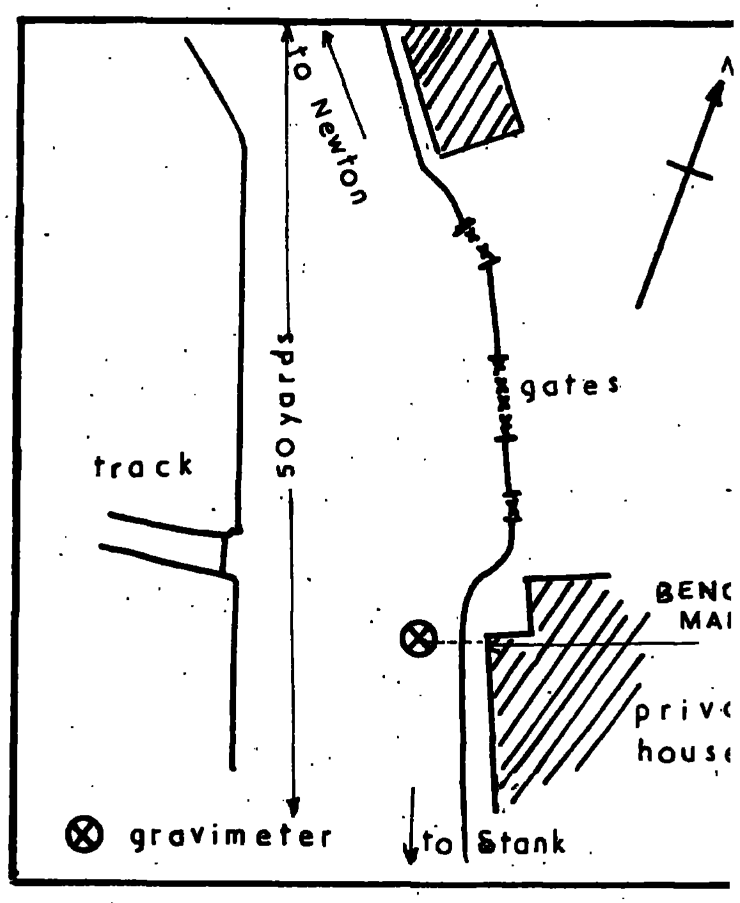
LATITUDE 54° 07' 34" N

LONGITUDE 3° 10' 32" W

ELEVATION 153.5 feet (Newlyn)

DATE 11.9.62.

OBSERVER R. G. B. Renner



APPENDIX II

Method for the derivation of the second ~~horizontal~~ derivative of gravity

The second ~~horizontal~~ derivative of gravity was obtained using the numerical method, described in 'Interpolation and Allied Tables' published by Her Majesty's Stationery Office, which is as follows.

Derivatives in terms of central differences

A function f(x) is tabulated at equal intervals h of the independent variable x; disucssion being restricted to points in the neighbourhood of a suitable tabular point x_o. An argument p where $x = x_o + ph$ is used; integral values of p correspond to tabular points but otherwise p is usually restricted to lie between o and 1. Further notational simplifications are obtained by writing.

$$f(x) = f(x_o + ph) = f(x_p) = f_p$$

First differences are formed by subtracting each value of the function from that for the following argument; they are written to the right of the function column and on the half line between the two arguments. The first difference $f_1 - f_o$ for example, is denoted by $\delta f_{\frac{1}{2}}$, or, where no confusion can arise by $\delta_{\frac{1}{2}}$. Second differences are formed from the first differences in exactly the same way and so are placed on the same lines as the function values. The second difference $\delta f_{1\frac{1}{2}} - \delta f_{\frac{1}{2}}$ is denoted by $\delta^2 f_1$, or by δ^2_1. Third and higher order differences are formed and denoted in a similar way, as indicated in the numerical and notational schemes below. Subscripts are constant along horizontal lines and this is known as the central difference notation. Arabic numerals are used to indicate the order of difference since δ may be regarded as an operator, obeying the same laws of algebra.

Argument	Function	Differences first	second	third	fourth
-2	f_{-2}				
		$\delta_{-1\frac{1}{2}}$			
-1	f_{-1}		δ^2_{-1}		
		$\delta_{-\frac{1}{2}}$		$\delta^3_{-\frac{1}{2}}$	
0	f_0		δ^2_0		δ^4_0
		$\delta_{\frac{1}{2}}$		$\delta^3_{\frac{1}{2}}$	
+1	f_1				
		$\delta_{1\frac{1}{2}}$			
+2	f_2		δ^2_1		

In the difference schemes, any quantity is equal to the result of subtracting the value diagonally above it to the left from the value diagonally below it to the left; it is also the sum of the quantity immediately above it and that diagonally above it to the right. Table IV shows the central difference scheme in operation for the derivation of the second derivative using the gravity profile shown in Fig.4.

The second derivatives in terms of central differences at a tabular point is given by

$$h^2 f_o'' = \delta_o^2 - \frac{1}{12}\delta_o^4 + \frac{1}{90}\delta_o^6 - \ldots\ldots\ldots\ldots$$

h, the distance between successive functions, being taken at quarter mile intervals in the case considered. Difference values up to δ^4_0 were taken, the contribution from $\frac{1}{90}\ \delta^6_0$ and higher terms being neglected. Table IV shows the results obtained.

When the values were plotted it was found that the critical turning values G" max and G" min lay between the tabular points x = 8h and x = 9h, and x = 10h and x = 11h respectively.

Derivatives were taken at half way points between these values using the formula

$$h^2 f_{\frac{1}{2}}'' = \mu\delta_{\frac{1}{2}}^2 - \frac{5}{24}\mu\delta_{\frac{1}{2}}^4 + \frac{259}{5760}\mu\delta_{\frac{1}{2}}^6 - \cdots\cdots\cdots\cdots\cdots$$

Values above $\delta_{\frac{1}{2}}^4$ were neglected

$\delta_{\frac{1}{2}}^2$ being the half way value between δ_0^2 and δ_1^2

$\delta_{\frac{1}{2}}^4$ being the half way value between δ_0^4 and δ_1^4

μ is an averaging operator with a defining relation of $\mu f_p = \frac{1}{2}(f_{p+\frac{1}{2}} + f_{p-\frac{1}{2}})$.

From this, values for the second derivative at the above half way points were found to be 24.73mgals./quarter mile^2 and 36.1mgals./quarter mile^2 respectively. These, together with the second derivatives at the tabular points can then be plotted (Fig. 3 in text) and the ratio $\frac{G'' \max}{G'' \min}$ determined.

x ($x = x_0 + ph$) (h in ¼ mile intervals)	δ milligals	δ_0^1	δ_0^2	δ_0^3	δ_0^4	$\frac{1}{12}\delta_0^4$	$h^2 f_0'' = \delta_0^2 - \frac{1}{12}\delta_0^4$	f_0'' mgals./¼ mile²
1	0							
		0						
2	0		0					
		0		0.1				
3	0		0.1		-0.1	-0.01	0.11	1.73
		0.1		0				
4	0.1		0.1		0.2	0.02	0.08	1.28
		0.2		0.2				
5	0.3		-0.1		0.2	0.02	-0.12	-1.92
		0.1		0.4				
6	0.4		0.3		-0.2	-0.02	0.32	5.12
		0.4		0.2				
7	0.8		0.5		0.8	0.07	0.43	6.91
		0.9		1.0				
8	1.7		1.5		-1.7	-0.15	1.65	26.40
		2.4		-0.7				
9	4.1		0.8		-1.8	-0.15	0.95	15.20
		3.2		-2.5				
10	7.3		-1.7		3.8	0.30	-2.00	-32.00
		1.5		1.3				
11	8.8		-0.4		-1.0	-0.1	-0.30	-4.80
		1.1		0.3				
12	9.9		-0.1		-0.7	-0.06	-0.04	-0.64
		1.0		-0.4				
13	10.9		-0.5		0.9	0.08	-0.58	-9.28
		0.5		0.5				
14	11.4		0		-0.6	-0.05	0.05	0.80
		0.5		-0.1				
15	11. 9		-0.1		-0.1	-0.01	-0.09	-1.44
		0.4		-0.2				
16	12.3		-0.3		0.5	0.04	-0.34	-5.44
		0.1		0.3				
17	12.4		0		-0.3	-0.03	0.03	0.48
		0.1		0				
18	12.5		0		0.1	0.01	-0.01	-0.16
		0.1		0.1				
19	12.6		-0.1		0	0	-0.10	-1.60
		0		0.1				
20	12.6		0		-0.1	-0.01	0.01	-0.16
		0		0				
21	12.6		0		0	0	0	0
		0		0				
22	12.6		0		0	0	0	0
		0		0				
23	12.6		0					
		0						
24	12.6							
25								

TABLE IV Central difference scheme for the determination of the second derivative across the gravity profile AA' (Appendix IV).

APPENDIX III

GRAVITY DATA SHEETS

The following points supplement the column headings:-

Col.1 Stations 1-227 and the base stations were occupied by the writer during the gravity survey.

Stations 360-564 were gravity stations previously occupied by Dr. M. H. P. Bott in his gravity survey of north-west England but reoccupied by the writer in the present survey. Fifty-four other stations of Dr. M. H. P. Bott's survey were used purely to gain a fuller understanding of the regional field to the east.

Cols.2 and 3. The values given are to the nearest second.

Col.6. Shows the measured gravity difference between the stations shown in Col.1 and Col.5.

Col.7. Shows the gravity value at the station entered in Col.1 as the difference from Pendulum House (Cambridge).

Col.9. Shows the Bouguer Anomaly against the International Gravity Formula at Mean Sea Level (Newlyn) based on 981.265 at Pendulum House.

Col.10. Two density values are given where the station lay above an uncertain geological boundary. Bouguer Anomalies were calculated using each density in turn, the anomaly which fitted most satisfactorily into the general trend of the isogals being plotted, and recorded as in Col.9.

Col.11. Gives the terrain correction incorporated in the Bouguer Anomaly given in Col.9 and the outermost zone compensated (Hammer nomenclature). Those stations with no given value for terrain correction are in the Furness area where due to the topography the correction could be neglected.

FILE REF. :-

GRAVIMETER SURVEY : *GRAVITY DATA SHEET*

1 OBSERVERS STATION NUMBER	2 LATITUDE N.	3 LONGITUDE (E. or W)		4 ELEVATION feet (Newlyn O.D.)	5 STATION TO WHICH CONNECTED	6 GRAVITY DIFFERENCE MEAN VALUE (milligals)	DEVIATION	7 TOTAL GRAVITY MEAN VALUE (milligals)	DEVIATION	8 FREE AIR ANOMALY (milligals)	9 BOUGUER ANOMALY ON I.G.F. (milligals)	10 DENSITY VALUES USED IN BOUGUER REDUCTION	11 TERRAIN CORRECTION (milligals)	ZONE	12 REMARKS	13 G.S.M. REFERENCE NO. OF STATION
BOOTLE	54 17 16	3 23 15	W	61·5	—	—		180·29			-4·14	2·33	0·40	M	BASE STATION	
SILECROFT	54 13 36	3 19 55	W	30·0	—	—		204·45			23·60	2·33	0·77	M	BASE STATION	
STANK	54 07 34	3 10 32	W	153·5	—	—		189·67			24·10	2·60	—	–	BASE STATION	
1	54 13 03	3 20 53	"	34·6	SILECROFT	- 8·89		195·56			15·25	2·33	0·23	M		
2	54 12 29	3 16 41	"	25·0	"	1·38		205·83			26·11	2·75	0·18	M		
3	54 12 20	3 16 39	"	38·0	"	0·12		204·47			25·30	2·60	0·16	M		
4	54 12 15	3 16 43	"	41·0	"	-0·16		204·29			25·32	2·60	0·15	"		
5	54 12 06	3 16 56	"	34·6	"	0·93		205·38			25·62	2·60	0·15	"	B.M. not found	
6	54 13 00	3 19 32	"	34·0	"	-1·63		202·82			22·61	2·33	0·30	"		
7	54 12 57	3 19 29	"	30·0	"	-1·17		203·28			22·90	2·33	0·31	"		
8	54 12 53	3 19 16	"	29·0	"	- 0·58		203·87			23·52	"	0·31	"		
9	54 12 56	3 19 09	"	35·0	"	-0·59		203·86			23·84	"	0·32	"		
10	54 12 55	3 19 02	"	23·0	"	0·53		204·98			24·36	"	0·47	"		
11	54 12 51	3 18 45	"	36·0	"	0·06		204·51			24·87	"	0·52	"		
12	54 12 46	3 18 32	"	68·0	"	-1·72		202·73			25·15	"	0·36	"		
13	54 12 41	3 18 14	"	32·5	"	1·18		205·63			25·57	2·75	0·26	"	B.M. (bench mark) not found	
14	54 12 35	3 17 34	"	42·0	"	0·28		204·73			25·31	2·75	0·20	"		
15	54 12 25	3 17 36	"	20·0	"	0·45		204·90			24·40	2·75	0·18	"		
16	54 12 14	3 17 29	"	20·6	"	-0·37		204·08			23·97	2·33	0·16	"		
17	54 12 07	3 17 39	"	29·0	"	-1·02		203·43			24·00	2·33	0·14	"		
18	54 11 58	3 17 37	"	20·0	"	-0·79		203·66			23·87	"	0·13	"		
19	54 11 54	3 17 10	"	18·0	"	-0·78		203·67			23·64	"	0·13	"		
20	54 12 53	3 19 31	"	23·5	"	-1·26		203·19			22·54	"	0·28	"		
21	54 12 48	3 19 32	"	18·5	"	-1·02		203·43			22·45	"	0·24	"		
22	54 12 44	3 19 36	"	19·5	"	-1·93		202·52			21·68	"	0·22	"		
23	54 12 42	3 19 39	"	18·0	"	-2·53		201·92			21·03	"	0·21	"		
24	54 12 36	3 19 36	"	14·5	"	-4·20		200·25			19·25	"	0·19	"		
25	54 12 32	3 19 51	"	33·0	"	-6·28		198·17			18·43	"	0·17	"		
26	54 12 27	3 19 57	"	39·0	"	-7·94		196·51			17·26	"	0·15	"		
27	54 12 18	3 20 10	"	14·0	"	-8·17		196·28			15·62	"	0·14	"		

GRAVIMETER SURVEY : *GRAVITY DATA SHEET*

FILE REF. :-

1 OBSERVERS STATION NUMBER	2 LATITUDE N.			3 LONGITUDE (E or W)				4 ELEVATION feet (Newlyn O.D.)	5 STATION TO WHICH CONNECTED	6 GRAVITY DIFFERENCE MEAN VALUE (milligals)	DEVIATION	7 TOTAL GRAVITY MEAN VALUE (milligals)	DEVIATION	8 FREE AIR ANOMALY (milligals)	9 BOUGUER ANOMALY ON I.G.F. (milligals)	10 DENSITY VALUES USED IN BOUGUER REDUCTION	11 TERRAIN CORRECTION (milligals)	ZONE	12 REMARKS	13 G.S.M. REFERENCE NO. OF STATION
28	54	17	15	3	20	24	W	643.4	BOOTLE	-22.93		157.36			7.84	2.15	1.18	M	rejected as bench	
29	54	17	14	3	20	34	"	574.3	"	-20.99		159.30			5.79	"	1.24	"	marks not found	
30	54	17	14	3	20	40	"	530.1	"	-15.59		164.70			7.99	"	1.26	"	B.M. not found	
31	54	17	15	3	20	47	"	449.8	"	-12.02		168.27			7.42	"	1.29	"	B.M. not found	
32	54	17	12	3	20	53	"	384.0	"	-9.02		171.27			6.76	"	1.44	"	rejected - B.M. not found	
33	54	17	09	3	21	05	"	280.0	"	-2.33		177.96			7.28	"	1.38	"		
34	54	17	04	3	21	11	"	311.0	"	-4.40		175.89			7.13	"	1.35	"		
35	54	17	01	3	21	23	"	252.7	"	-0.53		179.76			7.82	"	1.54	"	rejected - BM not found	
36	54	16	59	3	21	37	"	131.1	"	2.24		182.53			6.04	"	1.21	"	B.M. not found	
37	54	16	57	3	21	43	"	128.2	"	3.40		183.69			6.58	2.33	1.17	"		
38	54	16	55	3	22	02	"	78.5	"	3.24		183.53			1.21	2.33	0.91	"		
39	54	12	00	3	17	57	"	20.8	SILECROFT	-0.99		203.46			23.66	"	0.13	"		
40	54	12	05	3	18	10	"	21.65	"	-1.14		203.31			22.45	"	0.14	"		
41	54	12	10	3	18	32	"	23.80	"	-1.25		203.20			23.36	"	0.14	"		
42	54	12	13	3	18	42	"	25.36	"	-1.31		203.16			23.33	"	0.14	"		
43	54	11	54	3	17	48	"	21.0	"	-1.33		203.12			23.47	"	0.12	"		
44	54	11	51	3	17	55	"	17.8	"	-1.47		202.98			23.20	"	0.12	"		
45	54	11	48	3	18	03	"	17.35	"	-2.01		202.44			22.71	"	0.13	"		
46	54	11	45	3	18	09	"	17.75	"	-2.24		202.21			22.56	"	0.11	"		
47	54	11	42	3	18	16	"	20.35	"	-2.79		201.68			22.25	"	0.11	"		
48	54	11	40	3	18	19	W	20.85	"	-2.95		201.50			22.15	"	0.10	"		
49	54	11	49	3	18	21	"	21.25	"	-2.52		201.93			22.41	"	0.11	"		
50	54	11	52	3	18	30	"	24.45	"	-2.51		201.94			22.55	"	0.11	"		
51	54	08	28	3	06	05	"	180.1	STANK	-8.07		189.65			24.40	2.60	–			
52	54	08	25	3	07	09	"	138.0	"	2.46		192.13			24.39	2.60	–			
53	54	08	21	3	07	18	"	105.4	"	4.21		193.88			24.25	"	–		B.M. not found	
54	54	08	16	3	07	23	"	164.0	"	2.98		193.65			24.05	"	–			
55	54	08	10	3	07	31	"	108.7	"	2.47		193.14			23.97	"	–			
56	54	08	07	3	07	35	"	131.0	"	2.19		191.86			24.12	"	–			
57	54	08	02	3	07	44	"	96.1	"	4.62		193.99			24.24	"	–		B.M. not found	

· GRAVIMETER SURVEY : *GRAVITY DATA SHEET*

FILE REF. :-

1 OBSERVERS STATION NUMBER	2 LATITUDE N.			3 LONGITUDE (E. or W)				4 ELEVATION feet (Newlyn O.D.)	5 STATION TO WHICH CONNECTED	6 GRAVITY DIFFERENCE MEAN VALUE (milligals)	DEVIATION	7 TOTAL GRAVITY MEAN VALUE (milligals)	DEVIATION	8 FREE AIR ANOMALY (milligals)	9 BOUGUER ANOMALY ON I.G.F. (milligals)	10 DENSITY VALUES USED IN BOUGUER REDUCTION	11 TERRAIN CORRECTION (milligals)	ZONE	12 REMARKS	13 G.S.M. REFERENCE NO. OF STATION
58	54	07	56	3	01	49	W	65.2	STANK	5.75		195.42			23.95	2.60	—			
59	54	07	50	3	01	52	"	77.0	"	4.74		194.31			23.70	2.60	—			
60	54	07	42	3	07	56	"	45.8	"	6.24		195.91			23.59	2.60	—			
61	54	07	39	3	08	06	"	45.0	"	5.99		195.66			23.36	2.60	—			
62	54	07	[illegible]	3	08	18	"	36.0	"	6.46		196.13			23.38	2.33	—			
63	54	16	24	3	22	01	"	87.5	SILECROFT	-20.75		183.70			3.04	2.33	1.49	M	B.M. not found	
64	54	16	21	3	21	54	"	119.0	"	-21.30		183.15			4.62	"	1.29	"	B.M. not found	
65	54	16	15	3	21	49	"	128.0	"	-21.06		183.39			5.68	"	1.39	"		
66	54	16	11	3	21	49	"	123.0	"	-20.10		183.35			6.54	"	1.52	"		
67	54	16	08	3	21	47	"	112.5	"	-19.30		185.15			7.02	"	1.80	"	B.M. not found	
68	54	15	59	3	21	48	"	134.0	"	-19.07		185.38			8.71	"	1.67	"		
69	54	15	49	3	21	48	"	121.2	"	-16.87		187.58			10.37	"	1.71	"	B.M. not found	
70	54	15	40	3	21	50	"	111.0	"	-15.49		188.96			11.30	"	1.71	"		
71	54	15	37	3	21	50	"	115.0	"	-15.41		189.04			11.13	"	1.73	"		
72	54	15	25	3	21	50	"	91.0	"	-13.69		190.76			12.50	"	2.04	"		
73	54	15	23	3	21	45	"	107.2	"	-14.50		189.95			13.02	"	2.24	"		
74	54	15	19	3	21	44	"	142.9	"	-16.15		188.30			13.53	"	2.05	"	B.M. not found	
75	54	15	11	3	21	42	"	129.0?	"	-15.62		188.83			13.39	"	2.08	"		
76	54	15	08	3	21	39	"	130.0	"	-15.31		189.14			14.20	"	2.45	"		
77	54	15	05	3	21	36	"	104.0	"	-13.61		190.84			13.93	"	2.08			
78	54	14	58	3	21	31	"	117.8	"	-14.08		190.37			14.68	"	2.23	"	B.M. not found	
79	54	14	53	3	21	27	"	108.5	"	-13.08		191.05			14.76	"	2.13	"	B.M. not found	
80	54	14	13 [illegible]	3	21	08	"	113.2	"	-11.88		192.57			16.19	"	1.95	"		
81	54	14	37	3	21	01	"	114.0	"	-11.52		192.93			17.50	"	2.16	"		
82	54	14	28	3	20	58	"	115.3	"	-11.18		193.27			17.80	2.75	2.50	"	B.M. not found	
83	54	14	07	3	20	36	"	114.6	"	-9.91		195.26			20.15	2.75	2.41	"	B.M. not found	
84	54	14	02	3	20	33	"	131.0	"	-9.97		194.67			20.46	"	1.87	"		
85	54	13	56	3	20	25	"	138.0	"	-8.84		195.61			21.48	"	1.12	"		
86	54	13	53	3	20	19	"	134.9	"	-8.07		196.32			21.77	"	1.37	"		
87	54	13	44	3	20	[illegible]	"	[illegible]	"	-2.90		201.55			23.06	"	1.21	"	B.M. not found	

GRAVIMETER SURVEY : *GRAVITY DATA SHEET*

FILE REF. :-

1 OBSERVERS STATION NUMBER	2 LATITUDE N.			3 LONGITUDE (E. or W)				4 ELEVATION feet (Newlyn O.D.)	5 STATION TO WHICH CONNECTED	6 GRAVITY DIFFERENCE MEAN VALUE (milligals)	DEVIATION	7 TOTAL GRAVITY MEAN VALUE (milligals)	DEVIATION	8 FREE AIR ANOMALY (milligals)	9 BOUGUER ANOMALY ON I.G.F. (milligals)	10 DENSITY VALUES USED IN BOUGUER REDUCTION	11 TERRAIN CORRECTION (milligals)	ZONE	12 REMARKS	13 G.S.M. REFERENCE NO. OF STATION
88	54	13	46	3	20	03	W	45.9	SILECROFT	-1.29		203.16			23.18	2.75	1.10	M		
89	54	19	21	3	21	05	"	498.5	BOOTLE	-17.85		162.44			1.91	2.65	0.96	"	B.M. not found	
90	54	19	14	3	21	13	"	460.5	"	-15.49		164.80			1.98	2.65	0.82	"	B.M. not found	
91	54	19	13	3	21	27	"	385.1	"	-11.20		169.09			1.61	"	0.65	"	B.M. not found	
92	54	19	08	3	21	45	"	282.7	"	-7.51		173.78			1.77	"	0.86	"	B.M. not found	
93	54	14	22	3	22	02	"	330.4	"	-7.91		172.38			1.22	"	0.58	"		
94	54	19	31	3	22	13	"	235.0	"	-2.40		177.89			0.77	"	0.62	"		
95	54	18	38	3	24	48	"	25.60	"	0.08		180.37			-8.27	2.33	0.21	"	B.M. not found	
96	54	19	27	3	24	31	"	25.0	"	0.57		180.86			-9.21	2.33	0.25	"		
97	54	19	43	3	24	19	"	26.0	"	0.90		181.19			-9.18	2.33	0.25	"		
98	54	19	13	3	22	54	"	132.1	"	1.93		182.22			-1.87	2.65 (2.33)	0.48	"	B.M. not found	
99	54	19	21	3	22	32	"	165.6	"	1.23		181.52			0.44	2.65	0.66	"		
100	54	19	04	3	22	59	"	102.0	"	0.18		180.47			-3.83	2.33	0.50	"		
101	54	18	15	3	22	50	"	124.8	"	-2.74		177.55			-4.16	2.33	0.45	"		
102	54	17	12	3	23	19	"	100.8	"	-0.18		180.11			-1.45	2.33	0.65	"		
103	54	13	18	3	20	28	"	32.9	SILECROFT	-5.68		198.77			18.11	2.33	0.35	"		
104	54	14	20	3	19	11	"	219.0	"	-11.97		192.48			22.89	2.75	2.06	"	B.M. not found	
105	54	14	10	3	19	18	"	186.0	"	-4.56		194.89			22.99	2.75	1.46	"		
106	54	14	05	3	19	22	"	158.0	"	-7.08		197.37			23.61	"	1.14	"		
107	54	13	58	3	19	31	"	149.2	"	-6.82		197.63			23.36	"	0.97	"	B.M. not found	
108	54	13	52	3	19	48	"	88.3	"	-3.15		201.30			23.60	"	1.00	"		
109	54	12	47	3	17	21	"	31.9	"	2.04		206.49			26.35	"	0.24	"		
110	54	12	41	3	16	59	"	39.4	"	1.80		206.25			26.54	"	0.21	"		
111	54	12	43	3	16	08	"	24.0	"	4.47		206.92			26.27	2.72	0.20	"		
112	54	12	29	3	16	01	"	27.6	"	0.86		205.31			25.19	2.72	0.12	"	B.M. not found	
113	54	12	26	3	15	50	"	21.0	"	1.46		205.91			25.47	2.12	0.12	"	B.M. not found	
114	54	12	27	3	15	20	"	17.1	"	1.81		206.26			25.64	2.60 (2.12)	0.41	"		
115	54	12	24	3	14	53	"	25.5	"	1.54		205.99			25.94	2.60	[illegible]	"	B.M. not found	
116	54	12	16	3	15	51	"	23.0	"	1.06		205.51			25.43	" (2.12)	0.11	"	B.M. not found	
117	54	12	03	3	15	54	"	14.0	"	1.58		205.53			25.51	"	0.12	"		

GRAVIMETER SURVEY : *GRAVITY DATA SHEET*

FILE REF. :-

1 OBSERVERS STATION NUMBER	2 LATITUDE N.			3 LONGITUDE (E. or W)				4 ELEVATION feet (Newlyn O.D.)	5 STATION TO WHICH CONNECTED	6 GRAVITY DIFFERENCE MEAN VALUE (milligals)	DEVIATION	7 TOTAL GRAVITY MEAN VALUE (milligals)	DEVIATION	8 FREE AIR ANOMALY (milligals)	9 BOUGUER ANOMALY ON I.G.F. (milligals)	10 DENSITY VALUES USED IN BOUGUER REDUCTION	11 TERRAIN CORRECTION (milligals)	ZONE	12 REMARKS	13 G.S.M. REFERENCE NO. OF STATION
118	54	11	58	3	16	15	W	47.0	SILECROFT	-0.62		203.83			25.62	2.60	0.14	M		
119	54	07	54	3	10	36	"	236.0	STANK	-4.55		185.12			24.09	2.60	–			
120	54	08	06	3	10	45	"	188.0	"	-0.23		189.44			25.20	"	–		B.M. not found	
121	54	08	16	3	10	16	"	237.5	"	-2.76		186.91			25.44	"	–		B.M. not found	
122	54	08	22	3	09	54	"	239.0	"	-2.94		186.73			25.21	"	–			
123	54	08	36	3	10	02	"	249.6	"	-2.70		186.97			25.11	"	–		B.M. not found	
124	54	09	31	3	09	32	"	233.9	"	-2.75		186.92			24.88	"	–		B.M. not found	
125	54	08	34	3	09	31	"	141.3	"	2.94		192.61			25.35	2.33	–			
126	54	07	34	3	08	31	"	49.3	"	4.99		194.66			22.91	2.33	–			
127	54	07	30	3	08	43	"	86.1	"	2.51		192.12			22.89	"	–		B.M. not found	
128	54	07	26	3	08	41	"	59.0	"	3.90		193.57			22.63	"	–			
129	54	07	21	3	08	57	"	45.0	"	4.79		194.46			22.13	"	–			
130	54	07	16	3	09	06	"	101.5	"	1.13		190.80			22.83	"	–		B.M. not found	
131	54	07	06	3	09	10	"	113.5	"	-0.34		189.33			22.37	"	–			
132	54	06	49	3	09	34	"	93.4	"	0.55		190.22			23.39	"	–		B.M. not found	
133	54	06	49	3	09	55	"	58.7	"	2.99		192.66			22.54	"	–		B.M. not found	
134	54	06	52	3	10	07	"	96.1	"	1.0		190.67			22.94	"	–		B.M. not found	
135	54	06	51	3	07	04	"	24.48	"	5.68		195.35			23.03	"	–		B.M. not found	
136	54	04	43	3	10	20	"	21.0	"	-3.44		186.28			16.71	"	–			
137	54	05	37	3	09	42	"	93.0	"	-4.33		185.34			19.14	"	–			
138	54	06	11	3	10	13	"	84.0	"	-1.52		188.15			20.61	"			B.M. not found	
139	54	07	00	3	10	21	"	51.0	"	4.42		194.09 ~~189.85~~			23.25	"				
140	54	07	07	3	10	14	"	71.1	"	3.62		193.29			23.51	" (2.60)	–			
141	54	07	13	3	10	14	"	86.0	"	3.14		192.81			23.62	2.60	–			
142	54	07	22	3	10	18	"	102.1	"	2.70		192.37			23.15	2.60	–			
143	54	06	38	3	01	10	"	60.29	"	2.08		191.15			22.05	2.33	–		B.M. not found	
144	54	06	37	3	08	36	"	58.0	"	1.16		190.83			21.00	2.33	–			
145	54	06	31	3	08	01	"	24.51	"	3.39		193.06			21.23	"	–		B.M. not found	
146	54	05	44	3	09	02	"	22.22	"	-0.10		189.57			19.42	"	–		B.M. not found	
147	54	06	00	3	09	24	"	59.48	"	-0.90		188.77			19.95	"	–		B.M. not found	

GRAVIMETER SURVEY : *GRAVITY DATA SHEET*

FILE REF –

1 OBSERVERS STATION NUMBER	2 LATITUDE N.	3 LONGITUDE (E. or W)	4 ELEVATION feet (Newlyn O.D.)	5 STATION TO WHICH CONNECTED	6 GRAVITY DIFFERENCE MEAN VALUE (milligals)	6 DEVIATION	7 TOTAL GRAVITY MEAN VALUE (milligals)	7 DEVIATION	8 FREE AIR ANOMALY (milligals)	9 BOUGUER ANOMALY ON I.G.F. (milligals)	10 DENSITY VALUES USED IN BOUGUER REDUCTION	11 TERRAIN CORRECTION (milligals)	ZONE	12 REMARKS	13 G S M REFERENCE NO. OF STATION
148	54 06 56	3 11 14 W	48.0	STANK	2.03		191.10			20.71	2.60 (2.33)	–			
149	54 06 59	3 10 38 "	48.0	"	4.29		193.96			20.89	2.60 (2.33)	–			
150	54 17 27	3 23 36 "	64.2	BOOTLE	-1.10		179.19			-5.23	2.33	0.50	M		
151	54 17 26	3 23 59 "	59.4	"	-1.27		179.02			-5.81	2.33	0.34	"		
152	54 17 24	3 24 25 "	50.2	"	-0.88		179.41			-6.07	"	0.27	"		
153	54 17 34	3 24 27 "	42.8	"	-0.66		179.63			-6.57	"	0.26	"		
154	54 17 21	3 24 46 "	45.0	"	-1.00		179.29			-6.74	"	0.22	"		
155	54 17 31	3 25 04 "	36.10	"	-0.41		179.88			-6.75	"	0.19	"		
156	54 16 00	3 24 05 "	30.1	"	2.99		183.28			-1.46	"	0.30	"	B.M. not found	
157	54 16 02	3 23 46 "	22.6	"	4.07		184.36			-0.85	"	0.37	"	B.M. not found	
158	54 16 07	3 23 25 "	49.2	"	2.69		182.98			-0.57	"	0.43	"	B.M. not found	
159	54 15 57	3 23 06 "	31.1	"	4.98		185.27			0.90	"	0.54	"		
160	54 16 07	3 23 48 "	54.8	"	3.95		184.24			1.30	"	0.68	"		
161	54 16 25	3 22 26 "	58.9	"	3.73		184.02			1.35	"	1.11	"		
162	54 16 33	3 22 17 "	64.3	"	4.25		184.54			0.59	"	0.96	"		
163	54 17 37	3 21 36 "	300.0	"	-5.60		174.69			4.52	2.65	0.89	"	elevation taken on	
164	54 17 28	3 21 48 "	200.0	"	-0.64		179.65			3.15	2.65 (2.33)	1.02	"	contour line	
165	54 11 36	3 15 05 "	31.2	SILECROFT	1.11		205.56			24.94	2.60	0.22	"	B.M. not found	
166	54 11 38	3 15 24 "	36.1	"	0.91		205.36			27.00	2.60	0.18	"	B.M. not found	
167	54 12 01	3 14 42 "	22.7	"	1.30		205.75			26.12	2.60	0.28	"	B.M. not found	
168	54 07 31	3 07 58 "	92.0	STANK	2.91		192.58			23.33	2.60 (2.33)	–			
169	54 07 26	3 07 53 "	91.7	"	3.01		192.68			23.52	2.60	–		B.M. not found	
170	54 07 22	3 07 44 "	84.0	"	3.56		193.23			23.99	2.33	–			
171	54 07 20	3 07 18 "	80.0	"	3.98		193.65			23.93	2.60	–			
172	54 07 17	3 07 09 "	59.8	"	5.38		195.05			24.17	2.60	–		B.M. not found	
173	54 08 14	3 06 59 "	125.3	"	0.50		190.17			23.53	2.60	–		B.M. not found	
174	54 08 05	3 05 51 "	139.0	"	1.56		191.23			24.02	"	–			
175	54 08 20	3 05 28 "	188.0	"	-0.63		189.04			24.47	"	–			
176	54 09 07	3 07 45 "	130.0	"	4.30		193.97			24.13	"	–			
177	54 09 31	3 08 51 "	195.0	"	4.31		190.98			25.14	"	–			

GRAVIMETER SURVEY : *GRAVITY DATA SHEET*

FILE REF. :-

1 OBSERVERS STATION NUMBER	2 LATITUDE N.	3 LONGITUDE (E. or W)		4 ELEVATION feet (Newlyn O.D.)	5 STATION TO WHICH CONNECTED	6 GRAVITY DIFFERENCE MEAN VALUE (milligals)	DEVIATION	7 TOTAL GRAVITY MEAN VALUE (milligals)	DEVIATION	8 FREE AIR ANOMALY (milligals)	9 BOUGUER ANOMALY ON I.G.F. (milligals)	10 DENSITY VALUES USED IN BOUGUER REDUCTION	11 TERRAIN CORRECTION (milligals)	ZONE	12 REMARKS	13 G.S.M. REFERENCE NO. OF STATION
178	54 08 47	3 10 19	W	249.0	STANK	-2.39		187.28			26.61	2.53	-			
179	54 08 47	3 11 06	"	189.0	"	0.84		190.51			25.35	2.60	-			
180	54 02 55	3 10 33	"	17.7	"	-9.12		180.55			13.43	2.33	-			
181	54 03 14	3 10 37	"	20.0	"	-8.48		181.19			13.16	2.33	-			
182	54 03 06	3 10 56	"	23.1	"	-10.07		179.60			12.56	"	-			
183	54 02 57	3 11 27	"	22.0	"	-10.94		178.72			11.84	"	-			
184	54 02 56	3 11 52	"	22.0	"	-10.79		178.88			12.02	"	-			
185	54 03 08	3 12 14	"	17.0	"	-10.41		179.20			11.78	"	-			
186	54 05 42	3 13 28	"	24.25	"	-4.02		185.65			14.97	"	-		B.M. not found	
187	54 06 06	3 13 54	"	44.80	"	-4.09		185.58			15.64	"	-			
188	54 06 57	3 14 13	"	32.05	"	1.07		190.74			18.77	"	-			
189	54 07 05	3 13 34	"	34.33	"	2.15		191.82			19.18	"	-			
190	54 07 04	3 12 45	"	31.0	"	2.74		192.41			20.19	"	-			
191	54 06 29	3 13 09	"	[illegible]40.62	"	-1.14		188.53			17.77	"	-			
192	54 06 47	3 12 16	"	20.8	"	2.10		191.77			19.32	"	-			
193	54 03 22	3 12 51	"	26.9	"	-10.02		179.65			12.47	"	-		B.M. not found	
194	54 03 29	3 12 56	"	20.0	"	-9.63		180.04			12.25	"	-			
195	54 03 52	3 13 18	"	15.9	"	-8.58		181.09			12.49	"	-		B.M. not found	
196	54 03 41	3 13 15	"	20.0	"	-9.54		180.13			12.06	"	-			
197	54 04 00	3 13 22	"	14.0	"	-8.13		181.54			12.62	"	-			
198	54 04 19	3 13 35	"	11.0	"	-7.16		182.51			13.33	"	-			
199	54 05 18	3 15 00	"	27.0	"	-7.73		181.94			12.00	"	-			
200	54 05 36	3 15 14	"	26.0	"	-7.03		182.64			13.21	"	-			
201	54 06 15	3 14 42	"	48.4	"	-5.66		184.01			14.06	"	-			
202	54 06 09	3 14 51	"	40.3	"	-5.44		184.13			13.83	"	-			
203	54 07 51	3 15 23	"	44.0	"	-1.56		188.11			12.48	"	-			
204	54 06 [illegible]	3 15 37	"	64.0	"	-6.96		182.71			12.[illegible]	"	-			
205	54 06 43	3 15 21	"	25.0	"	-3.17		[illegible]			[illegible]	"	-			
206	54 06 48	3 15 06	"	38.0	"	-2.24		[illegible]			[illegible]	"	-			
207	54 06 58	3 15 01	"	11.0	"	-0.52		189.15			[illegible]	"	-			

GRAVIMETER SURVEY : *GRAVITY DATA SHEET*

FILE REF. :-

1 OBSERVERS STATION NUMBER	2 LATITUDE N.	3 LONGITUDE (E. or W)		4 ELEVATION feet (Newlyn O.D.)	5 STATION TO WHICH CONNECTED	6 GRAVITY DIFFERENCE MEAN VALUE (milligals)	DEVIATION	7 TOTAL GRAVITY MEAN VALUE (milligals)	DEVIATION	8 FREE AIR ANOMALY (milligals)	9 BOUGUER ANOMALY ON I.G.F. (milligals)	10 DENSITY VALUES USED IN BOUGUER REDUCTION	11 TERRAIN CORRECTION (milligals)	ZONE	12 REMARKS	13 G.S.M. REFERENCE NO. OF STATION
208	54 07 10	3 15 13	W	52.0	STANK	-2.99		186.68			15.67	2.33	–			
209	54 07 20	3 15 31	"	43.0	"	-2.60		187.07			15.35	"	–			
210	54 06 26	3 14 51	"	49.3	"	-5.35		184.32			14.19	"	–			
211	54 07 54	3 14 06	"	42.9	"	5.47		195.14			22.50	"	–		B.M. not found	
212	54 09 17	3 14 02	"	25.0	"	11.99		201.66			25.89	"	–			
213	54 09 17	3 12 15	"	177.0	"	1.95		191.62			25.75	"	–			
214	54 08 35	3 13 03	"	237.0	"	-4.85		185.09			23.96	"	–			
215	54 08 11	3 13 29	"	191.5	"	-2.99		186.69			23.19	"	–			
216	54 08 13	3 12 43	"	198.0	"	-3.95		185.72			22.60	"	–			
217	54 08 02	3 12 09	"	109.0	"	1.07		190.69			22.10	"	–			
218	54 07 15	3 11 56	"	45.0 ~~129.8~~	"	2.69		192.36			20.78	"	–			
219	54 08 56	3 11 17	"	151.0	"	3.69		193.36			25.68	2.60 (2.33)	–			
220	54 09 28	3 11 08	"	186.0	"	4.54		194.21			27.89	2.60	–			
221	54 09 16	3 10 23	"	171.0	"	3.72		193.39			26.44	"	–			
222	54 09 37	3 10 33	"	163.5	"	5.75		195.42			27.51	"	–			
223	54 10 13	3 10 17	"	265.0	"	0.51		190.18			27.59	"	–			
224	54 11 11	3 11 20	"	269.0	"	3.10		192.77			28.64	2.72	–			
225	54 10 53	3 12 19	"	80.7	"	12.64		202.31			27.55	2.60	–			
226	54 10 04	3 12 28	"	46.0	"	14.45		204.12			28.42	2.60	–			
227	54 10 09	3 12 41	"	109.8	"	10.83		200.50			28.50	2.60	–			
342	54 03 1[illegible]	3 12 30	"	14.[illegible]	"	-9.96		179.11			11.87	2.33	–			
343	54 04 3[illegible]0	3 13 357	"	17.0	"	-6.88		183.19			13.35	2.33	–			
344	54 06 20	3 15 25	"	52.0	"	-6.60		183.07			13.27	2.33	–			
345	54 07 44	3 12 41	"	162.10	"	-1.28		188.39			21.55	2.33	–			
359	54 08 29	3 05 28	"	113.0	"	3.71		193.58			24.16	2.60	–			
360	54 07 36	3 06 05	"	21.0	"	7.15		197.42			23.73	2.60	–			
361	54 07 06	3 06 56	"	34.0	"	6.35		195.92			23.73	2.60	–			
362	54 06 32	3 07 21	"	24.2	"	4.63		194.30			22.4[illegible]	2.33	–			
363	54 05 50	3 08 27	"	21.0	"	0.08		192.27			18.67	2.33	–			
364	54 06 15	3 07 46	"	23.0	"	2.60		189.75			20.12	2.33	–			

GRAVIMETER SURVEY : *GRAVITY DATA SHEET*

FILE REF. :-

1	2			3				4	5	6		7		8	9	10	11		12	13
OBSERVERS STATION NUMBER	LATITUDE N.			LONGITUDE (E. or W)				ELEVATION feet (Newlyn O.D.)	STATION TO WHICH CONNECTED	GRAVITY DIFFERENCE MEAN VALUE (milligals)	DEVIATION	TOTAL GRAVITY MEAN VALUE (milligals)	DEVIATION	FREE AIR ANOMALY (milligals)	BOUGUER ANOMALY ON I.G.F. (milligals)	DENSITY VALUES USED IN BOUGUER REDUCTION	TERRAIN CORRECTION (milligals)	ZONE	REMARKS	G.S.M. REFERENCE NO. OF STATION
365	54	05	17	3	09	31	W	31.0	STANK	-1.58		188.09			18.43	2.33	—			
366	54	05	03	3	10	08	"	26.0	"	-2.40		187.27			17.62	"	—			
367	54	04	27	3	10	22	"	24.0	"	-4.09		185.58			16.66	"	—			
370	54	08	39	3	07	40	"	111.0	"	3.84		193.51			23.80	2.60	—			
371	54	07	38	3	08	25	"	35.0	"	6.19		195.86			23.09	2.33	—			
372	54	07	00	3	09	16	"	111.0	"	-0.03		189.64			22.60	2.33	—			
373	54	06	33	3	11	02	"	60.0	"	0.18		189.83			20.25	"	—			
374	54	06	52	3	12	05	"	33.4	"	1.42		191.09			19.33	"	—			
375	54	08	23	3	11	57	"	131.5	"	0.37		190.05			22.42	"	—			
376	54	09	48	3	09	52	"	206.0	"	-2.99		192.66			27.08	2.60	—			
504	54	20	05	3	21	58	"	204.0	BOOTLE	-0.50		179.79			0.13	2.65	0.77	M		
505	54	19	41	3	22	33	"	117.3	"	4.28		184.57			0.08	2.65	0.63	M		
507	54	19	59	3	24	14	"	20.0	"	1.96		182.25			-8.86	2.33	0.27	"		
508	54	18	56	3	24	37	"	23.0	"	0.03		180.32			-9.13	2.33	0.23	"		
509	54	18	11	3	24	45	"	25.2	"	0.14		180.43			-7.83	"	0.22	"		
510	54	17	59	3	24	16	"	45.0	"	-0.21		179.48			-7.16	"	0.28	"		
511	54	17	44	3	23	49	"	61.6	"	-1.41		178.88			-6.25	"	0.36	"		
512	54	16	57	3	22	39	"	74.5	"	0.48		180.77			-2.20	"	0.57	"		
513	54	11	43	3	22	45	"	122.6	"	-2.96		177.33			-3.58	"	0.63	"	B.M. not found	
514	54	18	49	3	22	57	"	114.0	"	-0.86		179.43			-3.75	"	0.49	"		
515	54	15	32	3	21	51	"	102.0	SILECROFT	-14.19		190.26			12.30	"	1.31	"		
516	54	14	47	3	21	22	"	85.0	"	-11.92		192.53			15.26	"	2.55	"		
517	54	14	19	3	20	47	"	126.4	"	-10.68		193.77			19.14	"	2.48	"	B.M. not found	
518	54	12	40	3	19	52	"	36.0	"	-0.23		204.22			23.49	2.75	0.79	"		
519	54	12	24	3	20	13	"	33.0	"	-2.68		201.77			21.05	2.33	0.43	"		
520	54	13	10	3	20	40	"	49.6	"	-8.16		196.29			16.81	2.33	0.27	"		
593	54	19	04	3	21	33	"	321.7	BOOTLE	-11.26		169.05			1.40	2.65	0.58	"	B.M. not found	
620	54	12	43	3	16	27	"	32.8	SILECROFT	-0.68		203.77			27.21	2.72	0.18	"	B.M. not found	
621	54	11	47	3	17	19	"	18.9	"	-1.14		203.01			23.35	2.33	0.12	"		
622	54	12	26	3	17	43	"	28.0	"	1.28		205.73			20.48	2.75	0.22	"		

GRAVIMETER SURVEY : *GRAVITY DATA SHEET*

FILE REF. :-

1 OBSERVERS STATION NUMBER	2 LATITUDE N.			3 LONGITUDE (E. or W)				4 ELEVATION feet (Newlyn O.D)	5 STATION TO WHICH CONNECTED	6 GRAVITY DIFFERENCE MEAN VALUE (milligals)	6 DEVIATION	7 TOTAL GRAVITY MEAN VALUE (milligals)	7 DEVIATION	8 FREE AIR ANOMALY (milligals)	9 BOUGUER ANOMALY ON I.G.F. (milligals)	10 DENSITY VALUES USED IN BOUGUER REDUCTION	11 TERRAIN CORRECTION (milligals)	11 ZONE	12 REMARKS	13 G.S.M. REFERENCE NO. OF STATION
647	54	10	41	3	10	39	W	323.0	STANK	-0.91		188.76			28.55	2.72	—			
649	54	11	19	3	11	58	"	51.0	"	15.64		205.31			28.09	2.72 (2.60)	—			
651	54	09	32	3	12	47	"	116.1	"	2.39		198.06			27.39	2.60	—			
652	54	08	56	3	12	46	"	242.0	"	-4.05		185.62			24.32	2.33	—			
653	54	08	29	3	13	51	"	82.0	"	5.10		194.77			23.81	2.33	—			
654	54	06	57	3	14	13	"	32.05	"	1.07		190.74			18.77	2.33	—			
629	54	12	55	3	19	22	"	34.0	SILECROFT	-1.17		203.28			23.21	2.33	0.31	M		

UNIVERSITY OF DURHAM

FROM THE REGISTRAR
TEL. DURHAM 3355-6
In reply please quote P/Renner

UNIVERSITY OFFICE
46 NORTH BAILEY
DURHAM

4th September, 1963.

Dr. D.H. Griffiths,
Department of Geology,
University of Birmingham,
Edgbaston,
Birmingham.

Dear Dr. Griffiths,

I am enclosing herewith a copy of the thesis submitted by one of the two M.Sc. candidates - R.G.B. Renner - for whom you were appointed as external examiner, together with the abstract also submitted by this candidate. I also enclose a copy of the relevant Instructions to Examiners and two copies of a Report Form, one of which should be completed and returned to this office in due course.

I am also arranging for a copy of the candidate's thesis to be passed to Dr. Long of the Geology Department of this University, who will doubtless confer with Dr. Bott when Dr. Bott returns from America.

I will see that the thesis of the other candidate - G.G. Knott - is sent to you as soon as it is received.

Yours sincerely,

W.E. SAXTON.
Assistant Registrar.

WES/MB

Abstract of thesis submitted for the degree of M.Sc.

"GRAVITY INVESTIGATIONS OF THE PERMO-TRIASSIC DEPOSITS OF FURNESS AND SOUTH WEST CUMBERLAND"

by

R. G. B. RENNER

ABSTRACT

A detailed gravity survey was carried out by G. G. Knott and the writer on the coastal strip of New Red Sandstone of south-west Cumberland and Furness.

An account of the field work is given together with the necessary reductions of the instrument readings from which the Bouguer anomaly map was constructed. From this map the interpretation was performed using the methods described.

Two negative gravity anomalies were found, one over the New Red Sandstone deposits and the other over the Eskdale Granite. Interpretation was based only upon the former. Here the 16mgal. anomaly was attributed to the low density New Red Sandstone in relation to the adjacent denser Lower Palaeozoic rocks. Calculations aided by the use of an electronic computer showed that the New Red Sandstone basin possibly reaches a depth of 3,400 feet, while an even greater basin depth is required if there is underlying Carboniferous or Old Red Sandstone. The depths calculated conform with the known geology. The writer suggests that deposition of the New Red Sandstone occurred in an isolated basin with infilling contemporaneous with crustal downwarp.

It is further suggested that later faulting in the northern part of the area is the major cause of the westerly thickening but in the south crustal downwarp causes the thickening.

(g) The examiner recommends:

* (i) That the candidate be admitted to the degree of M.Sc.

* (ii) That the candidate be not admitted to the degree of M.Sc.

* (iii) That the candidate be not admitted to the degree of M.Sc. but be allowed to submit his thesis or dissertation in a revised form. †

* (iv) That the candidate be not admitted to the degree of M.Sc. but be allowed to submit himself for :

(a) a second oral examination
(b) a second written examination

within six months.

* words which do not apply should be deleted.

† the recommendation for re-submission of a thesis or dissertation should be made only in a case where there are defects in the presentation of what is otherwise acceptable.

Signature of Examiner ______________________

Date ______________________

Initials of Dean of Faculty ______________

UNIVERSITY OF DURHAM

DEGREE OF MASTER OF SCIENCE
IN THE FACULTIES OF SCIENCE AND APPLIED SCIENCE

EXAMINER'S REPORT

Name of Candidate ______________________ College __________

Subject of Advanced Course
or Title of Thesis ______________________________________

____

Name of Examiner ______________________________________

(The examiner is requested to answer each of the following questions where applicable and to complete sections (f) and (g).)

(a) Is there evidence of advanced knowledge of the subject of the thesis or dissertation including a satisfactory knowledge of the literature of the subject? ... ... __________

(b) Are the style and general arrangement of the thesis or dissertation satisfactory? ... ... __________

(c) Do you consider that the candidate has dealt with the subject in a competent manner displaying critical discrimination and a sense of proportion in evaluating evidence and the opinions of other? (It is not necessary that the thesis or dissertation should make an original contribution to knowledge or be worthy of publication.) __________

(d) Has the candidate been examined by written examination? __________

If so, was his performance satisfactory? ... ... __________

(e) Has the candidate been examined orally? ... ... __________

If so, were the results of the oral examination satisfactory ... ... __________

(f) General comments :-

p.t.o.

(g) The examiner recommends:

* (i) That the candidate be admitted to the degree of M.Sc.

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(b) a second written examination

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† the recommendation for re-submission of a thesis or dissertation should be made only in a case where there are defects in the presentation of what is otherwise acceptable.

Signature of Examiner ____________________

Date ____________________

Initials of Dean of Faculty ______________

UNIVERSITY OF DURHAM

DEGREE OF MASTER OF SCIENCE
IN THE FACULTIES OF SCIENCE AND APPLIED SCIENCE

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(b) Are the style and general arrangement of the thesis or dissertation satisfactory? ... ... ____________

(c) Do you consider that the candidate has dealt with the subject in a competent manner displaying critical discrimination and a sense of proportion in evaluating evidence and the opinions of other? (It is not necessary that the thesis or dissertation should make an original contribution to knowledge or be worthy of publication.) ____________

(d) Has the candidate been examined by written examination? ____________

If so, was his performance satisfactory? ... ... ____________

(e) Has the candidate been examined orally? ... ... ____________

If so, were the results of the oral examination satisfactory ... ... ____________

(f) General comments :-

p.t.o.

6. Having considered all the evidence at his disposal each examiner shall:

   (i) Present a written statement of his opinion concerning a candidate's performance.

   (ii) Make a specific recommendation about the award of the degree.

   Where the recommendation is for rejection he may, in exceptional circumstances recommend that the candidate be permitted to present his thesis or dissertation in a revised form within six months of the meeting of the Board of Faculty at which the examiner's recommendation is considered. It is intended that this provision should only apply in cases where the presentation of an otherwise acceptable thesis or dissertation is defective.

   If the candidate's thesis or dissertation is satisfactory but he fails to satisfy the examiners in the written and/or oral examination, the examiners may, in exceptional circumstances, recommend that he be allowed to submit himself for a second written and/or oral examination within six months of the meeting of the Board of Faculty.

7. The reports and recommendations of the examiners must be sent to the Registrar of the University.

8. The Registrar shall transmit the examiners' reports to the Dean of the Faculty, who may, if the examiners are agreed without qualification that the degree should be awarded, authorise the publication of the result forthwith. If they are agreed to the contrary, he may authorise the Registrar to inform the candidate of his non-success. In the event of doubt or disagreement he shall bring the matter before the Board of the Faculty, and the Board, after considering the reports, shall recommend the appointment of a third examiner, or take such other action as it may deem desirable.

   In all cases the examiners' recommendations shall be brought to the notice of the Board of the Faculty.

UNIVERSITY OF DURHAM

DEGREE OF MASTER OF SCIENCE IN THE FACULTY OF SCIENCE

INSTRUCTIONS TO EXAMINERS

1. Each candidate for the degree of M.Sc. shall be examined by two or more examiners of whom at least one shall be an external examiner.

   A candidate who is a member of the staff of the University or of either Division shall be examined by two external examiners with whom an internal adviser may be associated. If an adviser is appointed it shall be his duty to advise the external examiners on the standard required by a candidate for the M.Sc. in this University.

2. Candidates may proceed to the degree of M.Sc. by one of three methods:

   (a) by submitting a thesis;

   (b) by written examination (which may include a dissertation);

   (c) by a combination of (a) and (b).

3. The following criteria have been established in connection with theses and dissertations, and examiners are specifically asked to answer questions about them:

   (a) The candidate should show advanced knowledge of the subject of the thesis or dissertation, including a satisfactory knowledge of the literature of the subject.

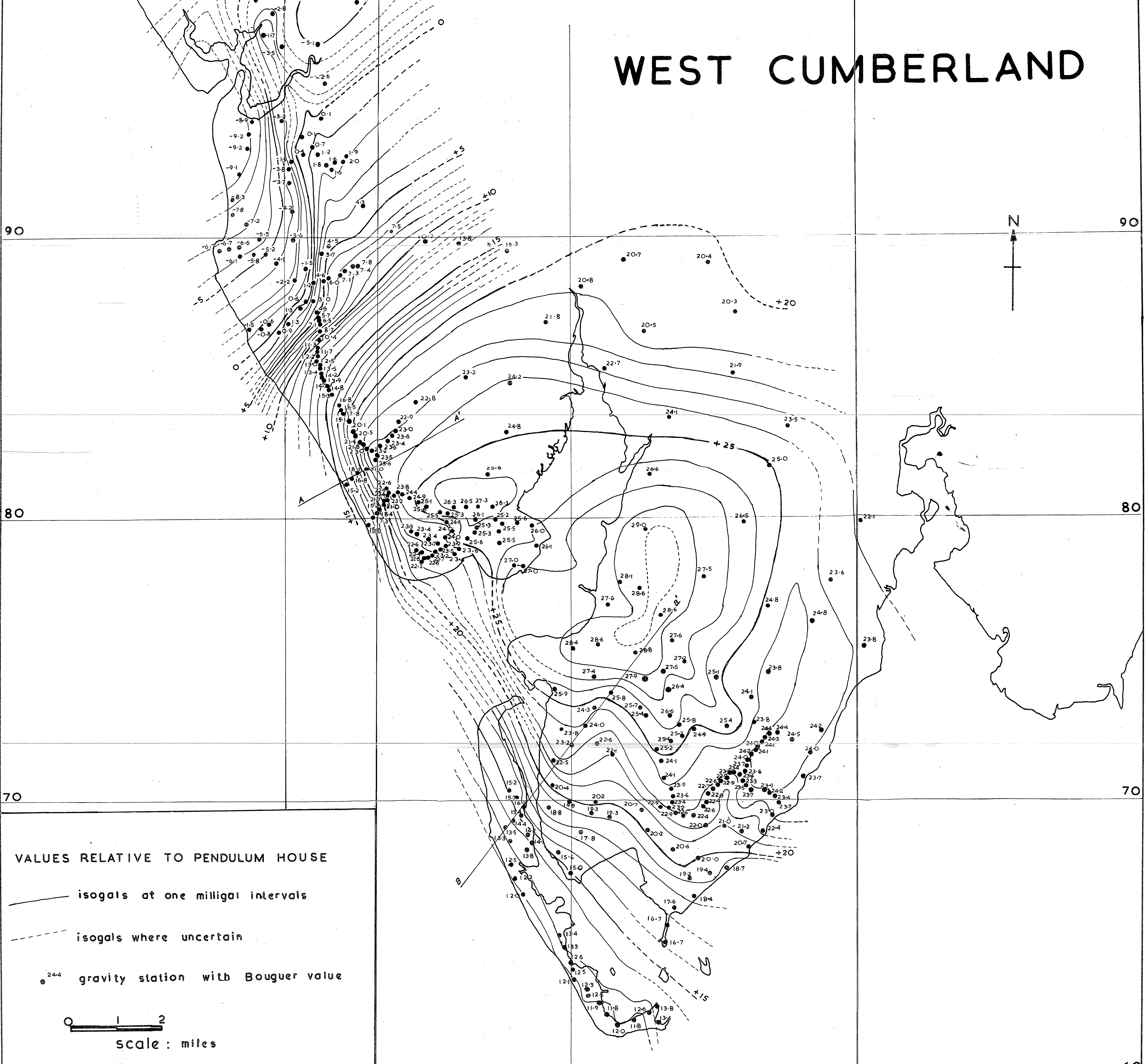
   (b) The thesis or dissertation should be clear, well-written and orderly in arrangement.

   (c) The subject should be dealt with in a competent manner. The candidate should display critical discrimination and a sense of proportion in evaluating evidence and the opinions of others. It is not, however, necessary that the thesis or dissertation should constitute an original contribution to knowledge or be worthy of publication.

4. Examiners of candidates proceeding by either of the other two methods should bear all the above criteria in mind when reaching their decisions. They must be satisfied that candidates taking a written examination have reached a satisfactory standard for the degree.

5. The examiners may, at their joint discretion, require a candidate to present himself for an oral examination at any convenient time or place, even if an oral examination is not prescribed in the regulations.

P.T.O.


WEST CUMBERLAND
N
VALUES RELATIVE TO PENDULUM HOUSE
isogals at one milligal intervals
isogals where uncertain
24·4 gravity station with Bouguer value
0 1 2
scale : miles