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Detailed gravity studies of the Fen complex

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DETAILED GRAVITY STUDIES OF THE FEN COMPLEX

LKAB Prospektering AB
Håksberg 1983-11-09

Henrik Öbrink

Detailed Gravity Studies of the Fen Complex

Background

The Fen area has already been covered by a regional gravimetric survey which has been reported by Ramberg (Contr. Mineral. and Petrol. 38, 115-134, 1973). Rambergs' conclusion is that to be able to explain the large anomaly, heavier rocks are needed than the carbonatites found on the surface. By suggesting that the carbonatites from a depth of 500 meters is replaced by a rock with density contrast between 0.4 and 0.5 (which is about double to that of the carbonatites) he is able to reach a god fit between measured and calculated data.

Goal

To reach a better estimate for the depth of the buried body, proposed by Ramberg, Fenco contacted LKAB Prospektering AB to have a detailed gravity survey carried out in the Fen area. One of the reasons for a more exact depth figure was to ascertain if drilling was feasable.

Method

In gravimetry the area around the contact is the part of the anomaly which is most sensitive to indicate depth of burial. In this case the depth is in the order of a few hundred meters. This means that the affected part of the anomaly will be stretched out to several hundred meters or a few kilometers. For this reason two long east west lines were measured starting and ending well out on the surrounding gneiss. These two lines are called Q and R. To make sure that the lines were really crossing the anomaly at its peak value a short east west line through center was also measured. This was line P. Finally a north south line was measured also crossing the central part of the anomaly. This line barely reaches the gneiss in the north part and not at all in the south. Unfortunately uncooperative farmers in the area imposed severe restrictions on where lines could be placed and how long they could be.

Fig. 1

The distance used between measuring stations was 100 meters, except for the eastern part of line Q where only points of intersection between line and roads were measured. In the central part of Q the point density was increased to 50 meter spacing when surface anomalies were found.

Field work

The gravimetric measurements were done with a Sodin gravimeter. A checkpoint was taken approximately every other hour to record the drift. The height of the gravity points were determined by levelling (done by Fenco). The error including levelling is within ±0.5 g.u.

Correction and Reductions

Appendix

The readings have been Bouguér reduced with both the density of the gneiss 2.67 and the mean density of the Fen carbonatites 2.90. After comparison between these two 2.90 was chosen, because the two curves were non parallel mainly on areas inside the carbonatite. The bouguér values have also been corrected for latitude dependence.

Fig. 2

As the lines are so short in comparison with the size of the whole anomaly no regional trend can be determined from them alone. The trend has therefore been taken from Rambergs' regional survey. After bouguér reductions latitude correction and the removal of the regional trend the values were finally given a zero level which makes them comparable to Rambergs' measurements. The zero level was determined by measuring 6 points already measured by Ramberg.

No topographic correction has been undertaken. Instead the local topographic effect have been estimated for a few points where the topography is especially rough. For the deep valley at about 51000 the effect of topography for most of the points lie below 0.5 g.u. In isolated points in the valley where the inclination reaches 25 % the effect will be about 2 g.u. The topographic correction is very sensitive to inclinations larger than 25-30 % where it can reach very high values. The topographic correction is always positive. This means that it is usually quite easy to see the effect of topography on the curves. As long as the topographic effect stays below 2 g.u. it will be no significance for the interpretation.

Interpretation

In the interpretation only a little consideration has been taken to the zero level. The fitting has mainly been a matter of matching curve forms. There are two reasons for this. Firstly the zero level depends on the level chosen by Ramberg from values of lower accuracy and the correctness with which this survey is connected to Rambergs'. Secondly you can easily construct bodies so deep in your model that the values within the line range is only affected by a constant value.

In interpretation a computer program has been used. It calculates the gravity effect from prismatic bodies with polygonal cross sections and limited length extentions (so called 2 1/2 dimensional bodies). The axis of the prisms can only be vertical or horisontal. The program takes into account angle and position between prism and line.

Fig. 3

The interpretation started with the definition of a body to represent the known carbonatite rocks. The body was vertical and its horisontal cross section was roughly the same as the shape of the Fen complex. Its density was set to 0.25. It was quite clear that this simple model could not alone explain the anomaly. A second body was therefore added to the model with density 0.45, which is the contrast to the gneiss for the heaviest rocks on the surface.

Fig. 4-7

The lines P, Q and R are strongly asymetric with a steep east flank and a gentle west flank. To atain this appearance you need a body with shallow depth in the east which gradually gets deeper to the west. By testing a lot of different shapes and depths for this body one can conclude that the depth to the top must lie in the range 0-300 meters. The deeper the body the broader and flater the top has to be to retain the fit with measurements. This also implies that if the body reaches the surface it must cover a small area. A more accurate depth estimation might be possible to achieve with denser measurements over the eastern flank.

Fig. 8-9

Line S is quite symmetric but here also the carbonatite body with density 0.25 cannot be made to fit measurements. With line S both flanks are to steep. To explain the anomaly a second body of density 0.45 and with horisontal top surface has been tried. It turned out that by moving the contact between carbonatite and gneiss within 100 meters one could reach a good fit for the whole range of depth from 0 to 500 meters. The reason for the ambiguity in the results is a consequence of the line being too short.

Fig. 4-7

By studying the four lines more in detail one finds that the east west lines P, Q, R have some anomalies around the maximum values which are caused by shallow bodies. When you compare with the

Fig. 1

geological map you find that two of the anomalies coincide with known outcrops of damkjernite, while the others lie on covered ground marked as rauhaugite. This implies that one can expect a lot more damkjernite on the surface in this area than what is known. This is the very region where the buried body had its minimum depth of 0-300 meters. Probably the buried body is the source of the surface damkjernite and therefore is of damkjernitic composition. Line S does not have these small disturbances.

Fig. 8

This indicates that the surface damkjernite is present as more or less north south striking dikes.

Let us now turn our interest from the eastern part of Fen to the gentle sloping values of the west. On the lines Q and R the fit is rather poor just above the contact between carbonatite and

Fig. 6, 7

gneiss. The measured curve descends steadily towards the west while the calculated has a distinct increased slope above the contact. The easiest and most efficient way to remove the anomaly over the contact is to let the carbonatite rocks dip to the west in under the gneiss. When you do that you also have to increase the dip of the damkjernite body to prevent the calculated slope from being too gentle. In this way you achive a good fit along the whole anomaly. This change of the model does not greatly influence

Fig. 10

the estimated depth in the eastern part. The reason for this is that one has just substituted some of the damkjernite for carbonatite while keeping both its total mass and its approximate distribution constant. To receive an additional check of the model a third body representing the sövit with known location and density 0.15 was inserted. This just makes the fit even nicer. There-

Fig. 11

fore one can say that there is nothing in the gravity measurements that contradicts an interpretation where the carbonatites dip in under the gneiss with a parallel damkjernite body below. It should be mentioned that when the vertical dip of the contact was changed one could no longer use a vertical prism to represent it in the program. Instead a horisontal prism had to be used. That representation was for practical reasons actually used also in the interpretation of line S above. This implies that the detailed information about the Fen complex borders on the surface could not be used, instead the horisontal cross section became a parallelogram. The difference though turned out to be very small and therefore neglectable.

The way the model has turned out in this detailed gravimetric survey it seems natural to propose a large scale model quite different from the model proposed by Ramberg based on the more regional survey. Rambergs' model consisted of a pipe of dense rocks with a thin cover of carbonatite. Our model suggests

Fig. 12 dipping pipe of carbonatite with a core of dense rocks. The reason the core does not reach the surface is that the pipe is cut by the faults which make up the eastern contact. In this model there will be gneiss again at depth under the Fen complex. This will tend to reduce the maximum anomaly value of the model. The depth to the top of the gneiss depends on the dip of the pipe and its real diameter. Imagine a dip of 60^o and a diameter of 3 km. In this case the fault cuts through the center of the Fen surface area and the top of the gneiss will be at 3 km. This will reduce the calculated maximum with 15 g.u. 15 g.u. is quite a large portion of the total anomaly of 200 g.u. and is of course a draw back for the model. You can though get very different results with other dips and diameters both larger and smaller. If you accept the dipping pipe model the question of dip direction

Fig. 13 arises. If one takes a look at Rambergs' regional map one can clearly see that the direction of the most gentle slope is towards the south west. That direction is supported by the

Fig. 8 metric appearanse of line S to which it is almost perpendicular. Finally one can with some imagination see how the distribution

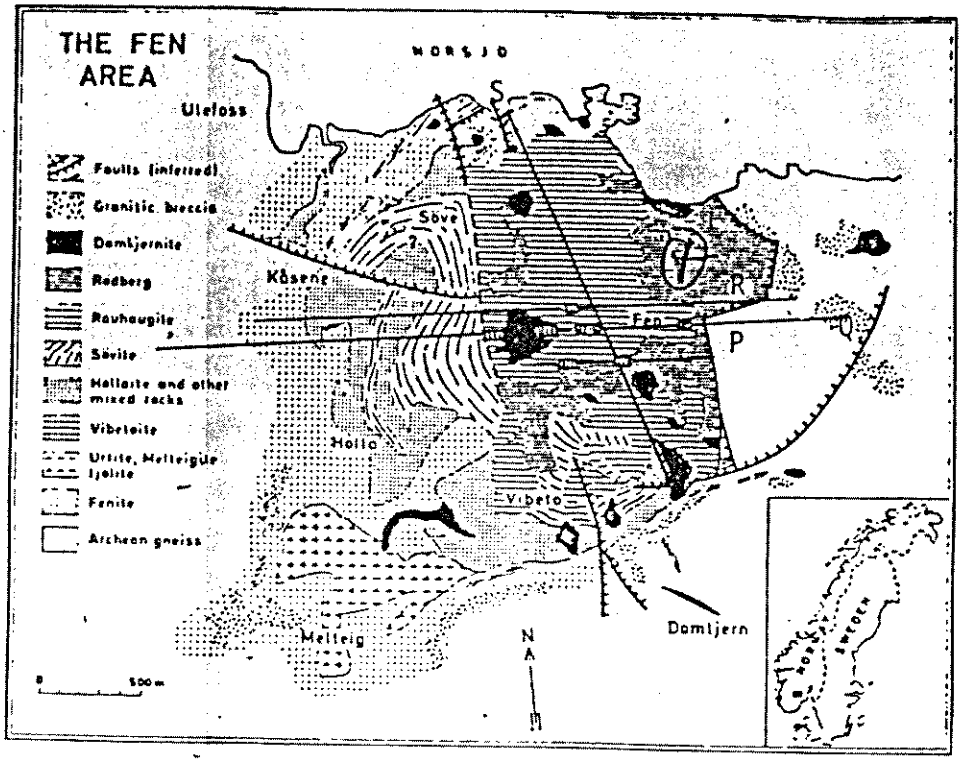
Fig. 1 of damkjernite outcrops follows this south west to north east direction just as the general form of the Fen complex covers half an ellips with its main axis in this direction.

Conclusion

The depth to the dense body has a minimum in the eastern part of the Rauhaugite where the depth is in the interval 0 to 300 meters. The body is probably of damkjernitic composition and is also probably connected to the damkjernite outcrops.

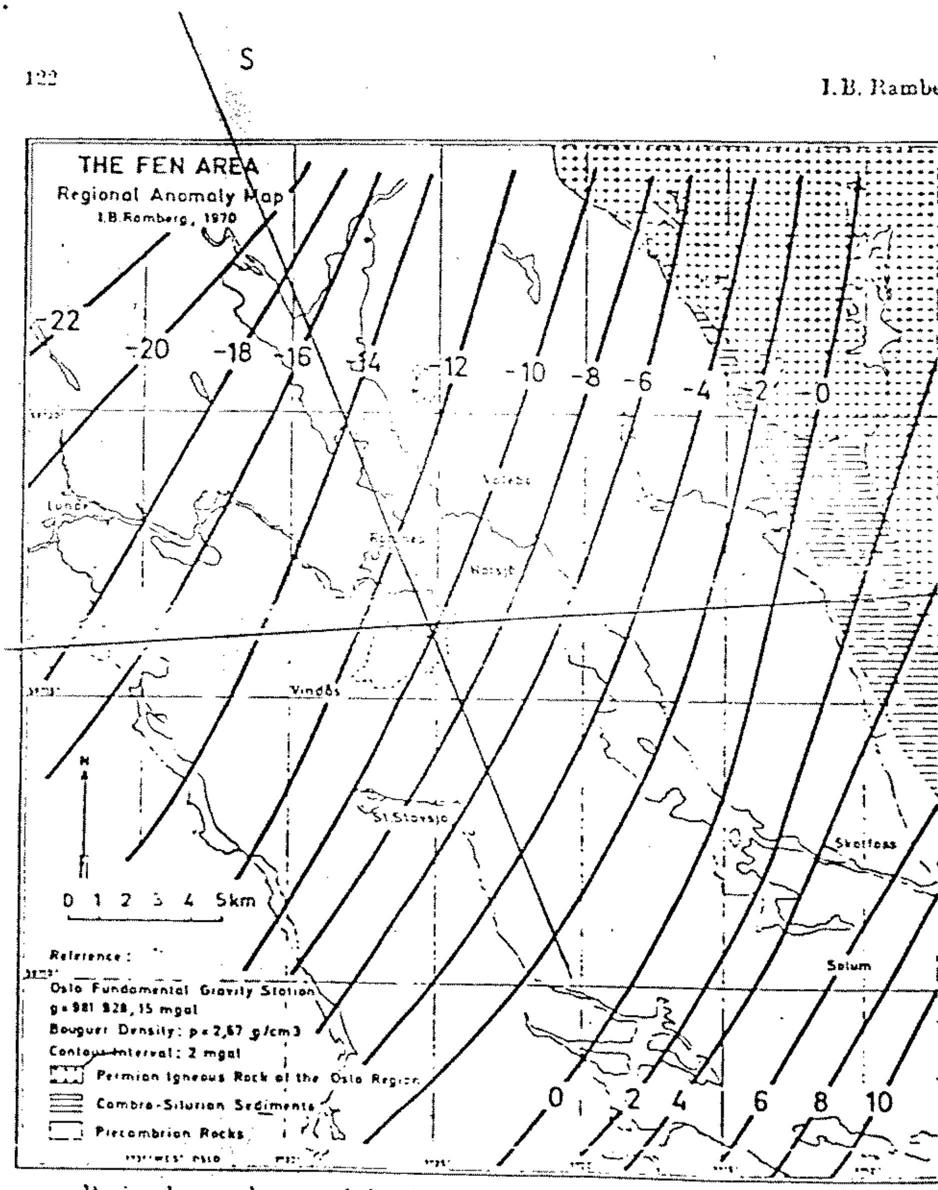
From the geophysical point of view it seems most probable that the Fen complex is a pipe dipping to the south west with a damkjernite core.

In case one wishes a more exact estimation concerning the depth of the damkjernite body supplementary gravimetric measurements over the eastern and southern contacts may aid further interpretation.



Geological map of the Fen alkaline complex. Based on Sæther (1957)

Fig.1. Measured lines are added to the map.
Surface anomalies are marked with: ⫼



Regional anomaly map of the Fen area and surroundings

Fig.2. Lines S and Q are marked.

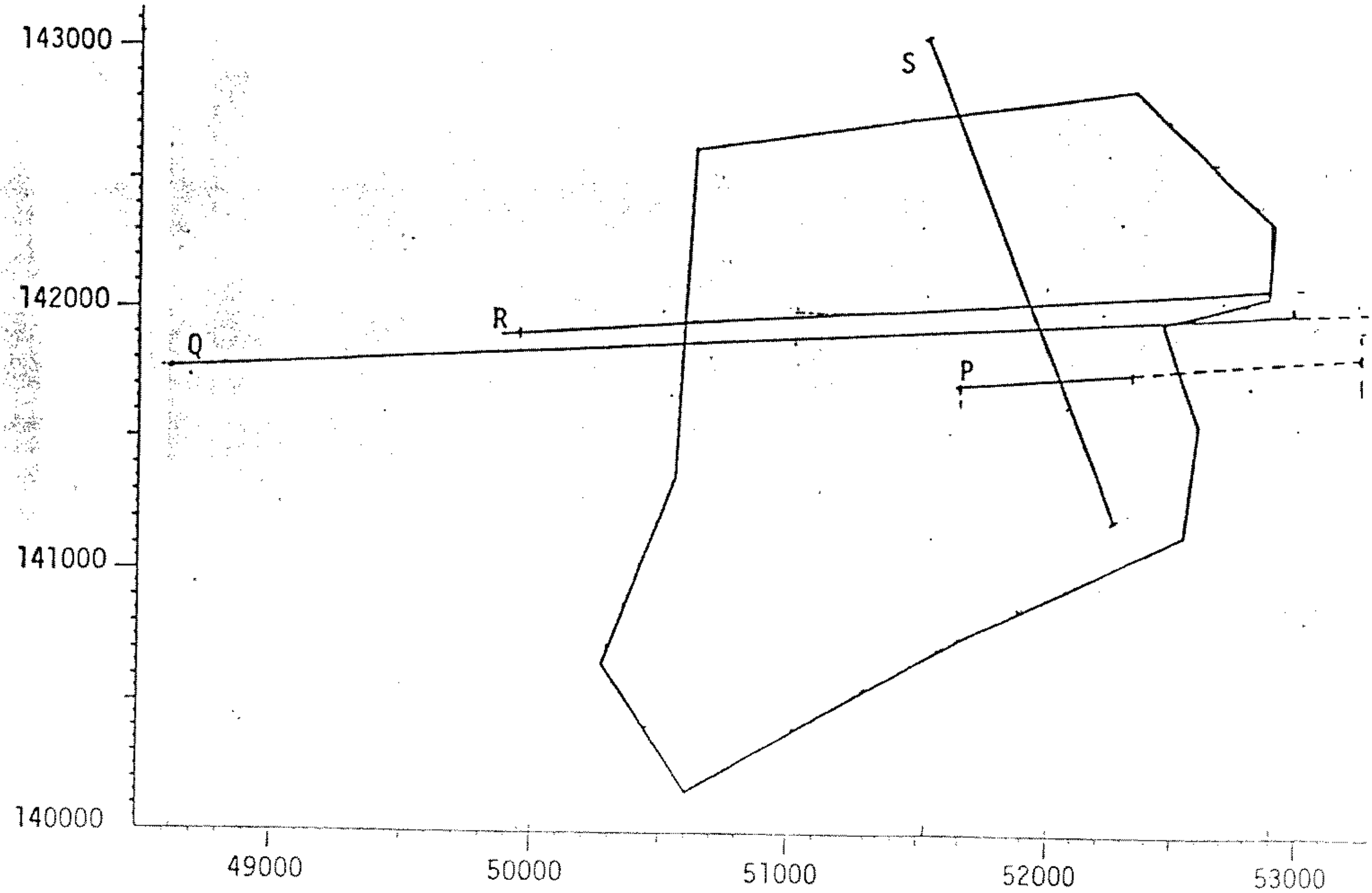


Fig.3. Shape of the body used to represent the carbonatites. Measured lines also marked.

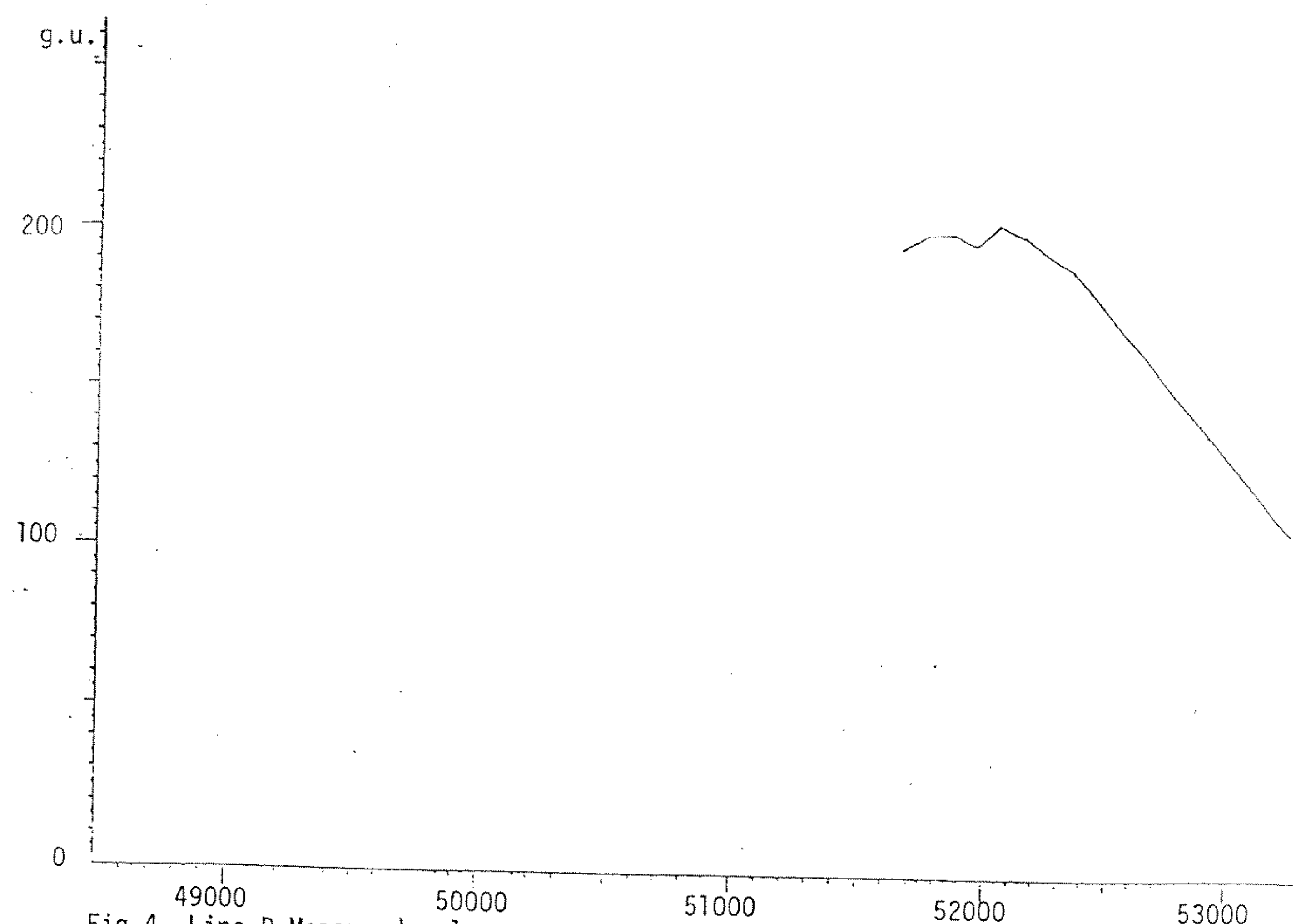


Fig.4. Line P Measured values.

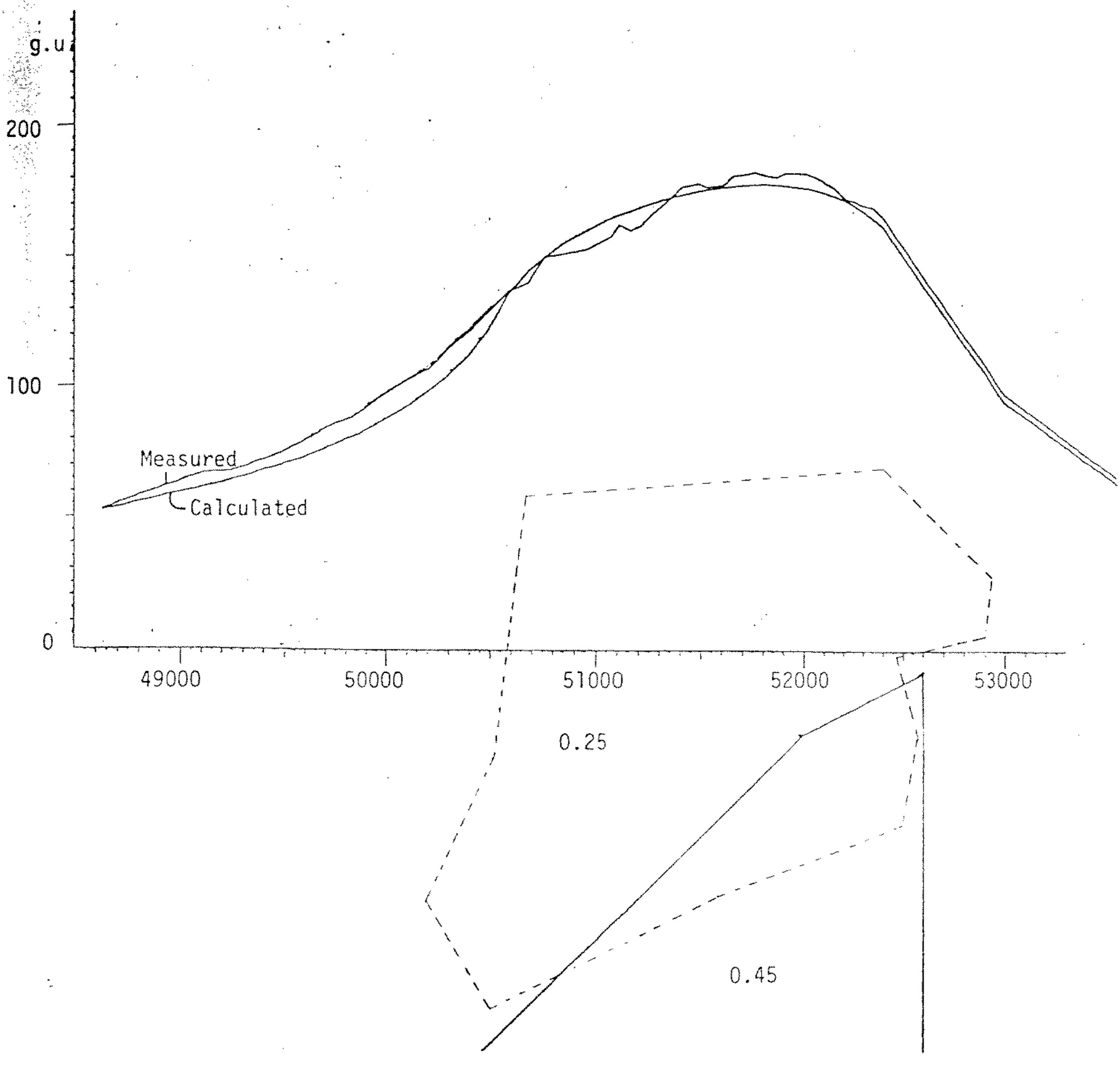


Fig.5. Line Q. Measured and calculated values.
A twobody model used consisting of a vertical body of density 0.25, shown in horisontal projection with dashed lines, and a body of density 0.45 shown in vertical projection with solid lines.

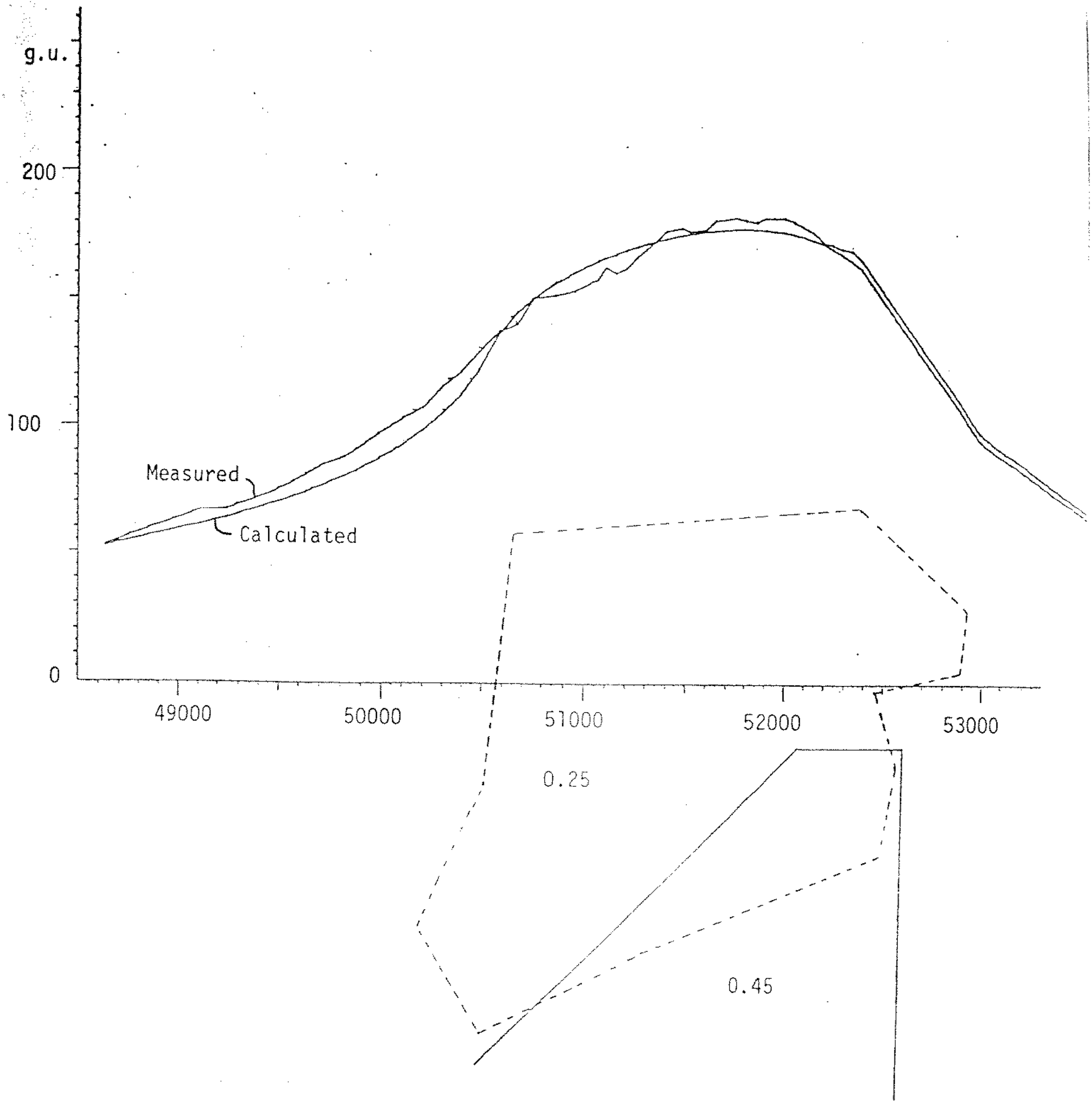


Fig.6. Line Q. Meausured and calculated values.
A twobody model was used consisting of a vertical body of density 0.25 shown in horisontal projection with dashed lines and a body of density 0.45 shown in vertical projection with solid lines.

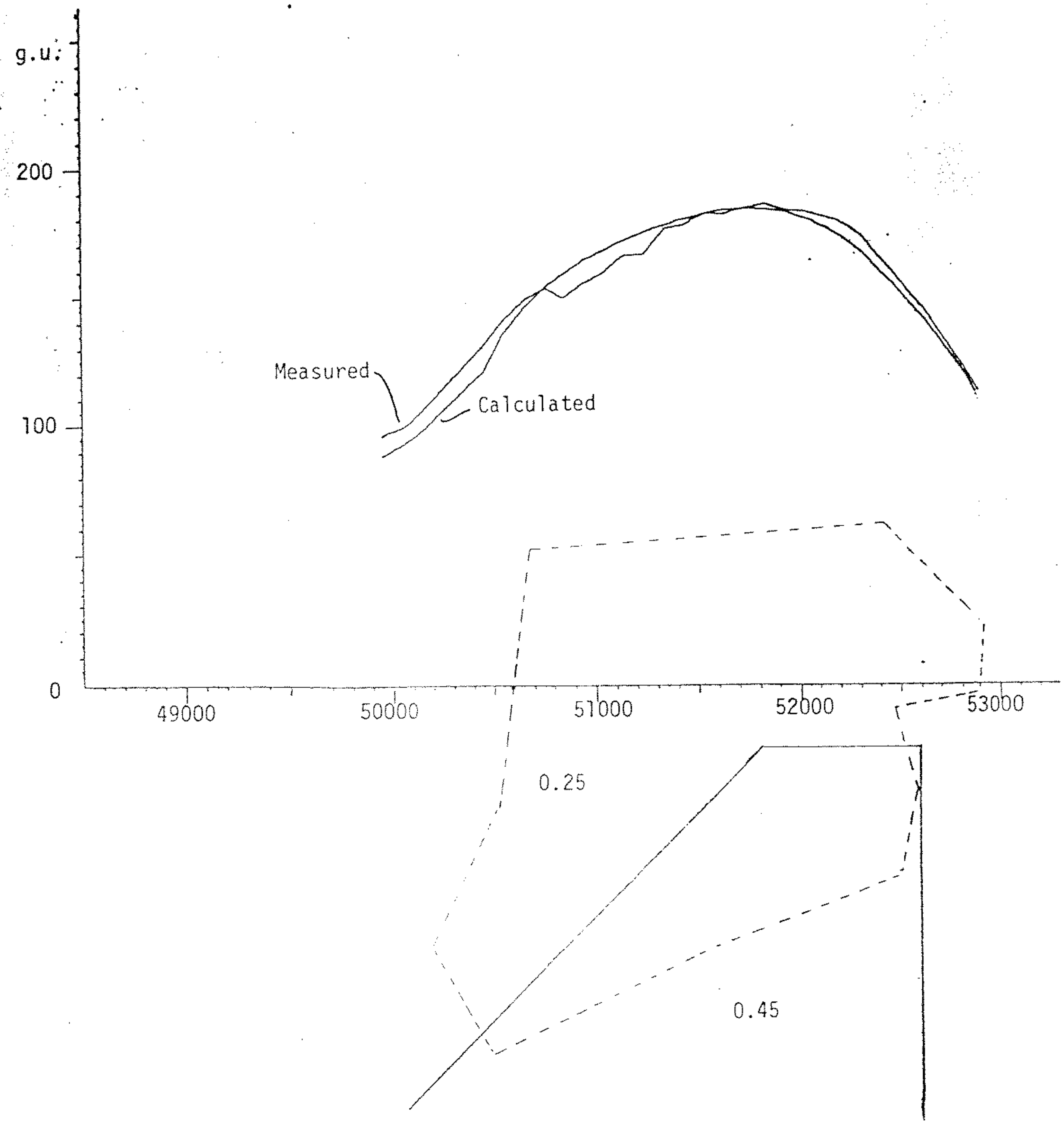


Fig.7. Line R. Measured and calculated values.
A Twobody model was used consisting of a vertical body of density 0.25 shown in horisontal projection with dashed lines and a body of density 0.45 shown in vertical projection with solid lines.

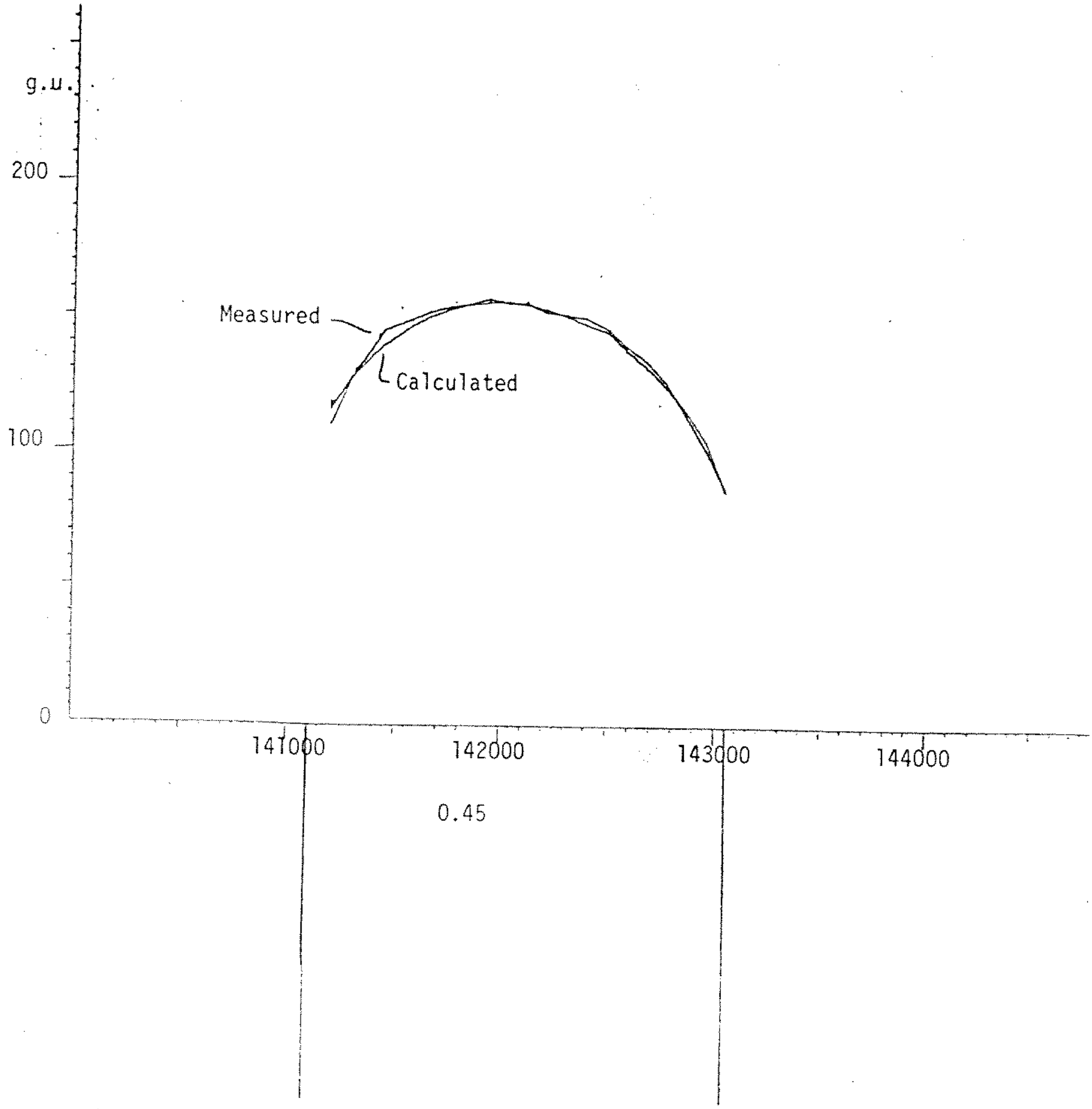


Fig.8. Line S. Measured and calculated values.
A onebody model was used shown in vertical projection and with a density of 0.45.

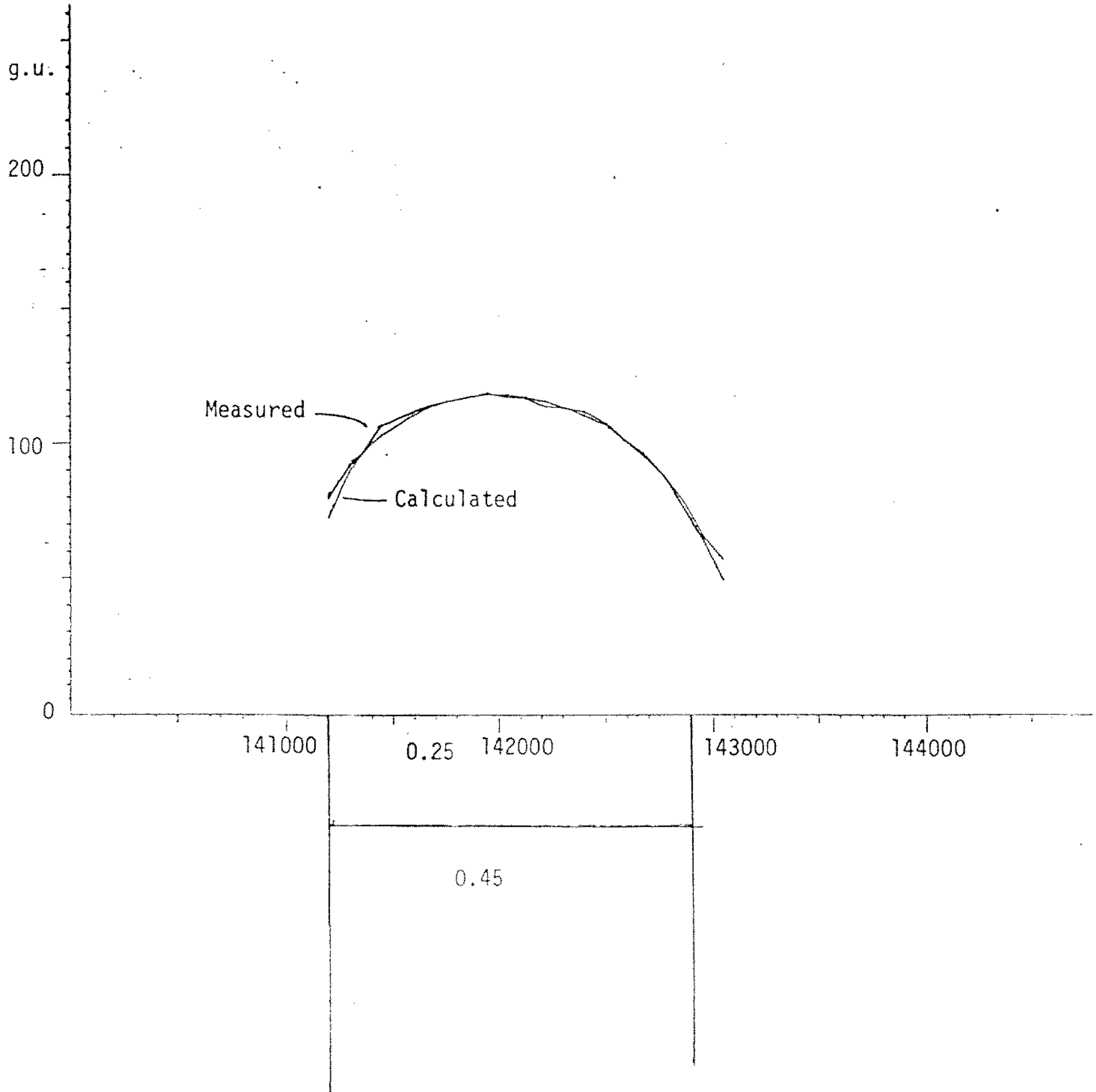


Fig.9. Line S. Measured and calculated values.
A twobody model was used shown in vertical projection and with densities of 0.25 and 0.45.

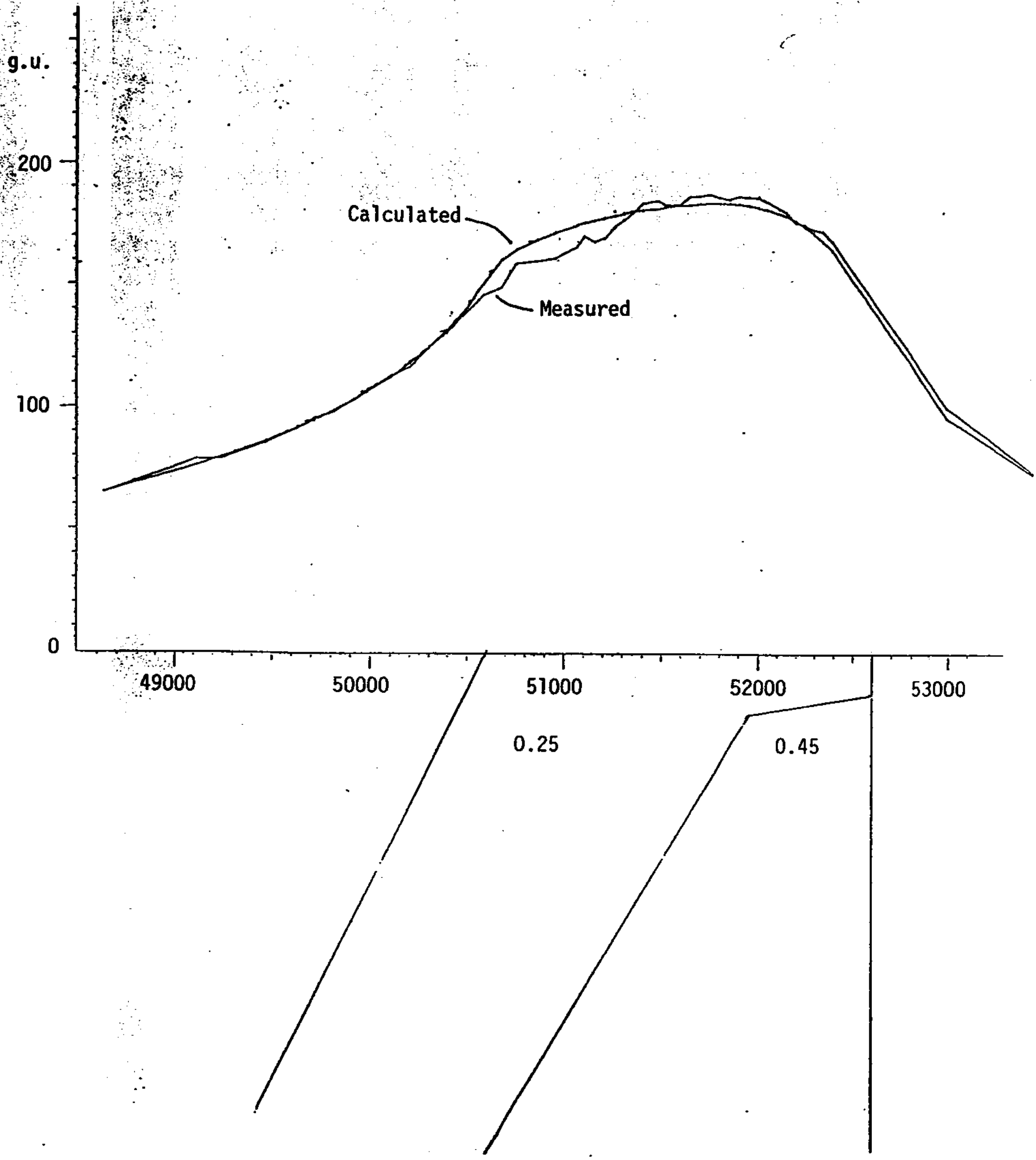


Fig. 10. Line Q. Measured and calculated values.
A twobody model was used with densities 0.25 and 0.45
shown in vertical projection.

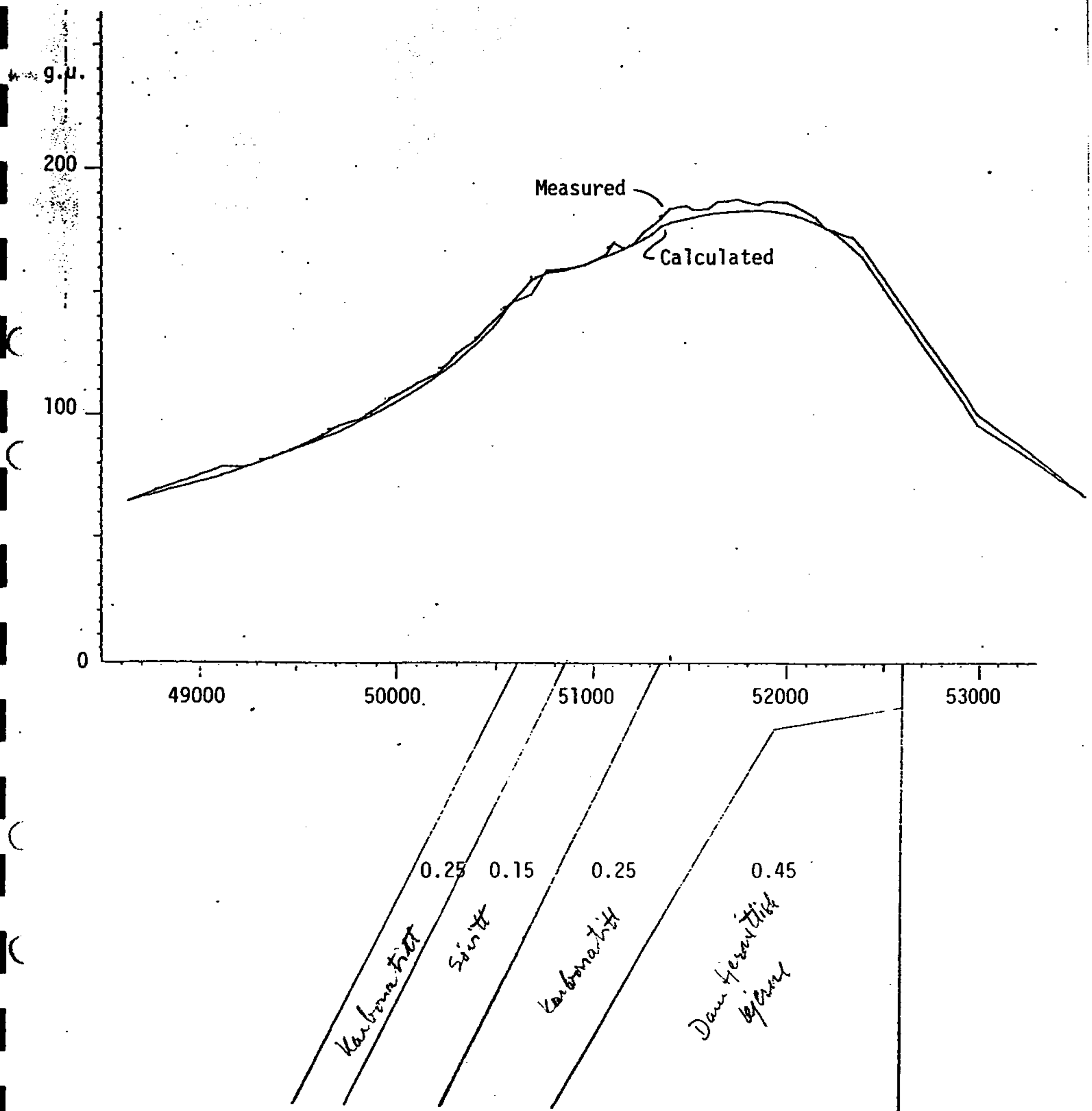


Fig.11. Line Q. Calculated and measured values.
A threebody model was used with densities 0.15, 0.25 and 0.45 shown in vertical projection.

Karbonatitt = Rauhaugitt 1-2, Rödberg?

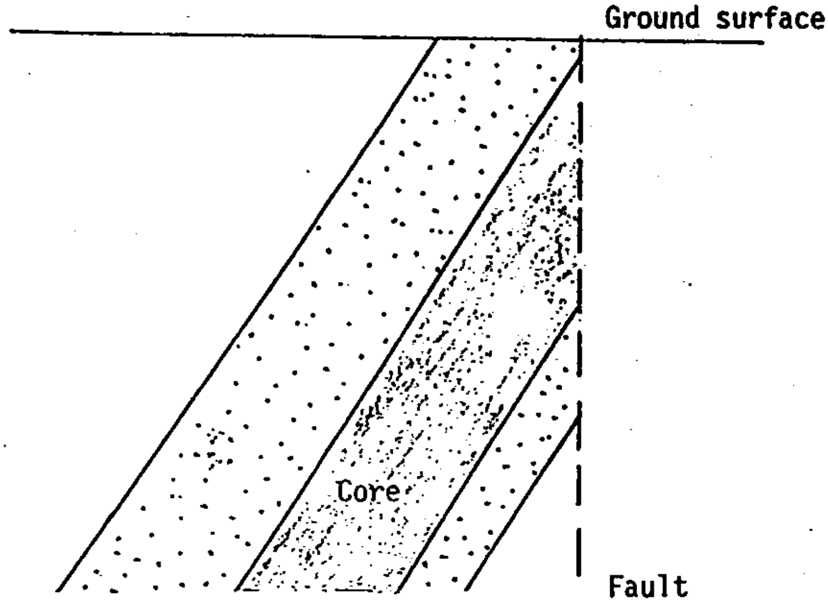
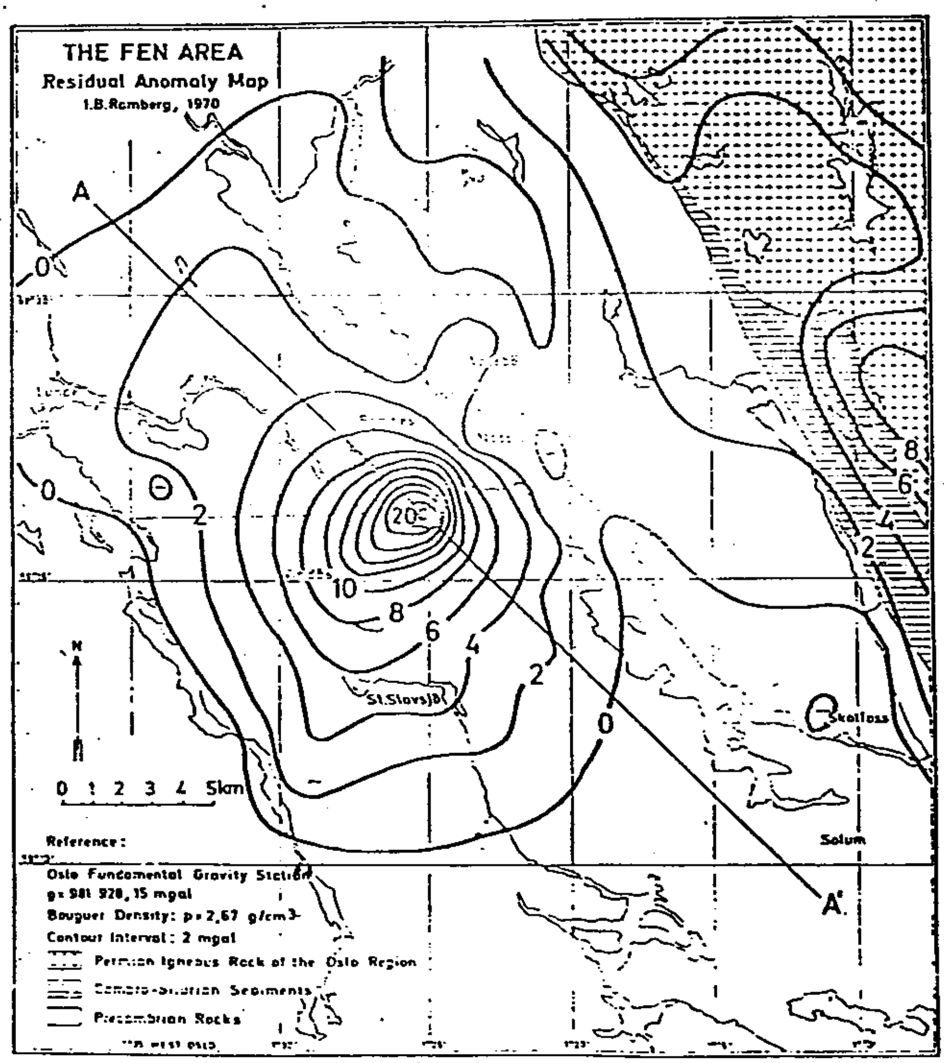


Fig.12. Dipping pipe model cut by surface and fault.

Gravity Studies of the Fen Complex, Norway 123



Residual anomaly map of the Fen area and surroundings

Fig.13.

Appendix. Measured values.

Points also measured in the regional survey:

INE:G ZEROLEVEL: Ø.Ø

OINT	N-KOORD	E-KOORD	READING	DRIFT	STAND HIGHT	LEVEL	LATT. CORREC.	REG. TREND	ANOMALY
Ø	141774	52358	69Ø.1	Ø.Ø	Ø.98	11Ø.48	2.6	Ø.Ø	9Ø9.9
1	14275Ø	5212Ø	712.7	Ø.Ø	1.Ø1	1Ø3.67	2.7	Ø.Ø	92Ø.2
2	141879	51483	734.3	-Ø.1	1.ØØ	89.58	3.6	Ø.Ø	914.8
3	14191Ø	5129Ø	74Ø.8	-Ø.2	1.Ø2	8Ø.54	3.7	Ø.Ø	9Ø4.3
4	14174Ø	5Ø175	599.9	-1.3	1.ØØ	117.68	2.7	Ø.Ø	83Ø.1
5	142ØØ5	5233Ø	687.6	Ø.3	Ø.95	11Ø.43	4.6	Ø.Ø	9Ø5.5
6	1425ØØ	5174Ø	765.9	2.1	1.Ø2	69.66	8.Ø	Ø.Ø	9Ø7.6

Formula used to calculate the ANOMALY value.

ANOMALY= (READING+DRIFT)*1.Ø184 + STAND HIGHT*3.Ø86 +
LEVEL*(3.Ø86-Ø.4191*2.9Ø) - ZEROLEVEL - LATT.CORREC. - REGIONAL TREND

Instrumental constant = 1.Ø184

LINE:P ZEROLEVEL: 830.6

POINT	N-KOORD	E-KOORD	READING	DRIFT	STAND HIGHT	LEVEL	LATT. CORREC.	REG. TREND	ANOMALY
0	141813	53264	601.7	1.5	1.02	118.07	3.0	-92.5	97.2
1	141774	52358	690.1	0.0	0.98	110.48	2.6	-101.0	180.3
2	141765	52256	696.3	0.0	0.99	109.00	2.6	-101.7	184.6
3	141760	52161	708.6	0.0	0.92	105.31	2.5	-102.5	190.9
4	141754	52047	719.4	0.0	0.92	101.17	2.5	-103.3	194.9
5	141750	51955	717.3	0.0	0.90	98.61	2.4	-104.1	188.8
6	141744	51862	722.1	0.0	0.95	97.48	2.4	-104.8	192.5
7	141737	51762	723.5	0.0	0.80	96.41	2.4	-105.6	192.2
8	141732	51659	719.4	0.0	0.95	95.39	2.3	-106.4	187.5

LINE:Q ZEROLEVEL: 829.3

POINT	N-KOORD	E-KOORD	READING	DRIFT	STAND HIGHT	LEVEL	LATT. CORREC.	REG. TREND	ANOMALY
-1	142010	53545	552.7	1.6	0.96	135.38	4.3	-89.6	76.7
0	141969	52995	608.5	1.5	0.99	119.97	4.1	-94.8	110.1
0.5	141935	52398	687.7	1.4	0.95	110.46	3.7	-100.6	178.9
1	141934	52347	695.0	0.0	1.00	109.15	3.7	-101.0	183.1
1.5	141931	52299	697.3	1.3	0.95	107.48	3.7	-101.4	183.8
2	141929	52249	706.1	0.0	0.96	104.19	3.7	-101.7	185.7
2.5	141925	52204	709.5	1.3	0.83	102.25	3.7	-102.1	186.8
3	141922	52152	716.1	0.0	0.99	101.05	3.6	-102.5	191.0
4	141916	52051	724.0	0.0	0.92	98.71	3.6	-103.3	195.2
4.5	141913	52004	730.9	1.2	0.86	95.15	3.6	-103.7	197.0
5	141911	51953	727.0	0.0	1.01	97.37	3.5	-104.1	196.9
5.5	141906	51905	732.4	1.2	0.83	93.99	3.5	-104.5	197.2
6	141905	51859	727.9	0.0	1.00	95.70	3.5	-104.8	195.4
6.5	141901	51806	731.3	1.2	0.92	93.52	3.5	-105.2	196.2
7	141898	51753	737.3	0.0	0.85	91.62	3.5	-105.6	197.7
7.5	141894	51702	736.6	1.1	0.85	90.71	3.5	-106.0	196.8
8	141891	51651	736.1	0.0	0.95	90.88	3.4	-106.4	196.3
8.5	141887	51605	734.1	1.1	0.90	89.61	3.4	-106.8	193.2
9	141887	51559	734.7	0.0	0.80	89.51	3.4	-107.1	192.5
9.5	141884	51521	732.3	0.5	1.03	89.90	3.4	-107.5	192.4
10	141879	51483	734.3	-0.1	1.00	89.59	3.3	-107.9	193.7
10.5	141891	51405	733.9	0.6	1.02	88.58	3.3	-108.3	192.6
11	141898	51357	733.4	-0.1	0.97	86.99	3.3	-108.7	188.6
11.5	141868	51309	747.0	0.6	0.75	78.06	3.2	-109.1	185.3
12	141865	51264	750.9	-0.2	0.85	74.70	3.2	-109.4	183.8
12.5	141861	51209	755.5	0.6	0.85	69.20	3.2	-109.8	179.4
13	141859	51157	767.8	-0.3	1.02	61.95	3.2	-110.2	178.4
13.5	141856	51108	782.3	0.7	0.85	55.15	3.2	-110.6	181.3
14	141853	51069	756.6	-0.3	0.73	66.49	3.1	-111.0	175.4
15	141847	50956	738.8	-1.0	1.00	72.77	3.1	-111.8	170.0
16	141840	50862	720.9	-1.0	0.95	81.01	3.1	-112.5	167.7
17	141833	50758	712.0	-1.0	0.98	84.45	3.0	-113.3	166.1
18	141831	50679	650.7	-1.1	0.98	110.72	3.0	-114.1	153.5
19	141823	50583	654.3	-1.1	0.93	106.85	2.9	-114.8	150.6
20	141816	50484	639.9	-1.1	0.93	109.78	2.9	-115.6	142.2
21	141811	50393	628.3	-1.2	0.95	111.60	2.8	-116.1	134.3
22	141805	50299	617.6	-1.2	0.90	113.87	2.8	-116.8	128.2
23	141803	50204	608.1	-1.2	0.93	114.11	2.7	-117.6	120.0
24	141794	50103	599.5	-1.3	1.03	116.05	2.7	-118.4	115.9
25	141785	49985	597.4	-1.3	0.93	113.76	2.7	-119.3	110.0
26	141779	49875	594.1	-1.3	1.00	111.88	2.6	-120.1	104.3
27	141777	49818	592.9	-1.4	1.04	110.58	2.6	-120.5	101.0
28	141768	49715	590.4	-1.4	0.97	110.19	2.5	-121.3	98.5
29	141765	49632	602.6	-1.4	1.03	101.36	2.5	-121.9	95.1
30	141762	49570	619.0	-1.5	0.90	91.21	2.4	-122.8	93.4
31	141753	49470	636.6	-1.5	0.97	79.74	2.4	-123.2	90.4
32	141740	49240	592.5	-1.5	0.90	98.43	2.3	-124.4	81.6
33	141735	49110	581.0	1.6	0.96	102.20	2.2	-125.0	81.0
34	141710	48630	532.5	1.7	1.00	118.28	2.0	-126.4	65.5

LINE:R ZEROLEVEL: 828.4

POINT	N-KOORD	E-KOORD	READING	DRIFT	STAND HIGHT	LEVEL	LATT. CORREC.	REG. TREND	ANOMALY
-4	142103	52896	644.5	0.5	0.89	107.65	4.9	-95.8	123.5
-3	142098	52836	668.2	0.5	0.85	98.82	4.8	-96.4	131.7
-2	142089	52735	688.8	0.5	0.86	93.85	4.8	-97.3	144.3
-1	142083	52637	679.9	0.5	0.93	100.88	4.7	-98.3	155.3
0	142075	52536	723.9	0.5	0.97	85.70	4.7	-99.2	167.1
1	142062	52317	704.9	0.4	0.95	104.74	4.7	-101.0	185.0
2	142057	52241	714.8	0.5	0.90	101.41	4.6	-101.7	189.6
3	142051	52140	728.8	0.5	0.90	95.17	4.6	-102.5	193.0
4	142044	52041	738.9	0.6	0.85	90.45	4.5	-103.3	195.3
5	142040	51945	745.1	0.7	0.80	87.25	4.5	-104.1	196.4
6	142034	51842	745.6	0.8	0.85	87.63	4.4	-104.8	198.7
7	142026	51742	741.1	0.8	1.02	88.39	4.4	-105.6	196.8
8	142020	51641	759.0	0.9	0.93	77.58	4.3	-106.4	195.6
9	142014	51544	748.4	1.0	0.90	82.82	4.3	-107.1	195.3
10	142010	51443	738.0	1.1	1.01	85.44	4.3	-107.9	190.8
11	142001	51343	734.7	1.1	0.93	86.00	4.2	-108.7	189.2
12	141995	51242	733.6	1.2	0.94	81.12	4.2	-109.4	179.8
13	141988	51145	784.5	1.3	0.83	54.28	4.1	-110.2	182.1
14	141982	51044	774.5	1.4	0.98	55.33	4.1	-111.0	175.2
15	141974	50948	751.9	1.5	0.95	64.41	4.0	-111.8	170.1
16	141970	50847	725.7	0.7	0.90	75.21	4.0	-112.5	163.3
17	141964	50766	722.4	0.8	0.94	78.25	3.9	-113.3	166.8
18	141959	50665	703.3	0.8	0.92	85.79	3.9	-114.1	162.2
19	141951	50552	679.9	0.8	0.90	93.19	3.9	-114.8	152.8
20	141946	50455	652.5	0.9	1.00	101.83	3.8	-115.6	142.4
23	141929	50131	599.7	1.0	1.00	114.31	3.7	-118.1	114.7
24	141925	50071	599.5	1.0	0.99	111.97	3.6	-118.5	110.6
25	141915	49948	597.5	1.1	0.90	110.36	3.6	-119.6	106.4

LINE:S ZEROLEVEL: 826.0

POINT	N-KOORD	E-KOORD	READING	DRIFT	STAND HIGHT	LEVEL	LATT. CORREC.	REG. TREND	ANOMALY
-2	141201	52266	590.5	1.5	0.89	147.72	-1.3	-94.2	151.5
-1	141294	52229	628.0	1.4	0.94	136.29	-0.7	-94.9	168.4
0	141387	52193	656.2	1.4	0.90	126.73	0.0	-95.7	179.2
1	141445	52173	676.1	2.5	0.95	118.92	0.7	-96.2	186.0
2	141570	52124	695.6	2.5	0.90	110.32	1.3	-97.3	190.1
3	141663	52087	706.5	2.4	0.80	106.14	2.0	-98.1	193.1
4	141753	52049	716.9	2.4	0.95	101.17	2.7	-98.9	194.9
5	141850	52012	722.4	2.4	0.90	98.66	3.3	-99.7	195.9
6	141944	51975	736.0	2.3	0.80	92.60	4.0	-100.4	198.0
7	142039	51947	744.1	2.3	0.80	87.24	4.6	-101.2	196.4
8	142126	51903	752.4	2.3	0.78	82.61	5.3	-102.0	196.2
9	142219	51865	745.8	2.2	0.75	84.53	6.0	-102.8	193.0
10	142313	51830	755.5	2.2	0.72	78.84	6.6	-103.6	192.3
11	142401	51795	763.8	2.2	1.01	73.13	7.3	-104.4	191.1
12	142509	51793	765.9	2.1	1.02	69.66	8.0	-105.2	186.8
13	142586	51719	768.4	2.1	0.95	65.21	8.6	-105.9	180.9
14	142681	51682	782.3	2.1	0.92	54.76	9.3	-106.7	175.5
15	142773	51646	784.7	2.0	0.91	48.93	9.9	-107.5	167.1
16	142866	51610	784.4	2.0	0.92	42.47	10.6	-108.3	154.9
17	142957	51573	786.0	2.0	0.97	34.81	11.3	-109.1	142.4
18	143050	51534	806.1	1.9	0.95	16.06	11.9	-109.9	127.8