*Read at the Annual Conference of the Ussher Society, January 1981*

# Geophysical studies across the Permian outcrop m central and east Devonshire

J.C. DAVEY

Davey, J.C. 1981. Geophysical studies across the Permian outcrop in central and east Devonshire. *Proc. Ussher Soc., 5,* 194-199.

Recent gravity traverses across the Crediton and Tiverton areas have provided further indication of the thickness of Permian deposits which they contain. In the former, clastic sediments up to 900m thick are thought to be present, their northern margin with the underlying Carboniferous strata being complicated in the east by a subsidiary trough, possibly reflecting the occurrence of the Exeter Volcanic Series. The sequence adjacent to the Carboniferous inlier at Ashclyst Forest is suggested to be over 400m thick, the finer sediments of the Aylesbeare Group overlapping the underlying Clyst Sands to overstep onto the Carboniferous strata. In the Tiverton area, the Permian deposits appear to be much thinner and although a maximum thickness of just over 300m may be attained, 100-200m is more typical.

*John C. Davey, Institute of Hydrology, Crowrnarsh Gilford, Wallingford, Oxfordshire.*

## Introduction

During the early stages of a hydrogeological study (Davey 1981) undertaken between 1975 and 1978, it became apparent that information regarding the thickness of potential aquifer material was required. In the absence of fully penetrating boreholes, and in the light of previous gravity work across the western end of the outcrop, it was decided to undertake further studies east of Crediton and in the Tiverton area. All gravity traverses are shown in Fig. 1.

Bott and others (1958) undertook the first closely spaced measurements through North Tawton (traverse G2) and found the breccio-conglomerates here to occupy a V-shaped trough approximately 335m in depth. During the remapping of the Okehampton One Inch geological map (sheet 324), Edmonds and others (1968) repeated this traverse and undertook four more (G, G 1, G3 and G4) between Jacobstow and Bow. Their interpretation suggested a depth of 445m for G2 and between 245m and 395m for the others. The density contrast between the Permian., formations and the Carboniferous Culm Measures was taken to be 0.17 gm/cm$^3$ for all five traverses.

Nine new traverses, numbered 1-9 in Fig. 1, with readings approximately 100m apart, were undertaken as part of the hydrogeological study.

## Field and Interpretative Procedures

At different times during 1976 and 1978, 584 gravity measurements were taken with La Coste and Romberg Model G Gravity Meters. They were all related to the National Gravity Reference Net 1973 primary base station No 1400 at Bridford by way of a more convenient temporary base established in Exeter. All stations were subsequently surveyed relative to Ordnance Datum.

Corrections for instrument drift and lunar - solar tides were calculated manually, the latter from tables supplied by the Applied Geophysics Unit of the Institute of Geological Sciences. Latitude, free-air and Bouguer corrections were calculated by computer, utilising the reduction procedure and standard equations given by any basic geophysics text, e.g. Telford and others (1976). Terrain corrections were considered to be unnecessary since between stations they are unlikely to exceed 0.3g.u.

Unlike the previous work, which used the International Gravity Formula 1930, the new interpretations have made use of the Chebychev approximation of the International Gravity Formula 1967 (Assoc. Intern. de Geodesic 1971). This equation avoids the extraction of square roots and has a maximum error of just 0.04g.u. The data thus reduced, using sea level as the datum plane, give the anomalies due to variations in geology - the "Simple Bouguer" anomalies.

Because these include the effects of large bodies some distance away, in addition to those of the Permian deposits, regional trends also have to be subtracted. In Devonshire, this is a particularly important procedure due to the dominance of the large negative anomaly associated with the Dartmoor Granite. The regional trend for each traverse was obtained from sheets SSE and SXE of the 1:63360 Complete Bouguer anomaly map

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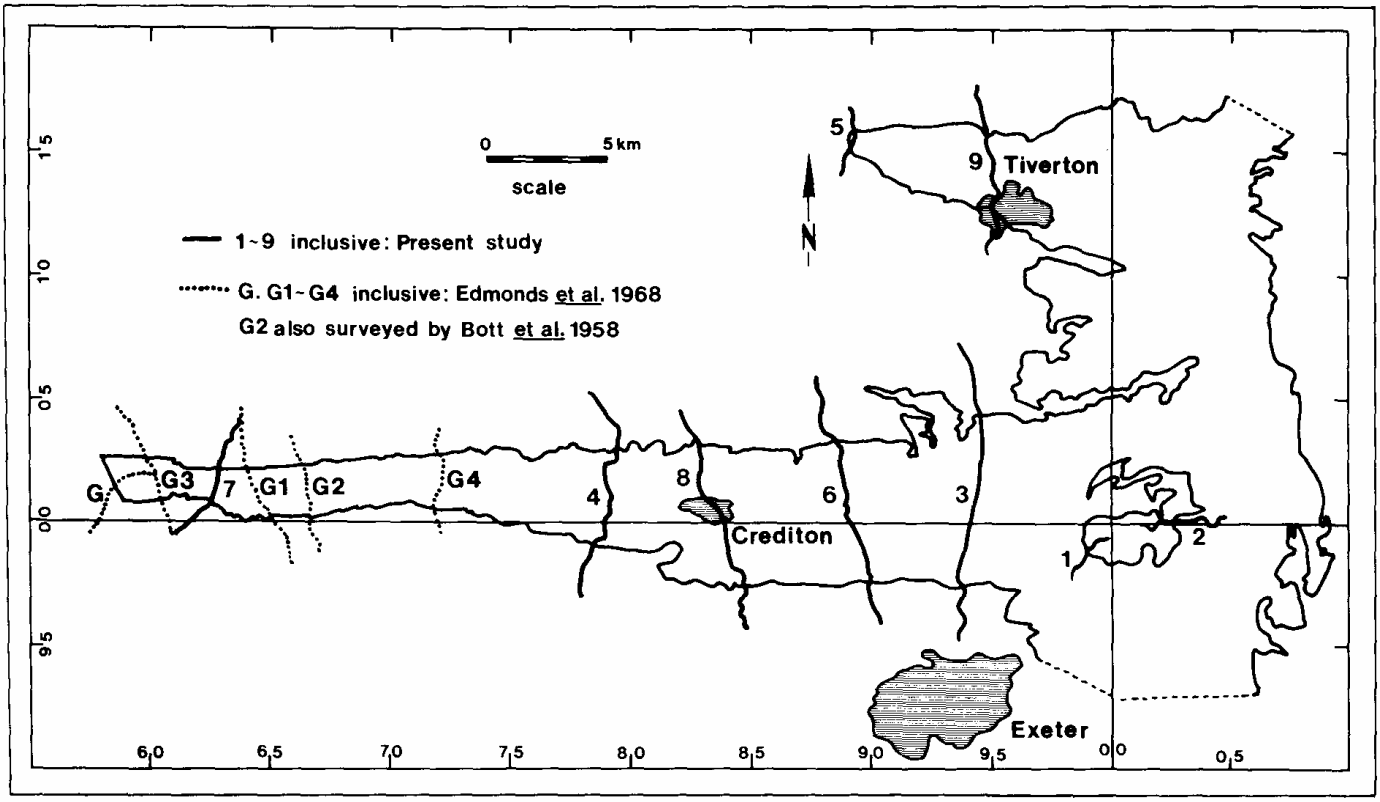


Figure 1. Gravity Traverses.

prepared by the Institute of Geological Sciences, having first subjectively filtered the isogals to remove any short wavelength anomalies which might be related to the strata under investigation.

Finally, having removed all other effects, the anomalies due purely to the Permian deposits were modelled. Because the most sensitive feature of this process is the choice of density contrast between the Permian and Carboniferous rocks, careful estimations of the lithological variations were made from outcrop patterns, core material, and geological and geophysical logs. During the last decade or so, a number of exploration wells, up to almost 200m in depth, have been drilled in the Crediton trough and provide suitable records from which to estimate such variations. Although most wells are to the east of Crediton, a few provide good evidence through the breccio-conglomerates to the west. Where very few records exist, such as in the Tiverton area, lithological variations have been assumed to be similar to those in the equivalent formations to the south; an assumption supported by the older records available. Similar assumptions were necessarily made for the strata below a depth of 200m. From the density values calculated by Edmonds and others (1968) in Table 1, a density contrast for each traverse was computed.

Table 1. Mean density values for each of the major rock types.

| | | |
|---|---|---|
| PERMIAN | Breccio-conglomerate | 2.47 g/cm$^3$ |
| | Sandstone | 2.35 g/cm$^3$ |
| | Aylesbeare Group | 2.50 g/cm$^3$ |
| | Exeter Volcanic Series | 2.41 g/cm$^3$ |
| CARBONIFEROUS | Culm Measures | 2.58 g/cm$^3$ |

Commencing with a simple rectangular prism, this was changed until the anomaly resulting from the model closely matched that observed from the field measurements. Repeating this procedure for each traverse produced a series of models which could be taken to approximate the true profile of the Permian deposits. As expected, they appear to occur in east-west troughs of variable depths.

## Tiverton area

Profiles 5 and 9, shown in Fig. 2, used density contrasts of 0.11 and 0.16 g/cm$^3$ respectively and provided the first indications of the thickness of the Permian sequence in this area. The former, at the western end of the trough, between Templeton Church (SS 88731399) and Rifton

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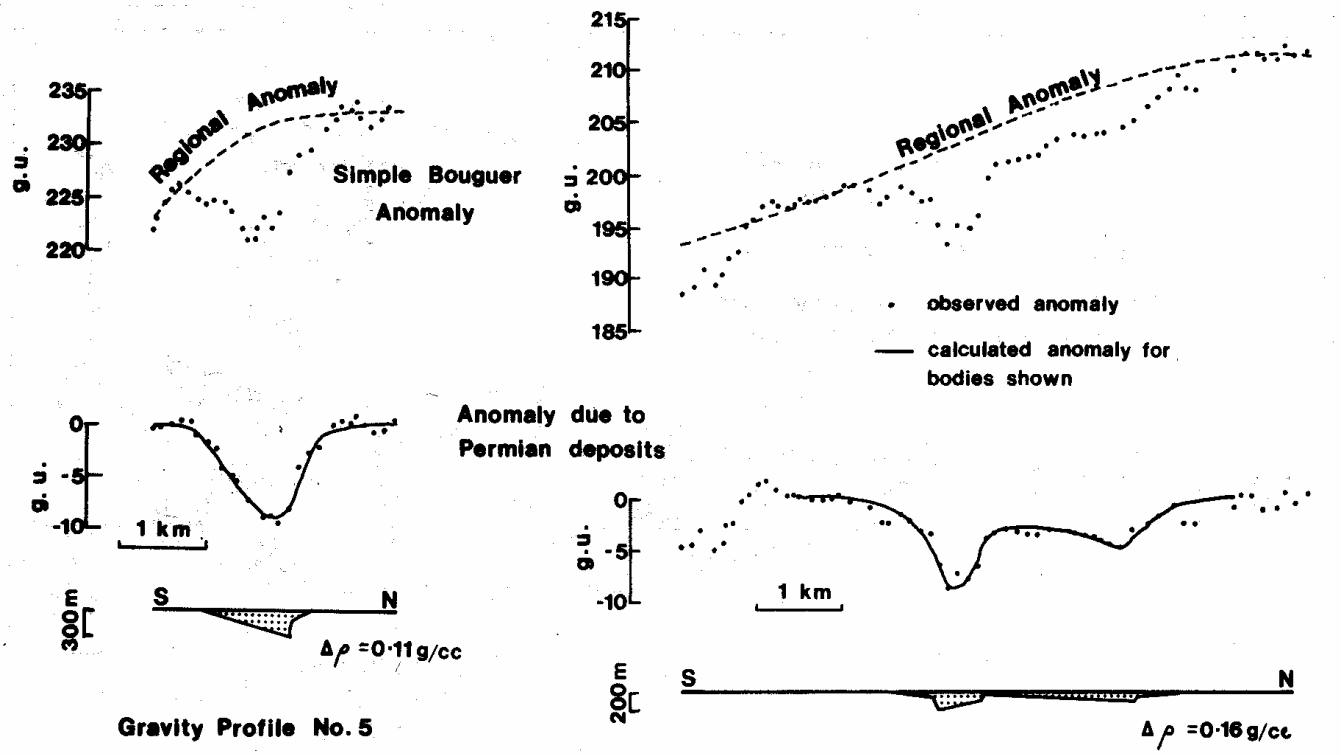


Figure 2. Gravity profiles across the Tiverton outcrop. Observed Simple Bouguer anomalies compared with the anomalies calculated for the two dimensional models.

Gate, Loxbeare (SS 89051686), shows an almost triangular cross-sectional area with a maximum depth of some 300m, a steep northern margin dipping approximately 55° and a 20° southern margin.

Profile 9, from Lower Ashley (SS 95211014), through Tiverton, to Iron Bridge, near Stoodleigh (SS 94301782) required a more complex body to interpret the observed anomaly. The centre of the trough appears to contain only a thin sequence; with deeper areas near the margins, up to 200m near Tiverton and a maximum of 100m in the north. Some support for this interpretation is provided by the drillers' record of the 95m-deep disused well at Tiverton Brewery (I.G.S. Well Record 310/93A). Drilled in 1893, it is situated on the edge of the Permian outcrop, just south of the southern "deep", where the model suggests a depth slightly in excess of 50m. "Blue shale and stone" is recorded below 67.5m, possibly indicating Culm Measures below this depth.

## Ashclyst Forest Inlier

Profiles I and 2 were measured across the margins of the Carboniferous outcrop at Ashclyst Forest, north east of Broadclyst, and are shown in Fig. 3. Profile 1, from Old Cross, Broadclyst (SX 98309727) to Rews Cross (SX 99989984) indicated a south eastern margin sloping at 20° to a depth of just over 400m. However, this immediately begins to thin, and at Broadclyst the thickness of the Permian strata is somewhat less. Because the Culm Measures crop out immediately north east of Exeter, such thinning might be expected and allowing for some marginal faulting such a slope beyond Broadclyst is not unlikely.

Profile 2, from Great Aunk (ST 04880030), through Clyst St Lawrence, to Counterlands Copse (SY 01439994) indicates a similar slope to the east, reaching a maximum depth of up to 500m. The thin westwards extension is thought to represent the uppermost Aylesbeare Group of interbedded sandstones, siltstones and claystones overlapping the underlying Permian formations to overstep onto the inlying Carboniferous strata.

## Crediton area

The remaining five traverses were measured across the Crediton trough. Profile 7, between the southern end of G3 and the northern end of Gl, was undertaken in an attempt to correlate the present work with the previous studies. The model proposed is almost triangular in cross-section with slopes of 40° and 65° on the southern and northern margins respectively. Although these correspond fairly well with the previous estimates, the

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depth of some 800m now suggested is well in excess of that proposed previously, largely because of differences in the density contrasts used, (0.17 gm/cm3 by Edmonds and others compared with 0.11 in the new work).

Profiles, 3, 4, 6 and 8 were undertaken between Crediton and Silverton. Profile 3, between Bickleigh Bridge (SS 93720757) and Compass Cottage, Stoke Hill (SX 93689516), is the most problematical of the set. In addition to being the longest, it is also the one in which topographical features are likely to have most effect. The proposed cross-section attains a maximum thickness of 900m near the southern margin with an overall slope of 35° Between the deepest point and the northern margin, there appear to be three broad steps, the overall slope to the south being approximately 10°

Profile 4, from Woodland Head Cross (SX 77949680) through Yeoford, to Higher Venn, Morchard Bishop (SS 98190537) and Profile 6, from Three Horse Shoes, Cowley, (SX 90509603) to White Cross (SS 87640638) both give cross-sections with a common feature; a minor "deep" at the northern edge of an otherwise fairly simple trough. Both profiles are shown in Fig. 4, the depths of the subsidiary and major troughs being 350m and 725m in Profile 4, and 230m and some 900m in Profile 6. It is unlikely that the true configuration is precisely that shown. The shallow zone in Profile 4 corresponds to the Knowle outcrop of the Exeter Volcanic Series. Since the minettes here are extremely dense, probably somewhat greater than the 2.41 g/cm$^3$ used in the interpretation, such an error is likely to be responsible, in part at least, for the apparent reduction in thickness of the Permian sequence. The similar zone in Profile 6 may represent the subsurface continuation of these lavas to the east. However, in the context of the hydrogeological study of which this work forms a part, the interpretations as they stand, are meaningful. Since the poor aquifer potential of the Exeter Volcanic Series is approximately the same as that of the Culm Measures the models may be taken to represent the configuration of the Permian clastic aquifers.

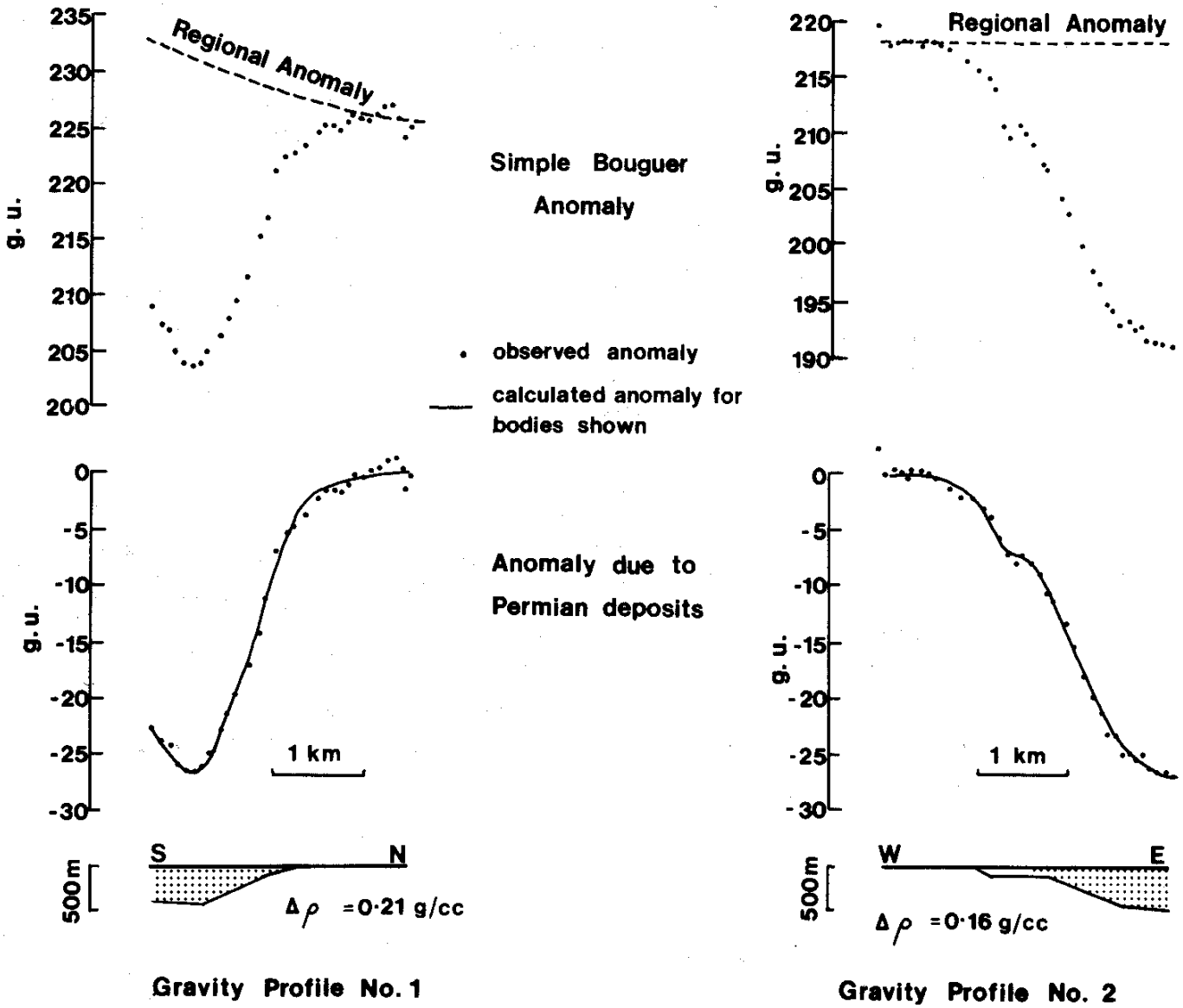


Figure 3. Gravity profiles across the margins of the Ashclyst Forest Inlier. Observed Simple Bouguer anomalies compared with the anomalies calculated for the two dimensional models.

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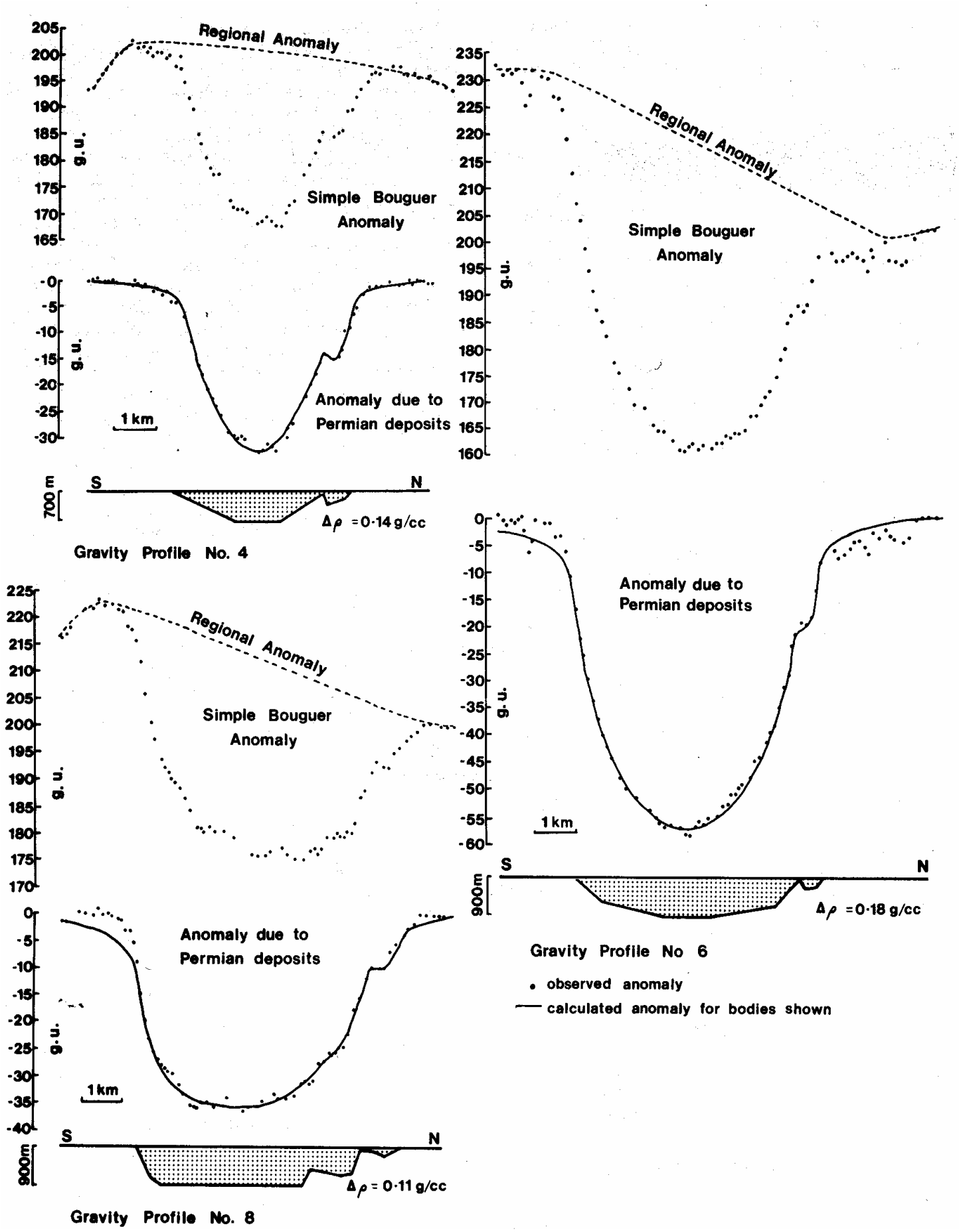


Figure 4. Gravity profiles across the Crediton area. Observed Simple Bouguer anomalies compared with the anomalies calculated for the two dimensional models.

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Between these two is profile 8, measured from Cuddiford Bridge (SS 84889948), through Crediton, to Thelbridge Bridge (SS 81910480) and also shown in Fig. 4. This is interpreted as a body some 900m in depth with a steep southern margin, approximately 55°, and a northern margin typical of the "graben" structures proposed by Whittaker (1975), the uppermost of the two northerly dipping steps, possibly corresponding to the minor troughs described above.

## Conclusions

The major conclusions from the work may be summarised as follows:

1. In the eastern part of the Crediton trough, the outcrop of Permian strata appears to be fault bounded in the manner shown, by Edmonds and others (1968), to exist westwards. Margins dipping at 35-55° are thought to be typical.

2. A thickness of up to 900m is suggested for the deposits in this area. The one estimate of some 800m suggested for the western end of the outcrop is, however, much greater than those made by previous workers.

3. The southern margin of the trough appears to be fairly simple but that to the north much more complex, possibly due to the presence of the Exeter Volcanic Series. A typical "graben" structure is indicated north of Crediton.

4. Eastwards, the Ashclyst Forest Inlier also appears to be fault-bounded, the margins sloping at approximately 209 with the Permian strata on either side 400-500m in thickness.

5. To the west of the inlier, the Aylebeare Group appears to overlap the underlying Permian formations to overstep onto the Carboniferous strata.

6. Estimates of the depth of the Tiverton trough suggest that it is very much shallower. A maximum of 300m is suggested, but 100-200m appears to be more typical.

7. The margin north of Tiverton is not indisputably faulted. The deepest Permian deposits appear to be in the south and it is possible that the northern margin is unconformable. Bearing in mind, however, the faulting elsewhere, it is likely that this has had some effect here.

*Acknowledgements.* Gravity meters were kindly loaned by the Institute of Geological Sciences and Camborne School of Mines. Dr P. Kearey offered advice on survey procedure and Dr J.W. Finch on modelling the observed anomalies. I.C. Trew assisted with the levelling work and P.M. Howell supplied both lunar-solar tide correction tables and regional gravity data. Miss J. Ridler meticulously prepared the illustrations.

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## Discussion

*Dr D.J.C. Laming* expressed considerable interest in the geophysical results and remarked that they were generally consistent with existing knowledge of the Crediton and Tiverton Basins. In particular, the evidence of half-graben faults intersecting the basal unconformity accorded with the interpretation of the basins as longitudinally faulted, though not necessarily as grabens, the faulting being at least in part subsequent to sedimentation.

*Author's reply:* I am pleased to learn that the geophysical results correlate well with Dr Laming's recent sedimentological and stratigraphical data, especially in respect of the relative thinness of the Permian deposits in the Tiverton area compared with those in the vicinity of Crediton.

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