PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

A Gravity Survey of the Western English Channel between Lyme Bay and St Brieuc Bay [and Discussion]

M. Bacon, A. E. Mourant and A. J. Smith

Phil. Trans. R. Soc. Lond. A 1975 **279**, 69-78
doi: 10.1098/rsta.1975.0041

Phil. Trans. R. Soc. Lond. A. **279**, 69–78 (1975) [69]
Printed in Great Britain

A gravity survey of the western English Channel between Lyme Bay and St Brieuc Bay

By M. Bacon
Institute of Geological Sciences, Edinburgh

A gravity map of the area between Lyme Bay and St Brieuc Bay drawn up from the results of surveys by the Institute of Geological Sciences in 1972 and 1973 shows the following main features:

(i) There is an east–west regional gradient of about 0.2 mGal/km† over the entire survey area north of the Channel Isles. This may be due to a westward thinning of the crust.

(ii) A region of low gravity in Lyme Bay is attributed to a Mesozoic basin at least 1 km thick. An anticline runs approximately east–west across this basin.

(iii) A ridge of high gravity extends eastward from Start Point and is probably associated with thrusting of dense Metamorphic rocks over the Devonian strata.

(iv) South of 50° N the gravity field is complex due mainly to the emplacement of granites in an area of shallow basement. The Hurd Deep Fault is, however, clearly visible, possibly owing to its having controlled Mesozoic basin formation.

Introduction

The results of two gravity surveys carried out by the Institute of Geological Sciences in 1972 and 1973 have been combined to produce a gravity map of the area between 4° and 2° W bounded to the north and south by the English and French coasts. A small amount of data obtained for the Hydrographic Office by H.M.S. *Hecate* in 1972 and 1973 has also been included.

Gravity data on land have been taken from three sources. Gravity surveys in Devon and Cornwall have been published by Bott, Day & Masson-Smith (1958), in the Channel Islands by Day (1959), and in France by the Bureau de Recherches Géologiques et Minières (1963, 1964).

Summary of geological structure

A simplified geological map of the survey area is shown in figure 1. A description of the English land geology has been given by Edmonds, McKeown & Williams (1969) and by Chatwin (1960). In the northwest corner of the map we see the eastern end of a major synclinorium of Carboniferous Culm Measures, whose axis passes east–west through central Devon; in the Armorican orogeny these rocks were folded along east–west lines by forces sufficiently strong to produce overfolding, faulting and thrusting. South of this Carboniferous Synclinorium, thick sequences of Devonian rocks are seen to have been similarly affected by the Armorican orogeny. Intrusion of the Dartmoor granite occurred during the closing stages of these movements. On Start Point a major fault separates the folded but little metamorphosed Devonian rocks to the north from the highly contorted low-grade schists lying to the south.

East of about 3° 30′ W the Palaeozoic rocks are overlain unconformably by Permo-Triassic

† 1 mGal = 10^{-5} m s^{-2}.

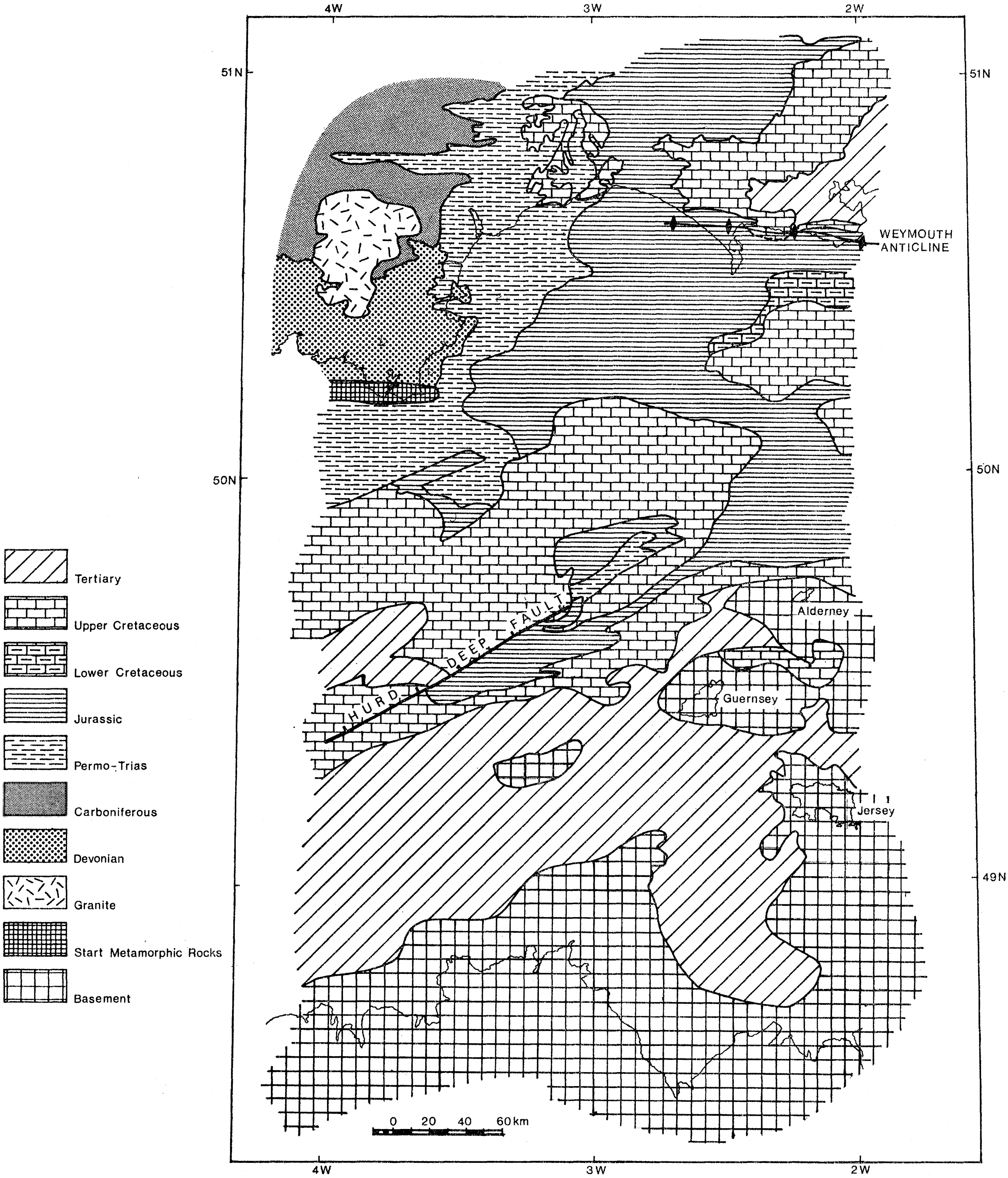

FIGURE 1

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

and later rocks. In these Mesozoic rocks there is a general gentle dip towards the east, into the Hampshire Basin. Outliers of Cretaceous rocks lie unconformably on the Lias, Trias and Permian. A notable feature of the Hampshire Basin is a number of east–west anticlines, most intense on the Dorset coast; they are characterized by a steep northern limb and a gently inclined southern limb, and were formed during Miocene times.

The geological map of the sea area has been discussed by Curry, Hamilton & Smith (1970, 1971). Our area is at the eastern end of the large syncline which occupies the central part of the Western Approaches to and western part of the English Channel. The Devonian–Carboniferous rocks of the Start Point area are overlain to the south and east by rocks of Permo-Triassic age. The structure in Lyme Bay parallels that on shore with the basin deepening eastwards. To the south, the base of the Upper Cretaceous is strongly transgressive, resting on strata of Jurassic and Permo-Triassic age. On the southern side of the syncline the basement is probably at shallow depth beneath Eocene cover landward of a line running from about 20 km north of Alderney to about 20 km north of Ushant. Over much of this eastern end of the West Channel syncline the Chalk is fairly thin and extensive inliers of Permo-Trias and Jurassic rocks are found; however, the basin deepens to the west of our area where a cover of Tertiary material is found. An important feature is the major fault running just north of the Hurd Deep.

The rock types which comprise the basement in Brittany and the southernmost part of the sea area have not been differentiated on the map. They range in composition from granite and gneiss to metamorphosed and unmetamorphosed Palaeozoic sediments.

Description of the gravity surveys

The tracks of the various surveys are shown in figure 2. The 1972 I.G.S. survey was made with a La Coste sea gravity meter, and the 1973 survey with an Askania GSS 3 meter mounted on a gyrostabilized platform built by S. G. Brown Ltd. In 1972 an Admiralty Hi-fix chain was used for navigation, whereas in 1973 an integrated satellite navigation/doppler sonar system was employed. Both 1972 and 1973 surveys called at St Helier and gravity bases at the berths occupied have been connected using a land gravity meter to the site at Queen Victoria's statue, St Helier, which had in turn been connected by I.G.S. in 1971 to the European base station network (g = 981013.60 mGal). Readings at 10 min intervals (generally a little over $1\frac{1}{2}$ km) along the tracks have been reduced to Bouguer anomalies using the 1967 International Gravity Formula and a density of 2.670 kg/m^3. No terrain corrections have been applied. The Admiralty data had been reduced using a different base and gravity formula, and the appropriate correction has been applied to their results.

During compilation, it became apparent that there were differences in general level between the 1972 and 1973 surveys and the Admiralty data. The 1973 I.G.S. survey was on average (based on 47 cross-overs, not all in the area presented here) 3.0 mGal lower than the 1972 survey, and also (15 cross-overs) 1.6 mGal higher than the Admiralty data. The cause of these differences is not known. It was decided to adopt the 1972 I.G.S. survey as standard since, although the weather was on average poorer than in 1973, the survey was carried out with the well-tried La Coste meter and had made more frequent calls into the base on Jersey; the general level of the other two surveys was adjusted accordingly. After this adjustment the mean cross-over error was found to be 3.2 mGal south of 50° N, and 1.8 mGal north of this latitude, where the survey had enjoyed appreciably better weather. The data have been contoured at a

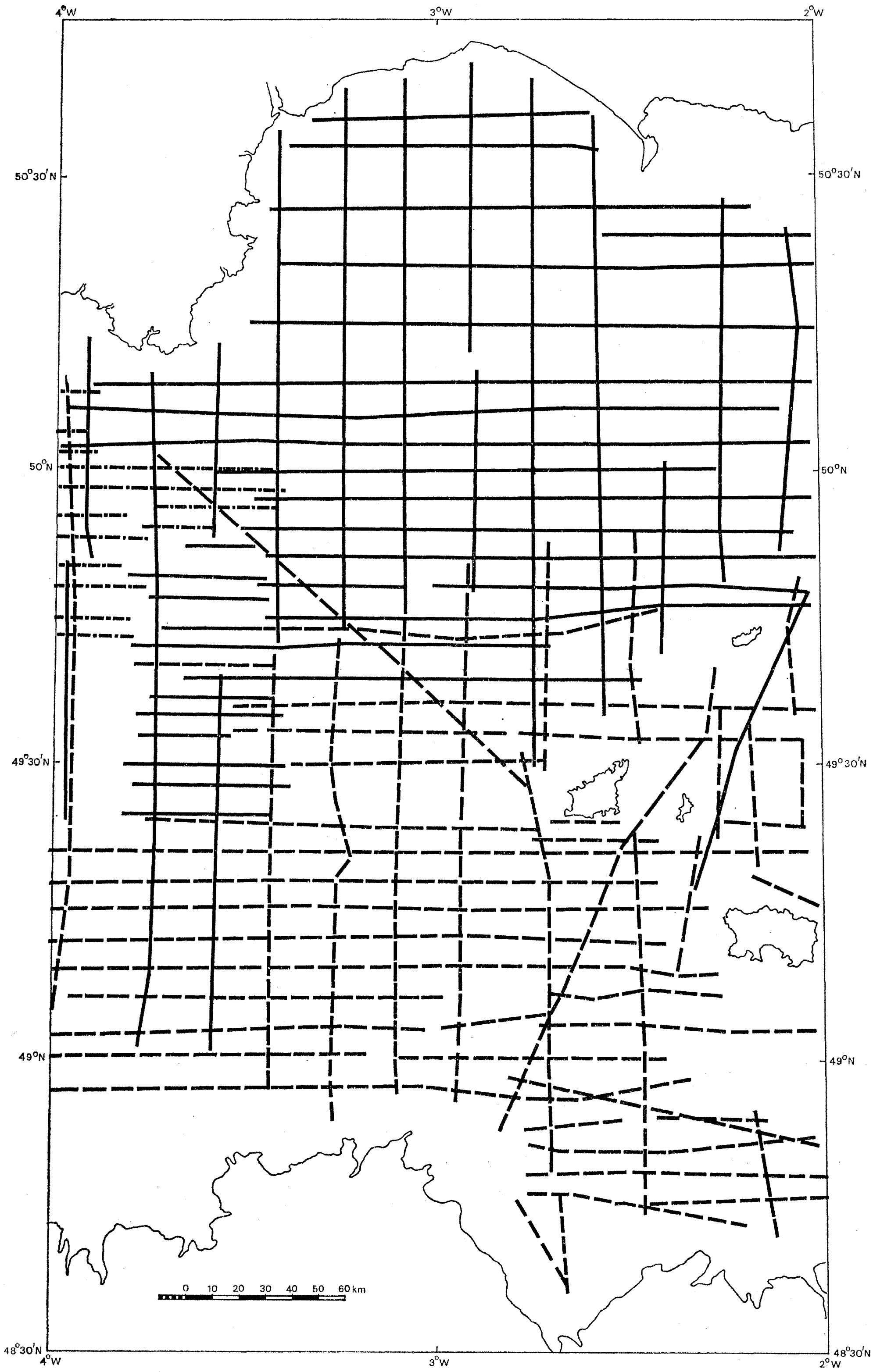

FIGURE 2. Gravity tracks. Solid lines, I.G.S. 1973; dashed lines, I.G.S. 1972; dash-dot lines, Admiralty data.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

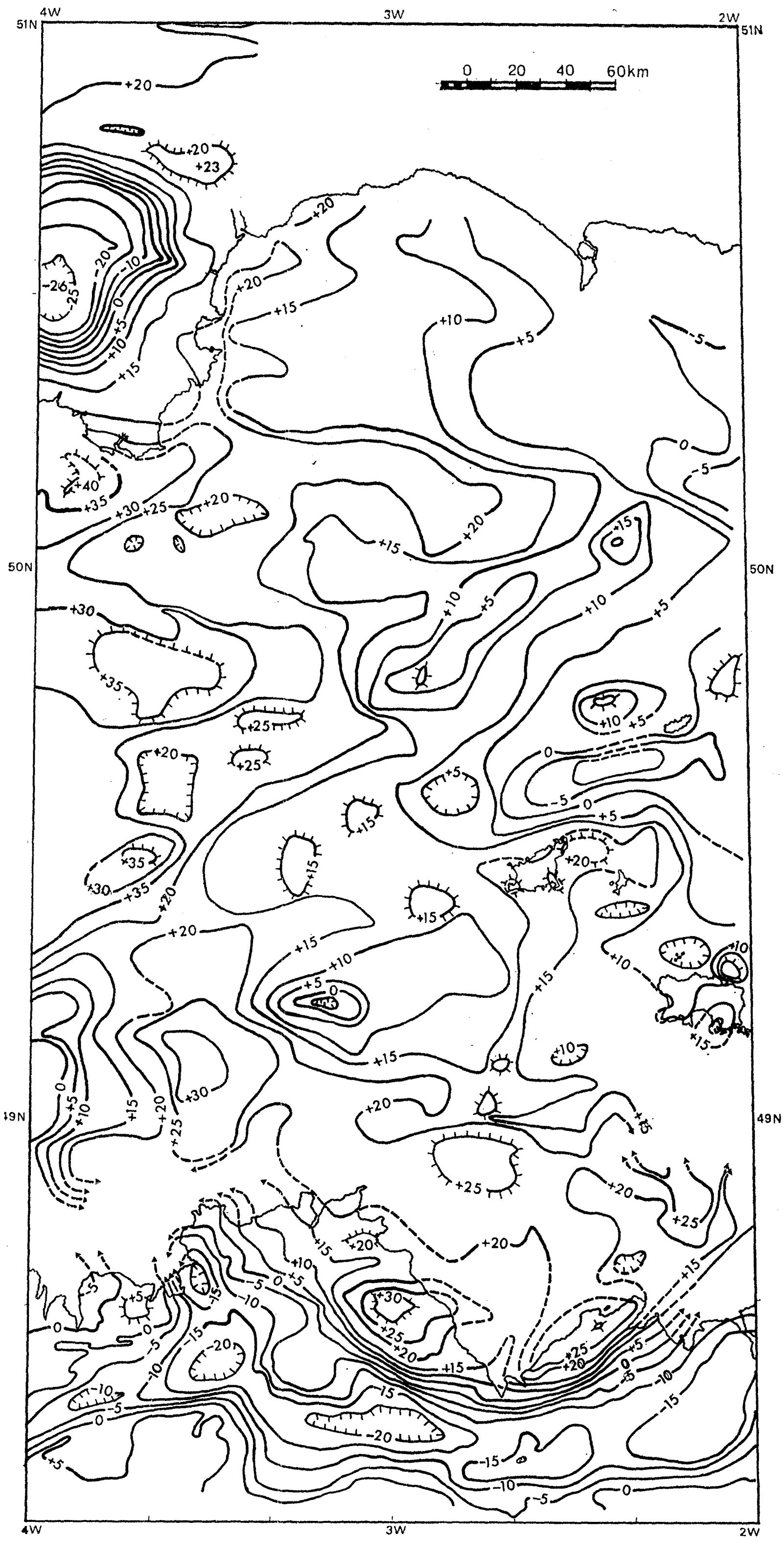

FIGURE 3

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

5 mGal interval and values on land (whose sources are mentioned in the introduction) were corrected to a datum and gravity formula consistent with the marine data and added to the map (figure 3).

Description of the gravity anomalies

The largest scale of anomaly visible on the map is a regional gradient from about +30 mGal on the western side of the map to about zero on the eastern side. This regional gradient extends about as far as the Channel Isles. Its value of 0.20 mGal/km is very similar to the values of 0.15–0.19 mGal/km deduced by Bott *et al.* (1958) over the Culm synclinorium. This regional gradient is therefore of wide extent in this area, and may therefore represent, as Bott *et al.* suggested, a variation in thickness of the crustal layers themselves, such as a slight westward rise of the Mohorovicic discontinuity. If the density contrast at the Moho were 500 kg/m³, then a rise of about 1.4 km from east to west across the map would be indicated.

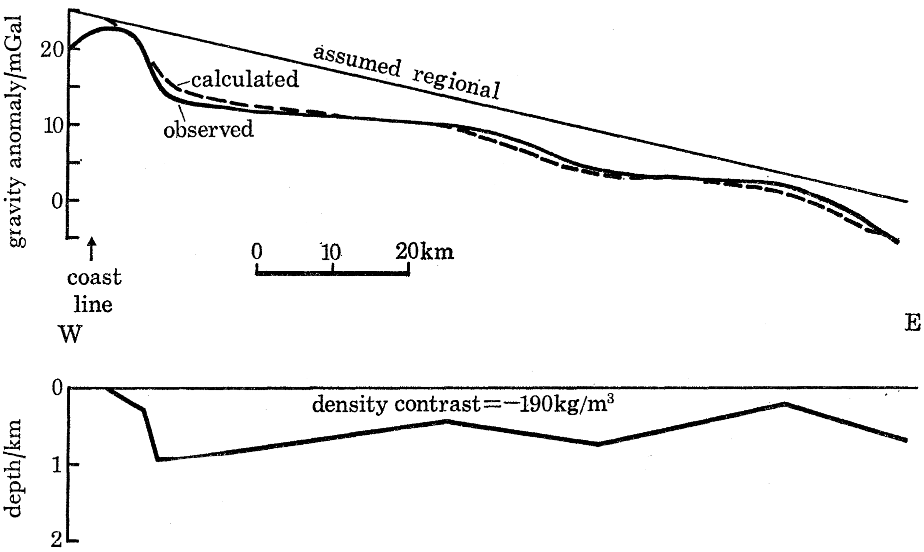

Figure 4

The interpretation of the Cornubian Peninsula anomalies has been discussed by Bott *et al.* Gravity over the Culm synclinorium shows small undulations striking east–west superimposed on a broad east–west trough. South of this the gravity effect of the Crediton New Red Sandstone trough can be seen, and south of this there is a large negative anomaly associated with the Dartmoor granite. South of the granite the values increase rapidly over the Start peninsula.

On the French side of the Channel the gravity anomalies are clearly related to changes in basement density, especially those due to the emplacement of granites in a higher density country rock. The main marine anomalies can be summarized as follows:

(i) A region of low gravity is associated with the Jurassic–Permo-Trias basin of Lyme Bay.

(ii) A gravity ridge extends eastwards from the Start Point positive anomalies.

(iii) A complex zone extends from 50° N to the French coast.

Lyme Bay

An impression of the structure of the Lyme Bay basin is shown in the east–west section along 50° 25′ N (figure 4). This represents a two-dimensional model whose calculated gravity effect is a fairly good fit to the observed gravity, except for the region at the extreme western end of the profile where proximity to the Dartmoor granite may be the cause of the lowered gravity. Clearly both the regional gradient and the density contrast to be assumed are fairly uncertain; for the latter we have used the value of 90 kg/m^3, corresponding to the contrast in mean surface density between Permo-Triassic and Devonian rocks found by Bott *et al.* (1958). The basin deepens rapidly just off-shore; possibly this is due to faulting. The maximum depth of the basin is computed to be 0.95 km; this may be compared with a depth of 0.67 km to a refractor of velocity 4.5 km/s found at a refraction station at 50° 30′ N, 03° 00′ W (Day, Hill, Laughton & Swallow 1956); however, *pace* Day *et al.* it is possible that this refractor lies within the Permo-Triassic. Two small anticlines are seen in the central and eastern part of the section.

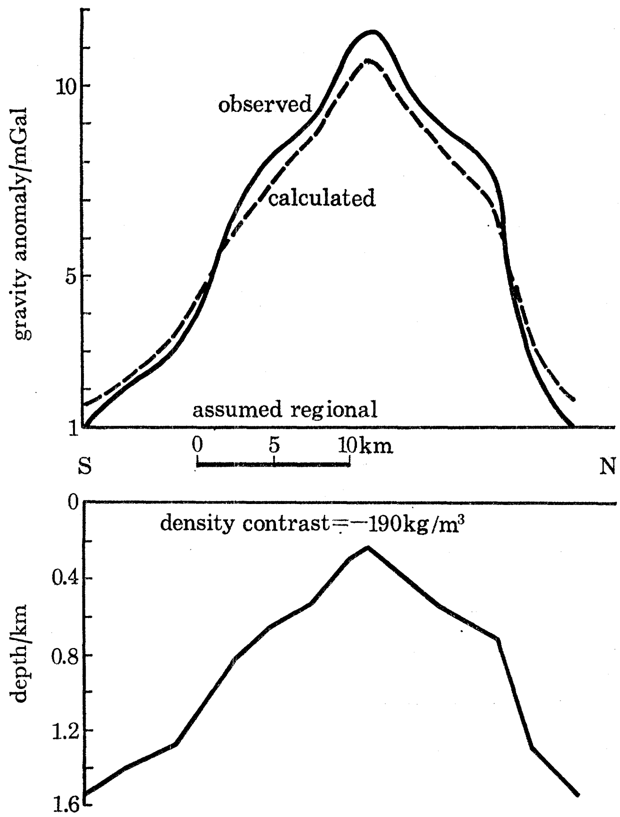

Figure 5

The more easterly of these is the larger and corresponds to the gravity ridge from about 50° 34′ N, 3° 19′ W to 50° 14′ N, 2° 04′ W. Figure 5 shows a model fitted to a north–south profile across this ridge along 2° 45′ W; the same density contrast as before has been used, and since this profile is perpendicular to the regional field a constant value of +1 mGal has been assumed. The anomaly is rather too small compared with the probable errors of measurement for conclusions on the detailed shape of the ridge to have much meaning; however, the ridge seems to be fairly symmetrical with probably a slightly steeper dip on the northern side; as noted above, the anticlines of the Hampshire Basin tend to have a steeper limb on their northern side.

Start Point area

Bott *et al.* found some difficulty in explaining their results on the Start Peninsula. Because the increase in gravity anomaly begins abruptly some 5 km north of the mapped fault boundary between the unmetamorphosed Devonian to the north and the schists to the south, they were forced to postulate an unexposed wedge of metamorphics, possibly a thrust slice, lying to the north of the fault. Our survey shows that gravity continues to increase out to sea, decreasing again only as the effect of the Permo-Trias basin begins to be felt. If we assume Bott's value of 50 kg/m³ for the density contrast between metamorphic and unmetamorphosed Devonian rocks, a vertical contact gives a quite reasonable fit to the marine observations (figure 6) except in the area at the southern end of the profile where we have ignored the effect of the Permo-Triassic basin. However, the contact must reach the implausible depth of 20 km. A density contrast of 100 kg/m³ extending to 8 km depth gives a fair fit for general amplitude of the anomaly but a poor fit to the shape. Probably the contact, though vertical at the surface, dips to the south at depth, the metamorphic rocks being thrust over the unmetamorphosed Devonian.

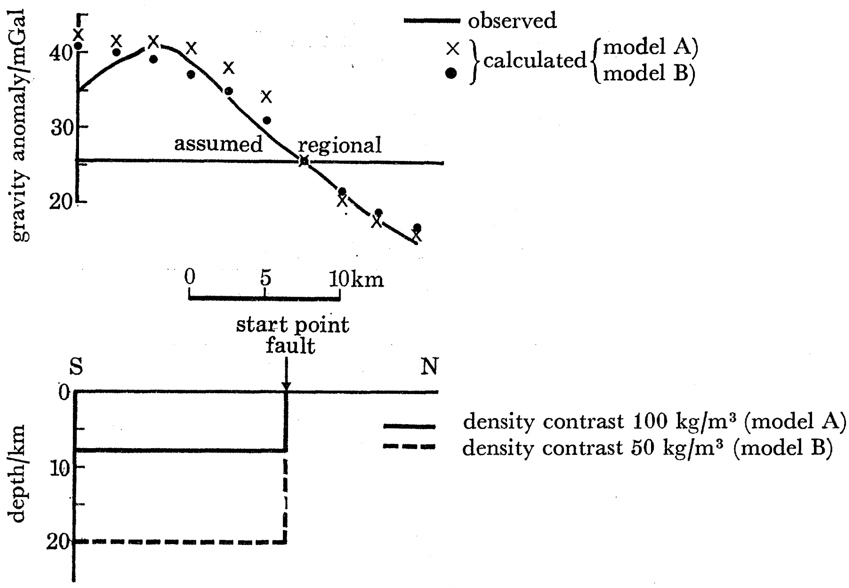

Figure 6

A gravity ridge extends eastward from the Start Peninsula. It seems likely from the refraction evidence of Day *et al.* (1956) that this is not due to a thinning of the Mesozoic sequence; at 50° 15′ N, 3° 04′ W, on the northern edge of the gravity ridge, they find the base of the Mesozoic strata at a depth of 890 m, while at 50° 03′ N, 3° 08′ W, well to the south of the ridge, they find the base Mesozoic at 670 m. Thus the gravity ridge is perhaps best attributed to the presence, within the Devonian rocks underlying the Mesozoic strata, of dense schists like those on Start Point. The gravity gradient on the north side of the ridge is steeper than on the south side, suggesting a more nearly vertical contact to the north. Figure 7 shows a model to account for the gravity profile along 3° W. Bott's density contrast of 50 kg/m³ has been used and a depth of 0.8 km for base Mesozoic taken from the refraction data. The northern contact is vertical whereas to the south the dip is fairly gentle.

South of 50° N

The complexity of the gravity field over the basement of the French mainland in the southern part of the maps warns against an attempt to interpret the areas of low gravity in this area as being due to sedimentary basins. Both the low at 49° N 4° W and that at 49° 12′ N, 3° 12′ W

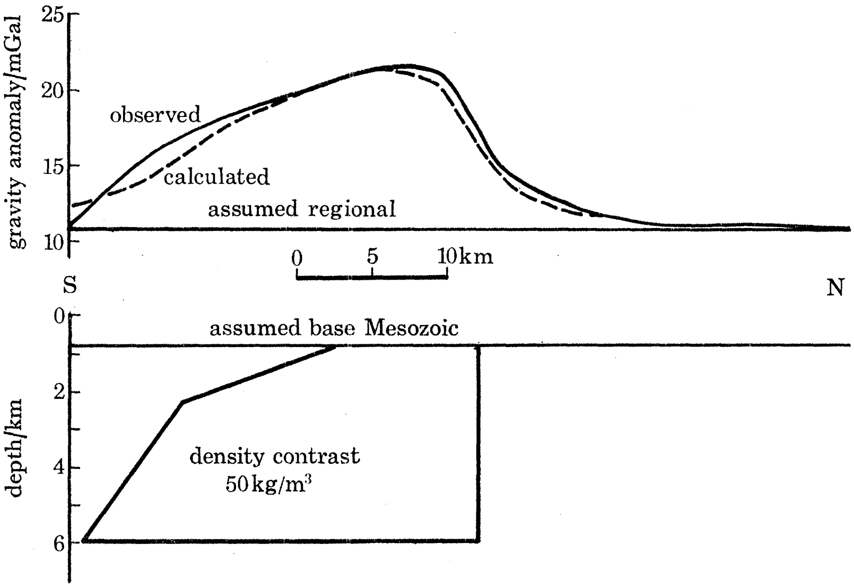

Figure 7

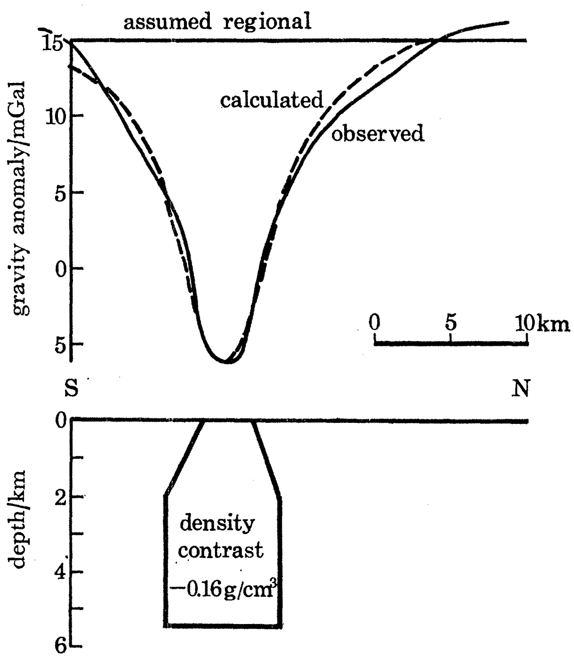

Figure 8

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

are in areas of basement with shallow Tertiary cover and are almost certainly due to granites. A possible two-dimensional interpretation of the latter is shown in figure 8; a small granite is adequate to explain the anomaly with a density contrast similar to that proposed by Bott *et al.* (1958). The low around 49° 48′ N, 2° 55′ W is situated, rather unexpectedly, over a Permo-Triassic inlier; it is probable, however, that a granite at shallow depth is again the cause. Trending southwest from this inlier a distinct lineation can be seen corresponding to the Hurd Deep Fault; to the southeast of this line gravity is slightly lower, possibly corresponding to a Mesozoic basin. Perhaps this fault was active during Mesozoic times and controlled sedimentation, as well as being active in post Eocene times, as shown by the geological map. The low between Guernsey and Alderney is very probably due to a granite, although in this case the possibility of a small subsidiary Mesozoic basin cannot be ruled out.

References (Bacon)

Bott, M. H. P., Day, A. A. & Masson-Smith, D. 1958 The geological interpretation of gravity and magnetic surveys in Devon and Cornwall. *Phil. Trans. R. Soc. Lond.* A **251**, 161–191.

Bureau de Recherches Géologiques et Minières 1963 Carte gravimétrique de la France at 1:320000: Sheet 11–16. Brest Lorient.

Bureau de Recherches Géologiques et Minières 1964 Carte gravimétrique de la France at 1:320000: Sheet 7–12. Cherbourg Rennes.

Chatwin, C. P. 1960 *The Hampshire Basin and adjoining areas. British Regional Geology.* Institute of Geological Sciences.

Curry, D., Hamilton, D. & Smith, A. J. 1970 Geological and shallow subsurface geophysical investigations in the Western Approaches to the English Channel. *Rep. no.* 70/3, *Inst. geol. Sci.*

Curry, D., Hamilton, D. & Smith, A. J. 1971 Geological evolution of the western English Channel and its relation to the nearby continental margin. In F. M. Delany (ed.), ICSU/SCOR Working Party 31 Symposium, Cambridge 1970: The geology of the East Atlantic continental margin. 2. Europe. *Rep. no.* 70/14, *Inst. geol. Sci.*

Day, A. A., Hill, M. N., Laughton, A. S. & Swallow, J. C. 1956 Seismic prospecting in the Western Approaches of the English Channel. *Q. Jl geol. Soc. Lond.* **112**, 15–44.

Day, A. A. 1959 Gravity anomalies in the Channel Islands. *Geol. Mag.* **96**, 89–98.

Edmonds, E. A., McKeown, M. C. & Williams, M. 1969 *Southwest England. British regional geology.* Institute of Geological Sciences.

Discussion

Dr A. E. Mourant (5 *Mercier Road, Putney, London SW15 2AW*)

At a recent meeting of the Geologists' Association Dr A. T. J. Dollar showed a map of earthquake epicentres in the British Isles and the surrounding region. There were numerous epicentres in southern England, and in northwestern France and the Channel Islands up to the Alderney–Ouessant line, but the main English Channel area appeared almost totally aseismic. Dr Dollar admitted that very small earthquakes in mid-Channel might have been missed, but he considered that there was a real deficiency of rather more intense ones, which needed explanation. I wonder whether one of the speakers or any other geophysicist would care to comment on this.

Dr A. J. Smith replied that the Channel area does indeed appear to be a seismic-quiet area: with the exception of the earthquake records described by the questioner in 1931, no epicentres have been located in the area in recent times.