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A possible concealed granite beneath part of Anglesey, North Wales

J. D. CORNWELL & I. F. SMITH
British Geological Survey, Keyworth, Nottingham NG12 5GG, UK

Abstract: A closed Bouguer gravity low is revealed by land and marine gravity survey data centred on Holyhead Bay, northwest Anglesey. The anomaly extends across areas on land and offshore mainly occupied by Precambrian rocks. A concealed granite offers the best explanation for the anomaly and a late Caledonian age seems most probable for the intrusion, although Precambrian–early Cambrian ages are also possible. The existence of a granite in this area could have influenced the development of mineralization and the low density rock mass also formed a relatively buoyant core to the basement block. It could therefore have been instrumental in the preservation of this Precambrian structural high.

The island of Anglesey, North Wales, has had a complex geological history involving several tectonic events and rock units with ages from late Precambrian to Carboniferous and Tertiary (Greenly 1919). A large part of the island (Fig. 1) is occupied by the oldest rocks ranging in age from late Precambrian to Cambrian and probably representing an assemblage of suspect terranes. Gibbons & Horak (1990) recognize three distinct tectono-metamorphic terranes: the Monian Supergroup, the gneisses and granitic rocks of central Anglesey, and the blueschist belt of southeast Anglesey. The Monian Supergroup of north and northwest Anglesey (Shackleton 1975; Barber & Max 1979; Gibbons & Ball 1991) is a sequence of metasedimentary and igneous rocks with a probable thickness of more than 7 km. The Lower Palaeozoic is mainly represented by Ordovician sedimentary sequences with minor amounts of Cambrian and Silurian rocks. All these were deformed during the Caledonian orogeny and are succeeded by a dominantly arenaceous sequence of Old Red Sandstone age. Lower and Upper Carboniferous rocks were subsequently deposited in elongated, fault-controlled basins. Igneous intrusions and volcanic rocks of various ages are widespread, the youngest being a suite of NW–SE trending Tertiary dykes.

The complexity of the geology is reflected by the regional Bouguer gravity and aeromagnetic data which reveal anomalies related to many of the lithological units and structures. During an examination of the local gravity anomalies (Cooper *et al.* 1990) it became apparent that a well defined Bouguer gravity gradient existed in the north-western part of the island which had no obvious geological explanation. An examination of the offshore gravity data shown by Hipkin & Chacksfield (1986) and in a recent compilation, including new data, by the British Geological Survey (BGS) (J. W. F. Edwards, pers. comm. 1991) indicated that this gradient was part of a discrete Bouguer gravity anomaly low centred near the coastline of Holyhead Bay. The evidence favours an interpretation of this feature in terms of concealed low density granite or, less probably, a thick sequence of acid volcanic rocks.

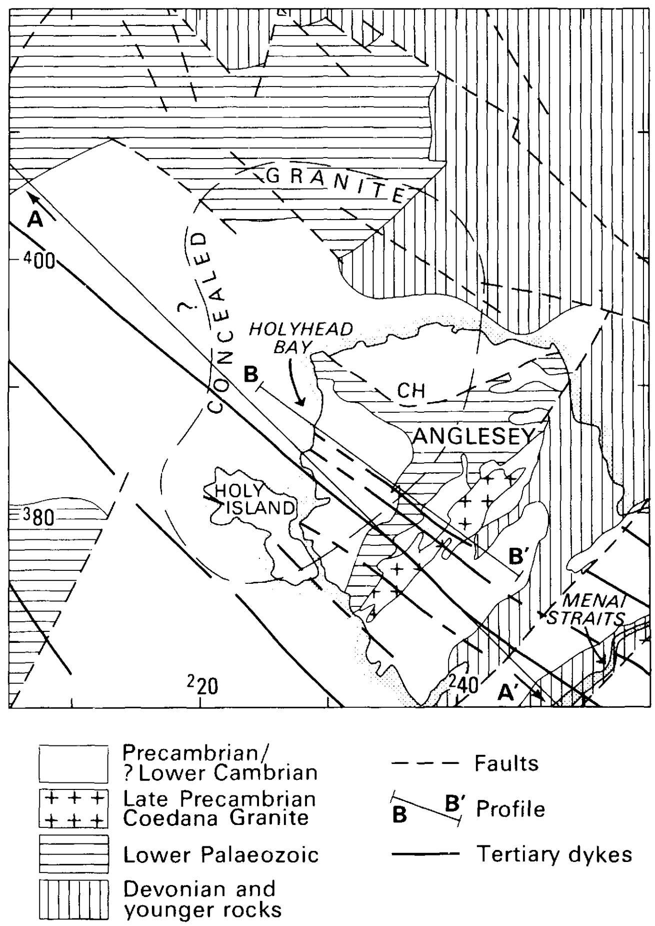

Fig. 1. Simplified geological map of Anglesey and adjoining areas with locations, based on geophysical evidence, of the postulated granite and Tertiary dykes. AA' and BB' are locations of profiles. CH, Carmel Head thrust. Ticks indicating the National Grid at 10 km intervals are shown at the margins of the map.

Geophysical and geological evidence

The Bouguer gravity anomaly map in Fig. 2A is based on data from the BGS databank obtained from land and offshore surveys. Onshore there is good coverage from surveys by the Department of Earth Sciences, University of Leeds, and BGS with an average of about 1 station per 1.3 km^2, while the offshore data were acquired during several marine surveys in the area indicated. The absence of near-shore data is apparent and presents a common problem in geophysical and geological studies around much of the UK coastline. The aeromagnetic data coverage for the area is complete (Fig. 2B) and was acquired at a flight elevation of 305 m along lines 2 km apart.

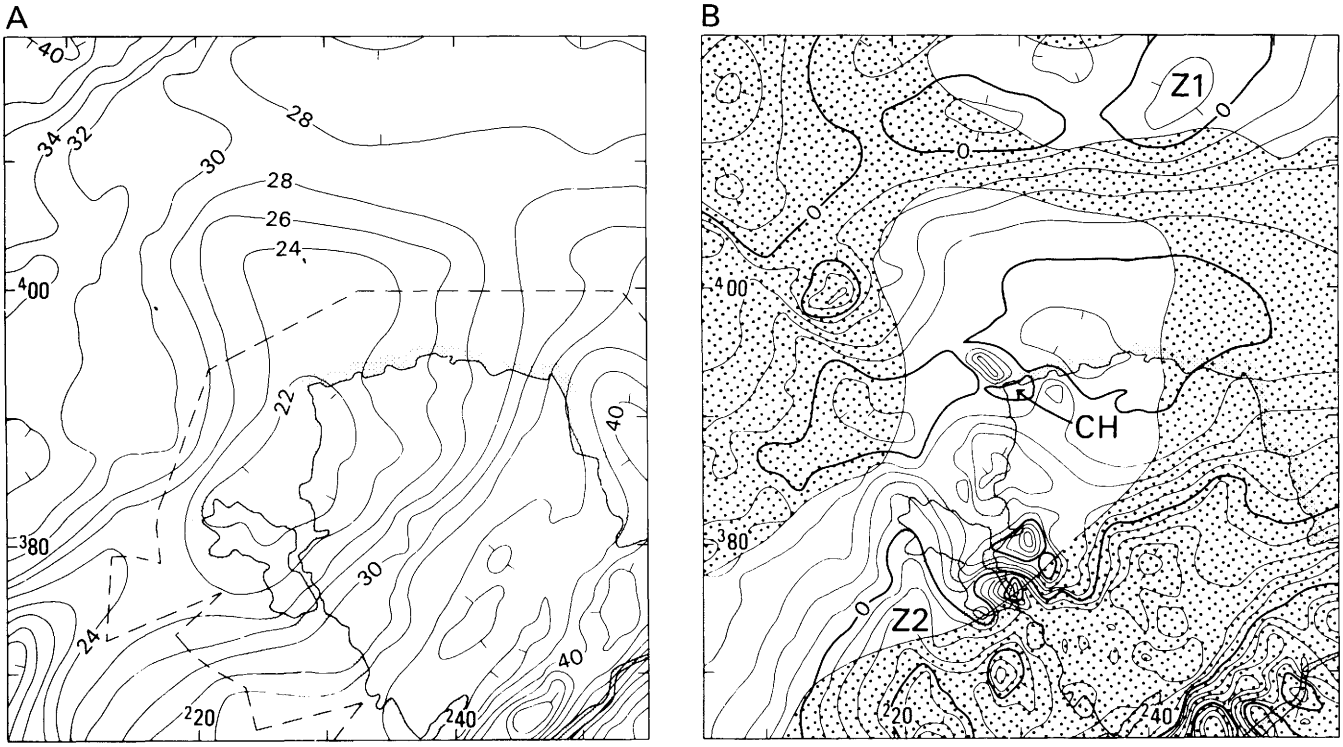

Fig. 2. (**A**) Bouguer gravity anomaly map of Anglesey and the adjoining areas. Contours at intervals of 2 mGal. Offshore contours from a recent BGS compilation of gravity data. Broken line indicates inshore limit of marine surveys.
(**B**) Aeromagnetic anomaly map with contours at 20 nT intervals. The stippled areas have gravity values greater than 28 mGal. CH, Carmel Head thrust; Z1 and Z2 are referred to in text.

The gravity data are sufficient to indicate the existence of at least one gravity closure with minimum values of about 20 mGal along the northwestern coast of Anglesey and extending over an area of about 1000 km^2. The gravity low appears to be constricted at the northern coastline approximately along the line of the Carmel Head thrust (CHT in Fig. 1). However this local high is not sufficiently well defined by the survey coverage available and the lows are regarded at this time as having one source. In the surrounding areas, the Bouguer gravity values form part of a regional high over the Irish Sea (Bott 1964; Blundell *et al.* 1971) and the background field appears to be about 40 mGal (Fig. 3).

The onshore portion of the main gravity low occurs mainly in an area of rocks belonging to the Monian Supergroup. Offshore, rocks of Precambrian age have been indicated by Wright *et al.* (1971) to occur beneath a thin sedimentary cover in the area of the gravity low. This restricts the source of the anomaly to low density rocks below or within the Monian Supergroup. In adjacent areas more sharply defined gravity lows occur over basins of Carboniferous and younger sedimentary rocks (Al-Shaikh 1970) and part of one of these is visible in the southwestern corner of Fig. 2A. A similar explanation for the Holyhead Bay anomaly is considered inappropriate because even if such a basin had escaped detection offshore it would fail to explain the considerable extent of the gravity gradient over the Precambrian and Lower Palaeozoic rocks on the island.

Density values for the main rock units on Anglesey have been reported by Powell (1956) and Cooper *et al.* (1990). The values can be divided into three broad groups; a high density (2.80 Mg m^{-3} and above) group comprising basic igneous rocks, hornblende schists, hornblende gneisses and glaucophane schists; a low density group (less than 2.70 Mg m^{-3}) of granite, felsite, acid volcanic and some sedimentary rocks; and the remaining group with intermediate densities consisting of many metamorphic rock types such as mica and quartz chlorite schists as well as most of the Lower Palaeozoic rocks. Average density values in the range 2.73–2.78 Mg m^{-3} therefore seem reasonable for the surface rocks in northwest Anglesey; high values of 2.80–2.85 Mg m^{-3} adopted for Monian rocks by Reedman *et al.* (1984) are probably only appropriate for the blueschist belt in southeast Anglesey where localized gravity highs were also observed (Cooper *et al.* 1990). It is difficult to explain the Holyhead Bay anomaly in terms of the surface geology; an area of predominantly volcaniclastic metasedimentary rocks forming the Skerries Group occurs near the gravity minimum but outcrops of similar rocks elsewhere do not have an obvious anomaly. Density measurements reported by Cooper *et al.* (1990) also indicate a wide range of values for these rocks. It is not possible to rule out, on the basis of the density sampling, the existence of a concealed, homogeneous low density group of Precambrian rocks as the source of the gravity low, such as a thick sequence of acid volcanic rocks. Such an interpretation was adopted by Reedman *et al.* (1984) for the pronounced gravity low associated with Arvonian rocks of the adjacent mainland of Wales (extreme southeast corner of Fig. 2A and in Fig. 3), although these are early Cambrian in age and the anomaly has also been regarded as having a granite source (Powell 1956). However, the most plausible explanation for the location, form and amplitude of the Holyhead Bay anomaly is considered to be that it is due to a large concealed

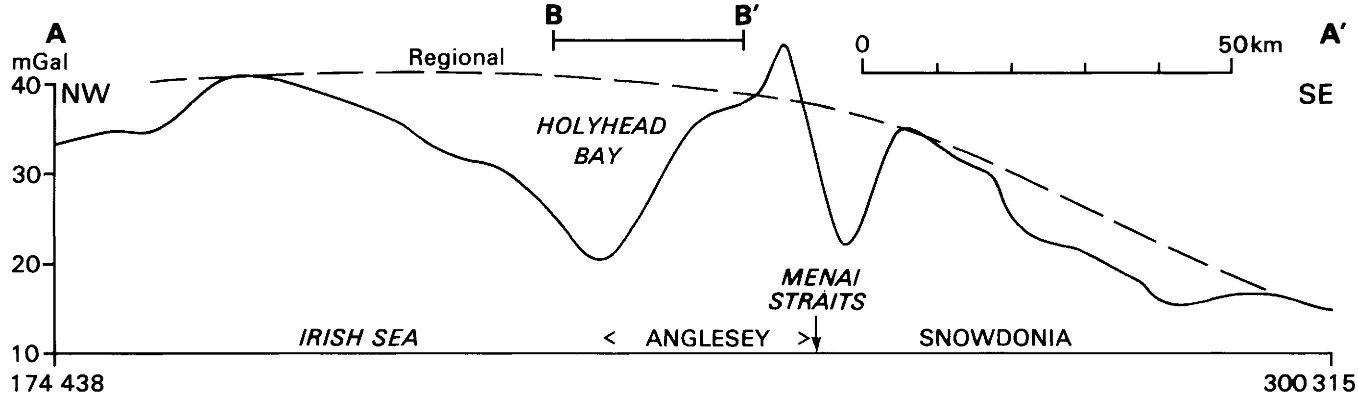

Fig. 3. Observed Bouguer gravity profile AA' across North Wales and part of the Irish Sea (see Fig. 1 for location). BB' is the projection of the profile shown in Fig. 4.

granite intrusion with a density contrast of about -0.10 to $-0.15\,\mathrm{Mg\,m^{-3}}$ with the country rocks.

Some information on the form and depth of the low density body can be derived from the more detailed onshore gravity data, although these only cover about a half of the southern part of the anomaly. Using the profile shown in Fig. 4, approximate depths to the top of the body can be estimated using the simple procedure described by Skeels (1963). The maximum depths obtained for two-dimensional rectangular block and vertical cylinder models with density contrasts of $-0.1\,\mathrm{Mg\,m^{-3}}$ are about 2.0 km. In both cases the models are 15–20 km wide. It is also noted from Fig. 4A that the position of the maximum gradient occurs nearer the centre of the anomaly, rather than at the flanks, a feature more consistent with the density interface dipping outwards from the centre. In order to achieve a satisfactory interpretation of the profile with an interface dipping inwards, low density material has to be introduced into the model at the margins of the anomaly (Fig. 4C).

The aeromagnetic data for the area (Fig. 2B) are highly disturbed, particularly by the magnetic effect of a swarm of northwest-trending Tertiary dykes. There is, however, a general correspondence between the area of the gravity low and low magnetic field values, suggesting that the low density material is only weakly magnetic. The correspondence is most clearly seen in the north of the area where the magnetic contours closely follow the margin of the gravity low (Fig. 2B), a feature which would be consistent with the truncation of the magnetic anomalies extending from the north. These anomalies form parts of elongated zones and it is possible that one of these (Z1 in Fig. 2B) at one time might have been continuous with the magnetic high Z2 located on the other side of the Holyhead Bay low. Because of their relationship to the surface geology and the considerable depth extent indicated by the forms of the aeromagnetic anomalies, these zones are considered to be due largely to Precambrian rocks. Smaller magnetic anomalies occurring over the centre of the gravity low, such as that associated with the Carmel Head thrust and its offshore extension (CH in Fig. 2B), are probably due to magnetic rocks in the 1–2 km thick roof region of the postulated intrusion.

Geological implications of the granite model

If the Holyhead Bay anomaly indicates the presence of a concealed granite batholith, the possible age of the intrusion ranges from Precambrian to Tertiary. At least three possible intrusive phases occur in the area within the Precambrian to Cambrian time span. In view of the uncertainty concerning the thickness and structure of the Monian Supergroup, it is possible that the granite forms a basement to these late Precambrian rocks. It could then have provided the granite clasts recorded within the Monian (Gwna) melange (Gibbons & Horak 1990). The existence of a late Precambrian granite (the Coedana Granite) on the flanks of the gravity anomaly (Fig. 4) suggests a second possible age for the concealed intrusion. The Coedana Granite has a suitably low density of $2.64\,\mathrm{Mg\,m^{-3}}$ (Cooper *et al.* 1990) but is associated with only a minor gravity low, suggesting that it must be a small intrusion or a tectonic slice). The likelihood of this intrusion being related to the source of the Holyhead Bay anomaly is reduced by the fact that it is separated from the Precambrian rocks to the northwest by a major fault zone, possibly representing a terrane boundary (Gibbons & Horak 1990). A third possible date for granite intrusion in the Precambrian/Cambrian time span is contemporaneous with the Arvonian volcanic activity on the Welsh mainland (Reedman *et al.* 1984). In this case, the granite could have been intruded in situ, whereas for the two earlier possibilities the intrusion would form part of suspect terranes.

At the other extreme, a Tertiary age might be suspected because of the coincidence of the Holyhead Bay anomaly with a well developed swarm of Tertiary dykes. These have been recognized by geological mapping but are shown to be major features by aeromagnetic surveys, particularly the low level survey described by Smith (1979). However, geophysical evidence from other Tertiary centres (e.g. Bullerwell 1972) on the west coast of Scotland, in Northern Ireland and Lundy in the Bristol Channel shows that the dominance at depth of high density basic intrusive rocks in the complexes produces gravity highs over the exposed low density granites.

The two main remaining possible ages are Caledonian and Hercynian but the latter is considered unlikely in view of the location and geological environment of the gravity low. The geophysical signature of the Holyhead Bay feature is comparable with those of the late Caledonian granites of northern Britain and Ireland; the gravity anomaly, for example, is similar in area and amplitude to that of the concealed Wensleydale granite beneath the Askrigg Block. The Wensleydale granite is also flanked by magnetic anomalies, although this, like other intrusions of this age south of the Iapetus Suture, is hosted largely by rocks of Lower Palaeozoic age. The presence of a

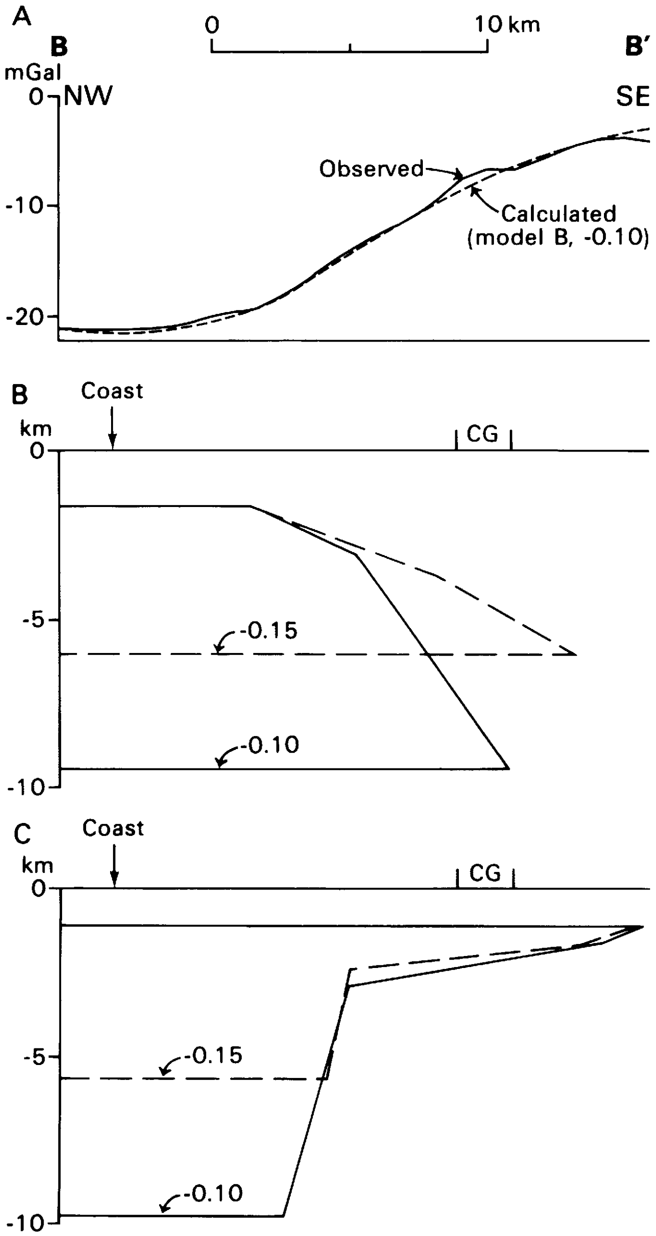

Fig. 4. (**A**) Residual Bouguer gravity data for the profile BB' (see Fig. 1 for location). The models shown (**B** and **C**) (with density contrasts in $Mg\,m^{-3}$) are considered to be symmetrical about the coast and to have strike extents of 40 km. The calculated profile for one model only is shown; the others are very similar. Background gravity field +40 mGal. CG, Coedana Granite.

late Caledonian granite might also help to explain some of the complex history of mineralization on Anglesey. Cooper *et al.* (1982) recognized three main phases of mineralization on the island; an early (Precambrian) series of copper veins, secondly copper (lead, zinc) mineralization largely in Lower Palaeozoic rocks and thirdly (?)Carboniferous barite volcanogenic mineralization. The middle group is by far the most important economically and includes the large deposits at Parys Mountain which have been dated at 394 and 353 Ma (Nutt *et al.* 1979), the second of which is the preferred age for the main mineralization. The origin of the 394 Ma event is less certain but is comparable with the ages of many of the late Caledonian intrusions of northern England (summarized by Allsop 1987). Occurrences of base metal mineralization do not appear to be spatially related directly to the roof area of the postulated granite although they do occur generally only in the north of the island. However, the intrusion of a granite at that time would have produced the increased heat flow and fluid movement likely to result in the formation or redistribution of mineral deposits in the adjoining areas. Some support for this is provided by the provisional results for the area from the BGS Geochemical Survey Programme. These indicate higher than average values for some elements in the area of the gravity low. Although interpretation of the results is at an early stage, one possibility is that they could be related to a concealed evolved granite (P. R. Simpson, pers. comm. 1991).

The Precambrian rocks of Anglesey and the adjacent offshore areas (Fig. 1) are surrounded on three sides by basins of Carboniferous and Mesozoic sedimentary rocks. On the fourth side the major Menai Straits Fault separates the low-lying island from the predominantly Lower Palaeozoic rocks forming the mountains of Snowdonia. In several areas of the UK, the isostatic effect of low density granite intrusions, all probably of Caledonian age, has been to enable fault-bounded blocks to resist subsidence during periods of crustal tension. This is particularly clearly demonstrated by the development of block and basinal environments during the Carboniferous on the English mainland and, in the Irish Sea, possibly by the existence of the Isle of Man as a basement high (Cornwell 1972). It is suggested that the proposed concealed granite beneath Holyhead Bay could have acted in a similar way to ensure the preservation of the Precambrian and Palaeozoic rocks of Anglesey and adjoining offshore areas as a structural high, compared with the younger basinal areas of the central Irish Sea. Such a geological environment would also have been favourable for the development of growth faults flanking the adjacent Carboniferous basins.

Conclusions

The Bouguer gravity anomaly gradient zone seen over the northwestern part of Anglesey is part of a distinct gravity low centred on Holyhead Bay. It occurs in an area occupied by Precambrian and Lower Palaeozoic rocks and its source is believed to be a low density granite intrusion or, less probably, a thick pile of acid volcanic rocks. A Caledonian age is preferred for a granite source, largely on the basis of the geophysical signature, but a Precambrian–early Cambrian age is also possible. The existence of a relatively buoyant granite could explain the preservation on Anglesey and beneath part of the Irish Sea of the block of Precambrian and Lower Palaeozoic rocks.

The significance of the gravity anomalies was recognized during an assessment of geophysical data for Anglesey as part of the Mineral Reconnaissance Programme supported by the Department of Trade and Industry. Further work was undertaken as a contribution to the Regional Geophysics Group's interpretations of gravity and aeromagnetic data for the UK, funded by the Department of Education and Science. Access to a recent compilation of gravity data for the 1:1 000 000 map of Southern Britain by J. W. F. Edwards and A. J. Gibberd is gratefully acknowledged. The comments on drafts of this paper by D. C. Cooper, C. J. N. Fletcher, G. A. Day, G. S. Kimbell and the referees are also gratefully acknowledged. The paper is published with the approval of the Director, British Geological Survey (NERC).

References

ALLSOP, J. M. 1987. Patterns of late Caledonian intrusive activity in eastern and northern England from geophysics, radiometric dating and basement geology. *Proceedings of the Yorkshire Geological Society*, **46**,335–353.

AL-SHAIKH, Z. D. 1970. The geological structure of part of the central Irish Sea. *Geophysical Journal of the Royal Astronomical Society*, **20**, 233–237.

BARBER, A. J. & MAX, M. D. 1979. A new look at the Mona Complex (Anglesey, North Wales). *Journal of the Geological Society, London*, **136**, 407–432.

BLUNDELL, D. J. DAVEY, F. J. & GRAVES, L. J. 1971. Geophysical surveys over the south Irish Sea and Nymphe Bank. *Journal of the Geological Society, London*, **127**, 339–375.

BOTT, M. H. P. 1964. Gravity measurements in the north-eastern part of the Irish Sea. *Quarterly Journal of the Geological Society of London*, **120**, 369–396.

BULLERWELL, W. 1972. Geophysical studies of the Tertiary volcanic structure of the British Isles. *Philosophical Transactions of the Royal Society*, **A271**, 209–215.

COOPER, D. C., NUTT, M. J. C. & MORGAN, D. J. 1982. *A regional geochemical survey of Anglesey*. British Geological Survey Mineral Reconnaissance Programme Report **51**.

——, SMITH, I. F., NUTT, M. J. C. & CORNWELL, J. D. 1990. *Geophysical and geochemical investigations on Anglesey, North Wales*. British Geological Survey Technical Report **WF/90/4** (BGS Mineral Reconnaissance Programme Report **112**).

CORNWELL, J. D. 1972. A gravity survey of the Isle of Man. *Proceedings of the Yorkshire Geological Society*, **39**, 93–106.

GIBBONS, W. & BALL, M. J. 1991. A discussion of Monian Supergroup stratigraphy in northwest Wales. *Journal of the Geological Society, London*, **148**, 5–8.

—— & HORAK, J. 1990. Contrasting metamorphic terranes in northwest Wales. *In*: D'LEMOS, R. S., STRACHAN, R. A. & TOPLEY, C. G. (eds) *The Cadomian Orogeny*. Geological Society, London, Special Publication, **51**, 315–327.

GREENLY, E. 1919. *The geology of Anglesey*. Memoir of the Geological Survey of Great Britain, 2 volumes.

HIPKIN, R. G. & CHACKSFIELD, B. C. (compilers) 1986. *Bouguer anomaly map of the British Isles. Southern Sheet. 1:625 000*. British Geological Survey, Keyworth, Nottingham.

NUTT, M. J. C., INESON, P. R. & MITCHELL, J. G. 1979. The age of mineralisation at Parys Mountain, Anglesey. *In*: HARRIS, A. L., HOLLAND, C. H. & LEAKE, B. E. (eds) *The Caledonides of the British Isles—reviewed*. Geological Society, London, Special Publication, 619–627.

POWELL, D. W. 1956. Gravity and magnetic anomalies in North Wales. *Quarterly Journal of the Geological Society of London*, **111**, 375–392.

REEDMAN, A. J., LEVERIDGE, B. E. & EVANS, R. B. 1984. The Arfon Group ('Arvonian') of North Wales. *Proceedings of the Geologists' Association*, **95**, 313–321.

SHACKLETON, R. M. 1975. Precambrian rocks of Wales. *In*: HARRIS, A. L. ET AL. (eds) *A correlation of the Precambrian rocks in the British Isles*. Geological Society of London, Special Report, **6**, 76–82.

SKEELS, D. C. 1963. An approximate solution of the problem of maximum depth in gravity interpretation. *Geophysics*, **28**, 724–735.

SMITH, I. F. 1979. *Airborne geophysical survey of part of Anglesey, North Wales*. Institute of Geological Sciences Mineral Reconnaissance Programme Report **27**.

WRIGHT, J. E., HULL, J. H., MCQUILLIN, R. & ARNOLD, SUSAN E. 1971. *Irish Sea investigations 1969–70*. Institute of Geological Sciences Report No. **71/19**.

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