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GRANITES OF THE WESTERN ANGLO-BRABANT MASSIF

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(8 Figures)

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ABSTRACT. Negative Bouguer gravity anomalies in the southern North Sea, at Canvey Island, England and near Reading, England, which are not associated with magnetic anomalies, may be caused by granitic intrusions, as other low density sources such as sediments and evaporites are most unlikely. Power spectrum analyses and three-dimensional modelling of the anomalies suggest that the granites lie between about 3 and 10 km below the surface. The anomalies align with similar negative anomalies in the SE North Sea and Belgium and possibly with Variscan granites in Germany and Poland to the east and with the Cornubian granites to the west. Their trend is different from the NW trend of Caledonian granites to the north and it is proposed that they are of Variscan age and formed by the closure of the Proto-Tethys Ocean that lay between the Old Red continent and northern Gondwana in Upper Palaeozoic times. The Anglo-Brabant Massif appears to be underlain by a spine of granites, which may have contributed to its stability as a positive region since Mesozoic times.

KEYWORDS: Anglo-Brabant Massif, gravity anomalies, seismic reflection, granite.

RESUME. Les granites du Massif anglo-brabançon occidental. Des anomalies gravimétriques de Bouguer négatives, reconnues dans le secteur britannique de la Mer du Nord méridionale à Canvey Island et près de Reading, non-associées avec des anomalies magnétiques, sont probablement causées par des intrusions granitiques, plutôt que par d'autres types de roches à densité faibles telles que des sédiments ou des évaporites. L'analyse spectrale et des simulations tridimensionnelles des anomalies suggèrent que le toit des granites est situé vers 3 et 10 km sous la surface. Les anomalies sont alignées avec des anomalies négatives similaires en Mer du Nord sud-orientale et en Belgique, les granites varisques en Allemagne et en Pologne vers l'est avec les granites des Cornouailles vers l'ouest. Les granites calédoniens dans le nord possèdent une direction NW fort différente. Ainsi, il est proposé que les granites sont d'âge varisque, formés par la fermeture de l'Océan Proto-Téthys, situé entre l'Old Red Continent et le Gondwana septentrional pendant le Paléozoïque supérieur. Le Massif anglo-brabançon semble être renforcé par une série de massifs granitiques ayant contribué à sa stabilité tectonique et sa position en surrexion depuis le Mésozoïque.

MOTS-CLES: Massif anglo-brabançon, anomalies gravimétriques, sismique de réflexion, granite.

1. INTRODUCTION AND PREVIOUS WORK

The Anglo-Brabant Massif stretches from south-central England (where it is known as the London Platform) across the southern North Sea into Belgium (where it is known as the Brabant Massif) (fig. 1). It has been a positive region since at least Mesozoic times and has consequently controlled sedimentation and tectonism in the region. The Massif is not exposed at the surface; consequently information on its nature and structure have been derived from borehole and geophysical data. Kearey(1991) interpreted the regional positive magnetic anomaly over south-central England in terms of a source of relatively low density basaltic rocks which might have buoyantly supported the westernmost part of the Massif. Busby *et al.*(1993), however, suggested that the source of the magnetic anomaly lies in magnetic Precambrian rocks of normal density. A negative gravity anomaly at the western margin of the Massif has been interpreted by Hopkins (1979) in terms of an unexposed granite. In the southern North Sea, Lee *et al.*(1993) modelled gravity and magnetic anomalies along a deep seismic reflection

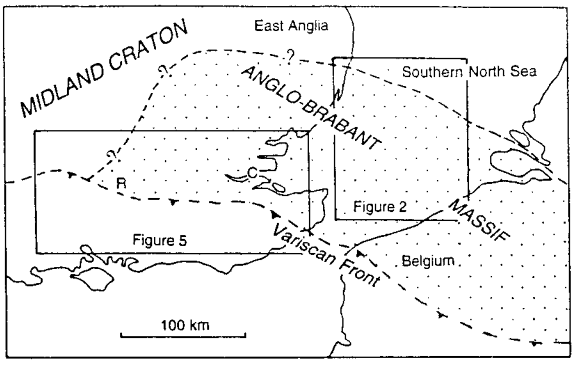

Figure 1. Location map showing the major tectonic elements of the study area and the locations of figs. 2 and 5. R = Reading, C = Canvey Island. Tectonic units after Watson & Dunning (1979) and Rijkers *et al.* (1993).

profile traversing the northern edge of the Massif. The regional gravity anomalies were explained mainly in terms of an increased Moho depth beneath the Massif and the magnetic anomalies to a mid-crustal source. Rijkers *et al.*(1993) and Rijkers & Duin(1994) interpreted a seismic profile further to the east and suggested that much of the Massif is underlain by Cambrian at shallow depth, although a small magmatic body was also believed to be present. In Belgium, de Vos *et al.*(1993) presented a subcrop map of the Massif using borehole data extrapolated by gravity and magnetic anomalies. Chacksfield *et al.*(1993) presented gravity and magnetic anomaly maps of the Massif which were correlated with basement structures. The Massif here is generally a gravity high, but a WNW-trending gravity low was interpreted in terms of an acidic intrusion. The magnetic anomalies were related to folded Tubize Group sediments. The Anglo-Brabant microplate originated in early Ordovician times during the closure of the Tornquist Ocean to the north (Ziegler, 1984), with formation of a foldbelt in Silurian times. Further construction also occurred prior to and during the Variscan Orogeny, as an ocean to the south closed in Late Carboniferous times. Only the work of Kearey(1991) provides an hypothesis for the persistent stability of the Anglo-Brabant Massif. However, the gravity field of the Massif contains several negative anomalies. These may provide further information on the mechanism of the stability of the Massif, and their interpretation is considered in this paper. None of the gravity anomalies considered is associated with a significant magnetic anomaly (Institute of Geological Sciences, 1965; Lee *et al.*, 1993), indicating an acid igneous or sedimentary source.

2. DATA ANALYSIS

The interpretation of gravity anomalies followed the same procedure in all cases. The anomaly was digitised onto a regular grid and the three-dimensional power spectrum computed, from which an estimate of the source depth was obtained. The regional field was computed by fitting a Tchebychev polynomial to the gravity field by least squares. This was subsequently subtracted from the observed Bouguer anomalies to isolate the residual anomalies. The residual anomalies were modelled using an extension of the method of Cordell & Henderson (1968) in which the anomalous body is simulated by a suite of right rectangular prisms whose vertical extent is automatically adjusted until the calculated anomaly matches the observed anomaly. In order to simulate a body with outward sloping contacts, it was assumed that the base of the prisms was at a constant level and several runs of the routine were necessary so that the top of the body reached the depth computed by power spectrum analysis.

3. SOUTHERN NORTH SEA GRAVITY ANOMALY

The Bouguer anomaly map of the southern North Sea (fig. 2), prepared from original digital data supplied by the British Geological Survey, shows a local circular negative anomaly of at least 80 g.u. (1 g.u. = 1 $\mu m\ s^{-2}$ = 0.1 mgal) amplitude centred on [665 170]. A seismic reflection profile, UK82-101 (Klemperer & Hobbs, 1991), which was acquired by Shell UK, crosses the gravity low in a NE-SW direction (fig. 2); an interpreted line drawing is shown in fig. 3 with the gravity profile along the line. Less than 0.5 s TWT (two-way time) of Upper Cretaceous to Quaternary sediments lie directly on Carboniferous or older strata of the Anglo-Brabant Massif (Klemperer & Hobbs, 1991). Other seismic lines (Blundell *et al.*, 1990; Klemperer & Hobbs, 1991) confirm that such post-Jurassic sediments on the Anglo-Brabant Massif are too thin to cause the anomaly. The northern 80 km of the profile show SW-dipping, mid-crustal reflectors which are believed to represent a mid-crustal magmatic layer within metasedimentary rocks with a magnetic susceptibility comparable to that of the of the Tubize Group within the Brabant Massif of Belgium (Lee *et al.*, 1993; Rabae, 1993; Kearey & Rabae, in press), although Klemperer & Hobbs (1991) have suggested that they might be Proterozoic thrusts. Between km 62 at 4.1 s TWT and km 82 at 2.0 s TWT there is a series of strong, NE-dipping reflectors which is located on the gravity map (fig. 2) between [678 205]

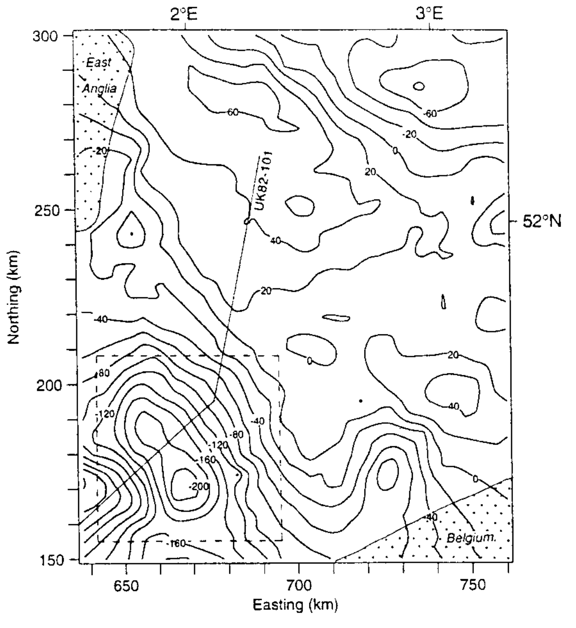

Figure 2. Bouguer gravity anomaly map of part of the southern North Sea. Contour interval 20 g.u. (1 g.u. = 1 mm s-2 = 0.1 mgal). The location of seismic line UK82-101 (fig. 3) is shown. The dashed square is the location of fig 4. Stipple = land. Coordinates refer to the British National Grid.

and [673 190] where there is a strong gravity gradient.

Between km 90 at 1.8 s TWT and km 95 at 2.3 s TWT there is a SW-dipping reflector. It is possible that these represent thrusts, but an alternative interpretation is that the reflections are from the top of a low density body responsible for the gravity anomaly in this area. These outward dipping reflectors and the subcircular anomaly shape suggest that the source of the negative anomaly is a granitic intrusion. The increase in gravity seen in the NE of the profile may indicate that the structures lying beneath the mid-crustal reflections are less dense to the south of the negative anomaly. The regional field and residual gravity anomalies are shown in Figs. 4a and 4b respectively. The residual anomalies were simulated by a model comprising 55 x 55 = 3025 prisms (fig. 4c). A flat base level of 10 km, as suggested by the seismic section (fig. 3b), using stacking velocities for depth conversion, and a density contrast of -0.10 Mg m^{-3} were required so that the top of the model reached ~2.6 km below O.D., as indicated by power spectrum analysis. It is apparent from the model that the granitic body trends NW-SE and has two major culminations at [668 170] and [656 190]; the small culmination at [684 175] may also be related to the granitic body. The computed anomalies of the model are shown in fig. 4d. A section through the model along seismic profile UK82-101 is shown in fig. 3a. This illustrates the similarity of the location and shape of the edges of the model with the unmigrated reflectors described above and shows that a granitic source is consistent with the reflection data. It should be appreciated, however, that the section passes through the NW flank of the model rather than its centre. The depth to the reflectors on the seismic reflection profile described above, computed using stacking velocities, is 4.0 - 4.5 km, which is in accord with the depth to the top of the model at this location (fig. 3). The model is probably not an exact simulation of the causative body as it was assigned an horizontal base.

4. GRAVITY ANOMALIES IN SOUTHERN ENGLAND

A Bouguer anomaly map of southern England, constructed from original digital data supplied by the British Geological Survey, is shown in fig. 5. There are two subcircular gravity lows in this region near Reading and at Canvey Island, which are delineated by squares on fig. 5.

4.1. CANVEY ISLAND GRAVITY ANOMALY

A circular negative Bouguer anomaly of at least 80 g.u. amplitude occurs over the Canvey Island region (fig. 6). The magnetic basement in this area is at about 13 km depth (Kearey, 1991; Rabae, 1993). This places a maximum limit on the source depth as the causative body of the gravity anomaly has no local magnetic anomaly. Consequently the gravity causative body cannot form a part of the regional magnetic model and must thus be above it. Several boreholes have been drilled in the area (fig. 6c) which penetrated Palaeozoic rocks (Smart *et al.*, 1964). Canvey Island [5821 1833] encountered Devonian at 398 m below O.D.; Fobbing [5724 1840], Lower Carboniferous or Devonian at 323 m; Cliffe [5730 1813], Silurian at 312 m; Isle of Grain [5820 1740], ?Silurian at 338 m; and Sheerness [5935 1740], ?Silurian at 408 m. The boreholes show that the Mesozoic and later sediments are less than 408 m thick and cannot account for the amplitude of the gravity anomaly. It is also known from the drilling that no concentration of evaporites occurs in these sediments. Smart *et al.*(1964) commented on the low mean density of the Devonian (2.49 Mg m^{-3}) in the Canvey Island borehole and suggested that a 900 m thickness could be the source of the negative gravity anomaly. This density is considerably lower than other measured densities of the Old Red Sandstone in SE England. No Devonian has been proved in the other boreholes of the region. This may suggest that the Old Red Sandstone encountered in

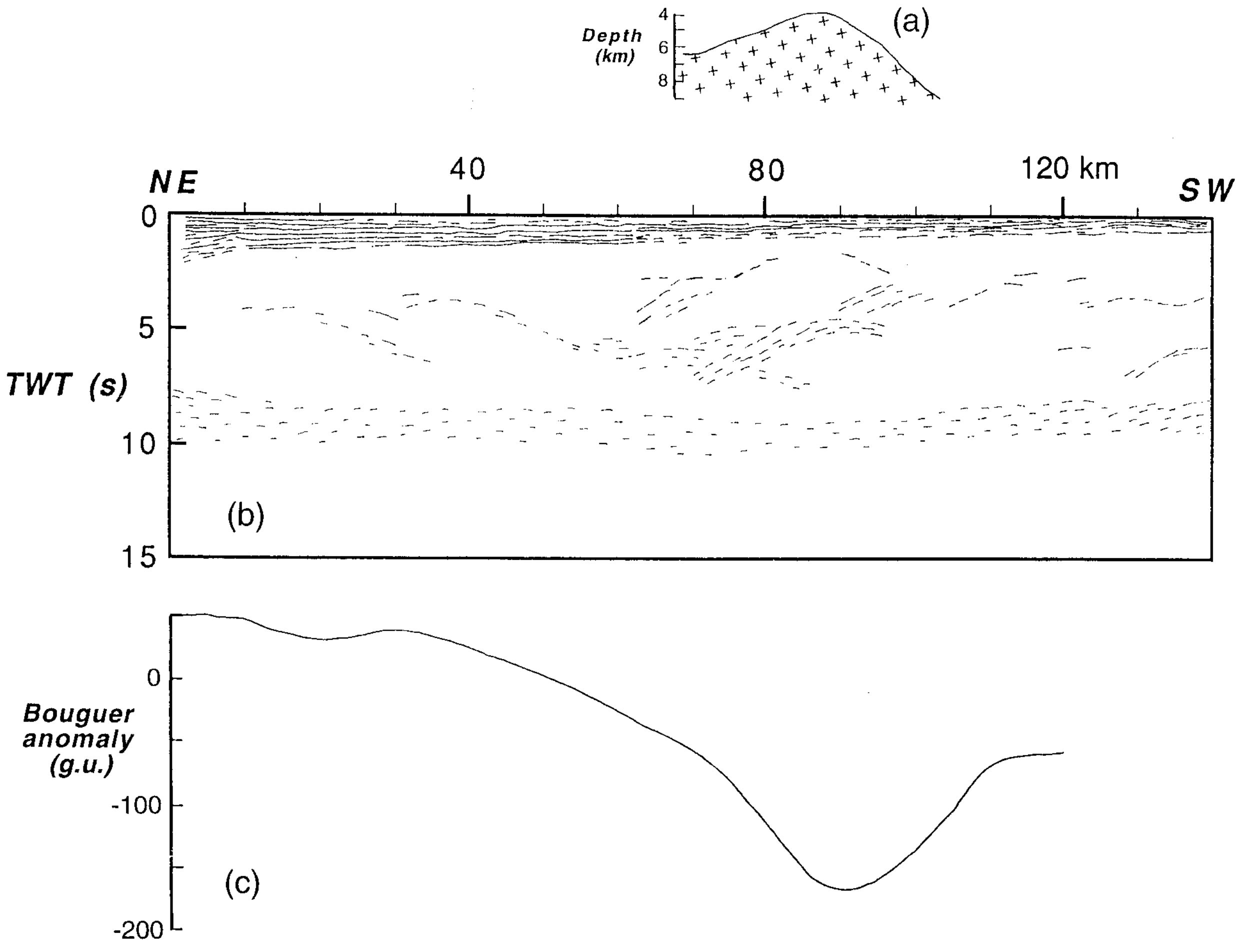

Figure 3. (a) Section through the gravity model of fig. 4. (b) Line drawing interpretation of seismic reflection line UK82-101; for location see fig. 2. TWT = two-way time. (c) Bouguer gravity anomaly profile along the seismic line.

the borehole is a laterally restricted facies. The borehole terminated when only 131 m of Devonian had been penetrated. Consequently, since pre-Devonian sediments are unlikely to be of low density (Falcon & Tarrant, 1950), it is suggested that an alternative source of the Canvey Island gravity anomaly may be a body of granitic rock. This is supported by the location of the inflection points of the residual gravity anomalies, which are near the centre of the anomaly rather than its periphery, indicating a source with outward-sloping contacts (Kearey & Brooks, 1991). The regional field and residual gravity anomalies are shown in Figs. 6a and 6b respectively. The residual gravity anomalies were interpreted by a model comprising 45 x 45 prisms (fig. 6c). The average regional density of the Palaeozoic in southern England has been computed by Falcon & Tarrant (1950) as 2.75 - 2.77 Mg m^{-3}; a reasonable density of granite is 2.64 - 2.67 Mg m^{-3} (Telford *et al.*, 1990; Kearey & Brooks, 1991). The density contrast was thus assumed to be -0.12 Mg m^{-3}. The base level of 9 km was obtained by trial and error so that the minimum depth to the top of the model was 3.0 km, as suggested by power spectrum analysis. The model shape approximates a cone, with a base ~25 km wide. The computed anomalies of the model are shown in fig. 6d.

4.2. READING GRAVITY ANOMALY

A local negative gravity anomaly of 60 g.u. amplitude is located 13 km south of Reading at [472 160] (fig. 7). The anomaly lies above a depression in the top of the magnetic models of the south-central England magnetic anomaly produced by Kearey (1991) and Rabae (1993). Hopkins (1979) has suggested that the gravity anomaly might be caused by a buried granite, although this work has only been published in abstract. There are two boreholes in the region of the anomaly (fig. 6c) (Foster *et al.*, 1985). Strat B-1 [468 165] proved Cretaceous and Jurassic sediments to a depth of 661 m below O.D. and bottomed in Coal Measures at 696 m. Foudry Bridge

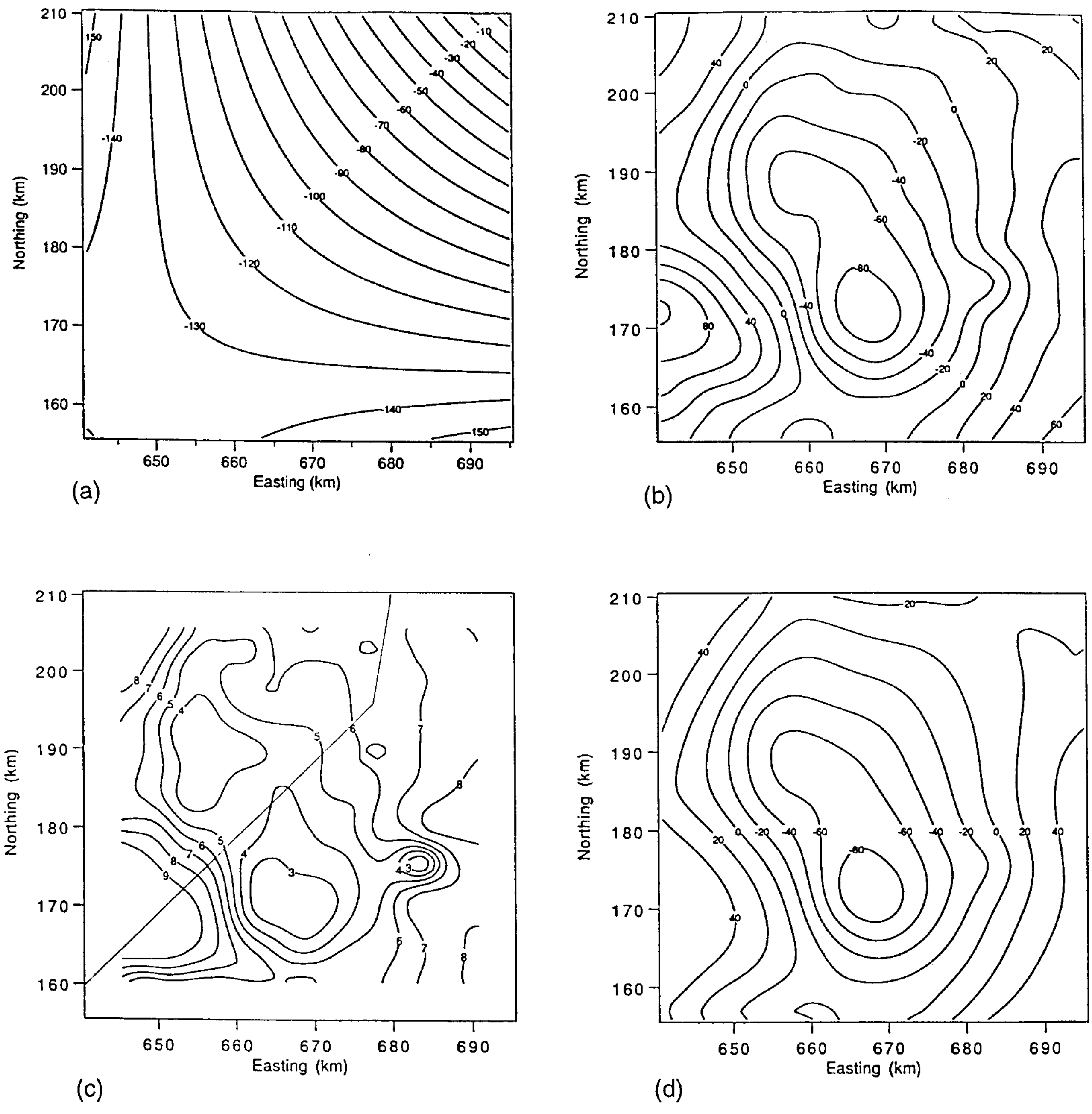

Figure 4. The southern North Sea gravity anomaly. For location see fig. 1. (a) Regional field, contour interval 10 g.u. (b) Residual anomalies obtained by subtracting the regional field of (a) from the observed Bouguer anomalies, contour interval 10 g.u. (c) Density model simulating the residual gravity anomalies, represented by contours on the centres of the tops of the 55 x 55 rectangular blocks comprising the model, whose common base is at 10 km. Contour interval 1 km. Density contrast = 0.10 Mg m-3. Contours in a narrow peripheral band have been suppressed because of edge effects associated with the modelling method. (d) Computed anomalies of the model, contour interval 10 g.u. Coordinates refer to the British National Grid. Straight lines = part of seismic line UK82-101. Stippling = area.

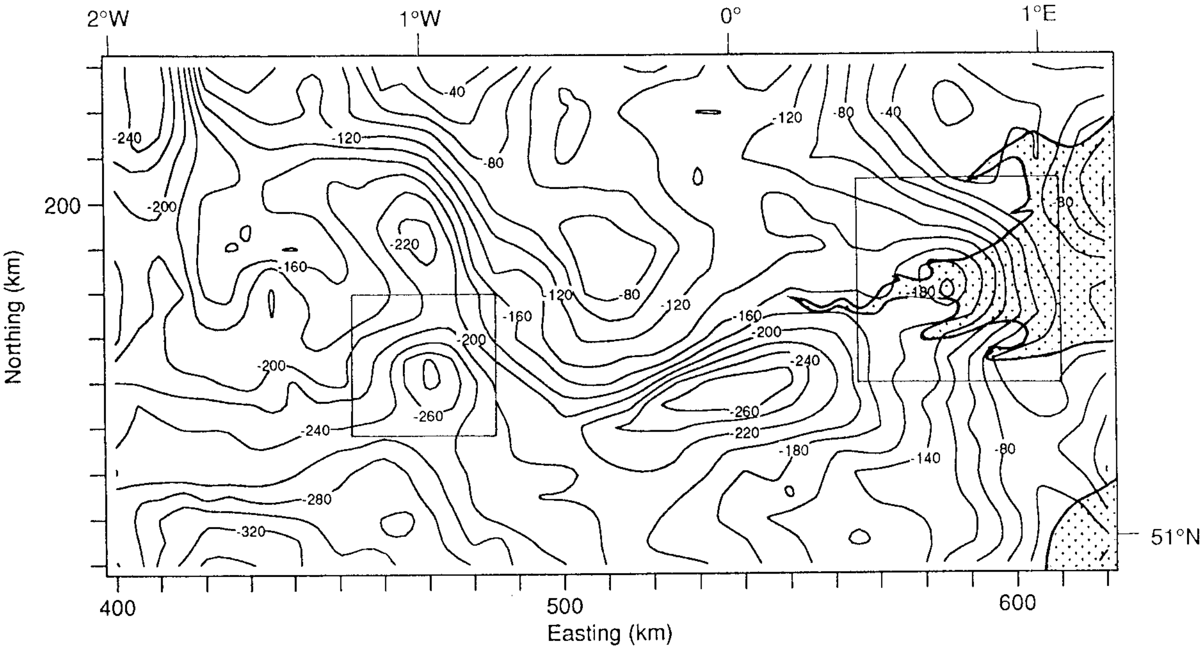

Figure 5. Bouguer gravity anomaly map of southern England. Contour interval 20 g.u. Squares refer to the locations of the Canvey Island (E) and Reading (W) anomalies. Coordinates refer to the British National Grid. Stippling = sea.

1[471 166] penetrated Cretaceous and Jurassic sediments to a depth of 625 m, passed into Coal Measures at 764 m and bottomed in Carboniferous Limestone at 779 m. Two short, unmigrated, seismic reflection profiles acquired by Ulster Petroleum Ltd. cross part of the Reading gravity anomaly (fig. 6c). The profiles provide reliable information only to about 1 s TWT and correlation of the reflections with borehole sequences proves that the gravity anomaly cannot originate from a thickening of sediments of Upper Carboniferous or younger age. The surface geology, boreholes and reflection profiles give no indication of the source of the negative gravity anomaly. Because the gravity anomaly has no associated magnetic anomaly, it cannot contribute to the regional magnetic anomaly and its source must be above the depth to the regional magnetic model in this area (Kearey, 1990; Rabae, 1993), which is 10 km. The circular shape of the gravity anomaly (fig. 4) indicates that the source of the gravity anomaly is unlikely to be a sedimentary basin. The location of the inflection points of the residual anomaly are also indicative of a source shape with outward-sloping contacts (Kearey & Brooks, 1991). The boreholes and seismic data do not suggest the occurrence of evaporitic deposits, which would in any case need to be unrealistically thick to give rise to the observed anomaly. Thus, since sediments and evaporites appear seem unlikely to be the cause of the anomaly, it is suggested that a granitic body is the most likely source. The regional field and residual gravity anomalies are shown in Figs. 7a and 7b respectively. The residual gravity anomalies were interpreted by a model comprising 45 x 45 = 2025 prisms (fig. 7c). For similar reasons for the Canvey Island anomaly interpretation, a density contrast of -0.13 Mg m-3 was assumed. A common base level of 7 km was required so that the top of the model reached a depth of about 3 km below O.D. as indicated by power spectrum analysis. The computed anomalies of the model are shown in fig. 7d. The local gravity anomaly at [468 194] (fig. 5) to the north of the Reading anomaly also has a circular shape and may also have a granitic origin.

5. DISCUSSION

The postulated granites at Reading, north of Reading and at Canvey Island are located within the London Platform and occur within a regional positive magnetic anomaly which has been interpreted as arising from a large Carboniferous igneous body intruded into the middle crust (Kearey, 1991), or as a Precambrian cratonic core of acidic to intermediate composition perhaps analogous to a similar basement block underlying the Ardennes in Belgium (Busby *et al.*, 1993; Chacksfield *et al.*, 1993). In the southern North Sea, seismic data show that the postulated granitic body is emplaced in Palaeozoic sediments. The possibility of a granitic source for this anomaly is supported by evidence from a seismic reflection profile some 50 km to the east, in which a granitic body has been interpreted at a depth of about 2.5 km underneath a local gravity low at [725

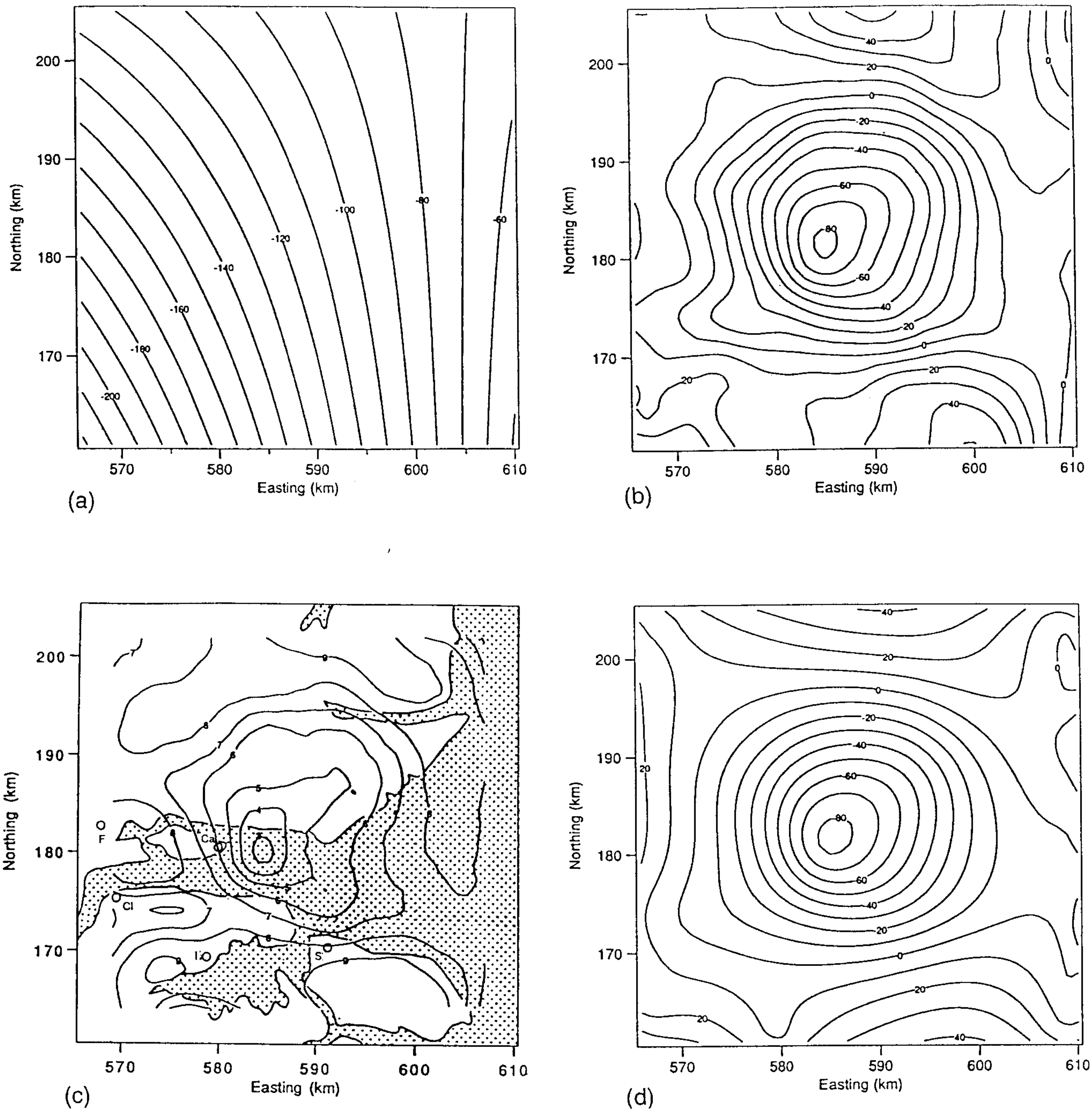

Figure 6. The Canvey Island gravity anomaly. For location see fig. 1. (a) Regional field, contour interval 10 g.u. (b) Residual anomalies obtained by subtracting the regional field of (a) from the observed Bouguer anomalies. (c) Density model simulating the residual gravity anomalies, represented by contours on the centres of the tops of the 45 x 45 rectangular blocks comprising the model, whose common base is at 9 km. Contour interval 1 km. Density contrast = 0.12 Mg m-3. Contours in a narrow peripheral band have been suppressed because of edge effects associated with the modelling method. Open circles = boreholes: Ca = Canvey Island, Cl = Cliffe, F = Fobbing, I = Isle of Grain, S = Sheerness. Stippling = sea.(d) Computed anomalies of the model, contour interval 10 g.u. Coordinates refer to the British National Grid.

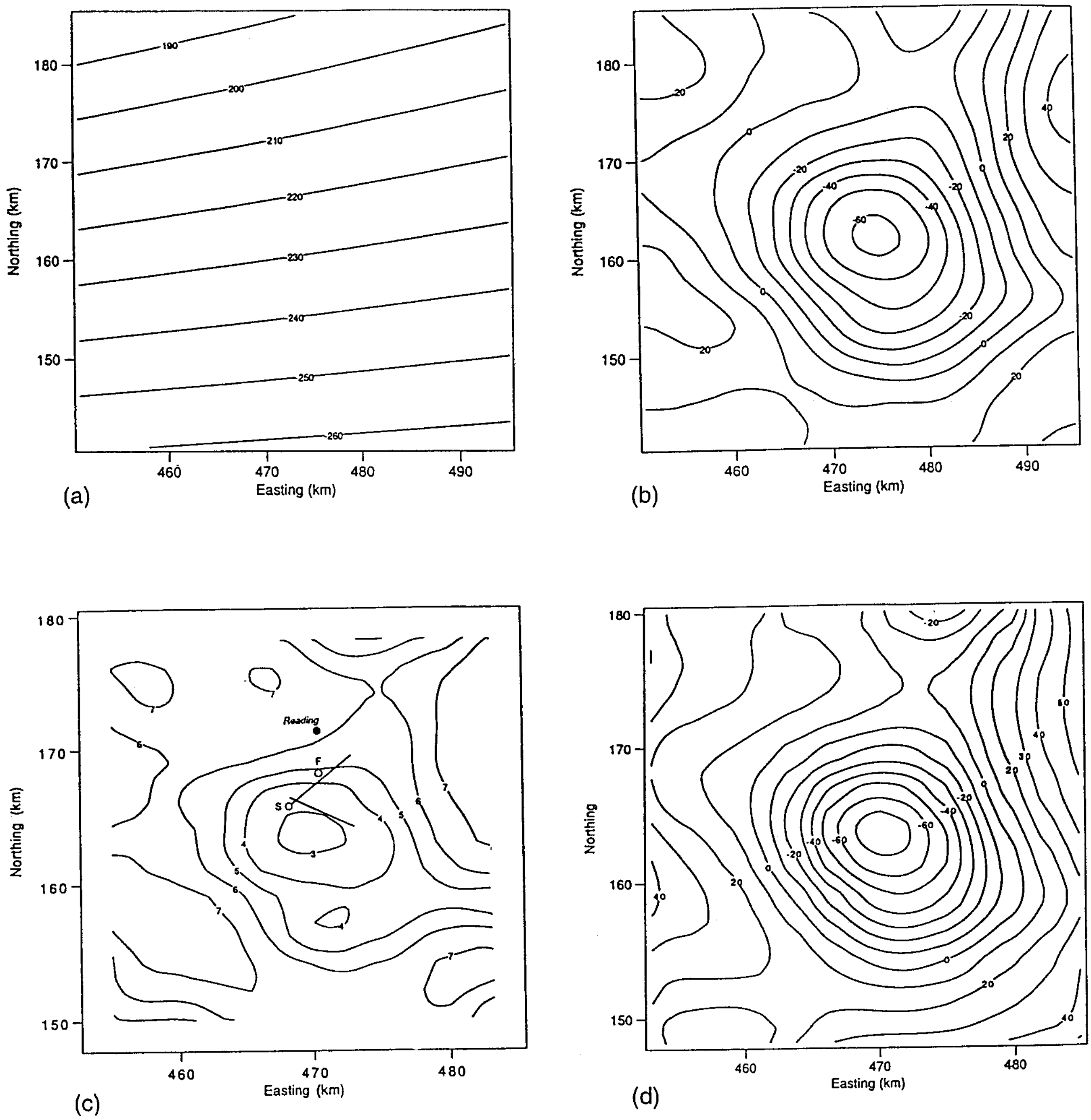

Figure 7. The Reading gravity anomaly. For location see fig. 1. (a) Regional field, contour interval 10 g.u. (b) Residual anomalies obtained by subtracting the regional field of (a) from the observed Bouguer anomalies, contour interval 10 g.u. (c) Density model simulating the residual gravity anomalies, represented by contours on the centres of the tops of the 45 x 45 rectangular blocks comprising the model, whose common base is at 7 km. Contour interval 1 km. Density contrast = 0.13 Mg m-3. Contours in a narrow peripheral band have been suppressed because of edge effects associated with the modelling method. Open circles = boreholes: F = Foudry Bridge, S = Strat B-1. Straight lines = Seismic reflection profiles. (d) Computed anomalies of the model, contour interval 10 g.u. Coordinates refer to the British National Grid.

170] (Rijkers *et al.*, 1993). Exposed granites and granites postulated on the basis of gravity anomalies in Britain, the North Sea and Belgium are shown in fig. 8. The locations of the "Caledonian" granites have been taken from the summary of Allsop (1987) and from Donato (1993). The locations of the granites in the Anglo-Brabant Massif are taken from the present work, Rijkers *et al.*(1993) and the gravity anomalies shown in Chacksfield *et al.*(1993). The latter are within the Brabant Massif of Belgium and have been interpreted as arising from granitic sources which are concealed at depths from about 3 km to over 15 km. Like the proposed granites in the west, there is no associated magnetic anomaly (Lee *et al.*, 1993). The Caledonian granites form a NW-SE trending belt. This may have originated during the final closure, in Late Ordovician/Lower Silurian times, of the Tornquist Ocean, which separated Baltica from Avalonia (on which most of the British Isles were situated) in Lower Palaeozoic times (Oliver *et al.* 1993) and closed by southward directed subduction. The more basic magmatic products of this subduction episode have been identified and characterised by André *et al.*(1986) and Pharaoh *et al.*(1993). The granites of the Anglo-Brabant Massif appear to form an arc with an E-W trend in a significantly different direction from the Caledonian granites (fig. 8). They run almost parallel to the Variscan Front, whose location is probably controlled by the southern edge of the Anglo-Brabant Massif in SE England (see, for example, Smalley & Westbrook, 1982). To the east, exposed Variscan granites have been described from the Harz Mountains of Germany (Ziegler, 1984) and from SW Poland (Oliver *et al.*, 1993) along a similar structural trend. To the west, the arc appears to align with the Variscan Cornubian granite belt of SW England. This batholith is probably allochthonous, but has been shown (Shackleton *et al.*, 1982) to have been emplaced along a S-dipping dcollement by a maximum of about 150 km of northerly movement, which does not seriously affect its alignment with the proposed granites further east. However, the granite bodies proposed in this work lie to the north of the Variscan Front, whereas the granites to east and west lie to the south (Ziegler, 1990). It is possible that the granites of the Anglo-Brabant Massif are of Variscan age. As such, they may have originated from the closure of the Proto-Tethys Ocean (Ziegler, 1984), which separated the Old Red continent of Armorica (Perroud *et al.*, 1984)/Laurasia (Ziegler, 1984) by northwards directed subduction. There may thus be a discontinuous belt of granites running from SW England to Poland formed by this process. The belt would not be expected to be perfectly linear because of the irregular geometry of the colliding continental margins (Ziegler 1984). The proposed granites form a spine running almost centrally along the Anglo-Brabant Massif. The buoyancy of the low density granites may have provided a tectonic influence to the area and assisted in the persistent uplift and stability of this region since Mesozoic times. A period of uplift commenced towards the end of the Variscan Orogeny (Rijkers *et al.*, 1993), suggesting that the granites may have been intruded at that time. Inparticular the granites may have controlled the location of the northern faulted margin of the Wessex Basin immediately to the S of the London Platform in SE England. As such they may have played a role similar to that of the Caledonian Weardale granite (fig. 7), which stabilised the Alston block and controlled the location of, and sedimentation within, its surrounding, normal fault-bounded basins. Consequently the stability of the Anglo-Brabant Massif may derive both from the proposed granites described in this work and the presence of a regional basaltic body of relatively low density (Kearey, 1991).

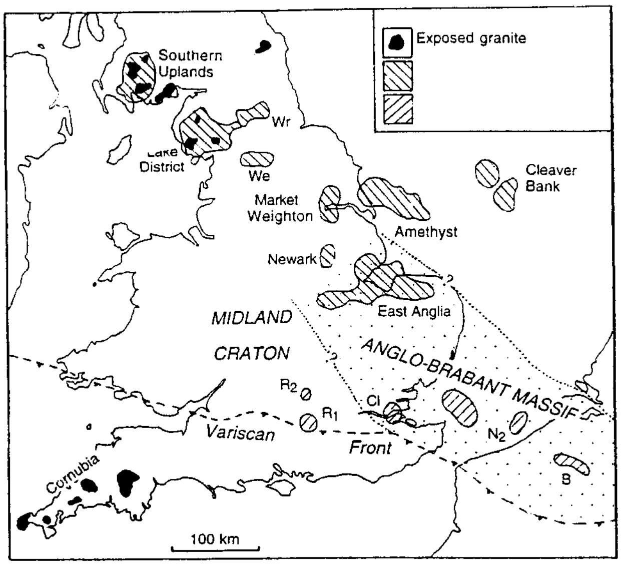

Figure 8. Locations of exposed and geophysically-postulated granitic bodies in Britain, the southern North Sea and Belgium. Postulated Caledonian granites from Allsop (1987) and Donato (1993); Wr = Weardale, We = Wensleydale. Postulated Variscan granites: R1 = Reading (this paper), R2 = north Reading (this paper), CI = Canvey Island (this paper), N1 = North Sea (this paper), N2 = North Sea (Rijkers *et al.*, 1993), B = Brabant Massif (Chacksfield *et al.*, 1993). Tectonic units after Watson & Dunning (1979), Rijkers *et al.* (1993), Pharaoh *et al.* (1993) and Blundell (1993) - The different shapes of the Anglo-Brabant Massif in figs. 1 and 2 reflect the uncertainty in defining this unit.

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