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Μια δυναμική εταιρεία στο χώρο των  
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Η μοναδική που προσφέρει πλήρη  
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Ψηφιακή Βιβλιοθήκη Θεόφραστος - Τμήμα Γεωλογίας, Α.Π.Θ.

## ON THE FORMATION OF THE INNER HEBRIDES SEA TERTIARY BASIN

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**Abstract:** The Inner Hebrides Sea Tertiary basin is the largest of three basins of that age in NW-Britain. An Oligocene age for the sediments has been inferred from seismic reflection data. Within the basin area an ultrabasic intrusion is revealed by strong magnetic and gravity anomalies. The Tertiary subsidence of the basin is suggested to have been caused by the loading of the crust by the intrusion's mass excess. An isostatic model of crustal block subsidence predicts a total subsidence comparable to the mean Tertiary sediment thickness in the basin.

### 1. The Tertiary sediments

The Inner Hebrides Sea Tertiary basin in NW-Britain lies between the smaller Tertiary basins: the Canna basin to the north and the North Irish Lough Neagh basin to the south. The offshore geology of the region (McQuillin and Binns, 1973; Binns et al., 1974) has derived from marine surveys undertaken by the Institute of Geological Sciences (Bacon, 1972; McQuillin and Bacon, 1974). The basin is bounded by the Camasunary-Skerryvore fault to the north-west and the Colonsay fault to the south-east (fig.1). The Tertiary sediments were identified using the following criteria (Smythe and Kenolty, 1975): (a) interval velocities; (b) the seismic character of the sparker and deep reflection data; (c) absence of dykes and sills intruding

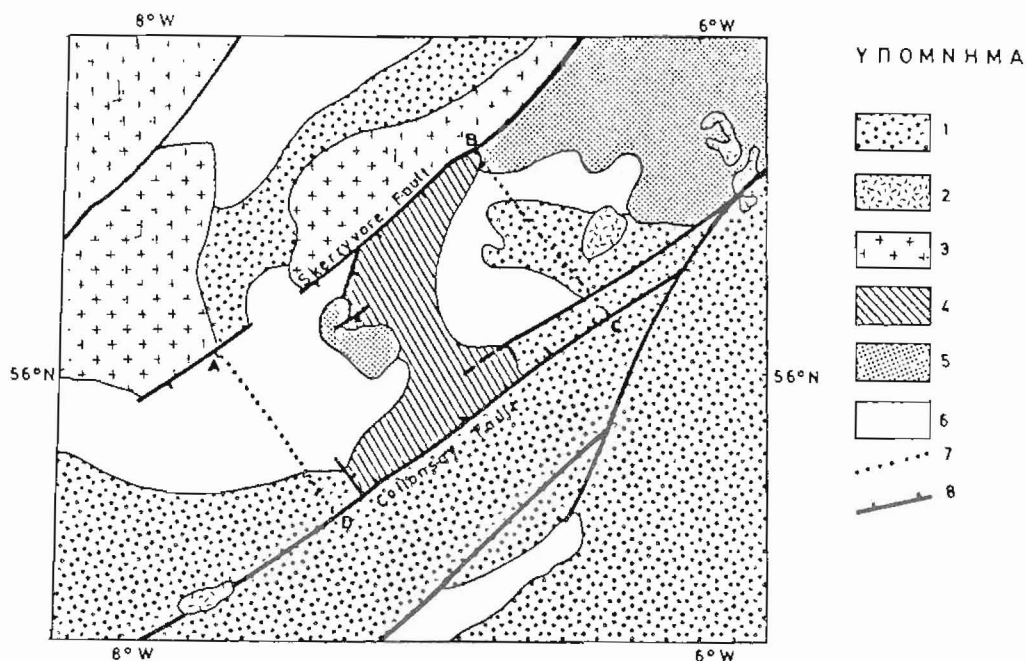


Figure 1. Simplified Sub-Pleistocene Geological Map of the region:  
 1. Torridonian basement; 2. Granitic intrusions; 3. Lewisian basement; 4. Tertiary sediments; 5. Basic intrusions and lavas; 6. Mesozoic sediments; 7. South-western and north-eastern limits of the area for the mass excess estimation; 8. Faults.

the post-Eocene sediments; (d) large negative gravity anomaly with steep gradients; (e) a marked angular unconformity with overlying younger sediments; (f) folding (with dips at least 10%) and faulting of a sequence too thick to be Quaternary. Similar criteria had been successfully used in the South Irish Sea to discriminate between Mesozoic, Palaeogene and Neogene-Recent sediments (Blundell et al. 1971, Dobson et al. 1973). According to Smythe and Kennolly (1975) 500m or more of Tertiary sediments are preserved in the basin below 200m of Quaternary.

An Oligocene age for the Tertiary sediments has been inferred from comparison with sediments of similar character in Northern Ireland

and Southern Irish Sea. Furthermore, a prominent regional seismic reflector (Stride et al. 1969) outcrops 60-70 km west of the basin (Bailey et al. 1974). The sediments overlying this reflector have been dated as Oligocene (Smythe and Kennolty, 1975). After the ending of the igneous activity on the self and NW-Atlantic during the Eocene, there was a period of rapid erosion, localized downwarping, faulting and deposition during the Oligocene.

## 2. The Blackstones igneous centre: previous work.

The existence of Tertiary igneous complex in the area of the Inner Hebrides Sea basin was suggested by aeromagnetic evidence (Bullerwell, 1963) and by a large positive gravity anomaly (Roberts, 1970). Gabbro and eucrite samples were collected from its outcrop (Binns et al. 1973), thus confirming its presence. The structure of the intrusion revealed through geophysical surveying and modelling (McQuillin et al. 1975).

### a. Seismic data

A single reflection seismic profile (McQuillin and Bacon 1974) shows a plutonic mass intruded into a trough of post-Palaeozoic sediments (McQuillin et al. 1975, fig. 3). Part of the intrusion is overlaid by sedimentary rocks about 1km thick. Four different layers have been interpreted; these are: (a) Quaternary sediments; (b) Tertiary sediments; (c) Mesozoic sediments; (d) Torridonian sandstones and/or crystalline basement. The sediment pocket on top of the pluton consists of the first three layers and is controlled by a fault bisecting the pluton and post-dating its main phase of intrusion. The emplacement of the pluton does not appear to have disturbed the pre-Mesozoic basement to any marked extent (McQuillin et al 1975), thus indicating a stoping mechanism of rising through it. Similar mechanism is suggested for the emplacement of the Mull basic-ultrabasic complex by Bott and Tantrigoda (1987). The Mesozoic sediments are gently tilted against the margin of the pluton suggesting a rather forceful type of emplacement (such as diapirism and doming) through

the uppermost part of the crust.

The travelttime plot of an unreversed refraction profile over the pluton indicated velocities of 2.02 km/s and 7.2 km/s. The calculated depth to the top of the 2.02 km/s layer was 260 m, so it may be top Tertiary.-McQuillin et al (1975) assuming that the 2.02 km/s layer extends down to the 7.2 km/s refractor, calculated its thickness to be 820 m. They suggested that a Mesozoic refractor was probably missed. The high velocity material lies therefore about 900 m below sea level (water bottom at 90 m), in agreement with the 1 km of sediments suggested by the reflection data.

#### b. Gravity modelling

The Bouguer gravity map (fig.2) shows an almost circular positive anomaly of 150 mgals over the pluton. The density of the intrusion is inferred from the 7.2 km/s velocity (using the Nafe and Drake (1963) velocity/density relationship) to be 3100 kg/m<sup>3</sup>. The accepted average densities of the surrounding formations are: Torridonian sediments 2700 kg/m<sup>3</sup>, Lewisian basement 2760 kg/m<sup>3</sup>, Mesozoic sediments 2450 kg/m<sup>3</sup>. A source of uncertainty for the gravity modelling is the value of the regional gravity field. To the north-west of the Skerryvore-Camasunary Fault the Lewisian basement prevails with a regional value of 40-50mgals. South-east of the Collonsay Fault the sub-Pleistocene geology consists of Torridonian sandstones (fig. 1) with a regional gravity value of 20-25 mgals.

McQuillin et al. (1975) produced a gravity model of the pluton (fig. 3) consisting of an almost cylindrical body of 16km diameter extending from 0-2 km at the top to 22-30 km at its base. The magnetic anomaly map also suggests such a diameter. The assumptions made for the construction of this model are: (a) the maximum gravity anomaly is 140 mgals; (b) the regional field is 50 mgals; (c) the density contrast of the intrusion with the surrounding rocks was 350 kg/m<sup>3</sup>. The maximum gravity value was underestimated, the regional was probably overestimated, and a mean density contrast of 400 kg/m<sup>3</sup> seems more appropriate. This contrast is also more compatible with the sub-Pleistocene geology of the area (fig. 1), which consists of Tor-

ridonian rather than Lewisian rocks. With these changes, the gravity model of McQuillin et al. (1975) is substantially correct.

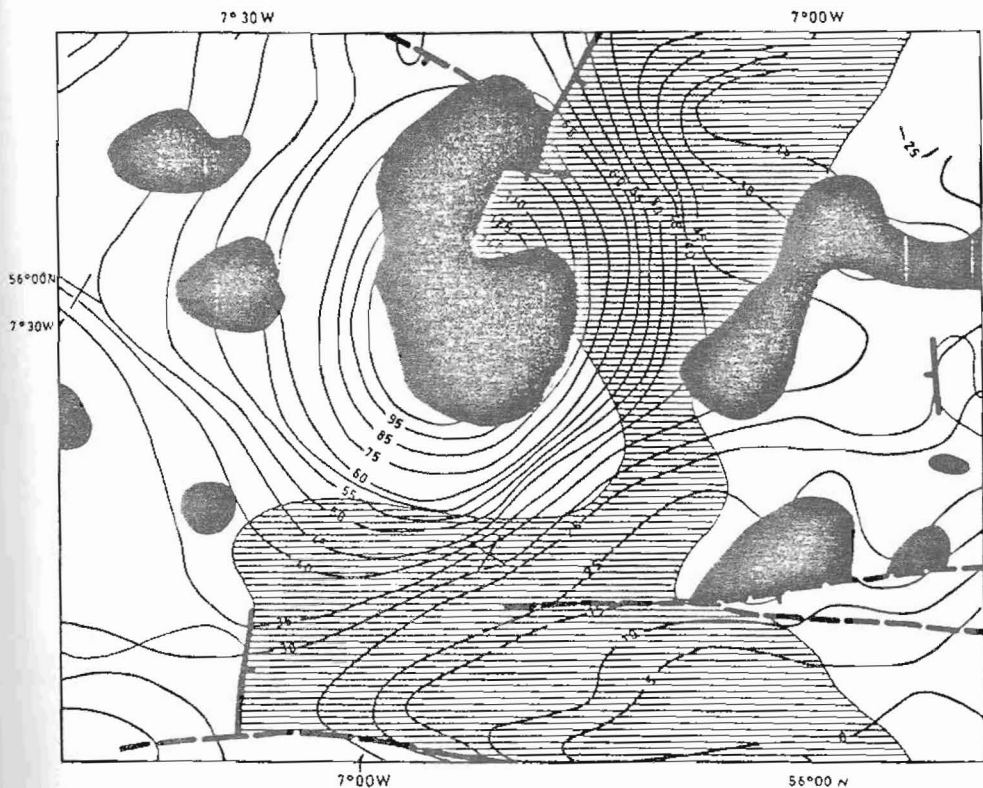


Figure 2. Bouguer Anomaly Gravity Map of the mass excess estimation area. Lined region: Tertiary sediments subcrop; Shaded region: Basic intrusion and lavas.

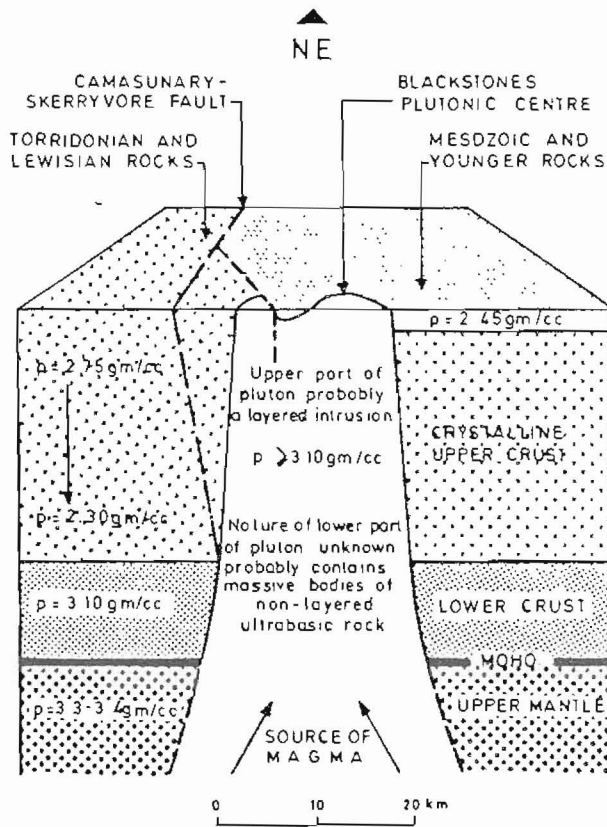


Figure 3. Schematic representation of the Blackstones pluton main features (after McQuillin et al. 1975).

### 3. Crustal loading and subsidence model

The mechanism examined for the subsidence of the basin during the Tertiary is to load a crustal block and let it subside in the upper mantle, where the load is isostatically compensated. The crustal block considered is bounded to the north-west and south-east by the Skerryvore-Camasunary and the Collonsay faults respectively, and is shown in fig 1. The load on the block is imposed by the mass excess of the pluton.

#### a. Mass excess

One way of calculating the pluton's mass excess is by using its model constructed by McQuillin et al. (1975). Assuming a density contrast of  $400 \text{ kg/m}^3$  and a mean thickness of 16 km for the cylindrical body (radius = 8km) a mass excess of  $2 \times 10^{15} \text{ kg}$  is estimated.

Another way is to integrate the Bouguer gravity map over the area of the subsided block, and to convert this integral to mass excess. A regional gravity value of 25 mgals is assumed to correspond to Torridonian rocks below the Mesozoic rocks in the basin (fig. 1). The integration of the Bouguer anomaly map suggests a mass excess of  $1.4 \times 10^{15} \text{ kg}$ . This value was corrected for the mass deficit caused by the Mesozoic, Tertiary and Quaternary sediments, assuming the following parameter values: areal extent of Mesozoic sediments,  $S_m = 2.8 \times 10^9 \text{ m}^2$ ; mean density contrast of Mesozoic sediments,  $\Delta\rho_m = -260 \text{ kg/m}^3$ ; areal extent of Tertiary sediments,  $S_T = 10^9 \text{ m}^2$ ; mean density contrast of Tertiary sediments,  $\Delta\rho_T = -670 \text{ kg/m}^3$ ; areal extent of Quaternary sediments,  $S_q = 3 \times 10^9 \text{ m}^2$ ; mean density contrast of Quaternary sediments,  $\Delta\rho_q = -770 \text{ kg/m}^3$ . A conservative assumption of the mean thicknesses of these sediments is: Mesozoic sediments,  $T_m = 800 \text{ m}$  (McQuillin and Binns, 1973; Binns et al. 1974); Tertiary sediments  $T_T = 300 \text{ m}$ ; Quaternary sediments,  $T_q = 100 \text{ m}$  (Smythe and Kennolly (1975). The mass deficit caused by a Mesozoic-Quaternary sequence as described above is  $10^{15} \text{ kg}$ . Thus, the effective mass excess estimated through the gravity integration becomes  $2.4 \times 10^{15} \text{ kg}$ .

The difference from the first estimation ( $2.0 \times 10^{15} \text{ kg}$ ) is mainly due

to the effect of the lava flows, which are known to have occurred in the area before the deposition of the Tertiary sediments and the extent and thickness of which is not known, and to an underestimation of the intrusion's volume: it is expected to be wider at its base.

#### b. Subsidence model

The crustal block of area  $S = 3 \times 10^9 \text{ m}^2$  under the load of the mass excess  $M_E = (2.0-2.4) \times 10^{15} \text{ kg}$  is thought to subside within the upper mantle until an isostatic equilibrium is attained. If  $T$  is the total amount of subsidence (and therefore the thickness of the accumulated sediments),  $\rho_m$  and  $\rho_s$  the densities of the mantle and the sediments respectively, then  $T$  is calculated from the equation:

$$T = \frac{M_E}{S} \cdot \frac{1}{\rho_m - \rho_s}$$

Assuming the densities  $\rho_m = 3350 \text{ kg/m}^3$  and  $\rho_s = 2050 \text{ kg/m}^3$  (the p-wave velocity of the Tertiary sediments 2.1-2.3 km/s suggests a density of 2000-2100  $\text{kg/m}^3$ ), the predicted thickness of the post-Mesozoic sediments is 510 m (if  $M_E = 2.0 \times 10^{15} \text{ kg}$ ) or 615 m (if  $M_E = 2.4 \times 10^{15} \text{ kg}$ ).

#### 4. Discussion

In the whole north-western Britain there are three Tertiary basins: the Canna and the Inner Hebrides Sea basins off western Scotland, and the Lough Neagh basin in Northern Ireland. The Inner Hebrides Sea basin is the largest in extent of them. A common characteristic of these basins is that, they are associated with lava flows prior to the deposition of the sediments, the age of which is thought to be the same (Smythe and Kenolty, 1975). The main differences of the Inner Hebrides Sea basin from the other two is that, it is bounded to the north-west and south-east by two almost parallel major trans-current faults, and that it has a close spatial relationship with an ultrabasic intrusive complex. It is the combination of these two

geological features, which is thought to have caused the subsidence of this basin after an initial stage of uplift related to the emplacement of the pluton. This point of view is consistent with the observation that, between the two faults the Tertiary basin is restricted in the neighbourhood of the intrusion, and that other basic or ultrabasic centres in north-western Britain (Mull, Skye, St Kilda, Rhum) are not associated with sedimentary basins of compatible to their intrusion age. The basin's subsidence should have been facilitated by the extensional regime prevailing during the Tertiary.

The crustal loading and subsidence mechanism examined here predicts post-intrusion sediment thickness compatible with the observed one. However the Tertiary sediments do not cover all the subsiding block's area. This may be attributed to the effect of topography. The subsidence of a wider area than the Tertiary subcrops is supported by the widespread preservation of the Mesozoic sediments.

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