A RECONNAISSANCE MAGNETIC SURVEY OF THE LUNDY TERTIARY IGNEOUS COMPLEX, BRISTOL CHANNEL

R. McCaffrey, S. Stewart, P. Dalzell, L. McCaffrey and J. McElroy


Spiral and linear magnetic surveys have been used to measure the orientation of anomalies on Lundy Island. Several of the anomalies are inferred to have been caused by dykes intruded into the Tertiary Lundy Granite. A high amplitude magnetic anomaly over the south-east corner of the island is ascribed to strongly magnetic Devonian metasediments.

R. McCaffrey, P. Dalzell and J. McElroy, Department of Geology, School of Geosciences, The Queen’s University of Belfast, Northern Ireland, BT7 INN. S. Stewart, Amerada Hess Limited, 33 Grosvenor Place, London, SW1X 7HY. L. McCaffrey, Department of Geological Sciences, University of Cape Town, Rondebosch 7700, Cape Town, Republic of South Africa.

INTRODUCTION

Lundy Island in the Bristol Channel, UK, is the southernmost of the British Tertiary Volcanic Province igneous centres. The island is largely composed of peraluminous leucogranite intruded into deformed Devonian metasedimentary rocks (Dollar, 1941; Thorpe and Tindle, 1992) (Figure 1). The island is intruded by a cogenetic bimodal dolerite/basalt-trachyte/rhyolite dyke swarm, emplaced relatively soon after granite emplacement (Thorpe and Tindle, 1992).

Arthur (1989) suggested that 28 to 40 km of Eocene sinistral strike-slip faulting along the north-west — south-east Sticklepath-Lustleigh Fault Zone (SLFZ) and Oligocene post-rifting subsidence caused the formation of a 'steer's head' basin up to 4 km deep, known as the Lundy Pull-apart Basin. The Lundy Igneous Complex was intruded into the basement during the sedimentary infilling of the graben. Oligocene or later reactivation of the SLFZ inverted the Lundy Rhomb Graben to form the Lundy Rhomb Horst, and following erosion of the sedimentary infill of the graben, only the Stanley Bank and West Lundy Basins are preserved (Arthur, 1989). Marine geophysical surveys have detected the magnetic signature of offshore dykes (Hains et al., 1983) and the orientation of these dykes has been used to infer stress directions during formation of the Lundy Rhomb Horst (Arthur, 1989). Roberts (1992) has previously used magnetometry to detect basic dykes on Lundy.

The present study was undertaken to prove the landward continuation of the marine magnetic anomalies, which would allow further constraints to be placed on the Tertiary evolution.
SPIRAL MAGNETIC SURVEY

The majority of geophysical surveying techniques involve collection of data along serial, linear sampling traverses (for example, offshore seismic surveys, onshore magnetic surveys). A disadvantage of this approach is that interpolation techniques are more successful at highlighting features which trend at right angles to the survey lines, than features which are sub-parallel to the direction of the survey. This means that the interpretation of a linear survey can be biased by the orientation of the survey lines, and it follows that the quality of interpretation may be significantly compromised if little is initially known about the trends of features in the area under survey.

Solutions to the problem include increasing the number of parallel survey lines, or collecting data along survey lines in several orientations, for example a grid. These options do not represent complete solutions to the problem, which is inherent in the linear nature of the traverses themselves. In any case, considerations of finance and time may prevent a higher density of data acquisition.

A novel solution to the problem was tested here, by collecting magnetic data along a spiral line (Figure 2a), with the aim of establishing the orientation of magnetic anomalies without predisposing the interpretation due to the initial geometry of the survey.

GEOMETRY OF THE SPIRAL SURVEY

The spiral followed on Lundy was defined by a constant rate of reduction \([k]\) in radius \([r]\) with angular displacement \([\theta]\). Together, these parameters give the equation of an Archimedean spiral (equation 1).

\[
r = k \theta 
\]

This type of spiral was chosen because it features a constant distance between loops, which gives a consistent density of data collection. At any point the tangent to the spiral is related to the angular distance from the centre of the spiral at that point (equation 2, Figure 2a):

\[
\tan \phi = \theta
\]

The survey on Lundy employed a spiral consisting of five loops and a maximum radius of 250 m. The spacing between the loops was therefore 50 m; constant \(k\) was 7.95, and \(\theta\) was 10\(\pi\) at \(r = 250\) m.

LAYOUT OF THE SPIRAL

The spiral survey was based upon a centre point, which was precisely located by three compass bearings on local objects. From the centre point, eight reference lines were marked out, extending towards the cardinal and inter-cardinal points of the compass (Figure 2a). Flags were positioned along these lines at the intercepts of the spiral. The flags were set at 50 m intervals on each reference line, beginning at the centre and progressively further away from the centre point on each reference line in turn, proceeding clockwise. This procedure gave the final layout of intercepts as depicted on Figure 2a.

The traverse was followed in an anti-clockwise manner, towards the centre point. A curved trajectory was followed between marker flags in order to adhere to the spiral geometry.
This was assisted by monitoring the decrease in angular distance remaining (θ), using compass bearings on the centre point, then calculating the correct azimuth of the survey (equation 2). Two measurements were taken and averaged every 10 m along the survey line giving a total of 406 data points.

LINEAR SURVEY, LUNDY ISLAND

Survey lines spaced at approximately 180 m were measured in a south-west — north-east direction over the whole of Lundy Island, during late December 1992 and early January 1993. Measurements were taken every 10 paces (about 10 m) using a Geometrics G816 proton precession magnetometer. In addition a north-south survey line was measured with readings every 20 m.

The survey pattern was designed to detect strongly magnetised major dykes. It should be noted that many minor dykes occur throughout the island and that the measurements at this spacing would not detect them. Additionally, it was noted whilst in the field that most of the trachyte/rhyolite dykes of Dollar (1941) and Thorpe and Tindle (1992) were not magnetically detectable (although see below).

The data has been corrected for diurnal magnetic variations using data from the Geophysical Observatory at Hartland Point, 25 km to the south-south-east. All data is normalised to a base level of 48030 nanotesla (nT) and has been computer interpolated and smoothed with UNIMAP software. Smoothing eliminates survey line artefacts from the final map and emphasises large-scale anomalies, whilst reducing their total amplitude. Additionally, the data from the Lundy Island Survey
has been processed using 'MAGPACK' software which calculates the root mean square horizontal gradient of five magnetic intensity measurements, multiplied by the number of changes of sign of gradient in the moving window ('Maggro' parameter, McCaffrey, 1992 and references therein). This procedure emphasises subtle variations in horizontal magnetic gradients caused by weakly magnetised structures.

RESULTS

Magnetic susceptibility survey

The results of a magnetic susceptibility survey of Lundy are presented in Table 1. The number of measurements reflects the preservation of the different rock types. For example granite exposure is common on the island but exposures of basaltic dykes are rare, usually being weathered and often represented by soil-filled gullies. The most magnetically susceptible rocks on the island are the Devonian metasediments, with basalt also strongly magnetised. The G2 phase of the granite can also be locally highly magnetic.

Spiral Survey

The spiral survey of Acklands Moor mapped two major magnetic anomalies, one (A-A') striking 112°-292° and another less easily recognised anomaly (B-B') striking 48°-228° (Figure 2 b, c). Anomaly A-A' corresponds in position and orientation to the extension of a basaltic dyke mapped on the coast by Dollar (1941) and anomaly B-B' corresponds to a major trachytic dyke mapped inland by Dollar (1941). The less well defined anomaly caused by the trachytic dyke is probably caused by its low magnetic susceptibility (see Table 1). A short linear anomaly at C was caused by the presence of a barbed-wire fence.

Lundy Island Survey

Due to the barrenness of Lundy, cultural artefacts in this survey are virtually absent, although a negative magnetic anomaly

Figure 3: Linear total field magnetic survey of Lundy (see Figure 1). a). Computer interpolated anomaly map of the survey area; b). Geological interpretation of the anomaly map, dykes not to scale; c). Maggro' map of Lundy Island; d). Geological interpretation of the Maggro' map of Lundy Island
around [SS 1352 4430] is probably caused by the island's aerogenerator (Figure 3a). On a large scale, the total field map is characterised by high fields (up to 400 nT above base level) at the south-east corner of the island reducing towards the north. The high field area is coincident with the occurrence of deformed Devonian metasediments on Lundy, and reflects their high magnetic susceptibility (see Table 1). Low values (0 to 40 nT above base level) of the magnetic field in the south of the island (around 'X') and in the northernmost one-third of the island (around 'Y') are roughly coincident with the occurrence of G1 granite (Dollar, 1941).

Over small scales, the magnetic map of Lundy Island is characterised by several elongate anomalies, and several of these correlate with dykes mapped around the coast by Dollar (1941). It is suggested that these anomalies are caused by strongly magnetised basaltic dykes (Figure 3b).

The 'Maggro' map is characterised by well defined northwest — south-east elongate anomalies (Figures 3c, d). Several of the anomalies coincide with the magnetic dykes previously located using the total field map (Figure 3a), and others may correspond to less highly magnetised dykes.

DISCUSSION

The major anomaly mapped by the spiral survey had a strike approximately north-west — south-east, and the linear survey lines were oriented to optimise the possibility of intercepting dykes in this orientation. The north-south survey line was undertaken to reduce orientational bias in the Lundy Island Survey. Dyke orientations inferred in this study are consistent with those suggested from geophysical mapping offshore (Hains et al., 1983), and with the main dyke orientation measured from dyke outcrop (Dollar, 1941). The main dyke orientation inferred from this study is similar to that used by Arthur (1989) to constrain palaeo-stress orientation during dyke intrusion. However, Arthur (1989) used the palaeo-stress orientation inferred from dykes to suggest the palaeo-stress orientation that existed during formation of the Lundy Rhomb Graben. The age of the bulk of the dykes of the Lundy Igneous Complex fall within 45 to 54 My (Mussett et al., 1976) and the Lundy Granite has been dated at 53 ± 5 My (Hampton and Taylor, 1983). There is a considerable spread in time in dyke intrusion and it is suggested that there may have been variations in the palaeo-stress directions in the crust during this time. In this case it would be an over-simplification to suggest that the palaeo-stress orientation inferred from dyke orientations was that which occurred during granite emplacement and was also that which occurred during the formation of the Lundy Pull-Apart Basin (cf. Arthur, 1989).

Additionally, the present authors note that the inference of regional palaeo-stress orientation from the fracture systems in Lundy may be compromised by palaeo-stress refraction through the Lundy Granite. The degree of stress refraction would have varied in proportion to the competence contrast, and in inverse proportion to the volume ratio, between the Lundy Granite and the surrounding metasediments (Strömgård, 1973). Since the competence contrast is not zero and the volume ratio is very low, refraction of stresses through the Lundy Granite would be expected. However, refracted stress can approach, but never pass through, the normal to a rheological interface. It follows that the angular relationship between fractures in the more competent block (Lundy Granite) and the regional stress field can be distorted, but the quadrant (relative to the rheological boundary) which contains the regional principal stress can still be identified. This means that while the use of the orientation of dykes intruded into the granite to infer the precise orientation of basin-forming palaeo-stresses is probably invalid, the deduction of a sinistral shear couple from the angular relationship between the SLFZ and the principle stress orientation (inferred from dyke orientation) is still appropriate (Arthur, 1989).

The recognition that the metasediments into which the Lundy Igneous Complex is intruded are highly magnetic has important implications for the interpretation of other geophysical surveys of the area. Burlay (in Edmonds et al., 1979) and Arthur (1989) suggested that the aeromagnetic high centred over the southeastern corner of Lundy is due to a basic part of the Lundy Igneous Complex. However, their aeromagnetic high is coincident with the area of high magnetism mapped during this study and ascribed in this study to magnetic metasediments. It may be possible to use the occurrence of other strongly magnetised areas around Lundy to map out the submarine contact of the Lundy Granite with similar magnetic metasediments.

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REFERENCES


TABLE 1: Magnetic susceptibility of common rock-types on Lundy. For G2 and shale, 'mean' values do not include rare very high 'maximum' values.

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<th>Rock Type</th>
<th>Magnetic susceptibility (SI units)</th>
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