The British Tertiary Igneous Province: Potassium–argon Ages of the Antrim Basalts

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Summary

Twenty-one K–Ar dates on thirteen lavas from Garron Point, Antrim, Northern Ireland yield a minimum age of 49.9 ± 2.2 My. It would appear that this large thickness (> 250 m) of lava was extruded over a period of at most a few million years, in agreement with the results of earlier palaeomagnetic work. There is a correlation between the degree of alteration and apparent age of the samples suggesting that the lavas have lost variable amounts of radiogenic argon.

Within the past few years a number of isotopic age measurements has been made on rocks from the British Tertiary igneous province. The quoted ages of acid rocks generally fall in the range 50–65 My. For detailed discussions of these various ages, the reader is referred to the original papers (Miller & Fitch 1962; Dodson & Long 1962; Miller & Harland 1963; Moorbatch & Bell 1965; Miller & Mohr 1965; Tarling & Gale 1968). There exist few published K–Ar dates on British Tertiary basic rocks. Miller & Mohr (1965) reported K–Ar ages on 13 rock samples from St Kilda. Among these were four ages on basic rocks; 57 ± 2 My for an olivine basalt, 62 ± 2 My for an olivine dolerite dyke, 64 ± 4 and 39 ± 28 My for two dolerite dykes. Moorbatch & Bell (1965) determined ages of 53 ± 3 and 54 ± 3 My for a biotite separated from a Skye basic dyke. The most extensive K–Ar study, to date, was reported by Tarling & Gale (1968) who measured the ages of 19 basalts from the Faeroe Islands, which may have a relation to the British Tertiary province. Tarling and Gale found an age range of 49–65 My for these basalts.

A systematic K–Ar age investigation of volcanic rocks from the British Tertiary igneous province has been initiated in this laboratory. The sample collection consists of drill core specimens, mainly of basic lavas and dykes, collected for both palaeomagnetic and K–Ar dating research. Collections have been made from Antrim, Skye, Mull, Arran and the Scottish mainland.

As a starting point on the dating programme, the basic lavas from Antrim, Northern Ireland were chosen. A full discussion of the palaeomagnetic results from these lavas has been given elsewhere (Wilson 1970). The Antrim lavas outcrop over an area of 1500 square miles (See Fig. 1) and, in places, reach thicknesses of a few hundred metres. The lavas are divided into a lower, middle and upper series, separated by inter-basaltic layers of laterite.

Samples were collected at Garron point from three exposures labelled the ‘A’, ‘B’ and ‘C’ profiles, (See Fig. 2). The 13 lavas from the ‘B’ and ‘C’ profiles selected for K–Ar dating have been marked with an asterisk on Fig. 2. Several lavas from the base of the ‘B’ section were analysed but were not dateable because they contained nearly 100 per cent atmospheric argon.
It is generally accepted that basalt samples selected for K–Ar dating should show no evidence of alteration in thin section. Nonetheless, various authors have shown that this criterion for sample selection may, in some cases, be too restrictive. McDougall, Allsopp & Chamalaun (1966) and Baksi, York & Watkins (1967) have shown that altered basalt samples may still give reliable K–Ar ages. In the present study, rigid adherence to the rule of rejecting samples showing alteration in thin section would have eliminated virtually all samples. Instead, samples showing varying degrees of alteration in thin section were analysed. A brief petrographic description of the analysed samples appears in the Appendix. Each sample has been assigned a number from I to IV which indicates in a relative manner the degree of alteration of the sample. The core samples were about 1 in. in length, two slices were sawn from either end, mixed and crushed to $-140$ mesh for potassium analysis. The remainder was sectioned and used for the argon measurements.

The purpose of the investigation was threefold:

1. To measure the time interval over which the lavas were extruded.
2. To obtain a precise date within a single reversed polarity interval.
3. To determine the duration of formation of the interbasaltic layer.

**Analytical techniques**

The argon was extracted from the basalt in vacuo by fusion using induction heating. The extraction and purification lines were conventional in design and constructed of glass and all metal bakeable valves. Nearly pure Ar$_{38}$ (>99 per cent) was used as a tracer.

The mass spectrometer was an A.E.I. MS10. Ar$_{40}$ and Ar$_{38}$ ion currents were measured to $\pm 0.2$ per cent while the Ar$_{36}$ ion current was measured to between 0.5 and 2 per cent. The error in the Ar$_{36}$ ion current was generally a function of the total amount of atmospheric argon present. The mass discrimination of the spectro-
Potassium-argon dating was used to determine the age of the lavas near Garron Point. From Wilson 1970. Lavas dated are illustrated by an asterisk.

The potassium concentration was measured using an Eel flame photometer. The technique of standard addition developed by Chow & Thompson (1955) for the determination of strontium in sea water was applied to potassium in the present study.
The standard addition technique allows one to correct for interference effects which affect the potassium concentration measurement. Briefly, the technique involves adding to each of several separate aliquots of the unknown rock solution, a known volume of solution containing different potassium concentrations. A plot of flame intensity of these solutions against concentration of potassium solution added to the unknown rock solution should delineate a straight line if the interference effects are constant within the range of potassium concentration being measured. A curvature in the plot would indicate that the interference effects were not constant. From the linear plot, the concentration of the potassium in the rock solution can be calculated.

Employment of this standard addition technique, as opposed to the comparison of flame intensity of rock solution and known potassium solution, has resulted in a significant reduction in the scatter among individual separate measurements (from several per cent to the order of 1-2 per cent). The reliability of our potassium data rests on the linearity of the plots obtained using the standard addition method. The standard error of potassium concentrations measured in triplicate or quadruplicate was generally better than 2 per cent and often better than 1 per cent. (see Table 1).

Table 1

Analytical Data

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>%K</th>
<th>*Ar40 × 10^-11 moles/gram</th>
<th>%*Ar40</th>
<th>Ar40/Ar36 (K40/Ar36)</th>
<th>Apparent Age MY</th>
</tr>
</thead>
<tbody>
<tr>
<td>B033-2</td>
<td>B033-2</td>
<td>0.274, 0.273, 0.275</td>
<td>2.470</td>
<td>63.3</td>
<td>822</td>
</tr>
<tr>
<td></td>
<td>B033-2</td>
<td>0.272, 0.275</td>
<td>2.521</td>
<td>59.4</td>
<td>738</td>
</tr>
<tr>
<td>B031-1</td>
<td>B031-1</td>
<td>0.270, 0.266, 0.261</td>
<td>2.381</td>
<td>56.4</td>
<td>686</td>
</tr>
<tr>
<td>B023-2</td>
<td>B023-2</td>
<td>0.178, 0.178</td>
<td>2.141</td>
<td>30.1</td>
<td>424</td>
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<tr>
<td>B021-3</td>
<td>B021-3</td>
<td>0.111</td>
<td>1.489</td>
<td>58.4</td>
<td>722</td>
</tr>
<tr>
<td></td>
<td>B012-3</td>
<td>0.112</td>
<td>0.852</td>
<td>39.8</td>
<td>495</td>
</tr>
<tr>
<td>B019-3</td>
<td>B019-3</td>
<td>0.194, 0.199, 0.199</td>
<td>0.859</td>
<td>33.1</td>
<td>448</td>
</tr>
<tr>
<td>CO18-1</td>
<td>CO18-1</td>
<td>0.309, 0.306, 0.311</td>
<td>2.784</td>
<td>77.1</td>
<td>1315</td>
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<tr>
<td>CO17-1</td>
<td>CO17-1</td>
<td>0.328, 0.328, 0.327</td>
<td>2.648</td>
<td>66.4</td>
<td>891</td>
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<tr>
<td>CO12-2</td>
<td>CO12-2</td>
<td>0.250, 0.262</td>
<td>2.544</td>
<td>54.3</td>
<td>654</td>
</tr>
<tr>
<td>CO09-3</td>
<td>CO09-3</td>
<td>0.173, 0.175</td>
<td>0.267</td>
<td>34.7</td>
<td>457</td>
</tr>
<tr>
<td>CO08-3</td>
<td>CO08-3</td>
<td>0.196, 0.205</td>
<td>1.672</td>
<td>36.8</td>
<td>470</td>
</tr>
<tr>
<td></td>
<td>CO08-3</td>
<td>0.200, 0.196</td>
<td>1.647</td>
<td>60.0</td>
<td>752</td>
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<tr>
<td></td>
<td>CO08-3</td>
<td>0.173, 0.175</td>
<td>1.495</td>
<td>45.2</td>
<td>544</td>
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<tr>
<td></td>
<td>CO06-1</td>
<td>0.083, 0.085, 0.083</td>
<td>0.496</td>
<td>27.0</td>
<td>413</td>
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<td>CO03-1</td>
<td>0.120, 0.115</td>
<td>0.134</td>
<td>48.4</td>
<td>585</td>
</tr>
<tr>
<td></td>
<td>C003-1</td>
<td>0.117, 0.119</td>
<td>0.890</td>
<td>41.3</td>
<td>520</td>
</tr>
<tr>
<td>C001-1</td>
<td>C001-1</td>
<td>0.127, 0.122, 0.129, 0.130</td>
<td>0.835</td>
<td>33.1</td>
<td>448</td>
</tr>
</tbody>
</table>

*Ar40 = radiogenic argon \( \lambda = 5 \cdot 30 \times 10^{-11} \text{ yr}^{-1} \)
\( K^{40}/K = 1 \cdot 19 \times 10^{-6} \) (atom ratio)
clearly worse than 2 per cent, yet these samples range from quite fresh (C012-2) to heavily altered (C003-1).

Two separate portions of the core specimens B033-2 and C003-1 were analysed for potassium. For sample B033-2 the potassium concentration measurements agreed very well. For C003-1 the difference between the mean potassium determinations was significant. Combined with the fact that the argon concentration determinations for C003-1 are non-reproducible, the suggestion is that the potassium and argon concentrations vary over short distances (less than 5 cm) in this sample. This variation could be due to initial inhomogeneities in the sample or to post-solidification alteration.

Sample C006-1 gave a very low age of 32.4±1.2 My despite the fact that it was the least altered of all the analysed samples. Lack of additional sample prevented the redetermination of the argon concentration.

The apparent ages range from 40 to 54 My (excluding C006-1) with no correlation between apparent age and stratigraphic position. The age range of 40–54 My is clearly outside the analytical precision to be expected and probably reflects variable argon loss.

A histogram of all of the individually determined apparent ages is shown in Fig. 3. The relative degree of alteration (I–IV) is also indicated. If for any one column of the histogram we define an index of alteration as

$$I.A. = \frac{\sum \text{number of samples} \times \text{relative degree of alteration}}{\text{total number of samples}}$$

and give the values 1–4 to the relative degree of alteration, we can get a semi-quantitative value for the degree of alteration in the various histogram ranges. The I.A. value will obviously be least for the group containing the least altered samples. Applying this analysis to the three columns in the histogram containing more than one sample, we

![Fig. 3. Histograms of apparent ages. Increasing degree of alteration is indicated by Figs 1–4.](https://academic.oup.com/gji/article-abstract/27/3/327/837200/1137762)
have the following:

<table>
<thead>
<tr>
<th>Age range (My)</th>
<th>I.A.</th>
</tr>
</thead>
<tbody>
<tr>
<td>50–55</td>
<td>2.0</td>
</tr>
<tr>
<td>45–50</td>
<td>2.6</td>
</tr>
<tr>
<td>40–45</td>
<td>3.0</td>
</tr>
</tbody>
</table>

This semi-quantitative analysis suggests that the 'age' of the samples is a function of the degree of alteration, or again, argon loss is indicated. From this analysis, a minimum age in the range 50–55 My is suggested for the Antrim basalts.

Another useful manner in which to analyse the data is to use an isochron plot (McDougall, Polach & Stopp 1969). For a sample containing only radiogenic and atmospheric argon, we have

\[
\frac{(Ar^{40})}{(Ar^{36})}_m - \frac{(Ar^{40})}{(Ar^{36})}_a = \left(\frac{K^{40}}{Ar^{36}}\right) \left(e^{\lambda t} - 1\right) \frac{\lambda}{\lambda_e}
\]

where \((Ar^{40}/Ar^{36})_m\) = measured ratio of \(Ar^{40}\) to \(Ar^{36}\) ion currents, corrected for the contribution to these ion currents from the tracer. \((Ar^{40}/Ar^{36})_a\) = true atmospheric \(Ar^{40}\) to \(Ar^{36}\) ratio = 295.5, \((K^{40}/Ar^{36})\) = mole ratio of \(K^{40}\) to atmospheric \(Ar^{36}\)

\(\lambda\) = total decay constant of \(K^{40}\)

\(\lambda_e\) = electron capture decay constant for \(K^{40}\)

\(t\) = age of sample

Provided there is no source of argon other than atmospheric and in situ produced radiogenic \(Ar^{40}\), a plot of \((Ar^{40}/Ar^{36})_m\) versus \((K^{40}/Ar^{36})\) should delineate a straight line (isochron) for a suite of rocks of the same age. The slope will be equal to \(\lambda/\lambda_e\) \((e^{\lambda t} - 1)\) and the intercept on the \((Ar^{40}/Ar^{36})_m\) axis will equal 295.5 the atmospheric \((Ar^{40}/Ar^{36})\) ratio.

The Antrim data have been analysed in the above fashion. Sample C006–1 was not included. A least squares analysis (York 1966) of the data split into various groups is given below in Table 2. 'S' is the minimized sum of the weighted squared deviates and a \(\chi^2\) test of significance was applied to S.

It can be seen from Table 2 that, within the precision quoted (twice the standard error), there is no significant difference among the ages of the various groups. Also the \((Ar^{40}/Ar^{36})_m\) intercepts do not differ significantly from 295.5, the atmospheric ratio. On the other hand, all the S values are much larger than the number of degrees of freedom, negating the postulate that the data points all lie on a single straight line. The fact that the data points do not lie on a single isochron could probably have been

Table 2

**Analyses of Ages by groups**

<table>
<thead>
<tr>
<th>Group</th>
<th>Apparent Age (\pm 2) My</th>
<th>((Ar^{40}/Ar^{36})) intercept (\pm 2)</th>
<th>Degrees of freedom</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>All lavas</td>
<td>49±9 (\pm 4).4</td>
<td>279±22</td>
<td>19</td>
<td>78</td>
</tr>
<tr>
<td>All lavas above interbasaltic layer</td>
<td>49.6 (\pm 5).4</td>
<td>279±30</td>
<td>11</td>
<td>63</td>
</tr>
<tr>
<td>All lavas below interbasaltic layer</td>
<td>49.6 (\pm 11).4</td>
<td>279±50</td>
<td>6</td>
<td>15</td>
</tr>
<tr>
<td>All lavas from 'B' profile</td>
<td>51.2 (\pm 4).2</td>
<td>276±19</td>
<td>6</td>
<td>10</td>
</tr>
<tr>
<td>All lavas from 'C' profile</td>
<td>49.4 (\pm 7).4</td>
<td>278±42</td>
<td>11</td>
<td>66</td>
</tr>
<tr>
<td>All lavas containing more than 35 per cent radiogenic argon</td>
<td>51.4 (\pm 5).8</td>
<td>266±34</td>
<td>15</td>
<td>68</td>
</tr>
</tbody>
</table>

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predicted from Table 1. Nonetheless, this type of analysis allows one to reject in an objective manner the postulate that these data are representative of a single age.

If argon loss is the reason for the scatter of the data points, as seems likely, then the isochron plot for all of the lavas will give a minimum age for the lava samples. This isochron plot is shown in Fig. 4. The slope of the straight line corresponds to an age of $49.9 \pm 2.2$ My.

Conclusions

(1) Variable argon loss from the samples is indicated by
(a) spread of apparent ages; (b) lack of correlation between apparent age and stratigraphy; (c) a larger scatter of data points about the isochron than can be accounted for from analytical precision; and (d) correlation of age with degree of alteration.

(2) From the isochron plot a minimum age for the lavas from Garron Point, Antrim, Northern Ireland is $49.9 \pm 2.2$ My.

The total time interval for lava extrusion and the duration of formation of the interbasaltic layer is not resolvable with the present data.

Acknowledgments

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References


Appendix

A brief petrographic description of the analysed samples is given below. The majority of the lavas are olivine basalt. The relative degree of alteration is indicated in Roman numerals below the sample number.

B033–2 Groundmass composed of interlocked plagioclase and feldspathoids. Some small patches of altered plagioclase in groundmass but larger plagioclase grains are unaltered. Pyroxene alteration is more advanced; epidote and chlorite are found on the outer rims.