Practical 49: Radiometric dating of Precambrian Terranes in the UK

Radiometric dating is particularly important in Precambrian areas because of the scarcity of fossils. In this practical you will first calculate a radiometric age from chemical data, and then interpret the pattern of ages in the Precambrian basement of Britain and Ireland. Note that several computing solutions are illustrated to these questions in R, Python and QGIS. These computing solutions are entirely optional for those who are interested and who want to take it further. There is no expectation that you know how to answer these practicals on a computer at Part 1A.

Aims of this practical session: Become familiar with the three main types of rock-

To learn how to calculate a radiometric age using the Rubidium-Strontium method.

To analyse the pattern of radiometric ages in Precambrian rocks of Britain and Ireland.

To locate the main geological terranes of the region and the faults that separate them.

Radiometric dating: the Rubidium-Strontium (Rb-Sr) method (5 minutes)

Click here for a video introduction to this practical

Rb substitutes in small proportions for potassium (K) in micas, K-feldspars and some other minerals. ^{87}Rb decays to ^{87}Sr with a half life (the time for half the original Rb atoms to decay to Sr atom) of 4.88×10^{10} years. At a time t after the formation of a rock the number of daughter atoms (^{87}Sr) present is related to the number of surviving parent atoms (^{87}Rb) by the basic equation of radioactive decay[1].

[1] You will lean much more about this at Part 1B.

$$^{87}Sr = ^{87}Rb(e^{\lambda t} - 1) \quad (1)$$

where λ is the radioactive decay constant, related to the half life ($T_{1/2}$) by:[2]

[2] make sure you remember why, for a reminder, click here.

$$\lambda = ln(2)/T_{1/2} \quad (2)$$

Typically, a rock already has some ^{87}Sr present, in addition to that produced from the decay of ^{87}Rb so eqn 1 becomes:

$$^{87}Sr_t = ^{87}Rb(e^{\lambda t} - 1) + ^{87}Sr_i \quad (3)$$

where subscripts i and t denote the initial amount of ^{87}Sr, and that at time t. It is analytically more convenient to measure the ratio of ^{87}Sr to the stable isotope ^{86}Sr, rather than to measure the absolute amount of ^{87}Sr. Therefore the decay equation is used in the form:

$$\left(\frac{^{87}Sr}{^{86}Sr}\right)_t = \left(\frac{^{87}Rb}{^{86}Sr}\right)_t (e^{\lambda t} - 1) + \left(\frac{^{87}Sr}{^{86}Sr}\right)_i \quad (4)$$

The first two ratios can be measured. The last one cannot unless the rock contains one mineral with negligible Rb, and therefore no addition of radiogenic ^{86}Sr. However an age can still be calculated from a number of analyses from the same rock body. Exercise 1 shows you how.

Figure 49.1: Scourie dykes from the Lewisian Complex, NW Scotland, UK.

Exercise 49.1: Rb-Sr age determination (20 mins)

You are given analytical data from 12 whole-rock samples (table 1) from dolerite dykes at Scourie (NW Scotland).

Table 49.1: Rb and Sr isotope data from dolerite dykes at Scourie

Sample No.	^{87}Rb/^{86}Sr ± < 2%	^{87}Sr/^{86}Sr ± < 0.00008
1	0.336	0.71395
2	0.133	0.70665
3	0.234	0.71038
4	0.352	0.7144
5	0.074	0.70458
6	0.297	0.71221
7	0.149	0.70757
8	0.488	0.71901
9	0.133	0.70683
10	0.266	0.71149
11	0.114	0.70594
12	0.429	0.71717

The data are available as a “csv" file here, and can be opened and plotted in any spreadsheet.

The variation in Rb/Sr ratios in different samples is due to minor heterogeneity in lithology.

If you don’t have time to plot all the data, make sure you at least plot several points at the extremes of the data range

Exercise 49.2:

Plot these data with ^{87}Rb/^{86}Sr horizontally against ^{87}Sr/^{86}Sr vertically.

If you do this by hand, a horizontal scale (range 0 to 0.6) of 0.1 = 25 mm and a vertical scale range 0.70 to 0.72) of 0.010 = 50 mm is appropriate.

Click here for the answer.

Exercise 49.3:

Estimate the best fit straight line to the data. Note the intercept value on the vertical axis and calculate the gradient.

intercept =..... gradient =.....

This is best done as a least squares fit on a computer. Geochemists spend a lot of time worrying about the uncertainty on such fits.

If you are interested and would like to know how to answer the question in the “R" language an explanation is provided here. You can download this script from here and run if you have “R" installed on your computer.

Exercise 49.4:

Look at the decay equation (eqn. 4) above. Notice that it is the equation of a straight line of form y = mx + c, with intercept c = $\left(\frac{^{87}\mathrm{Sr}}{^{86}\mathrm{Sr}}\right)_\mathrm{i}$ and gradient, $m = (e^{\lambda t} - 1)$. Your value of the

intercept in 1.2 is therefore the original strontium ratio. What is the age of the Scourie dykes? (use $\lambda = 1.42 \times 10^{-11} years^{-1}$)

age =.....

.

Exercise 49.5: Age pattern of British and Irish Precambrian terranes (15 mins)

The map shows representative age determinations from Precambrian metamorphic and igneous rocks in Britain and Ireland. Some of these rocks have suffered metamorphism during Phanerozoic time but ages from these events have been omitted. Some of the dates derive from the Rb/Sr method, but most of the remainder from the U/Pb method. These dates have uncertainties up to ± 10%. The basement terranes showing areas of contrasting geology are also shown on the map. The lines are major faults along which, terranes once separated in time and space have amalgamated together. In some cases these faults have been covered by later sediments.

A note about errors: The $^{87}Rb/^{86}Sr$ and $^{87}Sr/^{86}Sr$ measurements are subject to the analytical errors quoted at the top of the data columns. The resulting error in the position of each data point is taken into account when a radiometric age is computed accurately. A regression line is fitted to the data using standard least squares procedures. The quality of the fit is denoted by the 'mean square of weighted deviates' (MSWD). A fit of MSWD = 1 indicates that the scatter of data points could be due to the analytical errors alone. With the small data sets usually analysed (10-30 points) a regression line is taken to indicate a meaningful age or isochron if MSWD < 2.5, indicating a fit within the 95% confidence intervals. For the complete data set of 33 rock samples from the Scourie dykes the MSWD value = 2.1 and the error on the age = ± 20 million years (at the 95% confidence limit)

Exercise 49.6:

Plot two histograms, one for the Gondwanan terranes southeast of the Iapetus Suture and one for the Laurentian terranes to the northwest. Distinguish separately, by colour or shading, the ages from the North Armorican Terrane on the Gondwanan histogram. Similarly distinguish the ages from the Hebridean Terrane on the Laurentian histogram.

Remember a histogram is a bar chart showing the number of data falling in each successive age 'bin'. An age scale of 5mm = 100Ma, and a bin width of 100Ma are convenient.

You can either do this by hand, reading the ages of the map and noting whether they belong to Gondwanan or Armorican Terranes, or if you would rather use a computer, the raw data are provided as a "csv" file here. You can "bin" the data by hand, or you can use a program to do this for you.

If you want to know how to make the histograms in the "R" language click here. You can download this script from here and run if you have "R" installed on your computer.

Exercise 49.7:

The terranes southeast of the Iapetus Suture were originally attached to the large Gondwana continent. What is the age range of the most prominent metamorphic and igneous event to affect these terranes?

Age range of main event on Gondwana =.....

(This is termed the Cadomian event)

Exercise 49.8:

An earlier event on Gondwana can be recognised only in the North Armorican Terrane. What is its approximate age?

Age of the early event on Gondwana =.....

(This is termed the Icartian event)

Click here for the answer.

Exercise 49.9:

The terranes northwest of the Iapetus Suture were originally attached to the major Laurentia continent. Note how their age spectrum differs from that of the Gondwana terranes. What are

the age ranges of the four main metamorphic/igneous events to affect Laurentia?
Age ranges of events on Laurentia =.....
(These events are termed, in decreasing age order, the Scourian, Laxfordian, Grenvillian and Knoydartian events)

Exercise 49.10: Relating your ages to the geological map (10 mins)

Exercise 49.11:

On the Geological Survey map provided on Moodle, locate the Hebridean, Northern Highlands and Grampian terranes and the faults that bound them. List the major Precambrian units that occur in each terrane (Dalradian, Moine, Lewisian or Torridonian in the map key).

You can access a zoomable digital map of the UK here here.
Learn how to make your very own georeferenced digital map of the UK in 10 minutes here.

Exercise 49.12:

Note that the Moine Thrust, Great Glen Fault, Highland Boundary Fault and Southern Uplands Fault are exposed on the present land surface. By contrast, the faults of the Iapetus Suture are covered by later rocks, the age of which provides an upper age limit for fault movement. What age are these cover rocks?

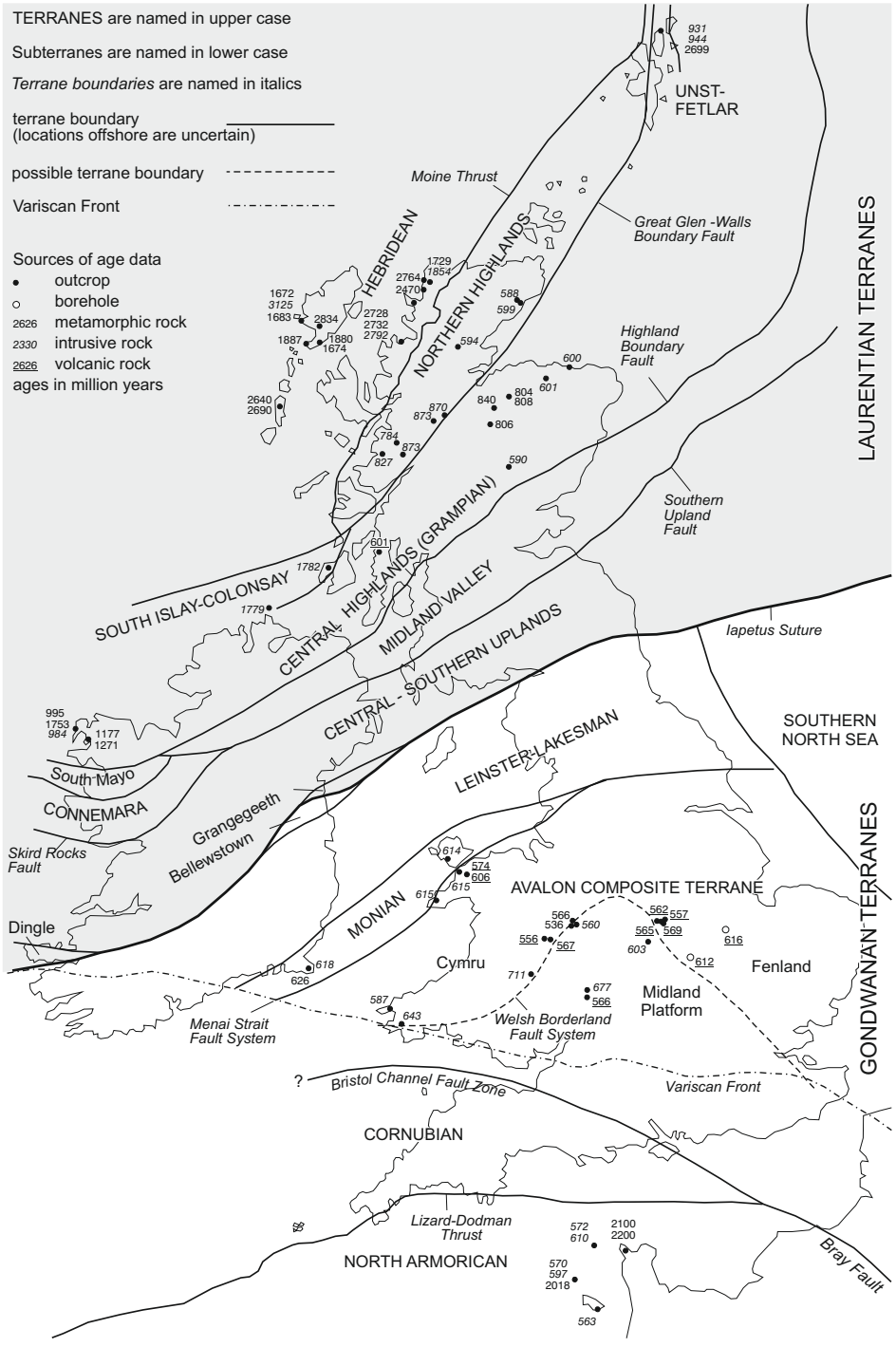

Figure 49.2: Simplified terrane diagram with selected radiometric ages indicated.