<u>SECTION 7:</u> DATING OF SURFACES AND MATERIALS

Naturally we would like to know the ages of the features we see on other planets, and the ages of samples of extra-terrestrial rocks that we have in our possession. There are various techniques which enable us to do this, some more accurate than others. Two methods will be discussed here - crater dating and radiometric dating.

7.1 Crater Dating

This is the least accurate of the dating techniques, but is still the most important when is comes to looking at planets or satellites from which we have no samples. In theory, if you know how many craters of a particular size are on a surface and you know the cratering flux, then you should be able to work out the age of the surface. In practice, this is not so easy, and there are several problems standing in our way.

Firstly, when counting the craters, secondary craters must not be used - secondaries associated with a particular crater are from a single event, no matter how many there are, and will give the impression that a surface is older than it really is by giving the appearance that many cratering events had taken place. Being able to distinguish between primaries and secondaries is therefore of great importance.

Secondly, craters will degrade at different rates depending on the terrain they have formed on, i.e. craters on a steeply sloped hill will be more likely to slump and degrade much faster than those on a flat surface, or those on a loose material will degrade through erosion faster than those on a harder surface if an atmosphere is present. Therefore it is very important to understand the degradation process in the terrain upon which the craters lie.

Thirdly, ancient crater records may be obliterated by the subsequent embayment by volcanics or impact ejecta. It is therefore important to be able to recognise when an area has been resurfaced. Most of the time this is obvious (i.e. mare regions on the Moon vs. highlands), but there may be times when it is a little more ambiguous.

As well as looking out for these pitfalls, there are certain things we need to know, understand and be aware of. Surfaces may become impossible to date after a particular time if it becomes saturated with craters. Imagine a surface being bombarded over time with impacts. Eventually a time will be reached when the whole surface has been cratered and new impacts will overlie old ones. This is the point of saturation and once this has been reached, a surface of a particular age and older will have the same number of craters. The lunar highlands are a good example of this.

Apart from being able to count the craters in the first place (and not mistaking them for other features such as secondaries, volcanoes etc.), the most important aspect of crater dating is knowing the cratering flux through time. This is not easy, and estimates can vary wildly depending on which model you use.

To work out the flux of cratering events, you first need to know the distribution of the meteoroids in space and time which will make the craters. After that, you need to work out the probability of them striking a particular target. To know this, an understanding of the gravitational interactions between bodies is required; for instance, we'd expect more impacts to have occurred on Earth than on the Moon in the same time period simply because of the greater gravitational pull of the Earth. Each of these steps will have uncertainties in them, and some will be calculated in different ways. This leads to great differences between models, and of course, each will have quite large errors associated with them.

One thing that seems to be clear from the dating of samples returned from the Moon is that there was an intense period of heavy bombardment in our region of the solar system around 4 billion years ago, indicating that the cratering flux has not been constant, and it certainly was not the same as it is now. In fact after the period of heavy bombardment, the cratering flux dropped dramatically in our parts, and there are some who believe that the cratering flux now is increasing again. So, the flux is neither constant, nor does it appear to increase or decrease in a consistent way. This is an added complication to the already difficult problem.

Even if it is possible to work out the cratering flux for a particular body, it can't necessarily be applied to all other bodies in the solar system. Perhaps the impacting material in the heavy bombardment period was left over from the from the accretion of the planets in the solar nebula. The distribution of material may not have been (and probably wasn't) even throughout the whole system - perhaps Mercury had the worst time of all - being so close to the Sun and its immense gravitational pull put Mercury in the firing line for incoming projectiles. The satellites of the outer planets may have had more cratering events than others because of the attraction of their huge parents. Perhaps even we had a higher cratering flux if the Moon was formed by a giant impact - there would have been lots of debris flying around in our orbit for a long time if it had. All these provide even more problems for the scientist trying to calculate cratering flux. The listing of these problems and unknowns alone should convince you that crater dating is neither an easy task, nor a very precise one. However, on surfaces for which we have no sample, i.e. Galilean satellites, Mercury etc., crater dating is all we have.

7.2 Dating of Meteorites

Meteorites are some of the most primitive material in the solar system, and we have thousands of pieces of meteorites in our museums and laboratories around the world. Whilst we appear to have quite a thorough understanding of their compositions and in some cases how they may have formed, the accurate dating of these rocks from space is extremely important in putting this information in context.

7.2.1 Radiometric ages

The half-life of a radionuclide is the time it takes one-half of the original amount to decay. The decay constant, λ, is related to the half-life, $T_{½}$, by

$$\lambda = \frac{0.693}{T_{½}} \quad \text{Equation 7.1}$$

If we let the amount of radioactive parent nuclide present at time t be P, and the amount present at the start (i.e. t =0) be P_0, the law of radioactive decay will be

$$P = P_0 e^{-\lambda t}$$

or

$$P_0 = P e^{\lambda t} \quad \text{Equation 7.2}$$

A radioactive nuclide will decay and form a daughter nuclide, D, the amount at time t of which is given by

$$D = D_0 + (P_0 - P)$$

or

$$D = D_0 + P(e^{\lambda t} - 1) \quad \text{Equation 7.3}$$

where D_0 is the original amount of the daughter nuclide. Some parent nuclides decay to more than one daughter. When this happens, the second term must be multiplied by a factor γ equal to the fraction of the decays that produce the daughter D:

$$D = D_0 + \gamma P(e^{\lambda t} - 1) \quad \text{Equation 7.4}$$

The values of γ and λ are generally well known and so a determination of D, D_0 and P will allow t to be calculated. Various nuclides are used for this kind of dating, outlined in Table 7.1

Table 7.1 Some radionuclides used to date meteorites (Wasson 1985)

Parent	**Daughter**	**Half-life, $T_{½}$ (b.y)**	**Decay Constant, λ (yr^{-1})**
^{40}K	^{40}Ar, ^{40}Ca	1.25	5.55×10^{-10}
^{87}Rb	^{87}Sr	48.8	1.42×10^{-11}
^{232}Th	^{208}Pb	14.0	4.95×10^{-11}
^{235}U	^{207}Pb	0.704	9.85×10^{-10}
^{238}U	^{206}Pb	4.47	1.55×10^{-10}

γ = 0.12 for the ^{40}K to ^{40}Ar decay.

7.2.2 Rubidium to strontium decay

^{87}Rb decays to a single daughter, so γ=1. Therefore,

$$^{87}Sr = {}^{87}Sr_0 + {}^{87}Rb\,(e^{\lambda t} - 1) \quad \text{Equation 7.5}$$

The problem here is how do we calculate the amount of $^{87}Sr_0$? The present amounts of ^{87}Sr and ^{87}Rb are both directly measurable, but of course we cannot measure the original amount of ^{87}Sr present. Fortunately $^{87}Sr_0$ is directly proportional to non-radiogenic strontium isotopes, i.e. ^{86}Sr. Because of this, and because ratios are easier to measure, we divide Equation 7.5 by ^{86}Sr:

$$\frac{^{87}Sr}{^{86}Sr} = \left(\frac{^{87}Sr}{^{86}Sr}\right)_0 + \frac{^{87}Rb}{^{86}Sr}(e^{\lambda t} - 1) \quad \text{Equation 7.6}$$

Now, ^{86}Sr is measurable and we are left with the two unknowns t and $(^{87}Sr/^{86}Sr)_0$. By measuring $^{87}Sr/^{86}Sr$ and $^{87}Rb/^{86}Sr$ in two or more fractions of the rock with different Rb/Sr ratios, we can solve for the unknowns. Figure 7.1 shows how the ^{87}Rb decays, an equal increment of ^{87}Sr appears. The points then move up and to the left of the diagram. In an ideal case, the points will move onto a straight line where the slope is given by $(e^{\lambda t} - 1)$ and the y-intercept is $(^{87}Sr/^{86}Sr)_0$. This intercept may be considered as a mineral that held no Rb at all, and so the $(^{87}Sr/^{86}Sr)$ ratio would remain constant. Because Rb has such a long T½, it can be used to date very old rocks back to the beginning of the solar system. In fact, this method has determined the oldest meteorites to be ~4.53 billion years old.

Reference List

"Meteorites: Their record of early solar-system history", Wasson J.T., 1985, W.H. Freeman and Company, New York