
Two meteorites collected in Antarctica, ALH A77005 and LEW 88516, have characteristics which link them to the shergottite group of SNC meteorites (e.g. 1). Essentially, ALH A77005 and LEW 88516 are feldspathic harzburgites (e.g. 2), being comprised of roughly equal quantities of olivine and pyroxene, with an additional few percent of feldspar which has subsequently been converted to maskelynite by shock (2,3). The meteorites represent samples of a cumulate rock which is itself composed of two different lithologies: in one, large pyroxenes poikilitically enclose olivine crystals, while the other consists of interstitial areas made up of pyroxene, olivine, maskelynite, whitlockite, troilite, ilmenite and chlorapatite (1). It has been proposed that meteorites such as ALH A77005 (and LEW 88516) are relict samples of the source peridotite from which the other shergottites formed (3). As such it should be informative to study in detail the carbon components present within these samples, in order to make comparisons with data from other shergottites (e.g. 4). Although not plutonic in origin (2), and therefore not sampling a truly deep source, analyses of ALH A77005 and LEW 88516 should assist with attempts to define the bulk carbon isotopic composition of Mars. This has been assessed previous through analyses of carbon of presumed magmatic origin in other SNC meteorites (4,5), but the carbon isotopic compositions obtained seem to be at variance with what might be expected. It is important to constrain the carbon isotopic composition of Mars as well as possible so that models of atmospheric evolution, based on carbon isotopic data (6,7), can yield the most reliable results.

As detailed in Wright et al. (5), the isotopic composition of magmatic carbon on Mars appears to fall in the region of $\delta^{13}C = -20$ to $-30\%_o$. This is substantially different to carbon of a juvenile composition in the Earth's mantle, which has $\delta^{13}C$ of -5 to $-7\%_o$. The apparent difference in carbon isotopic composition between the two planets is difficult to explain. Even if heterogeneous accretion is advocated, with differing sorts of late-stage veneers on the two planets, while it is possible to comprehend the Earth's $\delta^{13}C$ value in terms of known meteorite groups (i.e. C1 and C2 carbonaceous chondrites have $\delta^{13}C$ in the range -5 to $-10\%_o$), the data for Mars are at odds with meteoritic evidence. In order to provide some new information on this subject, ALH A77005 and LEW 88516 have been re-analysed by high-resolution (i.e. 25°C temperature increments), stepped combustion. This technique gives a measure of the variation of carbon concentration and stable isotopic composition with temperature (from ambient to ca. 1300°C, where melting begins).

A previous analysis of ALH A77005 (4) showed it to contain 141 ppm carbon with a $\Sigma\delta^{13}C$ of -28.7$\%_o$. Notwithstanding what appear to be three separate releases of carbon (200-400°C, 500-600°C and 900-1200°C), $\delta^{13}C$ values hardly deviate from the mean value. The results for the new analysis of ALH A77005 show 153 ppm carbon and a $\Sigma\delta^{13}C$ value of -26.4$\%_o$, in good agreement with the previous experiment. In detail, an obvious high temperature release of carbon is missing in the new analysis; it is likely that the release of carbon at 900-1200°C in the original extraction was the result of metal contamination, arising from the use of a stellite (stainless steel) pestle and mortar, during sample preparation. The analysis reported herein is from a sample which was manipulated in an agate pestle and mortar (as, indeed, are all analyses of SNC meteorites now performed in our laboratory). In the original analysis, 27 ppm carbon with $\Sigma\delta^{13}C$ of -27.6$\%_o$ were released from 900-1200°C; in the new analysis only 4.4 ppm carbon are liberated over the equivalent temperature range. Curiously the $\Sigma\delta^{13}C$ value recorded from 900-1200°C in the new analysis is -24.2$\%_o$, which is indistinguishable from that acquired previously. Since 900-1200°C is the temperature range over which magmatic carbon could be released, it would seem that this new
analysis of ALH A77005 provides an upper limit to the possible concentration of this component. It is considered to be an upper limit since, as demonstrated by the previous analysis of ALH A77005, contaminants can burn at high temperatures (there is also a contribution from system blank which is not accounted for here). The $\Sigma \delta^{13}C$ of -24.2‰ is no different to that proposed earlier for magmatic carbon in SNC meteorites (5).

In the analysis of LEW 88516 (sub-sample 8) a discrete release of carbon is discernible at 1000-1150°C. This amounts to 2.63 ppm carbon with $\Sigma \delta^{13}C$ of -22.2‰. However, on the basis of the $\delta^{13}C$ values recorded at different steps it appears that this carbon does not arise from a single component. From 1000-1050°C, 1.2 ppm carbon are released with $\delta^{13}C$ of -32.8‰, while from 1050-1100°C, 0.78 ppm carbon with $\delta^{13}C$ of -7.4‰ are evolved. The isotopically light material would be compatible with what has been found previously in SNC meteorites, and ascribed to martian magmatic carbon. On the other hand, the $\delta^{13}C$ value of -7.4‰ is perhaps more like what would be anticipated for magmatic carbon, based on the experience of terrestrial samples. However, SNC meteorites suffer from the complication of a component believed to be trapped martian atmospheric CO$_2$, present in shock-produced glass, which has $\delta^{13}C$ as high as +27‰ (8). Depending upon the location of magmatic carbon in SNC meteorites it may not be possible, using stepped combustion, to successfully resolve trapped CO$_2$ from the evolution of magmatic species. For instance, if magmatic carbon is dissolved in minerals, this may be released at a similar temperature to that where glass melts and liberates trapped CO$_2$. For the analysis of ALH A77005, trapped CO$_2$ was observed at temperatures greater than 1200°C, whereupon 0.5 ppm carbon with $\delta^{13}C$ of +15.9‰ was released. This tends to suggest that in this sample, at least, trapped CO$_2$ was resolved. The component with $\delta^{13}C$ of -7.4‰ in LEW 88516 may simply represent a mixing of trapped CO$_2$ and magmatic carbon with a $\delta^{13}C$ of -32.8‰. In any case an isotopically light component was observed at high temperatures in LEW 88516, which is consistent with previous analyses of SNC meteorites. Thus, it would seem apparent that magmatic carbon in SNC meteorites is distinctly different to that on Earth.

It is known that xenoliths from terrestrial basalts contain carbonaceous matter in the form of particles in cracks, and semi-continuous films in microcracks (9). The particles are considered to be graphite intercalation products, while the films are complex mixtures of organic and possibly graphitic compounds. These materials are thought to have formed abiotically by the reaction of volcanic gases with chemically active crack surfaces. Interestingly attempts to measure the carbon isotopic compositions of the carbonaceous materials using stepped heating extractions (10) have shown that they may combust at temperatures up to 1200°C and have $\delta^{13}C$ values of ca. -25‰, even though co-existing CO$_2$ fluid inclusions have $\delta^{13}C$ of about -5‰. It seems entirely possible that the SNC meteorite samples studied herein may show evidence for the presence of carbonaceous matter (with $\delta^{13}C$ of ca. -25‰), while any CO$_2$ originally present (with $\delta^{13}C$ of -5‰?) has been degassed from the samples without forming fluid inclusions.