CARBONATES IN ANTARCTIC ORDINARY CHONDRITES: EVIDENCE FOR TERRESTRIAL ORIGIN; H. R. Karlsson[1], A. J. T. Jull[2], R. A. Socki[1,3] and E. K. Gibson Jr.[1]. [1]SN2, NASA/JSC, Houston, TX 77058, [2]NSF Facility for Radioisotope Analysis, University of Arizona, Tucson, AZ 85721, [3]LESC, Houston, TX 77058.

Introduction. The discovery of the hydrated Mg-carbonate species, nesquehonite, in LEW 85320 demonstrates that carbonates form rapidly in the Antarctic environment (< 40 A) and opens up the possibility that carbonates in other Antarctic meteorites may also, to a large extent be terrestrial weathering products [1, 2]. In order to constrain the origin of bulk carbonate in Antarctic ordinary chondrites, we have determined their stable isotopic ratios ($\delta^{18}O$, $\delta^{13}C$) and ^{14}C contents. We chose ordinary chondrites because of their low intrinsic carbon content in order to minimize the contribution of meteoritic carbon and because they provided large samples (> 1g) with well-constrained terrestrial ages [3].

Experimental Methods. Powdered bulk meteorite samples (100-180 mg, grain size < 20 μm) were reacted with 100% phosphoric acid releasing CO_2 for stable isotopic analysis. The reaction was carried out in three consecutive steps: i) 25°C for 1h, ii) 50°C for 1 day, and iii) 50°C for 5 days following the procedures of Karlsson et al. [4].

In addition to $^{18}O/^{16}O$ and $^{13}C/^{12}C$ analysis, some the CO_2 was retrieved, reduced to graphite over hot iron and the ^{14}C abundance analyzed by accelerator mass spectrometry (AMS), using procedures described in [5, 6]. A total of 16 ordinary chondrites were studied.

Results and Discussion. The stable isotope data for bulk carbonates (all three acid extraction steps combined) are plotted in figures 1-3. We assume the acid-carbonate oxygen isotope fractionation factors appropriate calcite [7], although we realize that the carbonates are probably mostly present as hydrated Mg-phases [8]. Fig.1 shows the relationship between $\delta^{18}O$ and $\delta^{13}C$ in all the ordinary chondrites analyzed, along with data for some terrestrial carbonates in Antarctic rocks and soils. It is clear from Fig. 1 that the ordinary chondrite carbonates are isotopically indistinguishable from terrestrial Antarctic carbonates and thus stable isotopic data alone cannot be used to separate exterrestrial carbonate from terrestrial carbonate. Karlsson et al. [4] suggested that if the carbonates in ordinary chondrites were generated and/or modified by isotopic exchange with an Antarctic reservoir whose isotopic composition remained constant, then their isotopic composition should reach a constant value as a function of terrestrial age (our best proxy for "weathering" age). Fig. 2 shows the variation in $\delta^{13}C$ with terrestrial age. Excepting ALHA-77231, the bulk $\delta^{13}C$ values vary only between -2 and +5‰, reflecting an isotopically constant source. The most obvious of terrestrial source of C is atmospheric CO_2 (-7‰PDB). The two horizontal lines in Fig. 2 show the $\delta^{13}C$ composition of calcite in equilibrium with atmospheric CO_2 at 0°C and 30°C, respectively, calculated on the basis of Bottinga's equation (9). Using magnesite instead of calcite would shift these lines ~5‰ towards higher $\delta^{13}C$ values (Clayton unpub. results, 1991). Clearly, neither simple calcite-CO_2 or magnesite-CO_2 equilibria fully explain the data. Fractionation factors for ^{13}C in the most appropriate mineral systems, nesquehonite and hydromagnesite, have not been reported in the literature.

More variation is observed in bulk $\delta^{18}O$ values, +14 to +25‰, reflecting the fact there are at least two sources of oxygen, i.e., ice melt water (-37‰SMOW) and atmospheric CO_2 (+41‰SMOW). The two horizontal lines in Fig. 3 show the isotopic composition of calcite in equilibrium with these two sources, respectively. Using hydromagnesite instead of calcite would shift the lower curve up by 3‰. The simplest explanation of oxygen isotope data is that carbonate oxygen represents a mixture of oxygens from these two sources and/or the melt water has been enriched in ^{18}O due to evaporation.

We obtained 8 ^{14}C values for 7 Allan Hills meteorites, which had terrestrial ages ranging from 10 to 820 kA. These results are expressed in terms of percent modern (1950 AD) carbon ($^{14}C/^{12}C = 1.17 \times 10^{-12}$), and radio-carbon age (BP [6]). The ^{14}C data along with petrologic type, weathering class and terrestrial ages are shown in Table 1. The ^{14}C contents are markedly higher than the maximum cosmogenic ^{14}C activity (4% modern) which could be induced by recent irradiation of carbonate in space. Given the long terrestrial ages of 4 of the samples, all cosmogenic ^{14}C will have decayed. No apparent correlation between petrologic type or weathering class and carbonate ^{14}C content was observed. Carbonate from ALHA-77262 contains bomb ^{14}C, which indicates the carbonate has formed in the last 30 years. Another sample, ALHA-77294, has close to modern ^{14}C. There are two simple interpretations of the ^{14}C results. The first is that the carbonates formed as the meteorite sat on the surface of the ice and behaved as a closed system. In this case the ^{14}C would give an indication of the "weathering age" [10, 11], i.e. the time since the meteorite has been exposed on the ice surface. A second and

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more plausible interpretation is that either the extracted CO_2 represents several generations of carbonate of different age, or that the carbonates have requilibrated with atmospheric CO_2 after formation. In this case the radiocarbon age gives a lower limit to the age of the carbonates. The continuing formation of carbonate on LEW-85320 after recovery supports this view of an open system [1, 2].

Conclusion. Radiocarbon measurements of bulk carbonates from 7 ordinary chondrites demonstrate that a large portion of the carbonates are either recent terrestrial weathering products or they have undergone continuing exchange with atmospheric CO_2. The most significant finding of this work is that rapid growth of carbonate weathering products is probably a widespread phenomena in Antarctic meteorites and that LEW-85320 is not just an isolated case.

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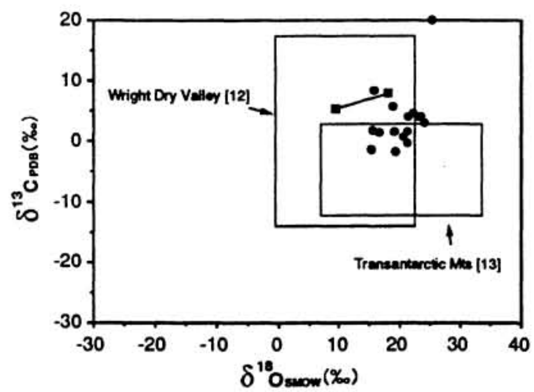

Figure 1. C-13 vs O-18 in some Antarctic carbonates. Circles: ordinary chondrites (this study). Squares: nesquehonite [1, 2]. Fields delinate terrestrial Antarctic carbonates.

Table 1. ^{14}C of bulk carbonates in antarctic ordinary chondrites

Sample*	Type	Weathering	^{14}C (% modern)	^{14}C Age	T_{terr} (kA)§
ALHA-77002,51 II	L6	B	14.4±6.1	15,000±3,400	820±80
ALHA-77182,41 II	H5	B	87.7±7.4	1,060±700	250±80
ALHA-77214,28 II	L3	C	74.5±3.1	2,325±335	120±80
ALHA-77262,47 I	H4	B/C	102.9±1.3	post 1950 AD	18±1
ALHA-77294,60 I	H5	A	98.3±2.5	135±200	10±1
ALHA-77299,28 I	L6	B	63.6±1.6	3,640±125	80±80
ALHA-77299,28 II	L6	B	61.8±3.2	3,870±260	80±80
ALHA-79033,13 I	L6	B	68.1±3.3	3,065±270	110±70

* Roman numerals refer to extraction number.
§ See reference [3].

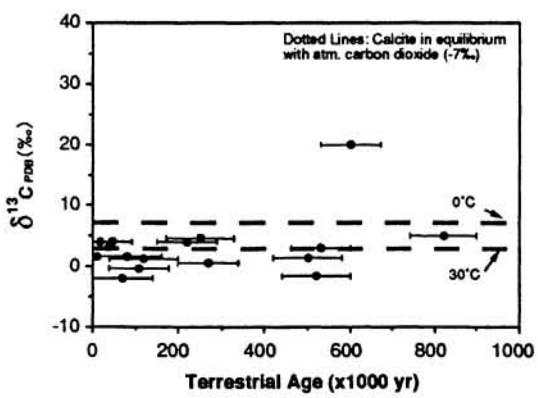

Figure 2. C-13 vs terrestrial age in bulk carbonate from Antarctic ordinary chondrites.

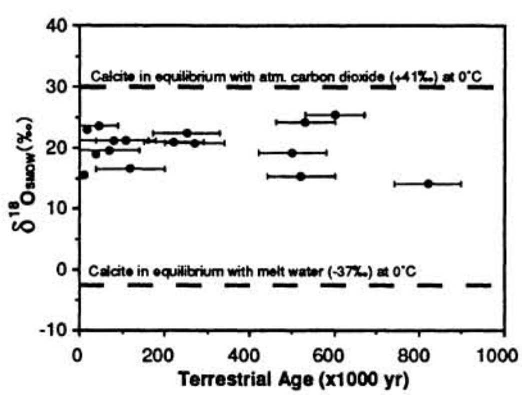

Figure 3. O-18 vs terrestrial age in bulk carbonate from Antarctic ordinary chondrites.