NOBLE GAS, $^{26}$Al, $^{10}$Be, AND $^{14}$C CONCENTRATIONS AND TRACK DENSITIES
OF BUR GHELUALI: EVIDENCE FOR A TWO-STAGE EXPOSURE HISTORY; R. Wieler
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Meteorites that have short conventional exposure ages and show signs of brecciation
may be especially good places to search for evidence for multi-stage irradiations [1]. Bur GHELUALI,
an H5 fall, is a meteorite of this kind. Aylmer et al. [2] presented the $^{26}$Al and $^{10}$Be
concentrations of 7 samples from Bur GHELUALI. The variations, >50% for each isotope, proved
that the meteoroid was large - at least 50 cm in radius - but left open the possibility of a
two-stage irradiation. To learn more about the exposure history we re-sampled at the Museo
di Mineralogia, Univ. Roma 6 specimens analyzed previously [2] and obtained material from
two others. Table 1 gives results for cosmogenic noble gases and for $^{14}$C, $^{26}$Al, and $^{10}$Be.
The various experimental methods used are described in references [3-7].

Noble gases - 1) The cosmogenic $^{21}$Ne concentrations ($10^{-8}$ cm$^3$ STP/g) of the 8 samples
range from 0.24 in T6 to 0.72 in T4, nearly a factor of three; the $^{3}$He and $^{38}$Ar$_c$
concentrations vary by a factor of two. Confirmed variations of this magnitude are rare for
stone meteorites. 2) The sample with the lowest $^{21}$Ne content, T6, has a $^{22}$Ne/$^{21}$Ne ratio ($R$
) consistent with just a few cm of shielding; $R$ in the other 7 samples is consistent with
shielding depths of 20 cm or so. While we would expect near-surface samples to have
somewhat lower production rates ($P$), a threefold increase in $P_{21}$ from surface to interior
cannot be explained by current models of a one-stage irradiation [e.g., 8,9]. 3) We have not
so far found solar gases in Bur GHELUALI. A few samples have $^{20}$Ne/$^{22}$Ne ratios as high as 2.5,
but these values probably reflect minor contamination of the gas extraction system. Our
search for solar gas will continue in samples with light-dark structure.

Tracks - Olivine crystals in sample T6 have a GCR track density of $(4.9\pm1.0)\times10^4$ tr/cm$^2$.
From this result and various estimates of meteoroid size and exposure age we infer a
shielding depth for T6 of 5-6 cm (see [10]); a correction for the different track recording
efficiencies of olivines and pyroxenes has been included. A depth of 5-6 cm is also deduced
from the $^{22}$Ne/$^{21}$Ne ratio [8] assuming a one-stage exposure. Tracks and noble gases together
suggest that T6 acquired all or most of its cosmogenic noble gases during its last exposure
stage. Sample T4 is essentially devoid of tracks, implying a shielding depth of > 20 cm.

$^{26}$Al and $^{10}$Be - The new determinations generally agree well with the old. The $^{10}$Be and
$^{26}$Al activities increase by about 50% overall, from 6 to 9 and 27 to 38 dpm/kg, respectively;
both activities correlate with the $^{21}$Ne concentrations as one might expect if shielding were
responsible. Best-fit lines show, however, that the relative increase in $^{21}$Ne is substantially
larger than that for either $^{26}$Al or $^{10}$Be (Fig. 1). This observation contradicts our expectation
for a one-stage irradiation: $P_{10}/P_{21}$ is nearly constant in chondrites of various size [8A];
according to model calculations [8,9], both $P_{10}/P_{21}$ and $P_{26}/P_{21}$ vary much less than our
observed $^{10}$Be/$^{21}$Ne and $^{26}$Al/$^{21}$Ne ratios.

$^{14}$C - The average value of $P_{14}$ for a chondrite is about 44 dpm/kg [11]. The observed $^{14}$C
activities range from about 20 to 30 dpm/kg. As $P_{14}$ should behave similarly to $P_{21}$ [9,12],
the structure shown in Figure 1 suggests that Bur GHELUALI must have undergone irradiation in
two or more stages, consistent with the conclusion reached above from the noble gas data.

DISCUSSION - For simplicity we will assume a two-stage exposure with spherical geometry.
These assumptions and our track and $^{21}$Ne data then require that Bur GHELUALI's second stage
lasted long enough to saturate $^{14}$C. The observed range of $^{14}$C activities suggests that the
meteoroid's radius (R) during the second stage lay between ~150 and 500 cm.
EXPOSURE HISTORY OF BUR GHELUAII: Wieler, R. et al.

Table 1. Cosmogenic nuclide concentrations in Bur Gheluai.

<table>
<thead>
<tr>
<th>Sample</th>
<th>3He</th>
<th>21Ne</th>
<th>22/21c</th>
<th>38Ar</th>
<th>14C</th>
<th>26Al</th>
<th>10Be</th>
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<tbody>
<tr>
<td>T1</td>
<td>1.27</td>
<td>0.393</td>
<td>1.082</td>
<td>0.046</td>
<td>31.06</td>
<td>6.76</td>
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<tr>
<td>T2</td>
<td>0.945</td>
<td>0.335</td>
<td>0.044</td>
<td>32.06</td>
<td>7.06</td>
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<tr>
<td>T3</td>
<td>2.04</td>
<td>0.624</td>
<td>0.072</td>
<td>22.2±0.7</td>
<td>27.4</td>
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<tr>
<td>T4</td>
<td>2.05</td>
<td>0.631</td>
<td>0.071</td>
<td>21.5±0.7</td>
<td>31.06</td>
<td>7.36</td>
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<tr>
<td>T5</td>
<td>2.23</td>
<td>0.674</td>
<td>0.083</td>
<td>9.4</td>
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<tr>
<td>T6</td>
<td>2.25</td>
<td>0.683</td>
<td>0.080</td>
<td>37.68</td>
<td>8.96</td>
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<td>T7</td>
<td>1.37</td>
<td>0.502</td>
<td>29.3±0.8</td>
<td>27.9</td>
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<td>N778</td>
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<td>0.054</td>
<td>28.66</td>
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<tr>
<td>Z</td>
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<td>0.233</td>
<td>19.5±1.4</td>
<td>25.1</td>
<td>6.4</td>
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<td>1.22</td>
<td>0.239</td>
<td>1.142</td>
<td>0.035</td>
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<tr>
<td></td>
<td>1.96</td>
<td>0.603</td>
<td>0.071</td>
<td>31.2±0.8</td>
<td>30.7</td>
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<td>0.072</td>
<td>21.66</td>
<td>4.76</td>
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</table>

Notes: 1) Gas concentrations in 10^{-8} cm^3 STP/g; 1-σ error = 4%. Radionuclides in dpm/kg; 1-σ error for 26Al and 10Be = 8%. 2) Typical masses for gas analysis, 200 mg; for cosmogenic nuclides, 100 mg. 3) 21Ne/22Ne because trapped gas corrections are small. 4) Reported only when uncertainty introduced by unknown composition of trapped component is less than 0.4% (less than 1% for values in parentheses). 5) 38Ar=c=calculated with canonical (36/38)=0.65. 6) Ref. 2. 7) T2 contained fusion crust; low 3He/21Ne probably indicates 3He loss.

The 21Ne and 14C concentrations of the sample T6 may place an upper limit on t_2. With P_21 calculated as (14C/P_21) x (P_21) = 44 dpm/kg [11]; P_21 = 0.33/Ma [13]) we obtain t_2 < 1.6 Ma. The model of [8] gives t_2 < 1.4-1.7 Ma for 150 < R_2 < 500 cm. Turning now to the first stage, T4 has the highest 21Ne content but a 14C content approximately equal to that of T6. Accordingly, if T4 and T6 have equal 21Ne contributions from the second stage, then T4 would have > 0.48 units of 21Ne from the first stage. According [8], t_1 should exceed 3 Ma.

In summary, Bur Gheluai experienced a two- (or multi-) stage exposure. The short duration of our model second stage implies that the concentrations of 26Al and 10Be "remember" the first irradiation. This result underscores the need for care in selecting the meteorites used to deduce noble gas production rates from cosmogenic radionuclide data [1].