THE HOLBROOK METEORITE- 99 YEARS OUT IN THE WEATHER.

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The Holbrook Fall and sample recovery: At 7:15pm on the evening of 19th July 1912, a bright fireball appeared in the sky above Navajo County, Arizona [1]. After several loud detonations, approximately 16,000 mostly pea-sized stones fell near the Arntz siding of the Santa Fe Railroad, 7 miles from the town of Holbrook. A search orchestrated by W.M.Foote resulted in nearly 220 kg of material being recovered; samples were exchanged with a great many of the World's Museums [2].

In 1931 Harvey Nininger revisited the site and was able to find another 23 kg that had originally been missed [3]. One of us (EKG) returned again in 1968 and found a further ca 1.5 kg specimen [4]. Meteorite hunters have been going back to Holbrook ever since in the hope of more finds. For example in 2001 a group of 45 searchers accumulated 440 g of previously overlooked L6 group meteorite fragments. In 2011, the 99th anniversary of the event, Rubin Garcia located 11 minimeteorites [5].

Meteorite weathering: It is well established that meteorite weathering causes the loss of various trace elements due to leaching by water; noble gases, for example, can be liberated and thus depleted [6, 7]. Iron metal and sulphides in chondrites can be oxidised and primary silicate minerals degraded to their secondary clay-like counter-parts, resulting in meteorites being almost totally destroyed on a relatively short timescale [8]. The mineral changes that occur are accompanied by small variations in the iron isotopic composition [9]. It is also known that the primary oxygen isotope compositions of various meteorite groups are significantly disturbed by the addition of oxygen during terrestrial weathering [e.g.10].

Samples studied: Since oxygen isotopes can be measured very precisely [11], on small samples, herein we investigate samples of the Holbrook meteorite collected over a well defined period, in a relatively stable climatic environment, to establish whether the changes are time dependent and thus could provide a short duration chronological scale. Secondarily, the results could provide information relevant to the storage and preservation of meteorites since their collection, assist with pairing specimens and may help to frustrate attempts to pass off samples from well known falls and multiple recoveries as new 'finds'.

Methods: We have studied four samples of Holbrook collected over a 99 year period: a specimen acquired by Foote immediately following the fall, one from the Nininger 1930s investigation, a fragment from the Gibson stone found in 1968 and finally a pebble kindly donated by Rubin Garcia from his collection made during the 99th anniversary field trip. Visual inspection suggests an increase in the degree of weathering with time. All the samples were analysed in triplicate (2 mg aliquots taken from a 100 mg crushed specimen) with a MAT 253 mass spectrometer using an infrared laser system to release oxygen by reaction with BrF_5 [11].

Results and discussion: The results (Table) are quoted as $\delta^{18}O$, $\delta^{17}O$ and $\Delta^{17}O$ values against V_{SMOW} and shown as two figures (1) $\delta^{18}O$ vs $\delta^{17}O$ and (2) $\delta^{18}O$ vs date of collection. As can be seen from Fig 1 all the specimens would be recognised as chondritic meteorites and classified as L type irrespective of the date of collection and degree of weathering. The data (Table) measured for the 1912 sample collected soon after the fall shows the smallest spread indicating that it could be nearest to homogeneous i.e. weathering had not begun to any large extent. Fig 1 also reveals that the $\delta^{18}O$ measurements for the samples are trending towards higher values with time spent exposed in the environment. The trend however is best illustrated in Fig 2, the plot of $\delta^{18}O$ vs date of collection; the two parameters for the time interval to 1968 have a straight line correlation factor of $R = 0.9987$ showing that the addition of oxygen during weathering is almost directly time dependent. After 1968 the straight line tends to curve downwards, i.e. flatten out, suggesting that weathering is nearing completion, with only the slower reactions, such as alteration of the silicate minerals, still taking place [8].

In a previous study Bland et al. (2000) concluded that for L type chondrites weathering takes place without a pronounced oxygen isotope effect [12]. However, these new data, from a tightly controlled set of samples, suggest that not only is there a measurable $\delta^{18}O$ shift associated with terrestrial weathering, but that it takes place very rapidly over a human lifetime.

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Table 1

SAMPLE	$\delta^{17}O$‰	1σ	$\delta^{18}O$‰	1σ	$\Delta^{17}O$‰	1σ
Holbrook 1912	3.66	0.02	4.69	0.03	1.22	0.01
Holbrook 1931	3.67	0.06	4.84	0.09	1.15	0.02
Holbrook 1968	3.83	0.03	5.09	0.06	1.19	0.01
Holbrook 2011	3.89	0.03	5.24	0.03	1.16	0.01

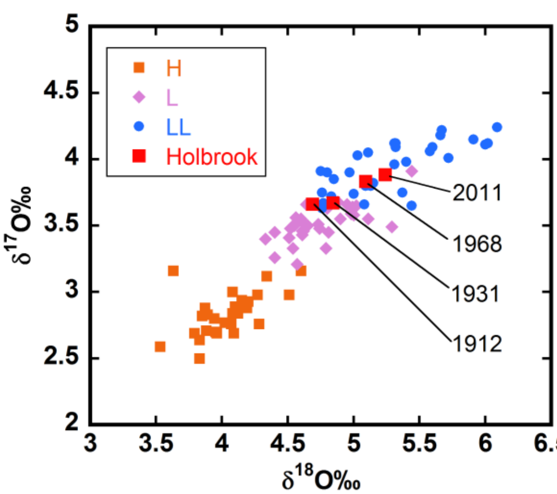

Fig. 1 Oxygen isotope composition of Holbrook meteorite samples shown in relation to the ordinary chondrite data of [13].

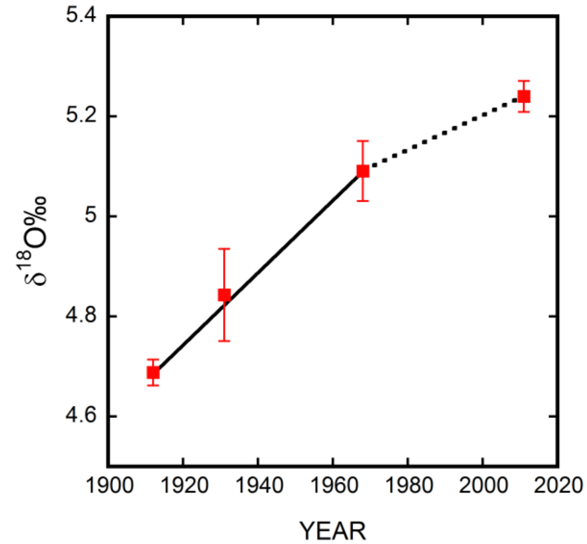

Fig.2 $\delta^{18}O$ vs. date of sample recovery.