Abundance and Composition of K and Ca Bearing Minerals in Ordinary Chondrites and their Application to Ar-Ar Dating.

J. R. Weirich[1] and T. S. Swindle[1], [1] University of Arizona, Tucson AZ 85721.

Introduction: The Ar-Ar dating technique is primarily used to measure the last heating event a rock experienced. In the case of ordinary chondrites, this is often the last large impact. The source of ^{40}Ar is natural radioactive decay of K. Neutron irradiation of a sample produces ^{39}Ar and ^{37}Ar from K and Ca, respectively. The age of the sample can then be determined from the $^{40}Ar/^{39}Ar$ ratio, and the K/Ca ratio of the outgassing mineral from the $^{39}Ar/^{37}Ar$ ratio. Thus far, no study has conclusively determined the mineral host(s) of K. The mineral host is not needed to determine the age; however, knowing the host phase(s) can aid in the interpretation of that age.

Bogard et al. [1] attempted to identify the source of ^{39}Ar in Chico, an L6 impact melt breccia. They found two K/Ca ratios in the released gas of the unmelted portion of the chondrite. The low temperature steps have a K/Ca ratio of 0.3-0.45, and the high temperature steps have a K/Ca ratio of about 0.04. While the K/Ca ratio of a mineral is necessary for identification, the abundance of the mineral is also needed to ensure that the amount of Ar released will be significant. In order to identify the source of these two releases, we used an electron microprobe to perform a mass balance study of K and Ca in Payson and Wagon Mound, both of which are H6 S2. Although we are interested in the Ar/Ar system in highly shocked chondrites, low shock chondrites were chosen because their history is simpler and the K/Ca release patterns are often similar between shock classifications (e.g., Fig 1). In addition, low shock chondrites will provide a base for interpreting the highly shocked chondrites.

Since most Ca bearing minerals have been studied extensively, the composition and abundance of these minerals is well understood. However, feldspar (which has both K and Ca) has been studied very little due to its fine grained nature. Therefore, we have performed microprobe work to characterize the feldspar. We confirm the composition reported in [2]. Probably because of feldspar's fine grained nature, reported modal abundances are typically much lower than the norm calculation of about 10% [2]. We have performed a more accurate analysis of modal abundance and confirm the norm calculation.

Microprobe Analyses: In order to find all traces of K and Ca, we made maps of Na, Mg, Al, Si, K, and Ca. Twenty of these maps were distributed evenly over one thin section each for Payson and Wagon Mound. Each map covered an area of 250x250 μm. The maps were created using 512x512 pixel maps at 15kV and 100nA, analyzed for 2ms per pixel. While the current was very high, the short duration ensured no evaporation of volatile elements occurred. After the maps were completed, spot analyses of 1μm in size were performed on each of the minerals. For the spot analyses on Payson, the microprobe was operated at 15kV and 20 nA, with a 20s duration for each element. Spot analyses on Wagon Mound were performed with two different conditions, 15kV and 4 nA for Na and K, and 15Kv and 20nA for all other elements. The duration was still 20s for each element.

Since feldspar has not been very well studied, many spot analyses spread over the entire meteorite were taken for both Payson and Wagon Mound. Since many of the totals in feldspar were far from 100%, only about 10 analyses from each meteorite were used to determine the average K and Ca wt% in feldspar. All of these analyses had totals in the range 98-102%. For diopside, 7 analyses were used for the average Ca wt%, and for all other minerals the average Ca wt% was taken from 2 or 3 analyses.

In addition, the modal abundance of feldspar was determined by analyzing the maps in Photoshop. Three elements at a time were combined into a single image by putting a different element into each of the RGB channels (sample image shown in Figure 2). All pixels that had the same color were counted, and the result was divided by the total number of pixels. The result was a point count analysis of about five million counts.

Microprobe Results: The only K bearing mineral found was compositionally uniform albite. The average feldspar compositions for Payson were K = 0.72±0.23 wt% and Ca = 1.51±0.05 wt%, while for Wagon Mound they were K = 0.94±0.20 wt% and Ca = 1.51±0.05 wt%. Error bars are one standard deviation. Most of the variability in K was probably due to totals above or below 100%, and a smaller amount due to actual variability in the meteorite. This corresponds to a normative composition of $Ab_{84}An_{11}Or_5$ for Payson and $Ab_{82}An_{11}Or_7$ for Wagon Mound. The modal abundance of feldspar was 12.0% for Payson and 8.7% for Wagon Mound, giving an average of 10.4%.

The other Ca bearing minerals (which contained no measurable K) are diopside (Ca=15.7±0.2 wt%), orthopyroxene (Ca=0.46±0.06 wt%), olivine (Ca= 0.07±0.03 wt%), and apatite. Since the microprobe was not calibrated for phosphorous, the apatite composition could not be measured accurately. However, based upon the chemical formula, Ca ≈ 39 wt%.

Mass Balance and Implications: Table 1 has the K and Ca we measured, as well as the modal abundances of each mineral. The resulting K and Ca abundances for the whole meteorite from each mineral is also shown. Since there is only one mineral bearing significant amounts of K, it *must* be outgassing at both the low and high temperature steps. If the meteorite shown in Table 1 had 55% of the feldspar outgas at low temperature, while the other 45% outgassed at high temperature simultaneously with the other Ca bearing minerals, the result would look like Figure 1. To compare with other low shock H chondrites, actual data from Kernouve [4], an H6 S1, is also shown in Figure 1. While it is not an exact match, this line of reasoning is promising.

One scenario that could cause two temperature releases of the feldspar is that the high temperature steps are a combination of crystalline feldspar and other Ca bearing minerals, while the low temperature steps are shock-deformed feldspar, which may allow Ar to escape more easily. However, Kernouve is only an S1, and hence should not have ~50% of its feldspar disrupted [7]. Another scenario is that the low temperature steps are due to feldspar by itself, while the high temperature steps are due to feldspar grains totally enclosed in pyroxene and hence *forced* to outgas simultaneously. Many times feldspar is associated with pyroxene, as can be seen in Figure 1, but it is doubtful whether 50% would be totally enclosed. Further, any crack penetrating to the feldspar would allow it to outgas as feldspar.

Both of these scenarios need to be investigated further, but the similarity of the idealized meteorite and Kernouve seen in Figure 1, and the lack of other sources of K, suggest some mechanism is causing the feldspar to outgas at two separate temperatures.

References: [1] Bogard D. D. et al. (1995) *Geochim. Cosmochim. Acta, 59,* 1383–1399. [2] Van Schmus W. R. et al. (1968) *Geochim. Cosmochim. Acta, 32,* 1327–1342. [3] Dodd R. T. (1981) Meteorites. [4] Turner G. et al. (1978) *Proc. LPSC IX,* 989–1025. [5] McDougall I. and Harrison T. M. (1999) Geochronology and Thermochronology by the ^{40}Ar/^{39}Ar Method. [6] Grier J. A. et al. (2004) *Meteoritics & Planet. Sci., 39,* 1475–1493. [7] Stoffler D. et al. (1991) *Geochim. Cosmochim. Acta, 55,* 3845–3867.

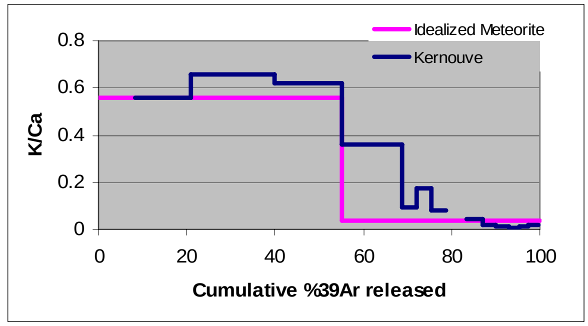

Figure 1. K/Ca ratios as a function of cumulative release for Kernouve [4] and the idealized meteorite shown in Table 1. **Note:** Since irradiation correction factors were not known for Kernouve, total K and Ca was scaled to match the idealized meteorite in Table 1.

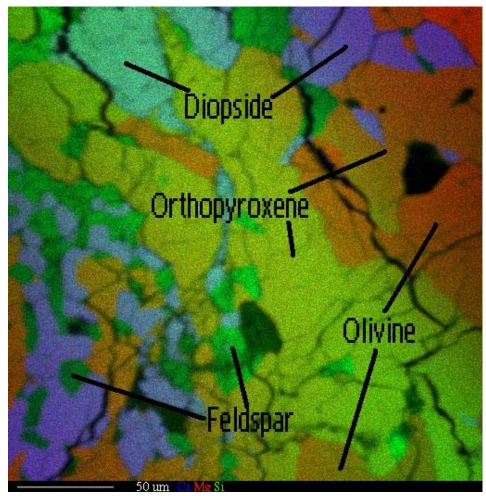

Figure 2. Microprobe map of Wagon Mound. Major minerals are labeled. **Note:** Due to limitations of probe, colors at the upper right and lower left are darkened.

Mineral	**K wt%**	**Modal Abund%**	**Total wt%**
Feldspar	0.83	10.4	0.086
Mineral	**Ca wt%**	**Modal Abund%**	**Total wt%**
Diopside	15.70	*4.00	0.628
Apatite	39.00	*0.60	0.234
Feldspar	1.51	10.4	0.157
Orthopyroxene	0.46	*24.5	0.113
Olivine	0.07	*36.2	0.025
	Total Ca wt%		1.157

Table 1. K and Ca mineral wt% and modal abundance for an ideal H6 chondrite. *From [3]. All other data from this paper.