ARGON DIFFUSION IN PYROXENE AND ALBITE. J. R. Weirich[1], C. E. Isachsen[2], J. R. Johnson[3], and T. D. Swindle[1]. [1]University of Arizona, 1629 E. University Blvd, Tucson AZ, 85721, [2]University of Arizona, 1040 E 4th St, Tucson AZ, 85721, [3]U.S. Geological Survey, 2255 N. Gemini Dr., Flagstaff AZ, 86001.

Abstract: Shock greatly raises the diffusivity of albite, and also explains why meteorites often have low activation energies. Unshocked pyroxene cannot explain the high temperature release of argon in meteorites, though shocked pyroxene is a possibility.

Introduction: Ar-Ar dating (a variation of K-Ar dating) has been a very useful tool for reconstructing the impact history of the asteroid belt. Because Ar is extracted via step-wise temperature heating, diffusion information is collected in tandem. For some time now, it has been known that L-chondrites have two major temperature releases of Ar [1,2]. While the lower temperature release is almost certainly Na-rich feldspar or albitic glass, the high temperature release has proven elusive. What is known is that shock seems to convert the low temperature release into the high temperature release [1,2]. Possible mechanisms include incorporation of K into pyroxene (Pyx) or Ca-rich feldspar [1], a change of diffusion distance from grain size to melt vein width [2], and enclosure of feldspar in pyroxene or olivine [3]. In addition to L-chondrites, many other meteorite types have poorly understood Ar release patterns.

To help study the effects of chemistry and shock, we are measuring the Ar diffusion parameters of albite (Ab), anorthosite (An), and pyroxene as a function of shock pressure. Additionally, we will measure the diffusion parameters of unshocked high-Ca pyroxene. A similar study has already been performed on anorthosite [4], but their analysis was on feldspar of a higher Ca content, lower maximum shock pressure, and was done with lower resolution (fewer temperature steps). Knowing the diffusion parameters of major meteoritic minerals as a function of shock pressure will greatly aid in interpreting Ar release patterns of meteorites.

Procedures: Samples were wrapped in Al-foil, irradiated at USGS-Denver for 30 hours (J factor of ~7.0e-3), and analyzed on a VG5400 at the University of Arizona. Corrections are made for blanks and decay. Because most samples have very low K content, Ca derived ^{37}Ar was used instead of ^{39}Ar.

The diffusion equation as a function of temperature is, $\dfrac{D}{a^2} = \dfrac{D_0}{a^2} \bullet e^{\frac{E}{RT}}$, where E is the activation energy, D_0 is the pre-exponential factor, T is the temperature, "a" is the grain size, and R is the gas constant. When plotted as Log (D/a^2) vs. 1/T, this equation will form a straight line whose slope is proportional to E and whose intercept is Log (D_0/a^2). Because grain size is often not known in a sample, E is usually a much better discriminator between structural or chemical domains. Duplicate temperature steps were frequently used to make sure multiple grain size domains were not outgassing simultaneously, and diffusion parameters were measured via the method developed by [5].

Samples: Samples of albite (Ab) [6], anorthite (An33-40) [7], and Pyx [8] were previously acquired by one of us (J.R.J.), shocked to various pressures (up to 55.8-60 GPa, depending on sample), and analyzed for changes in thermal infrared spectra [9,10]. Samples were crushed to create homogeneity, and for Ar analysis, washed and sieved to help reduce any effects of multiple grain sizes. Additionally, the Pyx was cleaned via a Frantz magnetic separator to reduce any influence from feldspar. A small amount of high-Ca Pyx is present in all Pyx samples, and currently it is not known if the major carrier of Ca is high-Ca Pyx or low-Ca Pyx. To differentiate the two, high-Ca Pyx was picked from an unused and unshocked portion, and will be run separately.

Preliminary Results: At this time, only Pyx shocked to 0GPa and 60Gpa, and Ab shocked to 0Gpa and 55.8GPa have been analyzed. Diffusion parameters for all samples can be found in Table 1.


Fig. 1

Pyx 75-150 μm
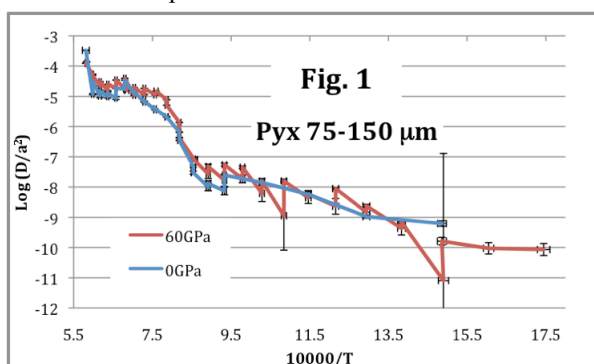
Pyroxene. Despite the magnetic separation, a small amount of feldspar (identified by the ^{39}Ar/^{37}Ar ratio) was still present in the Pyx samples. While the feldspar dominates the ^{37}Ar released below ~950°C, it only makes up about 6% of the total ^{37}Ar. Splitting the gas into feldspar and pyroxene release for data reduction has very little effect on the diffusion parameters, and is not reported here.

The unshocked Pyx has a very distinct linear trend from about 1000 to 1200°C. Higher temperature steps

are flat, and in this regime most steps taken at the same temperature do not agree with one another to within 2σ, most likely indicating multiple grain sizes. No higher temperature linear portion is observed.

The 60GPa shocked Pyx has grossly similar diffusion properties, but the extended linear trend above 900°C has almost disappeared. Analysis does identify a line in the same temperature regime, which is statistically significant given the errors, but only if we ignore some of the duplicate temperature steps. The duplicate steps which are ignored for the fit are located at the endpoints of the linear portion, and could just represent the first or last bit of gas from a different domain, so ignoring them could be warrented. However, since we do not know this for certain, it makes the fit questionable. A second linear portion can be identified at higher tempeature, with the same caveats. While these measurements are non-ideal, they do give the same E to within 1σ. However, the difference between the intercepts is larger than would be expected given the range in grain size, giving a mixed story at best. More splits of the 60Gpa shocked Pyx will be run with a higher temperature resolution to see if these two linear trends are real.

Fig. 2
Ab 38-75 μm
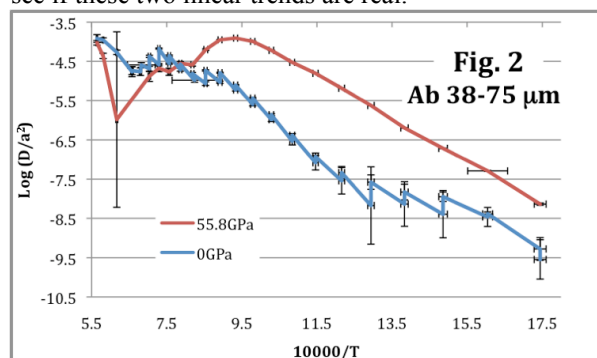
Albite. Unshocked Ab also has contamination at low temperatures (<550°C), possibly from amphibole. Again, this has little effect on the diffusion parameters since it releases only 2.5% of the total ^{37}Ar. A linear portion is observed from about 550 to 800°C. A second linear portion may be present from about 950 to 1050 or 1100°C, with about the same slope as the lower temperature linear portion, but it is difficult to tell with the small number of points available. The difference in D_0/a^2 is about what one would expect for a factor of 2 difference in grain size, which is to be expected given the range of sieves used.

The 55.8Gpa shocked Ab sample was not run with duplicate temperature steps, but nonetheless produces a very stable linear trend over much of the release, and is significantly different from the unshocked sample. The lack of contamination at low temperature is sur-

prising, but not inconceivable since the amphibole is heterogeneously distributed in the host rock [6].

Sample	Press. (GPa)	T range (°C)	E (kcal/mole)	Log D_0/a^2 (1/s)
Pyx	0	1000-1100	40.7 (2.5)	1.31 (0.41)
Pyx*	60	950-1050	88.7 (10.0)	10.0 (1.7)
Pyx*	60	1350-1450	95.5 (8.3)	8.2 (1.1)
Ab	0	550-700	39.2 (2.8)	2.89 (0.69)
Ab	55.8	300-700	25.21 (0.4)	1.43 (0.13)
Table 1. *Indicates a questionable fit				

Discussion: Shock has obviously changed the diffusion parameters of Ab, lowering E from ~40 to ~25 kcal/mole. This explains why many shocked meteorites exhibit an E lower than their suggested terrestrial mineral counterparts [1]. Intermediate shock pressure samples will be analyzed to determine if this transition is gradual or sudden, and whether it corresponds with the transition from feldspar to maskelynite.

While it is too early to confirm, preliminary results suggest that shocked Pyx could indeed be the cause for the high temperature release in shocked meteorites, which often have E>60 kcal/mole. However, at this time we cannot distinguish between K incorporated into the pyroxene structure and feldspar inclusions that are forced to outgas in tandem with the pyroxene. Additionally, these results indicate that unshocked pyroxene cannot explain any temperature releases that have a high E.

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