The shock effects and $^{40}\text{Ar}/^{39}\text{Ar}$ ages have been determined for a suite of crystalline clasts from the suevite breccia of the 24 km diameter impact structure at Ries, Germany. The purpose of these studies is to determine the effect of various shock levels on the retention of radiogenic $^{40}\text{Ar}$. The $^{40}\text{Ar}/^{39}\text{Ar}$ technique is commonly used to deduce the times of strong thermal events in a variety of samples, including shocked chondritic meteorites and lunar rocks. An inference made in dating many of these materials is that the time of the thermal event often can be determined when gas loss is partial rather than complete. Different degrees of Ar degassing are expected from some shocked materials because various fractional volumes of crater ejecta suffer different PT conditions spanning from whole rock melts to essentially unshocked species. The degree of degassing of Ar as a function of shock intensity in materials from a major impact is not well known, but may be fundamental to the dating of such structures. The Ries impact structure offers a useful system to study K-Ar ages as a function of shock intensity because the time of the impact (14.7 ± 0.7 My) is known from dating of impact glasses (1) and because the granitic basement rock of the Ries is of Variscian age, i.e., ∼ 300 My old. Recent studies by Jessberger et al. (2) showed no significant loss of $^{40}\text{Ar}$ from biotite, hornblende, and chlorite mineral separates made from several samples of ejecta, fall-back breccias, and brecciated bedrock recovered from a drill hole in the Ries Crater. The optically determined shock pressures of samples analyzed by (2) ranged from < 10 kbar up to 450 kbar. Except for melted glasses, the plateau ages reported by (2) were all 302 to 317 My and the percent $^{40}\text{Ar}$ losses (relative to the plateau ages) were all 0.5 to 20%.

We have made $^{40}\text{Ar}/^{39}\text{Ar}$ analyses of five whole-rock, granitic clasts from the Otting and Aumühle suevite quarries, which are located ∼ 3 km outside and 0.5 km inside the crater rim, respectively. Jessberger et al. (2) also reported on samples from Otting. Our samples were selected to span a range of shock intensities, which were determined via optical microscope and X-ray analyses. The latter technique yields a better estimate of the average shock pressure experienced by all component minerals. The pressures determined are given in the individual figures and are: Otting 604, ∼ 95 Kb; Otting 680, ∼ 450 Kb; Otting glass, > 600 Kb; Aumühle 174, ∼ 280 Kb; Aumühle 156, ∼ 350 Kb.

Otting 604, with the lowest determined shock pressure, contained very little atmospheric Ar, which permits us to show its argon data as a $^{40}\text{Ar}/^{39}\text{Ar}$ plateau plot (Fig. 1). Its plateau age of ∼ 292 My is similar to its total K-Ar age of ∼ 285 My and demonstrates that this sample lost very little Ar due to the impact. The other four samples contained significant amounts of atmospheric Ar. We have chosen to present their Ar data as $^{40}\text{Ar}/^{36}\text{Ar}$ versus $^{39}\text{Ar}/^{36}\text{Ar}$ isochron plots in which the slope of any linear correlation of data from stepwise temperature releases is proportional to a K-Ar age. Otting 680 shows loss of most of its radiogenic $^{40}\text{Ar}$ (Fig. 2). The 300° and 400° extractions released 51% of the $^{39}\text{Ar}$ and define an age of ∼ 14.4 My. Higher temperature data show a slightly larger, average age of ∼ 20 My. If we accept that Otting 680 had an original age of ∼ 300 My and was degassed by the Ries impact 14.7 My ago, it lost more than 99% of its radiogenic $^{40}\text{Ar}$ at that time.

Argon data for four temperature extractions of Otting glass are shown in Figure 3. Extractions between 500° and 1100°C showed no atmospheric argon and their measured $^{40}\text{Ar}/^{39}\text{Ar}$ ratios all fall within the dashed zone of the
figure, i.e., between apparent ages of ~18 and 20 My. Only the 420°C extraction, with ~3% of the 39Ar released, shows a lower age of ~14 My. Like Otting 680, the Otting glass has apparently been more than 99%, but not completely degassed of 40Ar. This may be due to the presence of weakly shocked mineral clasts in the glass. The 40Ar/36Ar intercept of ~450 is significantly higher than the atmospheric value (e.g., see Fig. 2) and suggests that inherited radiogenic 40Ar was mixed with atmospheric Ar and retained during melting and cooling of the glass.

Extractions from 250° through 1150°C of sample Aumühle 174 define an isochron of ~20 My (Fig. 4). The 1350°C datum (5% of the 39Ar released) falls significantly above this isochron. Assuming no atmospheric Ar, the maximum age which can be calculated for this extraction is 38 My. The Aumühle 156 sample shows the most complex Ar data (Fig. 5). The 300° and 450°C extractions contain 50% of the 39Ar released and define a 19 My isochron. Extractions from 525° through 1100°C approximately lie on an isochron of ~27 My. The 1350° and 1500°C extractions define a maximum age (assuming no air Ar) of 72 My. The 39Ar temperature release profiles and the K/Ca ratios of both Aumühle samples suggest a contribution from three different mineral phases. The highest temperature releases in both Aumühle samples show lower K/Ca ratios and indicate higher 40Ar/39Ar ages compared to the rest of the samples. We speculate that a specific mineral phase in these samples contains ~5 to 10% of the K, has a higher activation energy for Ar diffusion, and was less completely degassed by the Ries impact. Analogous conclusions for shock-degassed chondrites was made by (3). Both Aumühle samples have apparently been degassed of ~99% of their 40Ar (assuming a pre-impact age of 300 My).

These data demonstrate that some shocked materials ejected by the Ries impact have been nearly completely degassed of 40Ar. Additional petrographic investigations are planned to evaluate cratering-related, thermal histories of these clasts. For example, magnetic determinations of many suevite samples suggest that all were heated above the Curie point of magnetite, or above 500°C (4). Such heating places constraints on the cooling history of the ejecta, as Otting 680 and Otting 604 are from the same ejecta mass but have experienced quite different cooling histories judging from relative loss of 39Ar.

References:
Figures 1-5 (clockwise from lower left). $^{40}\text{Ar}/^{39}\text{Ar}$ age profile for Otting 604 ($\sim 95$ Kb); $^{40}\text{Ar}/^{36}\text{Ar}$ vs. $^{39}\text{Ar}/^{36}\text{Ar}$ isochron plots for Otting 680 ($\sim 450$ Kb), Otting glass, Aumuhle 174 ($\sim 280$ Kb), and Aumuhule 158 ($\sim 350$ Kb). Extraction temperatures in hundreds of $^\circ\text{C}$ are indicated.