“PSEUDOTACHYLYTES” THAT NEVER MELTED: A THERMAL STORY FROM ROTER KAMM CRATER, NAMIBIA.

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Introduction: Pseudotachylyte is a fine-grained rock that occurs as intrusive veins and breccia matrices within host rocks. The veins contain abundant clasts of the host rock and show evidence of the former presence of a melt [1]. Pseudotachylytes have been found associated with several impact craters [2], on major tectonic faults [3] and have been generated experimentally by localized cataclasis and frictional melting [4], and by impact shock [5].

Breccia veins in Roter Kamm impact crater of SW Namibia were originally described as pseudotachylytes [6]. Degenhardt et al. [7] retained the term pseudotachylyte but concluded that the veins had not actually melted. We report here results of $^{40}Ar/^{39}Ar$ analysis of samples from Degenhardt’s study and interpret these data in terms of the thermal history of the Roter Kamm breccia veins.

Locality: Roter Kamm is a simple crater 2.5 km in diameter located in SW Namibia [6]. Erosion has lowered the crater rim by 40-130 m and most of the ejecta, apart from a few patchy occurrences, have been stripped away [8]. $^{40}Ar/^{39}Ar$ analysis of a small impactite sample provided a crater age of 3.7 ± 0.3 Ma [9].

Gneisses and granites with a Rb-Sr age of 900–1,200 Ma in the crater rim are cut by numerous fine-grained dark-colored breccia veins. The veins range from dykes (meters thick) to fine submillimeter veinlets. They contain irregular clasts of a host rock displaying a wide range of grain size from several mm down to less then 1 μm. The finest grains display granoblastic texture suggesting recrystallization. The overall textural and geochemical characteristics of the veins are consistent with breccias formed by local comminution and were the heat generated was insufficient to melt the rock [7].

The veins show rare evidence for shock metamorphism at pressures of 20-35 GPa (planar deformation features ω and π in quartz) [6, 7]. Shock features, reported from a single impactite, include diaplectic quartz (~35-45 GPa) and vesicular glass (~45 GPa) [6]. Besides the dated impactite, melt was reported only in several suevite fragments [1].

Samples: We studied three samples of pseudotachylytic breccia, which were petrologically characterized by Degenhardt et al. [7]: RK-SR, RK-1, and RK-2. Sample RK-SR comprises a massive vein of dark breccia, 4-5 cm thick, in granitic gneiss. The vein contains multiple rock fragments in a fine-grained cataclastic matrix. The host rock is fragmented and penetrated by fine veinlets of the breccia. We separated and analyzed two K-feldspar concentrates. The first (RK-SR-VR) was from a fragment of the brecciated host rock adjacent to the vein and penetrated by breccia veinlets. The second concentrate (RK-SR-P) was vein material with feldspar clasts < 0.2 mm in diameter. Samples RK-1 and RK-2 are granitic gneisses cut by irregular networks of dark breccia veinlets up to 2-mm-wide. We analyzed one K-feldspar concentrate from each sample. Both concentrates contained mixtures of the veinlets with the host rock. All four concentrates contained microcline (60-80 vol.%) plus albite and quartz.

Data: $^{40}Ar/^{39}Ar$ analyses of the four K-feldspar concentrates yielded four similar step-heating age spectra. The plateau and lowest apparent ages for individual concentrates are 320, 275, 305, 295 Ma and 80, 29, 70, and 140 respectively for samples RK-SR-VR, RK-SR-P, RK-1-VR, and RK-2-V, with an uncertainty of about 5 %. The total-gas ages for these samples are all between 230 and 300 Ma.

We offer two end-member hypotheses for the observed patterns of the age spectra: 1) slow cooling since Carboniferous or 2) more rapid cooling in Carboniferous followed by a Pliocene impact-related heating event. Considering only the second scenario, the total-gas age divided by the plateau age approximates the fraction of argon lost from our samples during reheating processes associated with the impact: 5 % for host rock with veinlets, 7 % for host rock and 15 % for the vein.

Thermal modeling: Impact shock is known to have a little effect on Ar loss [10]. Since evidence for shock is slight in the Roter Kamm veins we assume that the K-Ar system has not been affected by shock. The impact, however, produces a significant amount of heat in the target rocks, which dissipates over a prolonged period of time. In addition to the impact, frictional heating along rock fractures can raise temperature rapidly above the melting point of granite, although the duration of this excursion will be quite brief, on the order of seconds [4, 11]

Based on our laboratory data, diffusion parameters were calculated for each sample and the results plotted in Arrhenius diagrams. Linear fits through low-temperature points in the plots defined activation energies E and frequency factors D_0/a^2 for the diffusion modeling.

Given the diffusion parameters, we calculated the duration of square-pulse heating events at various temperatures that would allow loss of argon estimated for each sample. Ranges of possible time-temperature combinations are very similar for all four samples. We attribute differences among the curves to uncertainty in determination of the diffusion parameters. We are unable to resolve any difference in thermal histories between RK-SR-VR (host rock) and RK-SR-P (vein).

In order to limit probable duration and peak temperature of the impact heating event we modeled various cooling histories of our samples. We assumed that a sample located at a particular depth was instantaneously heated by the impact and then cooled to ambient surface temperature. We further assumed one-dimensional diffusive heat loss and 1 mm^2/s for thermal diffusivity [12]. Samples located close to the surface cool faster than the samples located deeper and therefore require higher peak temperature to lose a given amount of argon.

To satisfy 5 % Ar loss from our most retentive sample RK-2-V the cooling had to start from 410 °C if the sample resided at 5 m depth, 380 °C at 10 m, 350 ºC at 20 m, 330ºC at 40 m or 310 °C at 70 m. To satisfy 7 % Ar loss from one of the least retentive samples RK-SR-VR the cooling had to start at 330, 305, 285, 265 or 250 °C, for the same depths respectively. Considering the amount of erosion at Roter Kamm the peak temperatures for depths of 40 and 70 m are particularly relevant. It is reasonable to assume that the impact heated the target country rocks to temperatures similar to those we estimated, and locally some material (crater floor and ejecta) to even higher temperatures. The cooling of rocks at the crater rim therefore could have been slower then in our model and the peak temperature required for observed Ar loss would be lower. On the other hand, hydrothermal activity would accelerate the cooling. The range of our peak temperature estimates is in good agreement with a temperature range, 170-300 °C, indicated by the shock pressure, 20-35 GPa, registered in the breccia veins [13].

Fluid inclusions found in quartz pebbles at the crater rim and interpreted as a product of a hydrothermal system associated with the impact indicate a range of equilibration temperatures between 200 and 230 °C [14]. Thus, any cooling scenario should start at or above 200 °C.

Our calculations of quartz precipitation rates from saline solution at 200-230 °C [15] indicate that minimally several months and probably several years are necessary to precipitate the amount of quartz formed together with the inclusions. Any of our models provides sufficient time for quartz precipitation.

The ranges of most of the parameters are well-established, but even if we assume ten times faster heat diffusion the duration of the cooling decreases by a factor of ten and the peak temperature rises by only 40-60 °C for RK-2-V and 30-40ºC for RK-SR-VR. The assumption that the Ar loss is related to impact and not to previous thermal history is hard to evaluate because we have not analyzed samples outside the crater. However, if this assumption is wrong then our estimate of the peak temperature during the impact event would be even lower.

Conclusion: The rocks at the crater rim have experienced recent Ar loss, which we associate with the thermal effect of the 3.7 Ma impact event. We were not able to resolve different thermal signatures for the vein and the host rock, which suggests that the frictional heating during the vein formation was less important than the impact induced heating. The peak temperatures during vein formation were lower than 400 °C and probably in the range of 250-330 °C. This conclusion is consistent with shock features observed in the breccias, equilibration temperatures of fluid inclusions in quartz, quartz precipitation rates, and the estimated degradation of the crater.

The Roter Kamm vein breccias have many superficial similarities to true pseudotachylytes, but this work confirms that the breccias never approached melting temperatures and are poor candidates for dating impact formation.

References: [1] Reimold W. U. et al. (1997) *Meteorit. Planet. Sci., 32*, 431-437. [2] Thompson L. M. and Spray J. G. (1996) *Contrib. Mineral. Petrol., 125*, 359-374. [3] Passchier C. W. (1982) *J. Struct. Geol., 4*, 69-79. [4] Spray J. G. (1995) *Geology, 23(12)*, 1119-1122. [5] Fiske P. S. et al. (1995) *Science, 270*, 281-283. [6] Reimold W. U. and Miller R. M. (1989) *Proc. Lunar Planet. Sci. Conf., 19*, 711-732. [7] Degenhardt J. J. et al. (1994) in B. O. Dressler et al., eds., *Geol. Soc. Am. Spec. Pap. 293,* 197-208. [8] Grant J. A. et al. (1997) *J. Geophys. Res., 102(E7)*, 16327-16338. [9] Hartung J. B. et al. (1991) *Meteoritics, 26*, 342-343. [10] Bogard D. D. et al. (1987) *Geochim. Cosmochim. Acta, 51*, 2035-2044. [11] Kelley S. P. et al. (1994) *Geology, 22*, 443-446. [12] Turcotte L. D. and Schubert G. (1982) John Wiley & Sons. [13] French B. M. (1998) *LPI Cotrib. 954*, pp. 120. [14] Koeberl C. et al. (1989) *Geochim. Cosmochim. Acta, 53*, 2113-2118. [15] Dove P. M. and Crerar D. A. (1990) *Geochim. Cosmochim. Acta, 54*, 955-969.