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IMPACTITE AND PSEUDOTACHYLITE FROM ROTER KAMM CRATER, NAMIBIA. J. J. Degenhardt Jr.^{1,2}, P. C. Buchanan¹, and A. M. Reid¹, ¹Department of Geosciences, University of Houston, Houston TX 77204, USA, ²Texaco Inc., E&P Technology Division, 3901 Briarpark, Houston TX 77042, USA.

Pseudotachylite is known to occur in a variety of geologic settings including thrust belts (e.g., the Alps and the Himalayas) and impact craters such as Roter Kamm, Namibia. Controversy exists, however, as to whether pseudotachylite can be produced by shock brecciation [1] as well as by tectonic frictional melting. Also open to debate is the question of whether pseudotachylites form by frictional fusion or by cataclasis [2]. It has been speculated that the pseudotachylite at Roter Kamm was formed by extensional settling and adjustment of basement blocks during "late modification stage" of impact [3]. The occurrence of pseudotachylite in association with rocks resembling quenched glass bombs and melt breccias in a relatively young crater of known impact origin offers a rare opportunity to compare features of these materials. Petrographic, X-ray diffraction, and electron microprobe analyses of the impactites and pseudotachylite are being employed to determine the modes of deformation and to assess the role of frictional melting and comminution of adjacent target rocks. The first findings are reported here.

The Roter Kamm Crater is located in the southern part of the Namib Desert about 80 km north of Oranjemund, Namibia. The crater rim has a crest diameter of ca. 2.5 km with the highest exposed point reaching 158 m above the lowest point of the crater floor. The impact, which excavated Precambrian granitic-granodioritic orthogneisses of the 1200–900-m.y.-old Namaqualand Metamorphic Complex, has been dated at 3.5–4.0 Ma by Hartung et al. [4]. No volcanic rocks have been discovered in the area [5]. This has been substantiated by others [3]. A detailed account of the crater geology was published by Reimold and Miller [6].

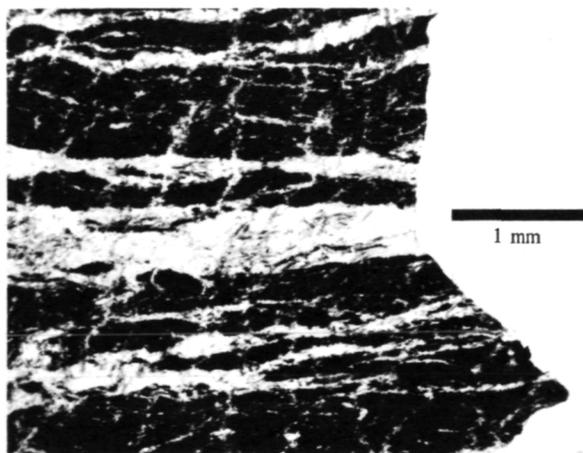


Fig. 1. Photomicrograph of flädle in transmitted light illustrating veinlets of subhedral mica and quartz set in opaque matrix. Veinlets terminate abruptly at edge of sample.

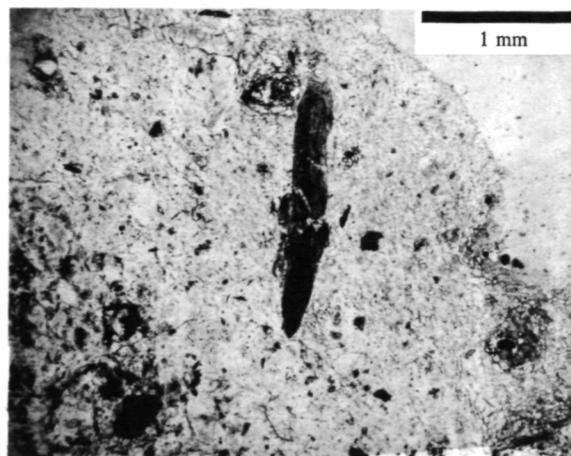


Fig. 2. Plane light photomicrograph of opaque clasts entrained in quartz breccia matrix. Large clast (center) is 1.6 mm in length.

A variety of impactites was collected from the crater rim. These have been described in the literature as "impact-melt breccias," "melt bombs," and "ejecta melts." In this study, three main rock types have been examined:

1. Meltlike rocks (also called flädle), common only along the northwest crater rim, are dark gray to black in color and exhibit apparent flow patterns characteristic of quenched glass "bombs." Because of their smooth, fluidlike shapes, the flädle have been interpreted as impact melt. In spite of their meltlike appearance, the specimens that were examined exhibited pervasive subparallel millimeter-wide veinlets containing subhedral mica and quartz. The fact that these veins are sharply (visibly) truncated by the surfaces of the flädle brings into question the interpretation that these rocks were melt-derived (see Fig. 1). XRD and electron microprobe analyses of the veins confirmed the mica-quartz composition and showed the mica to be a K, Mg-bearing variety. The finer-grained, optically opaque matrix is composed of mica and quartz similar to that of the veins. A Ti-rich mineral was also found to be present in the matrix, mainly in the form of clustered grains scattered throughout. Further analysis is being carried out to determine the cause of the opacity.

2. Quartz breccias containing large irregular shocked quartz fragments were also collected along the north crater rim. The fragments are cemented by an aphanitic matrix that resembles pseudotachylite in hand specimen. In contrast to the flädle, this matrix is not opaque in thin section, but appears finely crystalline. Of significance is the presence of opaque clasts (some containing micaceous veins) located throughout the matrix, which upon preliminary examination appear to be composed of the same material as the flädle (Fig. 2). Work is currently being done to determine if the chemical compositions of these entrained clasts match that of the flädle, and thus whether the flädle material predates the quartz breccia.

3. Pseudotachylite samples in the form of allochthonous fragments were collected at the south rim. Petrographic examination reveals the presence of angular entrained clasts that have not undergone recrystallization. However, finely crystalline quartz resembling the quartz breccia matrix appears in (plastically?) deformed grains and intermediate zones that often separate the pseudotachylite from its host rock. The composition of the vein material, including nonrecrystallized entrained clasts, was found to

be essentially that of the host rock. It is apparent from grain deformation that transport distances were on the order of millimeters to centimeters along the veins.

The textures of flädle, quartz breccia, and pseudotachylite are fundamentally different when viewed petrographically. Although each of the rock types appears darkly opaque (dark gray or black) in hand specimen, the only sample with a matrix that is truly opaque in thin section is the flädle. No clasts representing compositions and textures of the other impactites have been observed in the pseudotachylite thus far. Present work is directed at determining what textural and compositional changes were involved during formation and whether the pseudotachylite represents material comparable to associated impactites.

References: [1] Schwarzman E. C. et al. (1983) *GSA Bull.*, 94, 926-935. [2] Wenk H. R. (1978) *Geology*, 6, 509-511. [3] Koeberl C. et al. (1989) *GCA*, 53, 2113-2118. [4] Hartung J. et al. (1991) *54th Annu. Met. Soc. Mtg.*, Monterey, CA. [5] Fudali R. F. (1973) *Meteoritics*, 8, 245-257. [6] Reimold W. U. and Miller R. McG. (1989) *Proc. LPSC*, Vol. 21, 711-732.

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SUDBURY PROJECT (UNIVERSITY OF MÜNSTER-ONTARIO GEOLOGICAL SURVEY): (4) ISOTOPE SYSTEMATICS SUPPORT THE IMPACT ORIGIN. A. Deutsch¹, D. Buhl², P. Brockmeyer¹, R. Lakomy¹, and M. Flucks¹, ¹Institute for Planetology, University of Münster, Wilhelm-Klemm-Str. 10, D-4400, Münster, Germany, ²Institute for Geology, RU Bochum, Postfach 10 21 48, D-4630 Bochum 1, Germany.

Introduction: Within the framework of the Sudbury project [1-3] a considerable number of Sr-Nd isotope analyses were carried out on petrographically well-defined samples of different breccia units [4-7]. Together with isotope data from the literature these data are reviewed in this abstract under the aspect of a self-consistent impact model [5,8-10]. The crucial point of this model is that the Sudbury Igneous Complex (SIC) is interpreted as differentiated impact melt sheet [5,8-11] without any need for an endogenic "magmatic" component such as "impact-triggered" magmatism or "partial" impact melting of the crust and mixing with a mantle-derived magma [e.g., 12]. For the terminology used here we refer to the companion abstracts in this volume [1-3].

Strontium and Neodymium Isotopes: Impact melt rocks such as the sublayer [12], the SIC [11,12], and the clast-rich melt breccia on its top [5,6], as well as melt breccia bodies, matrix, and melt particles from the Onaping breccias [5,6], are characterized by ϵ_{Nd} between -5 and -12 with Onaping lithologies tending toward lower ϵ_{Nd} values (Fig. 1). Their Nd-model ages TDM relative to a depleted mantle [13] cluster around 2.7 Ga, which agrees well with the time of the last major crust-forming event in the Archean Superior Province northwest of the Sudbury structure [e.g., 14,15]. It is important to note that ultramafic inclusions in the sublayer plot among other SIC rocks with negative ϵ_{Nd} and positive ϵ_{Sr} [12]. Figure 1 shows that the SIC has highly radiogenic and variable I_{Sr} . All those findings fit with the proposed total melting of the crust in the Sudbury region by the impact event that leads to $\sim 1.5 \times 10^4$ km³ of impact melt [10], namely the SIC and the melt breccia, and the melt in the suevitic Onaping breccias [3]. In contrast, the data are incompatible with the input of fresh mantle magma as up to 75% contamination by upper crustal material would be required [12] to explain the Nd-Sr isotope systematics of these units, but an endogenic melt cannot assimilate such a high fraction of relatively cold material.

SUDBURY IMPACT STRUCTURE

$T_{\text{impact}} = 1.85$ Ga

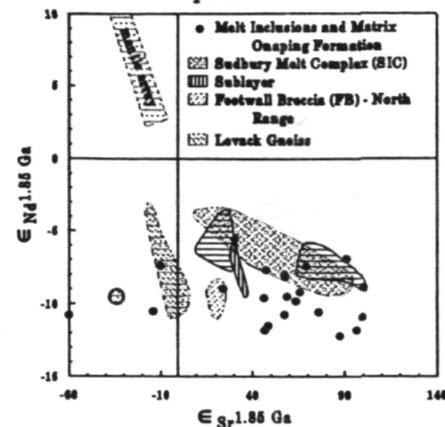


Fig. 1. ϵ_{Nd} - ϵ_{Sr} diagram for different lithologies of the structure with data recalculated to 1.85 Ga, the time of the impact event [14]; data sources [4-6,11,12,15-17,19].

Neodymium isotope ratios of the impact melt concur with Nd characteristics of the target lithologies in the Sudbury region, for example, the Levack gneiss [12]. The observed spread in ϵ_{Sr} reflects the widely varying $(^{87}\text{Sr}/^{86}\text{Sr})^{T=1.85\text{ Ga}}$ for the Archean basement [4,15], Proterozoic Intrusives [16,17], and the Huronian Supergroup [16,18] that were mixed into the melt. Distinct fields for the sublayer from different localities [12,19] in Fig. 1 show that the impact melt sheet (SIC) assimilated local bedrocks after its emplacement in the final modified crater. Strongly deviating Sr isotope ratios for some Onaping rocks in Fig. 1 with $(^{87}\text{Sr}/^{86}\text{Sr})^{T=1.85\text{ Ga}}$ as low as 0.700 [6,7] or 0.67 [20] are due to a reopening of the Rb-Sr system during the Penokean orogeny [4, see also 7]. This is demonstrated with selected growth curves in Fig. 2: Some recrystallized melt particles and devitrified glass have enhanced Rb/Sr ratios but the majority of the material has I_{Sr} identical to the granophyre. Together with their ϵ_{Nd} , this fact supports our view that the melt-breccia on top of the granophyre and the melt material in the suevitic Onaping breccias and in the Green Member originated from the same source as the SIC, namely impact-melted crustal material.

Oxygen isotope data [21] support our findings. The norite, the granophyre, and the matrix of Onaping breccias all show a considerable spread in $\delta^{18}\text{O}$, but typical trends as known from differentiated layered intrusions are absent. The $\delta^{18}\text{O}$ values of these lithologies are bracketed by oxygen isotopic compositions observed for local Archean and Proterozoic bedrocks with the Onaping breccias reflecting a higher input of Huronian greywackes. To explain the Os isotope ratios for the Sudbury ores [22] by mixing between a mantle magma and crust would need up to 90% crustal material. Therefore these data are also in line with a derivation of the ores exclusively from ancient crustal sources by impact melting followed by segregation of a sulfide liquid out of the melt sheet.

Summary and Outlook: While in the original contributions SIC isotope systematics were discussed preferentially in terms of a possible mixing between a hypothetical mantle component with up to 75% crustal material, the impact melt model does not have any problem explaining the crustal signatures of the SIC, the Onaping breccias, and the Sudbury ores—total melting of basement and supracrustal lithologies can only produce crustal signatures. Future studies on Sudbury should concentrate on combined analyses of