

DEGASSING PIPES AT THE RIES IMPACT STRUCTURE AS AN ANALOUGE FOR CRATER-RELATED PITTED MATERIAL ON TERRESTRIAL PLANETS. C. M. Caudill¹, G. R. Osinski^{1,2}, L. L. Tornabene¹, F. J. Longstaffe¹. ¹Centre for Planetary Science and Exploration / Dept. Earth Sciences, University of Western Ontario, Canada, ²Dept. Physics and Astronomy, University of Western Ontario, Canada.

Introduction: Impact structures and their ejecta deposits act as windows into the mineral, lithologic, and volatile composition of terrestrial crusts. The Ries impact structure (~24 km-diameter, Germany) has arguably the best preserved and best studied ejecta deposits on Earth. The two main deposit types described include a melt-poor/free ballistically-emplaced impact breccia [1, 2] overlain by discontinuous impact melt-bearing breccias (e.g., [3]). The top-most, melt-bearing breccia deposits at the Ries impact structure host evidence of post-impact hydrothermal alteration [e.g., 4, 5], one style being associated with disseminated vertical degassing pipe (DP) structures [6, 7]. As melt-rich ejecta deposits are emplaced over volatile-bearing material, a degassing of the underlying layer is proposed to have occurred [6, 8]; this is also the preferred interpretation of pitted material observed in Martian crater fill and ejecta deposits [9, 10, 11]. Following the observation of widespread crater-related pitted material on Mars, similar pitted material has been observed in impact craters elsewhere in the solar system, including Vesta and Ceres [12, 13]. Despite the proposed link between DPs and pitted materials on Mars, Vesta and Ceres, there have been no detailed studies conducted on the Ries DP in over 30 years. Here, we present the first detailed crater-wide field study of DP at the Ries and apply modern analytical techniques to determine their characteristics and origin.

Methods: Hand samples of degassing pipes, cm-scale alteration halos, and representative bulk melt-bearing breccias were collected from surficial exposures at Aumühle, Otting, and Altenberg quarries. Recent exposures of Aumühle quarry North wall revealed densely clustered degassing pipes (i.e., 20 degassing pipes over ~50m exposed wall) with sinuous, flame-like alteration halos 10s of cms across (e.g., Fig. 1c). The interiors of the DPs are lined with a very fine-grained – amorphous material. DPs were also observed in two drill cores, Otting core (0-10 m depth) and Wörnitzoshtheim 1965 core (27 m depth). Core samples were acquired from ZERIN Ries Krater Museum, Germany for use in this study.

Non-destructive, *in situ* point spectroscopy was used to evaluate coatings of very fine-grained to amorphous alteration material, retaining valuable contextual information. Spectral data was collected using an ASD FieldSpec 4 [14] tabletop point spectrometer (as an active detection, with provided light source) over 0.35-2.5 μm (UV-VNIR) ranges, with a spectral resolution

of 3 – 8 nm. The spectral characteristics were analyzed by comparison to laboratory-derived spectra [15].

Additionally, the < 2 μm size-fraction was isolated from powdered samples, and separate aliquots saturated with Ca and K. Ca-saturated samples were analyzed at 54% relative humidity (RH) and then glycolated. K-saturated samples were analyzed at 0% and 54% RH and then dehydrated by heating at 300 °C and 550 °C. Samples were analyzed after each treatment using a rotating anode powder X-ray diffractometer (pXRD).

Results: Spectral analysis indicates the presence of hydrated and hydroxylated mineral phases, as all samples are characterized by the presence of ~1.4 μm , ~1.9 μm , and 2.2–2.3 μm features. The ~2.21 μm absorption feature, which characterizes an Si-OH or Al-OH bond, is present in all samples. Coupled with the shape of the spectra (width of individual absorptions, the overall shape of the spectra over the detected wavelength), it can be interpreted as montmorillonite based on the close match the USGS spectra (Fig. 1). A 2.29 – 2.31 μm feature is also present in all samples, indicating Fe/Mg-OH bearing minerals. Fe-dominant clays are indicated closer to 2.29 μm (e.g., nontronite) and Mg-dominant species are closer to 2.31 μm (e.g., saponite) [16]. The ~1.91 μm absorption in all samples indicates hydration, and the ~2.39 μm absorption indicates an OH combination band. Combination bands at ~1.41 μm (H₂O) and ~2.39 μm (OH) vary based on the octahedral cation [17]. We interpret that Al, Fe, and Mg-smectites are characteristic of Ries DPs from Aumühle surficially-exposed samples and the two core samples (Fig. 1). These absorption features were also present in “pre-pipes”, observed at the contact between the hosting melt-bearing breccia and underlying Bunte Breccia lithology at the Aumühle quarry. The pre-pipes are orange alteration pathways that emanate from the underlying Bunte Breccia lithology. The pre-pipes are observed as vertical alteration pathways that eventually form degassing pipes, which have the characteristic clast-rich, fines-poor interior cavities.

The pXRD analysis provides vital confirmatory evidence for the mineralogy of the DP samples obtained by spectral analysis. The results for Ca-saturated samples are consistent with a smectitic composition with basal (001) spacing at ~ 1.5 nm at 54% relative humidity and ~1.7 nm when glycolated. When K-saturated, however, the basal spacing of the smectitic phase does not collapse completely to 1.0 nm upon dehydration, suggesting the presence of chlorite or

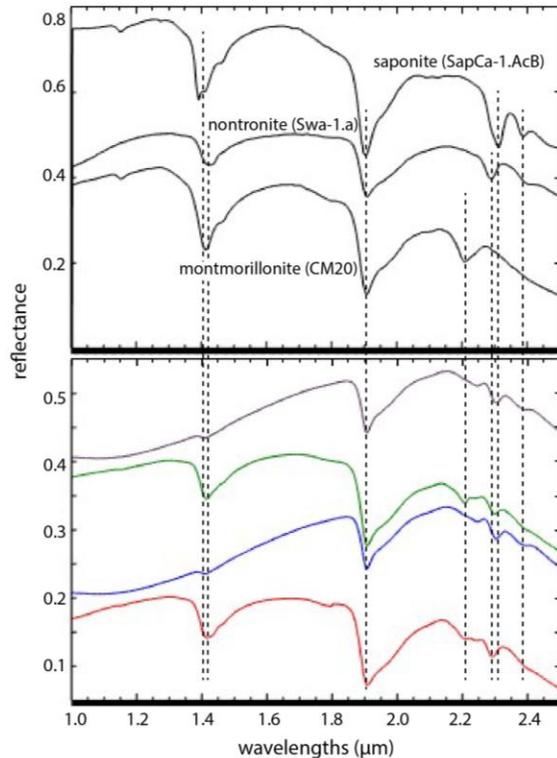


Figure 1. (top) USGS spectra [15] for Al, Fe, and Mg-smectites compared to (bottom) UV-VNIR spectra of samples from Ries DPs. Purple is a Wörnitzoshtheim core (27 m depth) DP; green is a sample from Otting core (9 m depth); blue is a sample from an Aumühle surficial DP; red is a “pre-pipe” sample from Aumühle quarry. USGS montmorillonite spectrum shows common absorptions of Al-OH bearing minerals at $2.21 \mu\text{m}$; vertical dashed line indicates this same absorption feature in the green spectrum. The green and red spectra show a $2.29 \mu\text{m}$ feature (also seen in the USGS spectrum for nontronite). This absorption shifts to $2.31 \mu\text{m}$ in the blue and purple spectra (also seen in the USGS spectrum for saponite). Vertical dashed lines at $\sim 1.4 \mu\text{m}$ indicates an H_2O overtone that shifts dependent on the octahedral cation. The vertical line at $1.9 \mu\text{m}$ indicates the presence of H_2O . The $\sim 2.39 \mu\text{m}$ absorption indicates an OH combination band, which shifts in position based on the proportion of Fe versus Mg in the smectite. In the Aumühle (blue) surficial and Wörnitzoshtheim core (purple), the $1.4 \mu\text{m}$ band is weak. This behaviour may result from mixing with Fe-oxides which can obscure these bands [18].

hydroxyl-interlayers [19]. Heating of the K-saturated samples produces broad, asymmetric peaks at $\sim 1.0 \text{ nm}$, in contrast to the sharp 1.0 nm diffraction expected for montmorillonite. The broad peaks also indicate highly disordered, poorly crystallized materials, and the peak asymmetry is suggestive of turbostratic stacking [19].

Discussion: The DPs at the Ries are vertical gas and fluid-flow pathways, lined with hydrothermal alteration products. In contrast to previous findings [e.g.,

6], this work indicates that the DPs contain complex, smectitic clays characteristic of formation in a low to moderate temperature hydrothermal environment. The degassing pipes and associated clay mineralogy presented in this study have been observed as disseminated throughout the ejecta and the crater interior. Cation and volatile sources associated with clay formation originate from: (1) fluids emanating from the contact between suevite and the degassing Bunte Breccia, where present; and (2) the melt-bearing breccia itself, including alteration of glass clasts, and to a lesser extent, shocked or unshocked basement inclusions in the path of the vertical flow within the suevite or entrained in the pipes. In particular, alteration of glass clasts by DP flow is commonly observed. Large glass clasts in the path of the DPs cause flow divergence, thus opening pore space above the clast in the direction of fluid flow. Ensuing glass clast alteration also provides a cation source for the secondary Fe-oxides and Fe/Mg smectites lining the DPs.

The field context and characterization of DPs provided in this study are consistent with previous suggestions that DPs at the Ries are an analogue for crater-related pitted material observed on Mars, Vesta, and Ceres. Mineralization of DPs likely depends on several factors, including lithologic texture and composition of the host impactite, emplacement temperature, and post-emplacement volatile availability.

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