HYDROTHERMAL ALTERATION OF CRATER LAKE DEPOSITS AT THE RIES IMPACT STRUCTURE, GERMANY.

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Introduction: Meteorite impact structures are ubiquitous features across all terrestrial objects in the solar system, and are possibly capable of forming environments where primitive micro-organisms could have been sustained and preserved [1]. The interaction between the heat from impact melt-bearing rocks and surface/near surface water (groundwater, lakes, oceans) could form hot, rock-water circulatory systems capable of dissolving and transporting solutes, precipitating secondary mineral species, and producing new biological niches [1]. If a crater lake develops in parallel with hydrothermal activity, the sediment preserved in the crater-lake environment are of interest in the search for evidence of post-impact biological successions. The potential for some craters to sustain life have made them primary targets for rovers on Mars such as Curiosity – currently studying Gale Crater.

The Ries impact structure in southern Germany is one of the best-preserved impact structures in the world. This structure provides a rare opportunity to study the contact between the heat source of an impact-generated hydrothermal system and the sediments deposited shortly after impact. This study's aim is to document the extent of hydrothermal alteration affecting these crater lake deposits, and the source of the associated fluids. We present findings for samples mainly of the Wörnitzostheim core with additional samples from the Nördlingen 1973 core, which were loaned from the Center for Ries Crater and Impact Crater Research (ZERIN) in Nördlingen. Limited sampling of the Wengenhousen and Hainsfarth outcrops was also conducted.

Objectives and Methods: This study has three main objectives: (1) to characterize the alteration of the basal lake sediments, (2) to constrain the extent of the alteration, and (3) to determine the nature of the alteration fluids using the oxygen and hydrogen isotope compositions of clay minerals formed during alteration of the Ries lacustrine deposits.

These objectives will be accomplished through bulk powder x-ray diffraction (XRD), optical microscopy, XRD of <2μm clay separates, visible / near infrared reflectance (VNIR) spectroscopy, scanning electron microscopy with energy emissions spectroscopy (SEM-EDS), electron microprobe analysis (EMPA), and isotope ratio mass spectrometry (IRMS).

Background: The 22-24 km diameter, 14.8±0.1 Ma Ries impact structure occurred in southern Germany [2], in sedimentary Mesozoic rocks unconformably overlying a crystalline Hercynian basement [3]. The lower sedimentary rocks consist of sandstone, siltstone and marl, with limestone dominating the upper parts. The basement consists of gneisses, amphibolites, ultrabasic rocks and later granitoid intrusions. The Ries is a complex impact structure with a central basin existing within the tectonic rim. Ries' central basin is bounded by a prominent "inner ring", ~12 km in diameter [3] (Fig. 1). A series of impact melt-bearing breccias termed "crater-fill suevites" infill the central ring and are overlain by ~336 m of post-impact sedimentary rocks [4]. Post-impact sedimentary units have also been documented outside the inner ring such as bioherms and palustrine deposits. The bioherms are characterized by the dominant ostracod and mesogastropod species, which occur in the marginal block zone (e.g. Hainsfarth) whereas the palustrine deposits are characterized by limestones and calcitic spring mounds (e.g. Erisberg spring mound) [5].

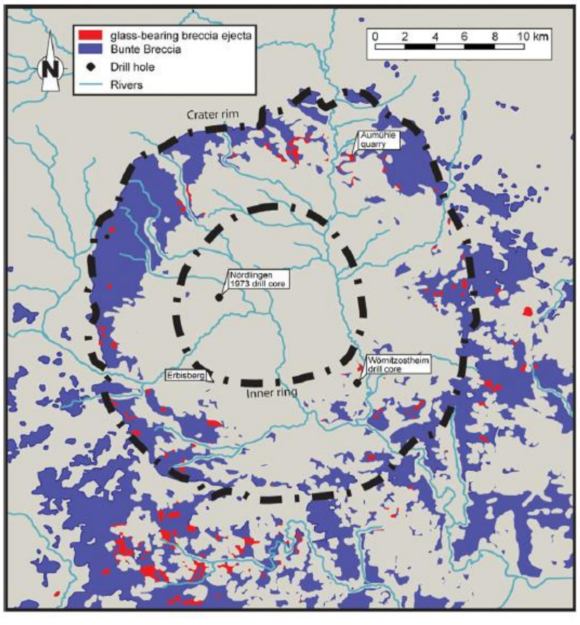

Figure 1: Geology of the Ries impact structure highlighting the differentiation between the inner and outer rim [6].

Results and Discussion: In the Ries, a case where the crater lake formed shortly after impact, hydrothermal alteration tends to be geographically wide-spread [6, 7]. Most alteration is concentrated in the crater-fill impact melt-bearing breccias suggesting that they are the main heat source for the hydrothermal system [7]. The Wörnitzostheim core was sampled from just outside the inner ring of Ries (Fig. 2) where it penetrated through crater-lake sediments, and the underlying impact melt-bearing breccia.

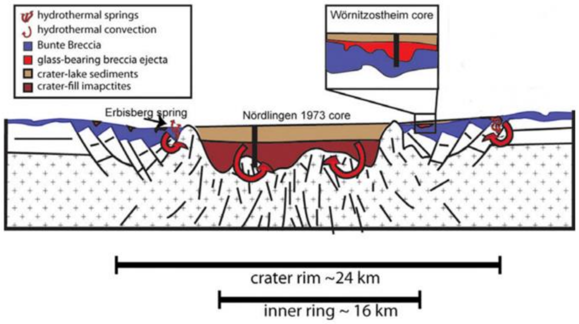

Figure 2: Cross section of the Ries impact structure showing hydrothermal springs, possible hydrothermal convection and locations of drill cores studied here [6].

The rock type of the Wörnitzostheim core gradually transitions from impact melt-bearing breccia to limestone. Areas of discolouration mark the alteration zones in drill core. Unweathered impact melt-bearing breccias are the dominant lithology below 19 m. At 27.3 m a coarse-grained, weakly lineated zone with a significant alteration halo is present – reminiscent of the degassing pipes observed elsewhere at the Ries [7]. The impact melt-bearing breccia shows evidence of reworking as the rock type gradually transitions into clay rich, basal lake deposits from 19 to 12 m. The clay-rich unit then grades into a carbonate-dominated unit at 9 m. Zones of alteration are present at ~15.30 m (Fig. 3a) and ~9.6 m (Fig. 3b). Carbonaceous lake deposits make up the upper 9 m of drill core.

Although many methods have been utilized in this study, bulk XRD and XRD of <2 µm clay separates have yielded some of the most informative results about the alteration. Alteration in the reworked impact melt-bearing breccia is associated mainly with mixed smectite-illite mineralization. Chlorite mineralization also appears correlated with altered zones. The alteration assemblage in the clay rich unit appears to have a similar alteration mineralogy, but is more carbonate rich. Smectite, illite, kaolinite and calcite are consistent occurrences throughout the upper 30 m of the Wörnitzostheim core. Other common members of the mineral assemblage include dolomite, microcline, plagioclase and pyrite identified using optical microscopy.

The clay mineral assemblage is consistent with low temperature (~100-130°C) argillic alteration, which is characterized by the presence of mainly smectites and kaolinites, with illite and chlorite. Transitioning from smectite to interstratified smectite-illite occurs at ~100 to 130°C [8]; possibly putting a minimum temperature restriction on the alteration. Weathering may have influenced the alteration [9], but the higher temperature mineral assemblages point to hydrothermal alteration as the dominant process in the samples studied here.

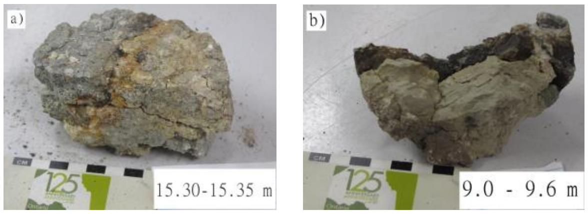

Figure 3: Samples in the Wörnitzostheim core exhibiting alteration. 3a) alteration in reworked impact melt-bearing breccia. 3b) alteration in clay-rich unit.

Conclusions: The stratigraphy of the Wörnitzostheim core may represent a palustrine environment [similar to 5]. The clay mineral assemblage is consistent with ~100 to 130°C argillic alteration, and the de-gassing pipe-like structure suggests the alteration origin may be predominantly hydrothermal. This work provides the first detailed study of the alteration mineralogy of the basal lacustrine sediments, and shows that impact-generated hydrothermal alteration and sediment deposition occurred concomitantly.

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