SEDIMENTARY CRATER FILL OF THE RIES IMPACT STRUCTURE: HYDROLOGICAL AND CHEMICAL EVOLUTION, SEDIMENT BODY GEOMETRY, AND IMPLICATIONS FOR MARTIAN CRATERS. Gernot Arp[1], Dietmar Jung[2] and James Head[3], [1]Geoscience Centre, University of Göttingen, Goldschmidtstraße 3, D-37077 Göttingen, Germany, garp@gwdg.de, [2]Bavarian Environmental Agency, Geological Survey, Hans-Högn-Straße 12, D-95030 Hof/Saale, Germany, Dietmar.Jung@lfu.bayern.de, [3]Department of Earth, Environmental and Planetary Sciences, Brown University, Providence RI 02912 USA, James_Head@brown.edu

Introduction: The 14.808 ± 0.038 Ma old [1], 26-km-sized Ries impact structure is an important terrestrial analogue study site for martian craters: It is a partly exhumed impact structure, showing a central crater, inner ring, terrace zone, and a well preserved dual-layer ejecta blanket with rampart structure [2, 3] reflecting an impact into volatile-rich target rocks [3, 4]. Fluviodeltaic conglomerates of the Ries demonstrate that impact preprocessing enables rounding of igneous and metamorphic rocks over comparatively short transport distances due to their increased susceptibility to abrasion - possibly similar to martian conglomerates [5]. Plio-Pleistocene erosion led to the exposure of a suite of different ejecta including suevite and lithic breccias of sedimentary cover or crystalline basement origin. This partial exhumation of the Miocene sedimentary crater fill succession [6] facilitates the study of chemical lake evolution and sedimentary crater fill geometry.

Sedimentary, chemical, and hydrological evolution: The post-impact crater fill comprises four lithostratigraphic units representing successive chronological stages of the crater lake [7]:

(i) A basal member of 60 m thickness, with alluvial conglomeratic sandstone reworked from suevite and minor playa lake sediment intercalations.

(ii) A laminite member of 145 m thickness composed of greenish-grey laminated claystone with authigenic silicates (analcime, clinoptilolite) and bituminous shale of a stratified, permanent lake. Lower parts are characterized by brine shrimp fecal pellets, while top parts show abundant diatoms.

(iii) A 60 m tick marl member showing light-grey dolomite marl and analcime-bearing argillaceous marl.

(iv) A clay member with 50 m preserved thickness, consisting of dark grey clay with intercalations of lignite, limestone, gypsum pseudomorphs and diatomite.

At the basin margin, green algal-cyanobacterial bioherms, carbonate sands, travertines [8] and local fluviodeltaic conglomerates [5] form stratigraphic equivalents of the laminite to clay member. Within the bioherms, stromatolites show an evolution from clotted peloidal fabrics to fabrics bearing well preserved calcified cyanobacteria. Finally, the youngest preserved carbonates show freshwater charophytes. This sedimentary succession reflects the successive erosion of different ejecta layers and chemical evolution within a hydrologically closed basin [9, 10]: The change from initial silicate-weathering derived ion influx (from suevite and crystalline basement) to weathering solutions from lithic breccias composed of Mesozoic siliciclastics and carbonates (Bunte Breccia) and finally solutions from the surrounding Upper Jurassic karstic aquifer led to an evolution from a stratified brackish soda lake to a halite lake with marine-like ion ratios and finally to an alternation of hypersaline and low-salinity conditions. This intrinsic chemical evolution of the crater lake strongly obliterates the impact of Late Miocene climate change from semiarid to humid conditions in this region.

A new drill core in the so-called "final freshwater sediments" now demonstrates that, contrary to previous views [9], the change from hydrologically closed to open basin conditions is not evident in the preserved Miocene succession. Earliest unequivocal drainage out of the basin, however, is documented by Early Pleistocene fluvial gravel deposits in the southeastern sector of the Ries at 485 m altitude, i.e. 70-80 m above the present drainage system of the central basin [11].

Geometry of the sedimentary crater fill: New shallow drillings and temporary outcrops, a comprehensive compilation of drill data and a newly discovered volcanic ash marker bed now reveal that the lithostratigraphic units of the central crater fill exhibit a concentric outcrop pattern below the Quaternary cover deposits [Fig. 1]:

(i) Sediments of the clay member are restricted to the innermost area of 10 km diameter.

(ii) An approximately 1 km wide zone of the marl member surrounds this innermost zone.

(iii) The outermost area of the central crater as well as subbasins of the terrace zone show marls and bituminous shales of the laminite member.

This outcrop pattern reflects a bowl-shaped geometry of the sedimentary crater fill, cut by the Pleistocene erosional plain. Stratigraphic correlation of the lower laminite member in drillings of the basin centre with brine shrimp pellet-rich parts of travertine mounds at the inner ring reveal a difference in altitude of 250-260 m. However, based on sediment compaction curves calibrated by drill core porosity data of the Ries [7], compaction accounts for a stratigraphic backstripping of only 70 m for a marker bed within the lower laminite member. Given that sedimentological evidence [7] and

benthic diatom associations [12] preclude water depths greater than 50 m, an additional crater floor subsidence of 130-140 m is required to explain the deeply bowl-shaped geometry of the sedimentary crater fill.

Implications for martian open and closed-basin lakes [13, 14]: *Chemical evolution of closed basin lakes:* An increasing number of lacustrine crater fill deposits is known from Mars, many of them formed under hydrologically closed conditions. Indeed, martian lake deposits form valuable climate archives. However, intrinsic factors such as the successive erosion of compositionally different ejecta layers and corresponding chemical changes in inflowing solutes probably superimpose or may even override climatic signatures. This might be especially true where impact structures are located in terranes with layered composition, e.g. unaltered basalt overlying carbonate- and phyllosilicate-bearing bedrock of the Syrtis Major Planitia [15].

Long-term crater-floor sagging. Subsidence of the fractured basement might also be expected in impact craters on Mars. However, a prerequisite for an effect of crater-floor-sagging on sedimentary crater fills is a close timely association of impact event and subsequent sedimentation within the newly formed basin.

As far as investigated, evident and likely sedimentary crater fills on Mars are flat lying or inclined to various directions reflecting foreset beds [16, 17] or possibly eolian, anticompensational deposition [18]. At Gale Crater mound, strata gently dip (1.7° - 4.5°) away from the central peak [19] to a ring moat, explained by compaction due to later sediment load [20]. In any case, wherever concentric outcrop pattern of layered deposits in martian craters were observed (e.g. unnamed craters within Schiaparelli basin [21] and West Arabia Terra [22], Crommelin Crater [23]), these are rather regional deposits draping (possibly duststones) over various, partially eroded craters [23, 24].

To date, the apparent absence of crater floor sagging on Mars may reflect either an observational lack or a high probability that most martian impacts occurred during cold and dry phases (no rain and flood generation, no significant groundwater influx, volatile-rich but icy grounds), with sedimentary fills following with a significant time lag during short intermittent wet phases. This would be consistent with the proposed short intermittent formation of deltaic systems in martian crater basins [25]. For Gale crater, the inclination of present-day surface beds may not necessarily reflect compaction of hidden strata beneath (with an estimated thickness of 1-2 km [21]), but could partially result from sagging in the impact-fractured subsurface. The Ries Crater lake record also provides insight into the transition from closed basin lakes to open basin lakes (as in Jezero Crater) and in the role of biology and potential biomarkers in more primitive systems.

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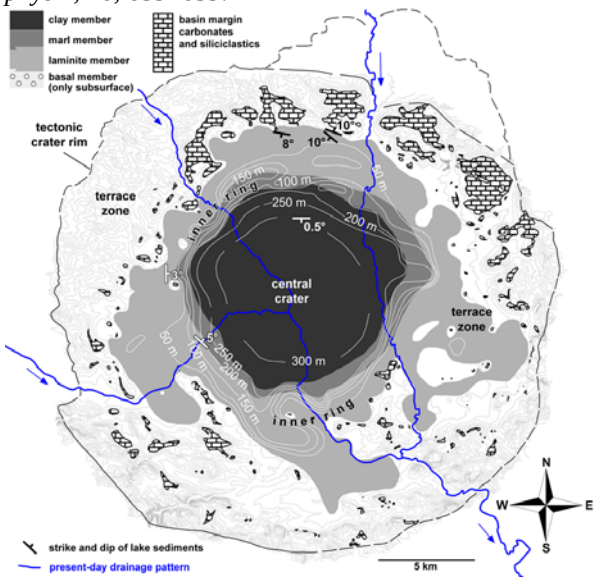

Fig. 1. Geological map of the Ries impact crater fill showing the concentric outcrop pattern of lithostratigraphic units. Miocene sediment thickness contour lines according to Ernstson [26], with modifications according to drill data.