**SEDIMENTARY CONGLOMERATES INSIDE IMPACT CRATER LAKES (RIES CRATER, GERMANY): PRE-PROCESSING, PROVENANCE, TRANSPORT DISTANCES AND IMPLICATIONS FOR GALE CRATER, MARS.**

Gernot Arp[1] and James Head[2], [1]Geowissenschaftliches Zentrum Universitaet Goettingen, Abteilung Geobiologie, Goldschmidtstrasse 3, D-37077 Goettingen, Deutschland, [2]Department of Geological Sciences, Brown Univeristy, Providence RI 02912 USA.

**Introduction:** Among the most enigmatic questions of Noachian climate history is the origin of valley networks (VN). Their extensive development and fluvial nature [1,2] argues for the sustained flow of liquid water on the Late Noachian surface, suggesting to many an origin from a warm and wet period of rainfall (pluvial) and overland flow [e.g., 3]. Alternatively, VN may have originated from melting of snow and ice (nivial) [e.g., 4] in a cold and icy climate [5] during which punctuated warming events [e.g., 6, 7] caused melting of the "icy highlands". Key to the interpretation of the nature of the VN fluvial activity is: 1) the catchment area, 2) the duration of the VN-forming process [8, 9]), 3) whether flow was sustained or episodic, and 4) how the nature of sedimentary deposits from the fluvial channels [10] can help address questions of sedimentary provenance, flow regimes, discharge, duration and episodicity.

Recently, exploration of Gale Crater floor by *Curiosity* has revealed the presence of polymict conglomerates (Fig. 1a) with a diverse suite of rounded pebbles [11]. Gale Crater, a closed-basin lake [12,13], is characterized by a several hundred km-long VN entering across the southern rim [14], and several channels along the crater interior walls forming fans and smooth deposits on the crater floor [15], some interpreted to be of lacustrine origin [16]. Isolated outcrops observed by *Curiosity* [11] were interpreted to be fluvial conglomerates on the basis of the presence of rounded 2-40 mm cemented pebbles (Fig. 1a) forming a grain-supported fabric. Substantial fluvial abrasion was indicated on the basis of pebble rounding; water flow velocities were estimated to be 0.20-0.75 m/sec, assuming 0.03-0.9 m water depth. Climate conditions required to transport these pebbles across at least several km were inferred to have differed substantially from the arid conditions of today [11]. Although the sedimentary conglomerates are interpreted to be derived from sedimentary processes within Gale crater, their overall stratigraphic context and relative age are unknown [11]. Nonetheless, the conclusion is [11] that "these ancient fluvial deposits indicate sustained liquid water flows across the landscape" [17].

These fundamental results about the nature of fluvial sedimentary conglomerates and their depositional regime [11] in Gale Crater raise several basic questions about Gale and broader Late Noachian-Early Hesperian valley network environments: 1) Sediment provenance (Where did the sediments originate?); 2) Catchment area (What was the size of the drainage basin?); 3) Sediment protolith (What were the parent rock types for the sediments and how did this change with time?); 4) Sediment pre-processing (What types and amounts of pre-processing did the source materials undergo before they entered the fluvial regime?); 5) Transport distances (How far did pebbles travel to explain observed rounding and grain size?).

In order to provide insight into some of these questions we examine fluvial sedimentary conglomerates (Fig. 1b) of the 15 Ma old 24 km Ries impact crater and related deposits that characterize the crater lake interior margins and floor, and conclude with some implications for the sediments on the Gale Crater interior.

**Ries Crater Lake Fluvial Landforms and Sediments:** There are several sites of unequivocal fluvial influx into the saline crater lake that contain conglomerates, including alluvial fans, deltas and shoreline deposits [18]. The Ulrichberg conglomerates are of special interest, because existing road-cuts as well as former gravel pits [19] are well documented (Fig. 1b) and show 4-5 m thick poorly-sorted pebbly sandstones and conglomerates with rounded crystalline rock clasts. The Ulrichberg conglomerates also help define the catchment area and provenance stratigraphy, showing a well-defined distribution pattern of crystalline and sedimentary ejecta: abundant crystalline rocks (granites, gneiss) and patchy suevite occurrences in the immediate vicinity of the delta, while the former upstream area is almost exclusively composed of allochthonous blocks and breccias of Triassic-Jurassic sedimentary rocks. Lenticular gravel bodies with unidirectional foreset beds of cross-bedding indicate an unequivocal fluvial origin, and the age of these fluviodeltaic deposits is well constrained due to marginal-lacustrine carbonates interfingering with the conglomerates and reworked algal bioherm clasts within the conglomerates; this period is known to mark the transition of the soda lake to a marine-like lake interval [18]. Furthermore, knowledge of the most distant occurrences of granites, isolated between sedimentary ejecta near the tectonic crater rim, indicate a maximum of ~7 km transport distance for crystalline pebbles; however, the scarcity of sedimentary components within the fluviodeltaic conglomerates point to a source within only ~3.5 km distance. Pebbles forming the conglomerates show a wide range of size (commonly 1-3 cm, maximum 9 cm) and roundness; however, many of the pebbles are strikingly well rounded although the conglomerates and pebbly sandstones are poorly sorted. Analysis suggests that the reason for pebble roundness despite short transport distances is the impact-shocked nature of the source material (much more friable and easy to abrade and round). Potential source rocks exposed in the Langenmühle quarry comprise displaced crystalline rocks and polymict breccias with poorly to moderately shocked components.

**Basic Characterization of the Ries Fluvial Sedimentary Environment**: 1) *Sediment provenance*: Ries fluvial sediments clearly originated from impact ejecta on the crater wall and rim. 2) *Catchment area*: Initially the Ries crater lake was characterized solely by internal drainage (internal closed-basin lake [12]) and early fluvial environments were limited to erosion of the steeper crater walls, leading to fluvial erosion of the rim crest and backwasting into rim ejecta deposits; thus, virtually all of the sediments were derived from Ries impact ejecta. 3) *Sediment protolith*: The parent rocks for the sediments were the target rocks for the impact (layered Triassic-Jurassic sedimentary rocks covering a Hercynian crystalline basement). 4) *Sediment pre-processing*: The Ries crater target rocks, and thus the source materials before they entered the fluvial regime, underwent changes in both coherence and mechanical breakdown due to shock effects and abrasion associated with ejection and transport, and physical and chemical alteration related to formation of the suevite and Bunte Breccia units. Furthermore, the target stratigraphy has been inverted and the erosional record indicates a change from (i) initial weathering of crystalline rocks and suevite to (ii) later mobilization of ejected Jurassic sediments (Bunte Breccia) in the catchment area. 5) *Transport distances*: Knowledge of the geology of the Ries crater [18], provenance, and the catchment basin shows that the origin of pebbles and sediments must be less than few km. Rounding of the particles is clearly more related to source material impact *pre-processing* than to transport and rounding over long travel distances..

**Implications for Sediments on the Gale crater Floor:** On the basis of the perspectives revealed by analysis of the Ries crater lake deposits, we infer that the Gale crater conglomerates and related sediments underwent significant sediment *pre-processing*, most recently by the Gale crater-forming event, but also by all previous impacts in the region that produced an early planetary megaregolith. This cumulative pre-processing includes de-lithification, grain-size reduction, particle abrasion and rounding, thermal and shock effects. Ries *basin catchment* and *provenance* strongly implicate small catchment basin size (crater walls and rim), local sources of sediment (pre-processed impact ejecta) and short transport distances (a few km), general characteristics that also apply to Gale Crater. Sedimentary processes in Gale Crater are very likely to be analogous to those in the Ries; sediment provenance is local, representing a significantly pre-processed protolith of friable, shocked impact ejecta that undergoes fluvial erosion, local transport and further particle rounding in alluvial fan and fluvial environments. The highly comminuted, often glassy sedimentary protolith should undergo rapid chemical weathering and breakdown, not clearly seen in the Gale crater examples [11]. Furthermore, additional analysis of Gale crater sediments might reveal evidence for vertical stratigraphic variations that represent a transition in provenance stratigraphy, such as the change observed in the Ries catchment fluvial sedimentary source area [18] from initial weathering of crystalline rocks and suevite to later mobilization of ejected Triassic-Jurassic sediments (Bunte Breccia).

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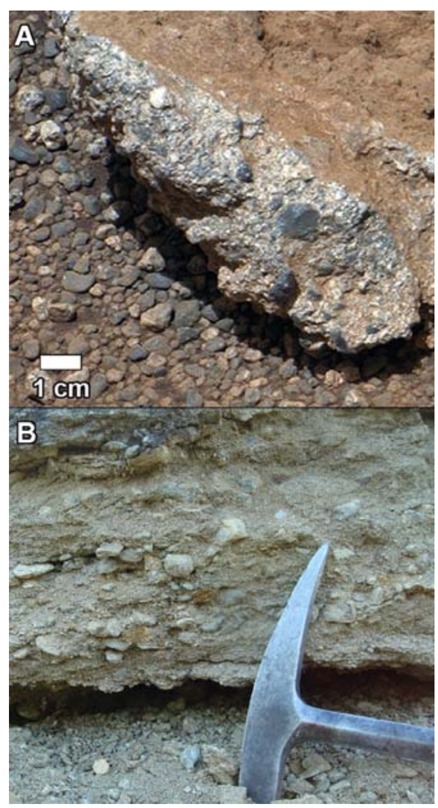


Fig. 1. A) Conglomerate at Gale crater Mars [11]. B) Fluvial conglomerate at the Ulrichberg, Ries Crater.