# Eberswalde Crater	Location (lat,lon):	23.8S, 326.7E

Summary of observations and interpreted history, including unknowns:

Eberswalde crater (first identified as “NE Holden crater” in 2003 by Malin and Edgett) contains a 10 km * 10 km fan structure interpreted by the large majority of the published works as a delta. The delta is up to 100 m thick and shows sinuous, locally meandering channels preserved from erosion and appearing in inverted relief. Sediments at the front of the delta contain clay minerals and are eroded by wind with well-exposed, fresh outcrops of clastic deposits. Opaline silica has also been detected in the deltaic deposits and other crater floor materials. The timing of the fluvial activity is constrained by the presence of Holden ejecta that are incised by the channels leading to the delta, and by the onlapping of delta sediments onto Holden ejecta deposits within Eberswalde crater. The crosscutting relationships show that Eberswalde delta formed later than Eberswalde crater itself, and after Holden crater, which is dated Early Hesperian. The TRN ellipse contains deltaic deposits in addition to the paleolake bottom. The material covering the Eberswalde crater floor is diverse, and it may contain local exposures of lakebeds. The ellipse also contains other units including pitted material of unclear origin, megabreccia that may correspond to Holden impact ejecta, and large veins. Origin of the vein-fill is also uncertain, although igneous processes and hydrothermalism have been proposed. The site does not show any clear evidence for in-place igneous rocks.

Summary of key investigations

- Determine the composition and origin of the clay- and opaline silica-bearing deposits inside the ellipse.
- Seek biosignatures in deltaic and lacustrine deposits
- Reconstruct delta architecture and lake-level history
- Understand the origin of megabreccia and the nature of individual blocks and search for impact glasses related to the Holden event (which could be sampled for age dating)
- Determine the composition and origin of vein material

Cognizant Individuals/Advocates:

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Link to JMARS session file | Link to Workshop 2 rubric summary

https://docs.google.com/spreadsheets/d/16Rmn2qHFQc6BKJtiyIeDLcyBxJqq8Oq4VO3etqrZ8lo/edit?invite=CNm8lqYF&pref=2&pli=1#gid=868597987

Key Publications list (grouped by topic):

Bhattacharya J.P. Bhattacharya, T.H.D. Payenberg, S.C. Lang and M. Bourke, Dynamic river channels suggest a long-lived Noachian crater lake on Mars, *Geophysical Research Letters* **32** (2005), pp. 1–4

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Jerolmack, D. J., Mohrig, D., Zuber, M. T., Byrne, S., 2004. A minimum time for the formation of Holden Northeast fan, Mars, Geophysical. Res. Letters, 31 (21) L21701.

Kleinhans, M.G., H.E. van de Kasteele and E. Hauber, 2010. Palaeoflow reconstruction from fan delta morphology on Mars, Earth and Planetary Science Letters 294, 378-392, doi:10.1016/j.epsl.2009.11.025.

Kraal, E.R., and Postma, 2008. The challenge of explaining Meander bends in the Eberswalde delta, *Lunar Planet. Sci. Conf.,* **39**, Houston, 1897.

Lewis K.W. Aharonson O., 2006. Stratigraphic analysis of the distributary fan in Eberswalde crater using stereo imagery, J. Geophys. Res., Planets, 111 (E6) E06001.

Malin, M. C., Edgett, K. S., 2003. Evidence for persistent flow and aqueous sedimentation on early Mars, Science, 302, 1931, 2003.

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Pondrelli M., Rossi, A.P., Platz, T., Ivanov, A., Marinangeli, L., Baliva A., 2011. Geological, geomorphological, facies and allostratigraphic maps or the Eberswalde fan delta, Planet. Spa. Sci., 59 (11-12) 1166-1178.

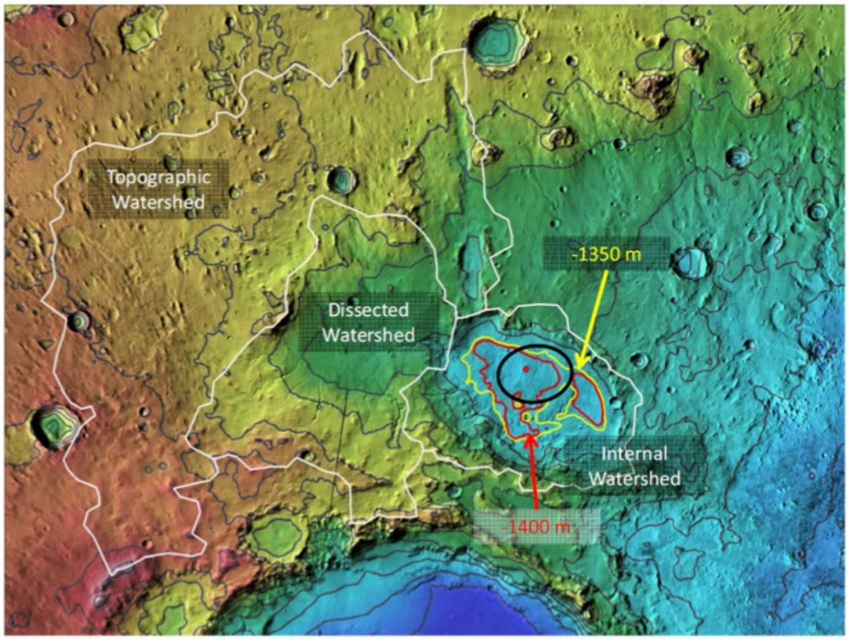
Poulet, F., Carter, J., Bishop, J. L., Loizeau, D., & Murchie, S. M. (2014). Mineral abundances at the final four curiosity study sites and implications for their formation. *Icarus*, *231*(C), 65–76. doi.org/10.1016/j.icarus.2013.11.023

Rice, M. S., S. Gupta, J. F. Bell III, and N. H. Warner (2011), Influence of fault-controlled topography on fluvio-deltaic sedimentary systems in Eberswalde crater, Mars, *Geophys. Res. Lett.*, 38, L16203, doi:10.1029/2011GL048149.

M.S. Rice, J.F. Bell III, S. Gupta, N.H. Warner, K. Goddard, R.B. Anderson (2013), A Detailed Geologic Characterization of Eberswalde Crater, Mars, *Mars*, 8, 15-59, doi:10.1555/mars.2013.0002.

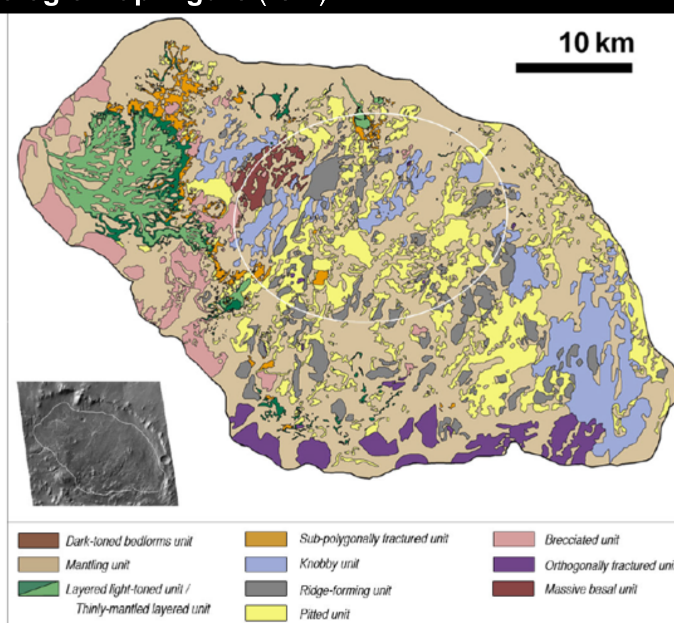
Wood, L.J., 2006. Quantitative geomorphology of the Mars Eberswalde delta, GSA Bulletin, 118 (5/6) 557–566.

Regional Context Figure (ref:)

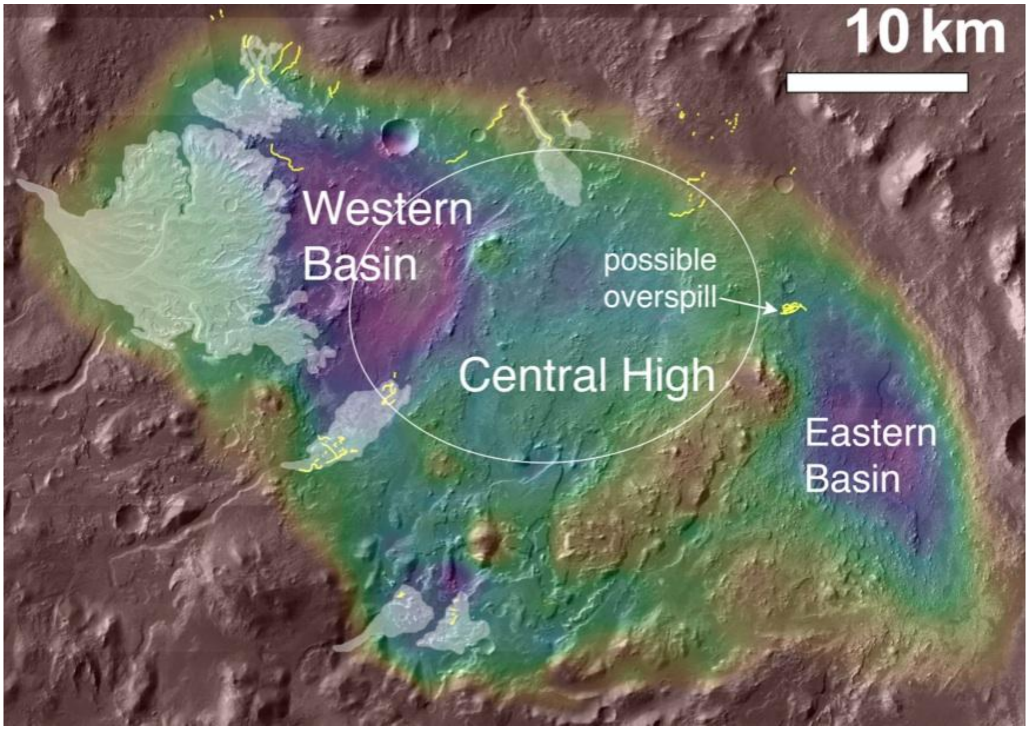


From Rice et al.2015 (2nd LS workshop). The -1350 and -1400 m elevation contours are respectively the upper and lower level of the Eberswalde paleolake based on the elevation of the delta plain.

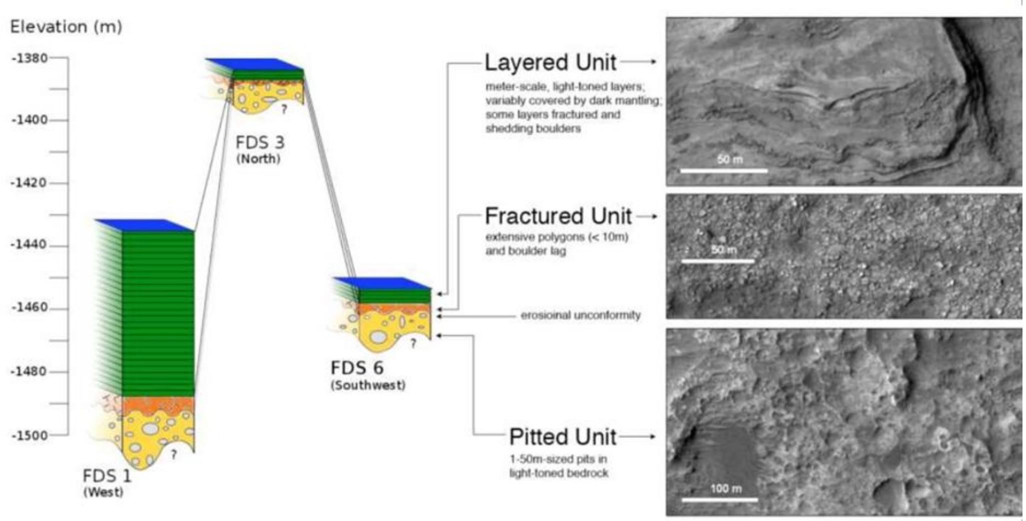
Ellipse ROI Map or Geologic Map Figure (ref:)



From Rice et al., 2013.

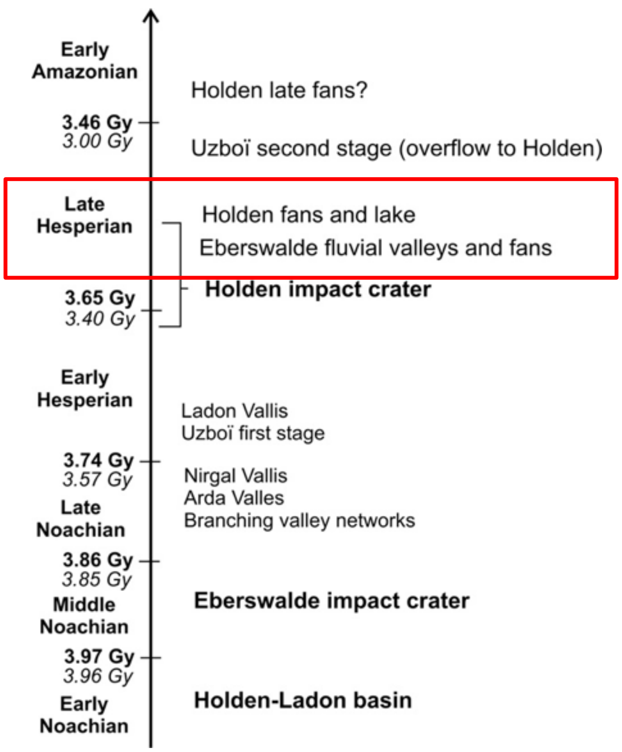


Regional (~3x ellipse) Stratigraphic Column Figure



From Rice et al., 2011. The pile of green sediments at left corresponds to the deltaic sediments.

Inferred Timeline Figure



Absolute model ages from Ivanov (bold) and Hartmann (italic). Establish thanks to cross-cutting relations (Mangold et al., 2012).

Summary of Top 3-5 Units/ROIs

ROI	Aqueous or Igneous?	Environmental settings for biosignature preservation	Aqueous geochemical environments indicated by mineral assemblages
Lake bottom deposits. Polygonally-fractured sediments and possible bottomsets	Aqueous	Lacustrine deposits have high preservation potential	Fe-Mg clay indicates neutral fluids, but authigenic vs. detrital is unknown
Deltaic sediments (coarser fluvio-lacustrine deposits)	Aqueous	Fluvio-deltaic sediments have lower preservation potential	Fe-Mg clay and opaline silica indicate neutral fluids, but authigenic vs. detrital is unknown
Megabreccia	Other	Ejecta containing intact blocks of Noachian bedrock may preserve ULM sediments	Fe-Mg clay could be hydrothermal or pre-existing in megabreccia blocks
Veins	Unknown	Impact hydrothermal system possible, could have high preservation potential	Alteration mineralogy unknown
Silica-bearing crater floor material	Unknown	Depositional environment unknown	Opaline silica may indicate low-T hydrothermal system

Top 3-5 Units/ROIs Detailed Descriptions

Unit/ROI Name: Exposed Lake Sediments

Aqueous and/or Igneous? Aqueous

Description: Layered, clay-bearing sediments make up part of the crater floor. Sediments are polygonally-fractured and contain Fe-Mg clays.

Interpretation(s): Fine-grained lacustrine sediments, likely siltstones to mudstones

In Situ Investigations:

- Search for organics/biosignatures in lacustrine mudstones
- Interrogate vertical stratigraphy, sedimentology, and geochemistry in outcrop of 100-m thick medium to fine grained section to evaluate evolution of depositional environment over time
- Mastcam-Z, WATSON, SuperCAM RMI imaging to document m-scale context to sub-mm textures.
- SHERLOCK mapping to seek organics and/or alteration minerals
- RIMFAX to examine internal layering, including geometry and scale

Returned Sample Analyses:

- Lacustrine sediments with potential biosignatures
- Light and electron microscopy to seek microfossils / mat textures
- Organic geochemistry to seek molecular microfossils
- Inorganic and isotopic geochemistry to seek element concentration and possible metabolic fractionation

Unit/ROI Name: Deltaic deposits (green on the map)

Aqueous and/or Igneous? Aqueous

Description: Up to 100 m thick deltaic deposits with various orbital facies (from block-free well-cemented layers to block-bearing layers), including channel deposits. Gently dipping layers eroded by wind after drying of the lake.

Interpretation(s):

- Siltstones, sandstones to conglomerate deposits from fluvial input inside the Eberswalde basin.

In Situ Investigations:

- Analyze grain size, texture, geochemistry, and mineralogy for sediment provenance and alteration history, cementing agents and diagenesis
- Search for organics/biosignatures in fluvial inputs
- Mastcam-Z, WATSON, SuperCAM RMI imaging to document m-scale context to sub-mm textures.
- SHERLOCK mapping to seek organics and/or alteration minerals
- RIMFAX to examine internal layering structure, including location of subsurface block-bearing layers and channel deposits; if possible, map basal boundary

Returned Sample Analyses:

- Fluvial deposits
- Light and electron microscopy to seek microfossils / mat textures
- Organic geochemistry to seek molecular microfossils
- Inorganic and isotopic geochemistry to seek element concentration and possible metabolic fractioning
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Unit/ROI Name:
Megabreccia (and pitted unit)

Description: Substratum of the Eberswalde lake deposits. Contains breccia with various compositions (as seen from color variations).

Interpretation(s): Breccia from the Holden impact, or perhaps previous impacts. Unlikely to be emplaced before the Early Noachian megabreccia because they post-date Eberswalde crater formation and degradation, but could contain blocks of Noachian material.

In Situ Investigations:

- Mineralogy of crustal blocks and ancient crustal alteration.
- Search for impact glasses related to the Holden event
- Analyze hydrothermal processes from large impacts.
- Mastcam-Z, WATSON, SuperCAM RMI imaging to document m-scale context to sub-mm textures.

- SHERLOCK mapping to seek organics and/or alteration minerals
- RIMFAX to examine structure of boundary between megabreccia and overlying deltaic sediments

Returned Sample Analyses:

- Age dating of impact glasses to date the Holden impact event
- Breccia of crustal material
- Light and electron microscopy to seek microfossils / mat textures
- Organic geochemistry to seek molecular microfossils
- Inorganic and isotopic geochemistry to seek element concentration and possible metabolic fractioning

Unit/ROI Name: Veins

Aqueous and/or Igneous? Unknown

Description: Large number of fracture-fills crossing the substratum and layered deposits

Interpretation(s):

- Fluid circulation and precipitation in veins. Mineralogy unknown. May be related to hydrothermal circulation from the impact ejecta.

In Situ Investigations:

- Determine mineralogy of veins
- Mastcam-Z, WATSON, SuperCAM RMI imaging to document m-scale context to sub-mm textures.
- SHERLOCK mapping to seek organics and/or alteration minerals
- RIMFAX to seek reflections from veins; if detectable, examine subsurface geometry. Map subsurface layering on either side of the veins.

Returned Sample Analyses:

- Light and electron microscopy to seek microfossils / mat textures
- Organic geochemistry to seek molecular microfossils
- Inorganic and isotopic geochemistry to seek element concentration and possible metabolic fractioning
- Age dating of primary igneous material (if present)

Biosignatures (M2020 Objective B and Objective C + e2e-iSAG Type 1A, 1B samples)

Biosignature Category	Inferred Location at Site	Biosig. Formation & Preservation Potential
Organic materials	Exposed lake sediments	Deposition in low energy lacustrine environment along with detrital or authigenic clays
Chemical	Exposed lake sediments	Deposition in low energy lacustrine environment along with detrital or authigenic clays
Isotopic	Breccia	Impact induced mineralization
Mineralogical	Breccia, veins	Impact induced mineralization, hydrothermal fluid circulation
Micro-morphological	Shallow water deposits or exposed lake sediments	Possible preservation of microfossils in shallow water mats. Possible preservation of microfossils in fine-grained lake sediments (shales)
Macro-morphological	Shallow water deposits	Any bacterial mats formed in shallow water

Dateable Unit(s) for Cratering Chronology Establishment

Impact glasses, if present in megabreccia deposits from the Holden event, could be dated to determine the age of the Holden impact.

Key Uncertainties/Unknowns about the Site

List the most important uncertainties, unknowns or potential drawbacks about the site

- How long was the lake there, and were lake levels fairly constant or fluctuating? Paleohydrology estimates a deposition timescale totaling ~10^4–10^6 years (Irwin et al., 2015)
- Exact timing of the fluvio-deltaic activity unknown, although it is constrained to after ~3.65 Ga because it post-dates the Holden impact event
- Units within the ellipse are diverse, but depositional environments of some materials (e.g. opaline silica, large veins) are unknown.
- Lack of definitive igneous units.