HELLAS BASIN WITNESS PLATE: SEQUENCE AND TIMING OF ALTITUDE-DEPENDENT GLACIAL FEATURES ON EARLY MARS. B. D. Boatwright and J. W. Head, Dept. of Earth, Environmental, and Planetary Sciences, Brown University, Providence, RI 02912 USA (benjamin_boatwright@brown.edu).

Introduction: The impact that formed the ~2300 km diameter Hellas basin is one of the most influential events in early Mars history, defining the base of the Noachian period [1] and preserving a geologic record of subsequent events throughout the entire Noachian, the transitional Hesperian, and the Amazonian [2]. The Hellas basin is located in the southern hemisphere and forms a large elliptical expanse consisting of the topographically lowest region of Mars, Hellas Planitia, surrounded by the Hellas basin rim, an annulus of the topographically highest regions in the southern hemisphere outside Tharsis, making up a combined ~5.6×10^6 km^2, or ~4% of the surface of Mars [3-4]. The combined Hellas basin and rim spans nearly half the range of martian global topography and the entire history of Mars from the Early Noachian to present.

We have presented evidence for cold-based glaciation on early Mars by identifying three key types of geomorphic features in the northwest Hellas rim region: closed-source drainage basins [5-6], pit-floored craters [7], and basins containing inverted fluvial channel networks [8]. These features all, in different ways, connect theoretical predictions of early Mars climate scenarios to observational evidence that we have interpreted as being related to major Late Noachian–Early Hesperian climatic events and geologic processes. Now that we have identified these features and their ages, we can begin to place them in a stratigraphic framework in order to test hypotheses of early Mars climate evolution. This "witness plate" can then be compared to other parts of the circum-Hellas highlands and to the rest of Mars.

Geomorphic evidence of highlands glaciation: The presence of steady-state glaciation on early Mars has become increasingly well described [9-11], and recent research has shifted toward characterizing disequilibrium phenomena to answer the question of how the climate transitioned from a primarily altitude-dependent temperature profile in the Noachian to the regime of latitude-dependent temperatures that has characterized the Amazonian [12-13]. We apply our analysis of the altitude and age distributions of crater basin lakes, pit-floored craters, and inverted fluvial channel networks to this problem.

Starting with closed-source drainage basins (CSDBs), we demonstrated how these hydrologically isolated crater basin lakes could have formed through localized top-down melting of cold-based crater wall glaciers in the Late Noachian to Early Hesperian, as late as ~3.6 Ga [5-6]. Additional identifications of CSDBs as well as breached crater basins containing inverted fluvial channel networks demonstrated that localized top-down melting of glacial ice could have provided runoff either directly from crater walls and rim crests or through modest integration and breaching of crater rims by glacially derived meltwater channels [8]. A range of observed crater rim crest elevations suggests that the glacial equilibrium line altitude (ELA) was changing during this time period due to progressively decreasing ice availability at low latitudes [8]. Finally, our conclusion that pitted terrains in circum-Hellas craters most likely formed through sublimation or melting of volatile-rich crater floor deposits demonstrated that water ice stability decreased in these locations due to gradual climate change beginning in the Late Noachian, as early as ~3.8 Ga, with pit floor modification continuing to present [7].

Sequence and timing of altitude-dependent glacial retreat: Combining all of these lines of evidence (Figs. 1-2), we can describe a transitional climate regime in which highland glaciers and other low-latitude volatile deposits were slowly removed and redistributed. At its maximum in the Late Noachian, cold-based glaciation would have encompassed most of the southern highlands [9-11] with only occasional melting due to peak seasonal heating [14] or other punctuated warming events [15-17]. Among the features we identified, pit-floored craters typically occupy the lowest elevations and have the oldest ages, suggesting that pit formation may have commenced during an earlier phase of Late Noachian glaciation characterized by transient snow and ice accumulation/ablation cycles below a largely stable ELA at +1 km [9-11].

The transition into the Hesperian would have seen a steady decline in atmospheric pressure leading to the simultaneous breakdown of greenhouse warming, resulting in colder global temperatures and decreased atmospheric water vapor content, and weakening of the adiabatic cooling effect (ACE) that would otherwise favor snow and ice accumulation in the highlands [13]. This would lead to a dual effect of decreasing water ice stability at low latitudes, causing the ELA to rise to higher elevations.

The comparative altitude and age distributions of pit-floored craters and proglacial paleolakes reveals evidence for these types of changes (Fig. 2). The wider, generally lower altitude distribution of PFCs indicates that these features formed mostly below the range of glacial ice stability starting in the Late Noachian; proglacial paleolakes are restricted entirely to altitudes above the +1 km ELA and would have formed later during a transitional period of glacial ice removal that extended into the Hesperian. This "rising ELA" scenario could account for both the wide apparent altitude distribution of proglacial crater lake basins as well as the favored formation mechanism for the pit-floored craters through sublimation and melting of volatile-rich crater floor deposits. Evidence presented for glacial melting in the high-altitude regions of Terra Sabaea to the west of Huygens crater is also consistent with this hypothesis [18-19].

Future work and relation to other circum-Hellas terrains: The completion of a Hellas basin witness plate will depend upon comparisons between the northwest Hellas region and other circum-Hellas terrains. Large areas of the Hellas basin floor and southeastern rim were resurfaced by Noachian–Hesperian flood volcanism [3-4,20], volcano–ice interactions [21-23], and Amazonian latitude-dependent mantles [24]. Other areas where Noachian-aged terrain is exposed, such as Promothei Terra (Fig. 1), may have experienced greater ice accumulation rates than in the northwest [23]; these ancient terrains could therefore contain evidence for proglacial fluvial and lacustrine activity. Future investigation of southeast Hellas geology will provide important information on potential mechanisms of climate change and atmospheric warming on early Mars.

While the possibility of snowmelt to explain geologic evidence of fluvial erosion on Mars has been entertained multiple times in the past [25-26], a broad-scale interpretive framework for glacially derived fluvial and lacustrine features in the Noachian has yet to be formulated. Using our Hellas basin witness plate, we hope to lay the groundwork for future investigations of early Mars glaciation in order to better understand how these processes operated in the context of global Mars climate evolution from the Noachian to the present.

References: [1] Tanaka K.L. et al. (2014) USGS SIM 3292; [2] Fassett C.I., Head J.W. (2011) Icarus 211; [3] Leonard G.J., Tanaka K.L. (2001) USGS I-2694; [4] Bernhardt H. et al. (2016) Icarus 264; [5] Boatwright B.D., Head J.W. (2021) PSJ 2; [6] Boatwright B.D., Head J.W. (2022) PSJ 3; [7] Boatwright B.D., Head J.W. (2022) PSS 222; [8] Boatwright B.D., Head J.W. (2023) PSS 225; [9] Wordsworth R. et al. (2013) Icarus 222; [10] Wordsworth R. et al. (2015) JGR 120; [11] Fastook J.L., Head J.W. (2015) PSS 106; [12] Fastook J.L., Head J.W. (2022) LPSC 53; [13] Head J.W. et al. (2022) LPSC 53; [14] Palumbo A.M. et al. (2018) Icarus 300; [15] Halevy I., Head J.W. (2014) Nat. Geos. 7; [16] Palumbo A.M., Head J.W. (2018) MAPS 53; [17] Segura T.L. et al. (2012) Icarus 220; [18] Bouquety A. et al. (2019) Geomorph. 334; [19] Bouquety A. et al. (2020) Geomorph. 350; [20] Bernhardt H., Williams D.A. (2021) Icarus 366; [21] Cassanelli J.P., Head J.W. (2018) Icarus 305; [22] Hargitai H.I. et al. (2018) Astrobio. 18; [23] Fastook J.L., Head J.W. (2023) LPSC 54; [24] Kreslavsky M.A., Head J.W. (2002) GRL 29; [25] Craddock R.A., Howard A.D. (2002) JGR 107; [26] Moore J.M., Howard A.D. (2005) LPSC 36.

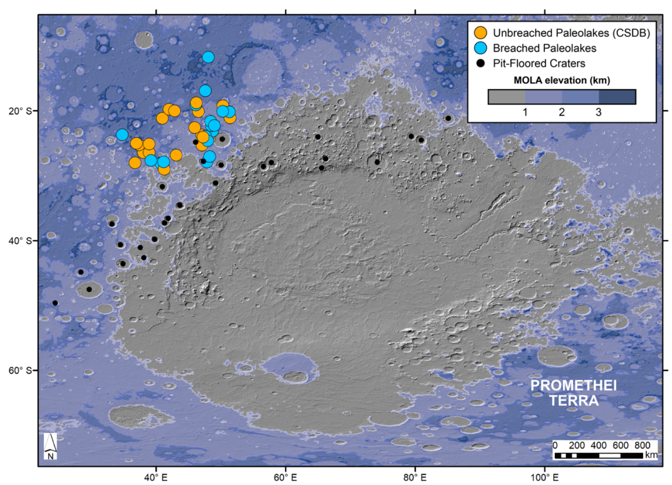

Fig. 1. Map of Hellas basin showing locations of previously identified proglacial paleolakes and pit-floored craters [5-8]. Color scale shows 1-km intervals corresponding to hypothesized glacial ice removal during the Late Noachian and Early Hesperian, starting at an initial equilibrium line altitude (ELA) of +1 km. Other Noachian-aged circum-Hellas terrains such as Promethei Terra may also contain evidence for proglacial fluvial and lacustrine activity.

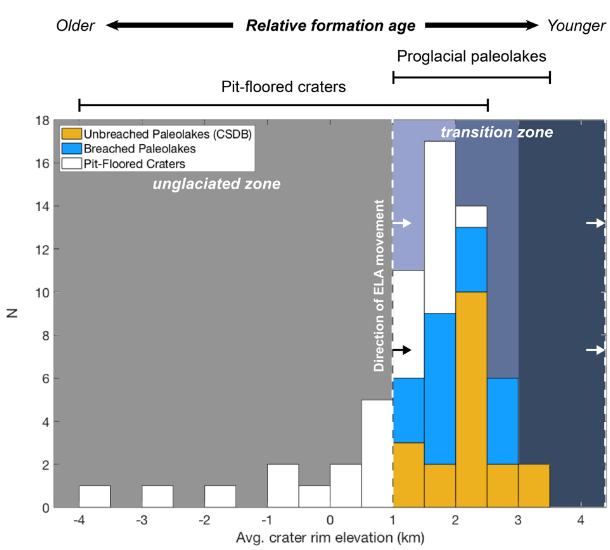

Fig. 2. Histogram of proglacial paleolake and pit-floored crater altitude distributions. PFCs occupy a wider, lower range of altitudes, while proglacial paleolakes are found exclusively above the nominal glacial ELA of +1 km. The ELA increased over time, resulting in melting and destabilization of ice at lower altitudes. The time dependence of glacial ice removal implies that PFCs generally formed prior to proglacial paleolakes. Background color shading corresponds to altitude contours shown in Fig. 1.