Introduction: The Late Noachian (LN) climate, be it warm and wet or cold and icy, is inherited from events that occurred earlier in Mars history [1]. We first outline what is known and what remains unexplained about Noachian/Hesperian history and events, and then examine the full range of geological processes known to precede and immediately follow the Late Noachian period of fluvial and lacustrine activity. We conclude that this new geologic/stratigraphic framework provides an important perspective in which to view the climate history of early Mars which we develop separately [2].

Knowns and Unknowns: Fassett and Head [3; see references therein for the following points] reviewed the sequence and timing of conditions on early Mars (Fig. 1), and we use this as a baseline for identifying key knowns and unknowns, focusing on the Noachian. 1) Mars was characterized by the existence of an *active magnetic dynamo*; unknown is whether this persisted into the Noachian, and the influence of its decay and demise on the retention of the atmosphere. 2) Early Mars was characterized by a *much higher impactor flux* and a more significant role for impact cratering at all scales; unknown is the flux size-frequency distribution, whether its decay was monotonic [4], and how much of the volatile inventory and atmosphere were provided by this exogenous mechanism. 3) *Multiple large impact basins*, the largest being the Borealis Basin, formed during this period, including, in the Noachian, Hellas, Isidis and Argyre; unknown in detail are the effects of these individual basin-scale events on the atmosphere, surface, and interior. 4) *Magmatic processes* (plutonism/intrusion and volcanism/extrusion) were of critical importance in building the crust, resurfacing the evolving cratered surface, and providing exsolved (endogenous) volatiles to build the atmosphere; unknown is the time of transition from pre-Noachian early crust to the dominance of mantle-derived magmatism and volcanic resurfacing, the volcanic flux and resurfacing rate, the ratio of effusive to explosive eruptions, the nature of mantle petrogenesis and implications for the surface mineralogy, and endogenous volatile contributions to the atmosphere. 5) A significant part of the *Tharsis rise/volcanic province* had been constructed by the end of the Noachian; unknown is the mechanism for its formation, the detailed volcanic flux and implications for endogenous atmospheric input, and even whether Tharsis could have been constructed after LN valley network (VN) formation [5]. 6) Formation of the Tharsis rise stabilized Mars from *true polar wander* (TPW); unknown is whether Tharsis emplacement caused TPW, and whether TPW ever occurred. 7) The emplacement of *widespread flood lavas* occurred in the Late Noachian and Early Hesperian, resurfacing at least 30% of Mars and played a huge role in endogenous atmospheric input, potentially significantly warming and altering the climate episodically; explosive volcanic activity, forming paterae and ash deposits, also occurred; unknown is the petrogenesis, magmatic volatile content and flux, and the influence of emplacement on the climate. 8) Impact craters underwent significant degradation during the Noachian, erasing craters <~10-20 km; larger craters lost sharp rim crests and ejecta and underwent significant infilling and shallowing; unknown is the exact mechanism(s) of degradation and infilling, the relation to warm and wet [6] or cold and icy [7-9] climates (Fig. 2) and the implications for climate history. 9) Crustal rocks underwent *widespread aqueous alteration and phyllosilicate formation* during the Noachian, requiring environments above 273K for a range of times (Figs. 2, 3); unknown are the required ranges of elevated temperatures and times, and the exact environments of formation (subsurface hydrothermal, surface climate environmental?). 10) Minerals readily altered by the *presence of liquid water*, apparently dating from the Noachian (e.g., olivine), are *often preserved* to the present, in apparent contradiction to the extensive development of phyllosilicates and related alteration minerals. 11) Weathering/erosion rates were *orders of magnitude higher* in the Noachian than immediately thereafter, although still much lower than those on Earth; unknown are the process(es) responsible and the cause of the radical decrease. 12) An *assemblage of liquid water-related features* (VN, hundreds of open and closed-basin lakes, and perhaps oceans), provides extensive geologic evidence for aqueous precipitation (rainfall), regional overland flow and drainage, lake formation and perhaps oceans; unknown are the specific climatic condition that
led to this assemblage of features, and whether they formed contemporaneously, continuously or episodically. 13) Estimates of the initial global water budget range over several orders of magnitude; the surface/near-surface water budget at the end of the Noachian has been estimated at ~ 24 GEL [10]; unknown are the original global abundances, additions and losses with time, and evolution of the total water budget, its partitioning to the surface/near surface inventory, and its state. 14) Noachian Mars was characterized by a much higher atmospheric pressure than today, perhaps even as much as several bars; unknown are the sources and relative proportions of the gases contributing to the atmosphere, their accumulation and loss rates, fluctuations during the Noachian, and the nature of the transition to Hesperian/Amazonian atmosphere and climate. 14) The Noachian transition to the Hesperian period involved major changes in cratering (decreased flux, no major basins), volcanism (flood basalts decrease after Early Hesperian), mineralogy (phylllosilicates to sulfates), fluvial processes (VN to LH outflow channels), atmospheric pressure, and erosion rates; unknown are the rates of these changes, their possible relationships, and their influence on climate history. 15) The Noachian climate has been interpreted to be characterized over some period by warm and wet conditions [6] (Figs. 2, 3) required by pervasive phylllosilicate alteration, extensive crater degradation and infilling, and the presence of valley networks and related pluvial, fluvial and lacustrine features; unknown is the nature of the ambient background climate (e.g., was it “warm and wet”, “warm and arid” both with MAT >273 K) (Fig. 3) or “cold and icy” (MAT ~225 K) (7-9) (Fig. 4) with episodic, periodic punctuated excursions to 273 K (Fig. 3).

**Summary:** On the basis of these Noachian knowns and unknowns, we apply a stratigraphic approach to the major geological processes and observations [2] to provide insight into potential changes as a function of time.

![Fig. 2. Temperature-time framework for Noachian climate history illustrating key MAT (mean annual temperatures).](image)

![Fig. 3. Baseline “warm and arid/wet” climate conditions.](image)

![Fig. 4. Baseline “cold and icy” climate conditions.](image)

**References:**