McCauley, 1978; see also Chapters 5 and 6); and (iii) Chasma Boreale may have formed from meltwater from the north polar cap (Clifford, 1980; Fishbaugh and Head, 2002).

Numerous estimates have been made of peak discharges and the volumes of water involved in the floods. The main difficulties are knowing the flood depth and how long the floods lasted. Channel depths can be measured but they give only an upper limit for the stream depth. Most estimates of peak discharges for the largest channels range from 10^7 to 10^8 m^3 s^{-1} depending on the channel and the assumed depth (Baker, 1982; Leask et al., 2007; Robinson and Tanaka 1990). If the floods formed by water, then a groundwater source appears almost inescapable for channels such as Shalbatana, Tiu, Maja, and Ares that originate in chaos-filled depressions and for those such as Mangala and Athabasca that originate at graben. The sources are likely extensive aquifers trapped below a thick cryosphere. The discharges from such aquifers would be restricted by the dimensions of the aquifers, their permeability, the hydrostatic head, and the dimensions of the conduit to the surface (Carr, 1979; Manga, 2004). Andrews-Hanna and Phillips (2007), by modeling the eruption of groundwater from an overpressurized aquifer trapped below a kilometers thick cryosphere, estimated that for a typical Ares flood peak discharge ranged from 10^6 to 10^7 m^3s^{-1} and that 10^3–10^4 km^3 of water were erupted. The volume of Ares Vallis is roughly 8×10^4 km^3, so many floods may have been needed to erode it, according to this model. The high discharges require that the aquifer be pressurized. This could result simply from the aquifer topography and supply of water from highs such as Tharsis and Elysium (Carr, 1979; Harrison and Grimm, 2005a, 2005b) or from tectonic pressurization, particularly for channels such as Mangala and Athabasca that start at faults (Hanna and Phillips, 2005). Emplacement of dikes may also have contributed to water release, by melting of ground ice and creating fractures that act as both horizontal and vertical conduits (Head et al., 2003).

The apparent scarcity of groundwater eruptions to form large floods in the Noachian may have resulted from the lack of a thick cryosphere. Their repeated occurrence in the Hesperian may be another consequence of a change in surface conditions at the end of the Noachian that is implied by the decline in the formation of valley networks and hydrated weathering products. The change led to the growth of a thick cryosphere, thereby enabling the trapping of water and large groundwater eruptions. The decline in groundwater eruptions toward the end of the Hesperian could result from a variety of causes such as depletion of water below the cryosphere, growth of the cryosphere to engulf most of the high-porosity megaregolith, and declining tectonic and volcanic activities.

2.5.2 Valles Marineris

The Valles Marineris present some of the most puzzling issues of Martian geology, including how and when they formed, the origin of their interior layered deposits, whether the canyons ever contained lakes, and if so how the lakes formed and dissipated (Chapters 5 and 6). The primarily structural origin by movement along faults radial to Tharsis was recognized early (Blasius et al., 1977; Sharp, 1973).