2007). The Columbia Hills (Squyres et al., 2006) may be typical of the cratered Noachian uplands in general. They comprise mostly basaltic rocks of various types, including pyroclastic flows and impact breccias. Many of the rocks have undergone aqueous alteration, suggestive of circulation of hydrothermal fluids. Detection of primary igneous minerals, particularly olivine, in much of the Noachian terrain (Bibring et al., 2006) may indicate limited weathering after the deposition of the uppermost layers. However, the widespread presence of hydrated silicates deeper in the section and in alluvial fans indicates widespread aqueous alteration prior to deposition of the upper olivine-rich units.

Formation of Tharsis deformed the Martian lithosphere on a global scale to create a trough around the rise, an antipodal high, and gravity anomalies, as predicted by loading of a spherical elastic shell with the Tharsis topography (Phillips et al. (2001). That Tharsis was largely in place at the end of the Noachian is demonstrated by slope indicators such as valley networks and lava flows. Roughly 3×10^8 km^3 of rock accumulated to form Tharsis, the equivalent of a global layer 2 km thick. If the magmas contained amounts of water similar to the Hawaiian basalts, the global equivalent of a layer of water 120 m deep would have been outgassed, together with significant amounts of sulfur. If all of Tharsis accumulated in the Noachian, the extrusion rate would have been 0.75 km^3 year^{-1}, roughly equivalent to the Hesperian extrusion rate estimated by Greeley and Schneid (1991) for the entire planet. For comparison, the extrusion rate for the Earth is 4 km^3 year^{-1} (Crisp, 1984). Another possible site of large accumulation of Noachian volcanics is the northern basin, including Utopia.

2.4.1 Erosion rates

The Noachian terrains are clearly more eroded than younger terrains. While Hesperian craters as small as a few kilometers across generally preserve all their primary impact features, even delicate textures on their ejecta, Noachian impact craters hundreds of kilometers across mostly have highly eroded rims and partly filled interiors. However, even though average Noachian erosion rates were 2–5 orders of magnitude higher than they were subsequently, they still appear to have been close to or well below terrestrial rates (Carr, 1992; Golombek and Bridges, 2000; Golombek et al., 2006). The number of fresh appearing craters with well preserved ejecta patterns on Noachian terrains is comparable to the number on Hesperian terrains, which suggests that high erosion rates persisted until the end of the Noachian and then rapidly declined (Craddock and Maxwell, 1993).

Low average rates of erosion in the Noachian compared with the Earth are consistent with preservation of the planet's larger features. The Noachian era is roughly equivalent to the time on Earth from the end of the Silurian to the present day. On Earth, during this time, continents assembled and disassembled, the present-day ocean basins opened, and numerous mountain chains formed and were eroded away. The fact that the Hellas basin is preserved gives an indication of the average Noachian erosion rates. The denudation rate for the continental United States is roughly 50 m 10^{-6} years (Judson and Ritter, 1964), or 20 km in 400 Myr, the