depression itself. From the geologic evidence the dichotomy could have formed at any time between the formation of the crust 4.5 Gyr ago and the formation of the oldest of the clearly superimposed impact basins, such as Utopia and Chryse, around 4.1 Gyr ago according to the Frey (2003) chronology.

The mode of formation of the dichotomy is also uncertain. One possibility is that the dichotomy is the result of one or more large impacts (Andrews-Hanna et al., 2008; McGill and Squyres 1991; Wilhelms and Squyres 1984). The outline of the basin is roughly circular except in Tharsis where younger volcanics are superimposed on the boundary and in Chryse where there may be a younger superimposed basin. Zuber et al. (2000) and Neumann et al. (2004) expressed skepticism that the northern lowlands could be an impact scar because there is little evidence for extreme thinning of the crust as there is within Hellas and Isidis, nor is there a perceptible rim around the basin. They prefer an early internal origin, tied to global mantle convection (Wise et al., 1979; Zuber et al., 2000; Zhong and Zuber 2001; Solomon et al., 2005). However, the thicker crust and absence of a rim around the proposed impact basin may simply reflect an extremely old age, and Andrews-Hanna et al. (2008) have recently attempted to reconcile the geophysical data with an impact origin. If the basin formed very early, soon after formation of the crust, it would have experienced erosion, sedimentation, isostatic rebound, and volcanic filling for hundreds of millions of years, an era almost as long as the terrestrial Phanerozic, before a more complete geologic record emerged after the formation of the Hellas basin at the start of the Noachian.

Surface conditions in this early era prior to the formation of Hellas are very uncertain. One certainty is that the surface was episodically disrupted by very large, basin-forming impact events. Formation of these large (>500 km diameter) craters and basins would have resulted in the ejection of large amounts of rock vapor and rock melt into and beyond the atmosphere, evaporated any oceans that might have been present, and raised the surface temperatures to several hundred kelvin (Segura et al., 2002; Sleep and Zahnle 1998). Despite the low solar luminosity, surface temperatures could have remained above freezing for years after each large impact event. Water that was injected into the atmosphere during the initial impact and during the subsequent warming of the surface and subsurface could rain out over years, the time depending on the size of the impact. Conditions during the long (possibly millions of years) periods between basin-forming events would have depended on the effects of smaller impacts and on the ability of the atmosphere to provide significant greenhouse warming during this era of low solar luminosity, which in turn would have depended on the thickness of the atmosphere and it composition, particularly the abundance of trace greenhouse gases such as CH_4 and SO_2.

In summary, the geologic record of the pre-Noachian era extending from the time of formation of the planet 4.5 Gyr ago to the time of formation of Hellas estimated at around 4.1 Gyr ago is sparse. The planet differentiated into crust, mantle, and core within a few tens of millions of years of planet formation, the global dichotomy probably formed early, and the planet had a magnetic field. Large impact craters and basins that formed episodically would have had devastating environmental effects.