THE TERRESTRIAL RECORD OF AN EXTENDED LATE HEAVY BOMBARDMENT. Donald R. Lowe¹ and Gary R. Byerly², ¹Dept. of Geological and Environmental Sciences, Stanford University, Stanford, CA 94305 USA, drlowe@stanford.edu. ²Dept. of Geology and Geophysics, Louisiana State University, Baton Rouge, LA 70803 USA, glbyer@lsu.edu

Introduction: While the primary record of the early bombardment history of the Solar System is preserved on extraterrestrial bodies, it should not be overlooked that there exists a terrestrial record of giant impacts until at least 3.2 billion years ago (Ga). That record includes 8 major impact layers 3.2 to 3.5 Ga discovered and described by the authors from Archean rocks in the Barberton greenstone belt (BGB), South Africa, and Pilbara Block, Western Australia [1,2,3]. These layers have led to the inference that the terrestrial flux of large asteroids during this interval was perhaps several orders of magnitude greater than that of the modern era and that the Late Heavy Bombardment (LHB) had a very long tail that was still depositing large bolides on the terrestrial surface at 3.2 Ga [4,5,6,7]. The known layers represent distal settings, far removed from the impact sites, and contain distinctive spherical particles (spherules) formed by the condensation and solidification of impact-generated rock vapor clouds [2,3]. These impacts also produced globe-encircling tsunamis and widely fractured surface rock layers. Several spherule beds coincide with stratigraphic horizons marking major tectonic events, suggesting that the Earth’s crustal development was probably influenced or controlled by impacts to at least 3.2 Ga.

Barberton spherule beds: The BGB spherule beds range from 3.23 to 3.47 Ga in age (Fig. 1). Individual layers reach up to 5 m thick but most have been widely removed by nearly syndepositional erosion. With the possible exception of S7, all include spherules (Figs. 2 and 3) formed by condensation of impact-generated rock vapor clouds. All of the BGB spherule beds represent settings far removed from the impact sites: there is an absence of coarse ballistic ejecta and thick breccia layers, and the spherules more resemble those found in younger distal ejecta blankets [2,3,5]. For the three layers where we have Cr-Mn isotopic analyses (S2, S3, and S4), the results indicate that the bolides were carbonaceous chondrites [8].

The great thicknesses of relatively pure fall-deposited spherule layers, up to 35 cm, their distal depositional settings, and, in a few cases, modeling based on estimated bolide vs target rock contents [9] suggest that all represent bolides larger than 20 km in diameter and some may have exceeded 70 km [6, 7]. All were large compared to virtually all known post-2.5 Ga bolides.

Figure 1. Stratigraphy of the Barberton belt showing distribution and ages of impact layers S1 thru S8. Vertical lines, mafic and ultramafic volcanic rocks; v’s, felsic volcanic rocks; black, cherty sediments; stippled, detrital sedimentary rocks. * indicates spherule beds dated by detrital zircon geochronology. Stanford SHRIMP single-zircon analyses with ±3 Ma precision.

These layers document the profound effects that large impacts had on the early terrestrial surface, surface environment, and, probably, life. The detailed records of surface events before, during, and following the individual impacts are quite variable but almost all show evidence of major current- and/or wave-activity that mixed the spherules during and immediately following deposition with debris eroded from the sea floor and surface volcanic rocks. We have interpreted these events as tsunamis generated by the impacts or resulting crustal movements. The inferred distal depositional sites imply that there were few or no large landmasses to impede propagation of the tsunami waves around the globe. Consistent with this observation, the geochemistry and mineral composition of the spherule beds, including the lack of shocked quartz and zircons, and available geochemical modeling of impact layer compositions, indicating that the target rock was mafic crust, collectively suggest that there was a paucity or absence of large continental blocks at that time.

Several of the impacts triggered fracturing of the
crust in the present BGB area. In the case of S2, open fractures extended through at least the upper 100 m of surface rock and were filled by the downward flowage of surface sediments and loose spherules [10]. At least 2 of the spherule beds, S2 and S8, are associated with major regressive events, and exposure and erosion of the sea floor. Throughout the southern part of the BGB, S2 (3.256 Ga) marks the end of over 250 million years of anorogenic, largely basaltic and ultramafic volcanism and initiation of large-scale, long-term deformation and orogenic activity that culminated 175 myr later in the formation of the Kaapvaal Craton. In the northern part of the belt, this transition occurred somewhat later, about 3.243 Ga, and is marked there by spherule bed S3. Much of the Archean development and evolution of the Earth’s crust and geodynamic system may have been triggered by large impacts.

These early impact layers also hold an accessible record of the latest LHB. While much of the time interval represented by the Barberton greenstone belt is represented by volcanic rocks (Fig. 1), many of the interbedded thin sedimentary layers preserve records of impact events. The frequency of large-body impacts implied by the beds discovered to date exceeds by several orders of magnitude the impact rates for comparably-sized bodies during later geologic time [5]. These results indicate that the Late Heavy Bombardment did not end abruptly at about 3.8 Ga but fell off gradually, with common large impacts persisting until at least 3.2 Ga. These results must be incorporated into models of the bombardment history of the inner Solar System.

Acknowledgments: Funding from Stanford University to Lowe; Louisiana State University to Byerly.