Introduction: Noble gases serve as tracers of planetary processes, including accretion and differentiation, mantle outgassing, and atmospheric loss. Of particular interest is xenon, with 9 stable isotopes. Xenon reservoirs are usually thought of in terms of mantle and atmosphere, but noble gases have solubilities 2-3 orders of magnitude higher in layered phyllosilicates than in mantle minerals [1-3], and so they could act as another reservoir. During magma ocean solidification, a significant fraction (70-99%; [4]) of mantle volatiles are outgassed to build up a dense atmosphere (Fig. 1a; [4]). These conditions are ripe for significant aqueous alteration of the early crust [4,5], potentially forming a thick layer of phyllosilicates [5]. Here, we explore the possibility of sequestering significant amounts of Xe in early hydrated crusts formed from a steam atmosphere.

Model Set-up: A box model was used to assess the potential of an early, hydrous crust to trap and store Xe. Initial I, U, and Pu contents and isotopic ratios were back-calculated from modern Bulk Silicate Mars, as well as the initial $^{129}$I/$^{127}$I ratio of C3 chondrites [6-9]. The decay products of $^{129}$I and $^{244}$Pu were calculated for a fully degassed mantle 40 Myr after solar system formation, with all Xe produced in the first 10 Myr assumed to be lost from the system during accretion. The total mass of phyllosilicates, partial pressure of Xe in the atmosphere, and solubility of Xe in phyllosilicates were then used to calculate the total mass of Xe stored in the hydrous crust [3,10].

Results: In the most conservative case, a global layer of clays 15-20 cm thick is able to retain concentrations of Xe in excess of those observed on Mars today. In combination with mass-dependent fractionation, sequestration of Xe in phyllosilicates can produce a unique set of Xe isotopic ratios on planetesimals that may be preserved to this day.

Discussion: Clay minerals have been identified on the surface of large planetesimals like Ceres [11], but the exact formation mechanisms remain unclear. Based on the results of this model, the Xe isotopic system on these planetesimals may be able to distinguish clays formed very early in the body’s history from those formed due to later alteration.

Figure 1. Diagram of Xe sequestration model. a) Outgassing of volatiles to form a thick, steam atmosphere with chondritic Xe during magma ocean phase b) Hydration of early crust sequesters Xe into clays with I-derived $^{129}$Xe anomaly, but without Pu-derived Xe; atmospheric loss produces mass-fractionation slope.