WARMING EARLY MARS BY IMPACT DEGASSING OF REDUCED GREENHOUSE GASES. R.M. Haberle[1], K. Zahnle[1], and N. G. Barlow[2] , [1]Space Science and Astrobiology Division, NASA/Ames Research Center, Moffett Field, CA 94086, [2] Dept. Physics and Astonomy, Northern Arizona University, Flagstaff, AZ 86011.

Introduction: Reducing greenhouse gases are once again the latest trend in finding solutions to the early Mars climate dilemma [1,2,3]. In its current form collision induced absorptions (CIA) involving H_2 and/or CH_4 provide enough extra greenhouse power in a predominately CO_2 atmosphere to raise global mean surface temperatures to the melting point of water provided the atmosphere is thick enough and the reduced gases are abundant enough. Surface pressures must be at least 500 mb and H_2 and/or CH_4 concentrations must be at or above the several percent level for CIA to be effective. Atmospheres with 1-2 bars of CO_2 and 2-10% H_2 can sustain surface environments favorable for liquid water. Smaller concentrations of H_2 are sufficient if CH_4 is also present.

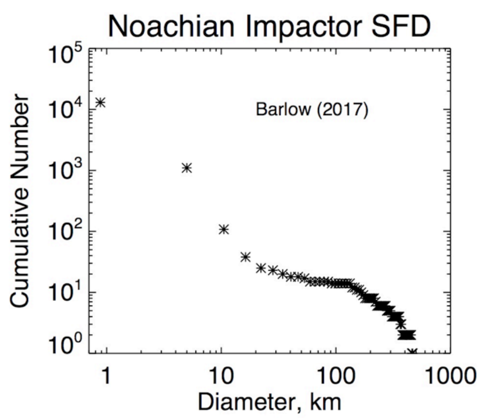

Fig 1. Cumulative number of Noachian impactors greater than a given size.

If thick CO_2 atmospheres with percent level concentrations of reduced gases are the solution to the faint young Sun paradox for Mars, then plausible mechanisms must be found to generate and sustain the gases. Possible sources of reducing gases include volcanic outgassing, serpentinization, and impact delivery; sinks include photolyis, oxidation, and escape to space. The viability of the reduced greenhouse hypothesis depends, therefore, on the strength of these sources and sinks. In this paper we focus on impact delivered reduced gases.

A Simple Model. To assess the potential for warming early Mars by impact degassing of reduced greenhouse gases we construct a simple model that time marches through the Noachian keeping track of gases added to a 1 bar CO_2 atmosphere by impacts (sources) and removed from the atmosphere by escape (sinks). We then relate the gas concentrations to surface temperatures using the model of [2].

Sources. The source of reduced gases is impactors. Thus, we need to determine the impactor size-distribution, the delivery history, and the fraction of mass of each impactor converted to H_2 and CH_4. The impactor size-distribution is determined from the observed crater distribution of Noachian surfaces using the catalog compliled by [4]. We identified all craters superposed on Noachian-aged terrain which no longer retain an obvious ejecta deposit, an indication of formation during the Noachian period [5]. We also used the list of Quasi-Circular Depressions with ages younger than 4.2 Ga from [6] to identify buried craters. We then used scaling relationships to convert from crater to impactor diameter. The results are shown in Fig 1. Except for those impactors with known ages (e.g., Hellas), the delivery history is random, a typical example is shown in Fig 2. The fraction of mass converted to reduced gases is based on the gas equilibrium calculations of [7,8,9]. We expect that the quenching temperature of a cooling gas following an impact event is in the 1000-1500 K range and we make use of the molar abundaces of gases produced at these temperatures estimated by these authors. Various chondritic materials are considered, but in all cases the major gases (assuming H_2O condenses) are CO_2, CO, H_2, and CH_4 with the relative concentrations depending on impactor type. We scale the results to the carbon or water content of a given impactor type to estimate the fraction of impactor mass converted to these gases. For our assumed quenching temperatures it turns out that CH_4 is a minor constituent so we ignore it for now noting that we are therefore determining a lower limit. For H_2 the mass fraction (f_{H2}) ranges from 0.04% for the H-chondrites to 0.4% for comets.

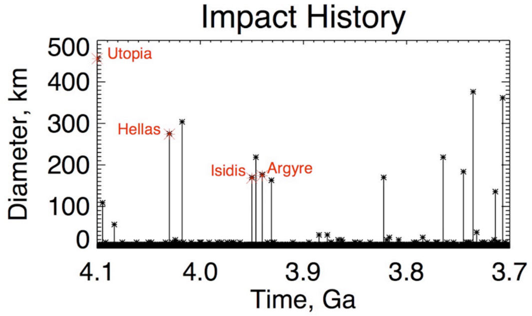

Fig 2. Impact history for a typical run.

Sinks. H_2 escapes in the model at the diffusion limit provided the volume mixing ratio (VMR) is below that corresponding to the energy limited regime which depends on the Sun's XUV flux, a time dependent quantity in the model. Fig 3 illustrates these two regimes. The transition between them occurs for a H_2 VMR ~1 at 4.1 Ga when the XUV flux is about 20 times its present value. VMR's this high can be achieved by volatile-rich cometary impactors greater than 300 km in diameter.

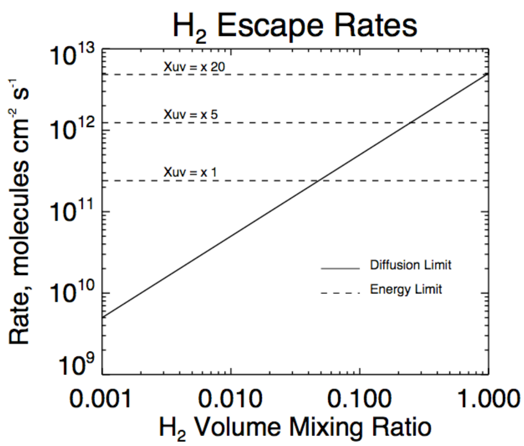

Fig 3. Hydrogen escape rates. Diffusion limit = (H_2 VMR) x b/H where b/H=10^{13} molecules cm^{-1} s^{-1}. Energy limited escape is shown for several values of the XUV flux. For a given VMR, the model uses the smaller rate.

Results. Fig 4 shows a typical result for a single simulation with f_{H2}=0.4%. Large impactors (> 100 km) raise surface temperatures well above freezing on multiple occasions.

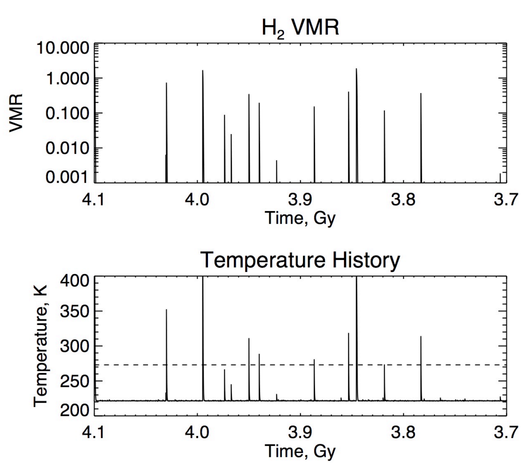

Fig 4. H_2 VMR and temperature history for a simulation with f_{H2} = 0.4%. Dashed line is melting point of water.

The total time spent above freezing in Fig 4 is ~6 My; it is ~3x10^5 years for H-chondrite impactors. For the large impactors (see Fig 5) the time spent above freezing for individual events (~10^5 years) is much longer than that of the energy based model of [10]. Furthermore, temperatures following large volatile rich impacts are warm enough (>300K) and last long enough to enable the formation of phyllosilicate-rich outcrops on the surface of Mars. Clay formation in transient warm wet environments, such as those produced in this study, is favored by [11].

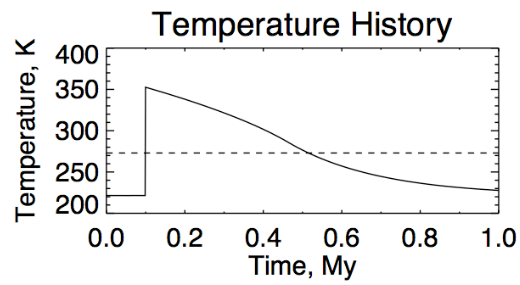

Fig 5. Temperature history for the Hellas impact event.

Conclusions. These results point to a new role for impacts on early Mars. Instead of warming just with the energy they deliver they also warm by degasing reduced greenhouse gases and H_2 in particular. The strength of this hypothesis is that impacts did occur and they must have degassed significant quantities of reduced gases. Furthermore, the events are transient but longer lived than the original Segura et al. models - long enough, therefore, to cause more erosion and mineral alteration. The weakness of the hypothesis is that it requires thick CO_2 atmospheres and that most of the warming comes from the large impactors which are thought to occur early in the Noachian. Thus this mechanism may not explain the valley networks which are believed to occur later in the Noachian. Nevertheless, impacts did occur and they must have had an effect. These results open up a new line of research for early Mars that merits careful consideration.

References: [1] Ramirez R. et al. (2014) Nature Geo. 7, 59-63. [2] Wordsworth R. et al. (2017) Geophys. Res. Lett., 44, 665-671. [3] Ramirez R. (2017) Icaurs, 297, 71-82. [4] Barlow N. G. (2017) LPS XLVIII, Abstract #1562. [5] Barlow N. G. (1990) JGR, 95, 14191-14201. [6] Frey H. (2008) GRL, 35, L13203. [7] Schaefer L. and Fegley B. (2007) Icarus, 186, 462–483. [8] Schaefer L. and Fegley B. (2010) Icarus, 208, 438–448. [9] Hashimoto G.L. et al. (2007) J. Geophys. Res., 112, E05010. [10] Segura T.L. et al. (2008) J. Geophys. Res., 113, E11007. [11] Bishop J.L. et al. (2017) Fall AGU, New Orleans, Abstract P31F-04.