Determining Planetary Tectonic State Through Time Using Observations of the Terrestrial Planets. M. S. Duncan[1] and M. B. Weller[2]; [1]Geophysical Laboratory, Carnegie Institution of Washington, 5251 Broad Branch Rd. NW, Washington, D.C. 20015, mduncan@carnegiescience.edu; [2]Institute for Geophysics at University of Texas, Austin, 10100 Burnet Road, Austin, TX 78758, mbweller@ig.utexas.edu.

The current and past tectonic states of the planets are directly related to the processes that are active and visible on their surfaces today. In particular, changes in large-scale tectonic behavior, e.g., the transition from a stagnant lid regime to a mobile lid regime, have the potential to significantly influence the current geomorphology, geochemistry, and surface state (e.g., atmosphere composition and temperature) of a planet. We must understand what controls a change in global tectonic regimes, as well as the current differences in tectonic states for the planets that we can most easily observe (Earth, Mars, Mercury, and Venus). Therefore, understanding the planets in terms of the feedbacks between its geodynamic and geochemical histories, for example, is critical to make predictions of the future states of planets as well as the potential habitability of intra- and extra-solar planets.

One method of combing the geochemical and geodynamic is via determinations of mantle potential temperature (T_P) through time in concert with mantle convection models. We use measurements of surface basalts of these planets to calculate their mantle T_P through time, with appropriate assumptions, and feed these temperatures into the geodynamic models in order to describe past, present, and future lid state. These kinds of determinations are relatively easy for the Earth, due to the wealth of measured surface basalts, but are necessarily limited for the other terrestrial planets. In particular, the level of information that exists for Venus is abysmally low, and while significantly more information exists for Mars, and even Mercury, the number of assumptions required to make these predictions is uncomfortably large. With the current level of data we can make preliminary calculations of mantle T_P of the terrestrial planets (Fig. 1). Overall the Venus T_P values show overlap with the Earth values, while the calculation based on martian meteorites show much lower mantle temperatures and the Mercury values are quite scattered.

We run mantle convection experiments of fixed parameter values that allow for transitions in lid states (Fig. 2) that provide information about how the internal temperature (T_P) changes as a function of lid state rather than by specific parameter values. Using these results with well-known internal temperature-heat production scaling arguments [9], we have shown that shown estimates of mantle potential temperatures can be used as a diagnostic of lid-state and lid-state evolution [1]. The caveat is that these results are currently tantalizing, but informed by very limited datasets, particularly in regards to Venus.

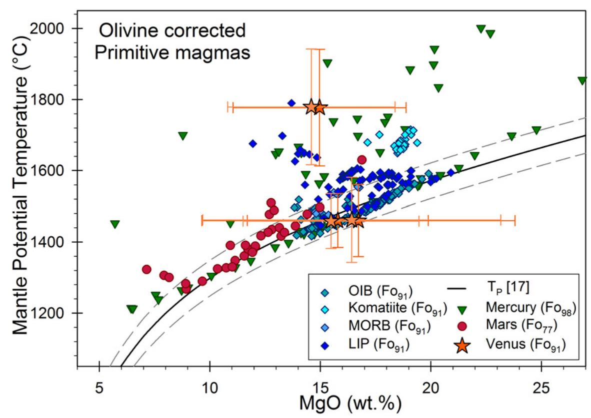

Figure 1: Calculated T_P of mantle based on olivine corrected 'primitive' melt compositions, mantle 'equilibrium' olivine Fo values in parentheses [1]. Calculated potential temperatures based on Ti partitioning between bulk silicate mantle and melt, compared to the parameterization of [2]. Earth T_P values (blue diamonds) calculated from basalts in various tectonic settings tabulated from the GEOROC database. Mercury T_P values (green triangles) determined from MESSENGER data [3-5], Mars T_P values (red circles) determined from martian meteorites and measurements of surface basalts [6,7], and Venus T_P values (orange stars) determined from surface compositions measured by the Venera and Vega landers with the 2σ error [8].

In order to understand the planets in a comparative evolutive sense demands at the very least a comparable amount of data to use in baseline observations. In the case of Venus, this indicates that analysis and understanding of the basaltic plains, which encompass the vast majority of the planetary surface (upwards of 80%) [10], need to be a priority for mission design and development. For Mercury, a vast improvement for future missions would be to specifically measure the major and minor elements independently of each other [3-5], and include a focus on in situ measurements for cross-correlation within major regions (each of the geologic terrains). For Mars, while there is a cornucopia of surface data, the focus has been on water. For our purposes (thermal-tectonic evolution) we need to focus on regions that have not undergone significant (or any) hydrothermal alteration such as Tharsis, Thaumasia/Solis Planum, and northern lowland locations.

With higher spatial and temporal sampling of the inner terrestrial planets, we have the ability to infer the tectonic history of these bodies. Armed with this new found knowledge, we can not only test hypotheses of Earth's evolution, but also infer its eventual fate. These results can further be used to extrapolate habitability through time in our Solar System, and infer the potential for habitability in the ever increasing catalog of extra-solar planets being discovered.

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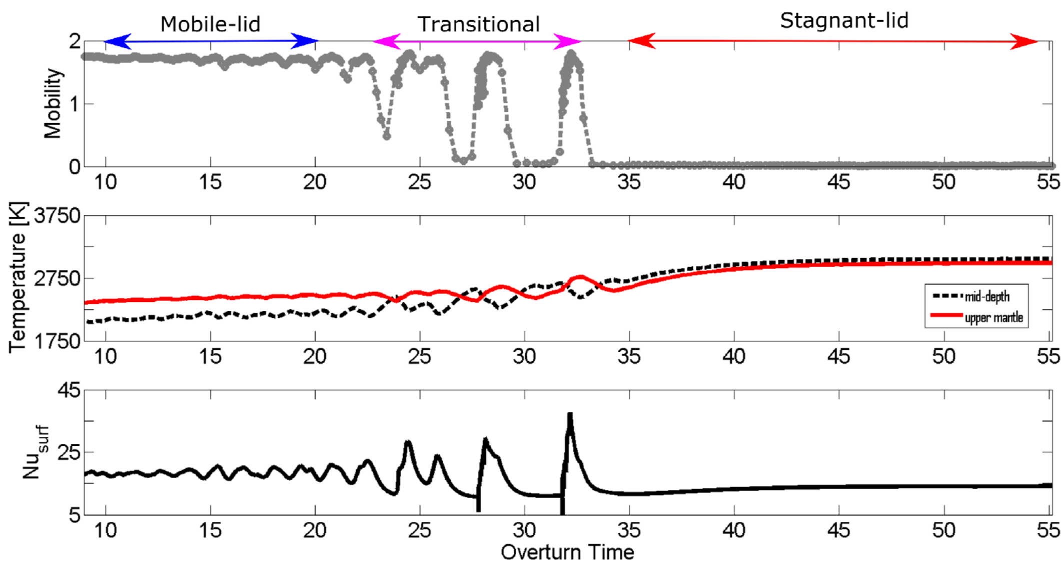

Figure 2: Results from 3 dimensional spherical mantle convection code CitcomS [11] showing a global tectonic regime evolution (for fixed model parameters). Top panel Mobility, is a measure of surface velocity versus system velocity (Mobility = Surface V_{rms} / Total System V_{rms}, where V_{rms} is the root mean square velocity). Middle panel Temperature, are temperatures in the upper mantle (red line) and lower mantle (dashed black line). Temperatures are dimensionalized using a total system temperature contrast of 3000 K (for use in T_P calculations). Bottom panel, Nu_{surf}, non dimensional surface heatflow. The overturn time (x-axis, all panels) corresponds to the time a parcel takes (on average) to traverse the mantle (computed from the V_{rms}). The Rayleigh number (standard definition for basally heated systems using the viscosity at the system base) is 3e5, with an input internal heating rate set at 65 (moderately high levels of internal heating).