INVESTIGATING THE INTERIOR OF TERRESTRIAL PLANETS AND MOONS USING ELECTRICAL LABORATORY MEASUREMENTS. A. Pommier[1], A. S. McEwen[2], and L. P. Keszthelyi[3]. [1]UC San Diego - SIO (pommier@ucsd.edu), [2]LPL, University of Arizona, [3]U. S. Geological Survey.

Introduction: Electrical conductivity of mantle and core analogues is particularly relevant to investigate the structure and dynamics of planetary interiors. Being a transport property sensitive to temperature, pressure, and chemistry (including volatiles and fluids), electrical conductivity can be used to explore the present-day compositional and thermal state of planets and moons. In particular, the combination of electrical experiments in the laboratory (using the impedance spectroscopy technique) and field electrical data (using electromagnetic (EM) measurements) has proved to be efficient at placing constraints (e.g., fluid fraction, chemistry) on planetary mantles [1 and refs. therein, 2]. Electrical conductivity can also be used to study the state of a metallic core and investigate the generation of an intrinsic magnetic field by thermochemical convection, as suggested for the cores of Earth, Mars, Mercury, Ganymede, and the Moon [3-7].

On Earth, the combination of field (EM) and lab electrical data is used to explore both time and space evolution of different tectonic contexts (e.g., subduction zones, mid-ocean ridges), and in particular, locate the origin of primary magmas, constrain the extent of melting, locate aqueous fluids reservoirs, and identify the main chemical fluxes at depth, thus providing critical constraints for petrological and geodynamic modeling [1]. Several space missions have also demonstrated the relevance of combining field and laboratory electrical measurements to probe the interior of planets and moons [e.g., 2, 8]. This approach, which does not require the presence of a lander for field measurements, has a unique potential to improve significantly and even transform our knowledge of planetary bodies as part of future space missions.

In particular, the Io Volcano Observer (IVO) mission concept [9] will use the electrical technique to study the interior of Jupiter's moon, characterized by tidal heating and intense volcanism. The combination of field electrical data (obtained using a Dual Fluxgate Magnetometer (DMAG) and a Plasma Instrument for Magnetic Sounding (PIMS)) with lab electrical experiments on Io analogues at relevant conditions will place constraints on the abundance and distribution of melt in Io's mantle, therefore providing insight on the distribution and migration of melt at depth. This knowledge is necessary to understand tidal heating processes and the heat-pipe tectonics of Io, the latter being considered as an analogue for early terrestrial planets, including Hadean Earth [10].

Here we emphasize the unique potential of lab electrical measurements to explore planetary interiors as part of space missions. In particular, we show that electrical measurements in the lab can be used 1) to identify the presence and storage conditions of aqueous fluids and melts in mantles, and 2) to characterize the state of metallic cores and the intrinsic magnetic field.

Electrical models of planetary mantles: Field observations considered in tandem with lab electrical measurements and petrological constraints can be used to refine models of the composition and thermal state of silicate mantles. In particular, the presence of interconnected fluids (such as a melt reservoir or a subsurface ocean) and the presence of volatiles (e.g., H,C-bearing species) lead to electrically conductive anomalies [e.g., 8,11].

On Earth, the interpretation of EM images across subduction zones using lab studies has improved our understanding of H and C cycles, slab dehydration, and upward melt migration from the mantle wedge [1]. Electrical lab studies applied to the mantle of the Moon suggested that the electromagnetic sounding data from the Apollo era support the hypothesis of the presence of interconnected melt at the base of the lunar mantle [2,12]. In the case of Io, tidal forcing is thought to be responsible for the presence of melt in the mantle. The amount and distribution of melt in Io's mantle is not known yet and represents one of the science objectives of IVO. *Fig.1* illustrates the importance of the geometry and chemistry of the melt phase on bulk conductivity.

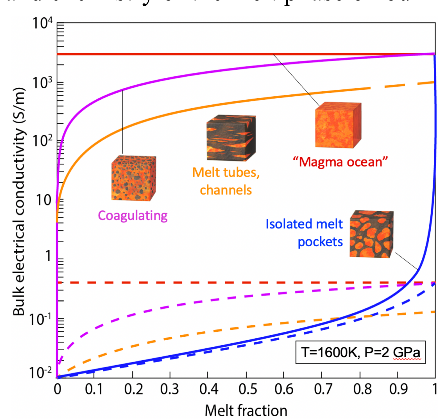

***Figure 1**: Laboratory-based electrical models of a S-rich (~7at.% S), Fe-rich (12.7at.% Fe) basalt in an olivine matrix at 1600K and 2GPa using different geometries [e.g., 11, 13]. Dashed lines correspond to models using an Fe-free basalt with a similar S content. S-rich lavas have been observed at Io's surface [13].*

A bulk electrical value can correspond to several possible scenarios, due to a complex interplay between melt fraction and distribution, temperature, and chemistry [11]. The number of plausible scenarios can be narrowed down using input from field observations (e.g., DMAG data in the case of IVO), thermal and petrological constraints.

Electrical properties of metallic cores: The investigation of core dynamics requires constraining the superadiabatic heat flux, i.e. the heat available to drive convection, which depends strongly on the thermal conductivity of the core materials. Thermal conductivity k can be estimated from electrical conductivity σ at a temperature T using the empirical Wiedemann-Franz law: $k = L_0 \times T \times \sigma$, with L_0 the Lorenz number. This law provides lower bound estimates of k for iron alloys, and at first approximation, an upper bound of k for Ni-bearing alloys can be calculated assuming a 30% increase in thermal conductivity values [14]. The heat flux q_a along the adiabat in the core is then obtained:

$$q_a = -k \times \frac{dT_a}{dr} \text{ with } \frac{dT_a}{dr} = -\alpha \times g \times \frac{T_a}{C_P}$$

with r the core radius, α the thermal expansivity, g the gravity, and C_p the heat capacity [e.g., 15].

Applied to the cores of Ganymede and the Moon and assuming homogenous cores, lab electrical measurements up to 8 GPa provided q_a estimates that highlight the effect of core chemistry on the heat flux (*Fig. 2*). A similar amount of heat is conducted at any depth along the adiabat gradient of a Fe-Ni(-S) core, whereas less heat is conducted down this gradient at shallow depth in a Ni-free core. Because variation in heat conduction is critical to drive convection, these results imply that it is possibly easier to drive convection in a Ni-free core than in a Ni-bearing core. New modeling studies considering fractional crystallization scenarios are required to assess the importance of k gradients with depth on convection.

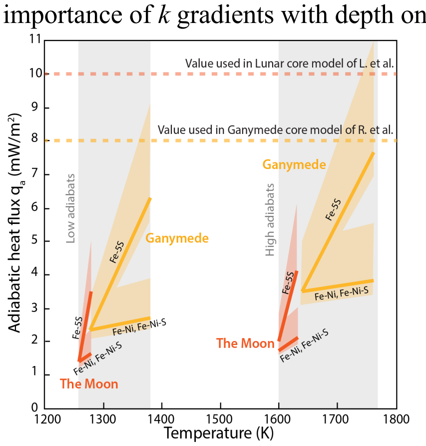

***Figure 2**: Heat fluxes q_a across Ganymede and the Moon cores considering Fe-S and Fe-S-Ni systems [14]. The red and yellow shaded areas are q_a with varying α ($1.05 \cdot 10^{-4}$ ($\pm 2.5 \cdot 10^{-5}$) K^{-1}). Dashed lines are q_a values used in previous core modeling studies [5-6], gray areas are adiabats from [15].*

In Mercury, the structure and present-day state of the metallic, Si-bearing core remains largely unconstrained [16]. Electrical experiments on core analogues up to 10 GPa and under T show that, if present, an FeS layer at the core-mantle boundary is liquid and insulating, and that the electrical conductivity of a miscible Fe-Si(-S) core is comparable to the one of an immiscible Fe-S, Fe-Si core (*Fig. 3*). Corresponding k estimates suggest that a thick (> 40 km) FeS-rich shell is expected to maintain high temperatures across the core. If temperature in this layer departs from an adiabat, then this might affect the core cooling rate. The presence of an insulating shell is consistent with a thermally stratified core.

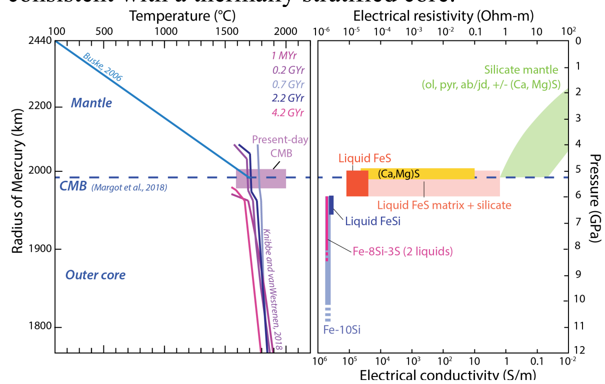

***Figure 3**: Internal thermal (left) and electrical (right) structure of Mercury's mantle and outer core [after 12]. The depth of the core-mantle boundary (CMB) is from [16]. Thermal structure for the present-day and past is from [17, 18]. Mantle resistivity calculated using the geometric means.*

Conclusion: Lab electrical studies help understand the structure and dynamics of planetary mantles and cores. The future of space exploration would highly benefit from combinations of field and lab electrical measurements. In particular, electrical data as part of the IVO mission will contribute to determine the amount and distribution of melt at depth, which is required to investigate tidal heating processes.

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