Electromagnetic geophysics and CIG

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A wide range of active and passive electromagnetic (EM) geophysical methods have been developed for determining variations in electrical conductivity (or resistivity) within the Earth. Most rock forming minerals are highly resistive, but small amounts of ionic fluid, interconnected reduced carbon, as well as some minerals (e.g., sulfides) can dramatically increase bulk rock conductivity, provided these phases are interconnected. Mantle minerals are semiconductors, with conductivity sensitive to temperature, oxidation state, and the small amounts of water. Natural (passive) source methods such as magnetotellulrics or geomagnetic depth sounding (using only magnetic field variations) are most relevant to studies of deep crustal or mantle conductivity; active source methods are limited to shallow targets and are most often used for near surface or resource industry applications.
Data quality has increased steadily over the past few decades—until digital data acquisition and processing were fully developed the subtle signatures of subsurface conductivity variations were not easy to pull out. EM fields satisfy a diffusion (actually, vector Helmholtz) equation in a conductor, and as a result resolution tends to be proportional to depth. Compared to seismology, EM methods will always have poor resolution. However, they do have much better intrinsic vertical resolution than potential field methods, and are sensitive to physical properties (probably most importantly, the presence and connectivity of fluids) that are often not well resolved (at least not uniquely) by seismology. EM methods thus have the potential to provide complementary and useful constraints on the composition and physical state of the crust and mantle. With recent development of 3D modeling and inversion capabilities, EM methods are in a position to make important contributions to our understanding of deep Earth processes.

A meeting to discuss what the EM community can do to be more organized and share resources more effectively was held in Berkeley, March 11-13, 2009. One topic discussed was open source shared software, for tasks from data processing to modeling and inversion codes. Perhaps CIG could provide a mechanism for maintaining and distributing at least the modeling and inversion codes, which have so far are of the “heroic” variety. This would be conceptually comparable to supporting seismic modeling codes, though it would serve a smaller community. Obviously this is something that needs to be discussed within the EM community (I am raising the issue, as part of ongoing efforts to produce a white paper on the Berkeley meeting), and also obviously resources would have to be available for CIG to support something new. I am bringing this up so that the proposal writing committee is aware of this possibility to expand the community served by CIG. I can provide further information if necessary.

Appendix: Some recent results (my group).

As examples, I attach figures from two recent studies that I have been involved in. The first (Patro and Egbert, 2008, GRL; see also OnSite, the EarthScope National Office newsletter, Sept. 2008) is an image of conductivity beneath the Pacific Northwest, based on 3D inversion of MT data collected as part of EMSCOPE, the MT component of the EarthScope transportable array (TA: we hope to cover 20-25% of the continental US at the same spacing as the seismic TA). The most striking and robust feature revealed by the inversion is an extensive, triangular-shaped area of high conductivity in the lower crust beneath the southeastern part of the array (C1 in Figure 1); the area is bounded to the north by a line running from the coast to the Blue Mountains and includes the Northwest Basin and Range (BR) province of southeastern Oregon. The conductance of this layer, which is about 15 km thick with a top at roughly 20 km depth, exceeds 3000 S beneath the BR. This lower crustal conductance is comparable to the highest values seen in other tectonically active areas around the world. The high conductivity in this region is inferred to result from fluids – including possibly partial melt at depth – associated with magmatic underplating and BR extension.

The lower crust is much more resistive to the northwest of C1 beneath the Coast Range, Willamette Valley and Puget Lowlands of Western Washington and Oregon (R1a), and beneath the Columbia Plateau (R1b). These parts of the crust were derived from a large fragment of thickened oceanic lithosphere that was accreted to North America at approximately 48 Ma. Geological and geodetic studies show this section of crust is strong, accommodating tectonic stresses through rigid block rotations. In contrast, the area to the southeast characterized by high conductivity in the lower crust is actively deforming, consistent with an important role for fluids in weakening of continental crust. An elongated N-S zone of high conductivity beneath the Cascade volcanoes (C2) breaks up the resistive lower crust of R1. High conductivity beneath the volcanoes also most likely reflects the presence of interconnected fluids, in this case released from the subducting Juan de Fuca plate. Significant variations in upper mantle conductivity are also revealed by the inversions, with the most conductive mantle beneath the northern part of the array in the backarc (C3) and the most resistive corresponding to subducting oceanic mantle under the western edge of the array (R2).

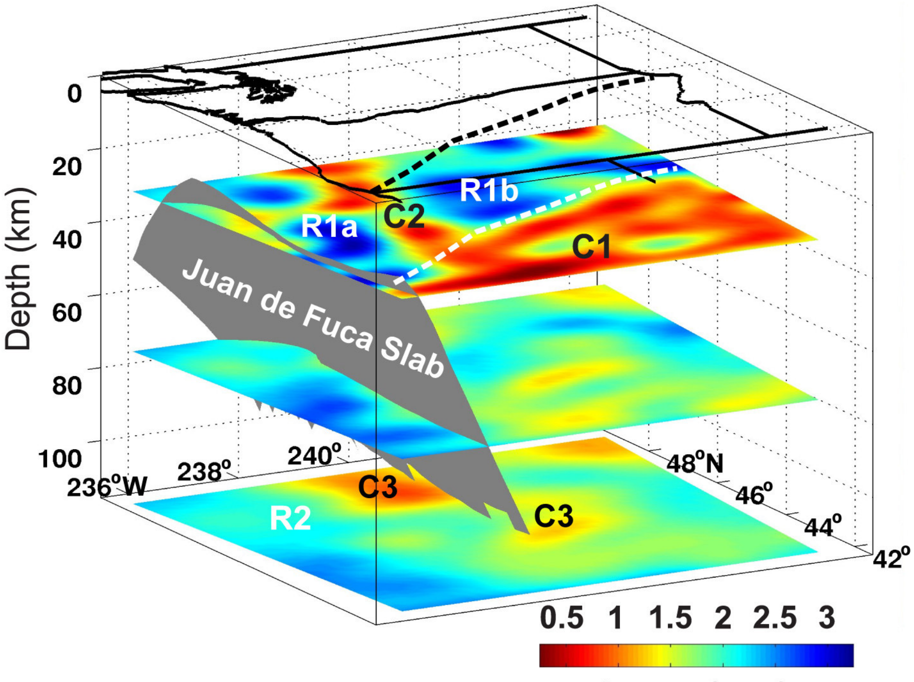

Figure 1: 3D resistivity image of the Pacific Northwest from 3D inversion. C1-C3 and R1-R2 conductive and resistive features are discussed in the text.

The second example is an initial application of a 3D spherical Earth inversion we have developed, fitting geomagnetic observatory transfer functions for periods of 5-100 days (Kelbert et al., submitted to Nature, 2009. The inversion, reveals variations in the electrical conductivity within the transition zone of approximately one order of magnitude. Conductivities are high in cold, seismically fast, areas where slabs have subducted into or through the transition zone. Note that in this initial effort (based on previously processed data) there are significant gaps in data coverage—e.g., no sites in South America are included. Significant variations in water content throughout the transition zone, from less than 0.1 wt% (e.g. in the central Pacific) up to at least 1 wt% (in the Japan backarc) provide a plausible explanation for the observed patterns. These results would support the view that at least some of the water in the transition zone has been carried into that region by cold subducting slabs. Efforts to refine this initial inversion, in particular improving data coverage and control over possible external source complications are underway.

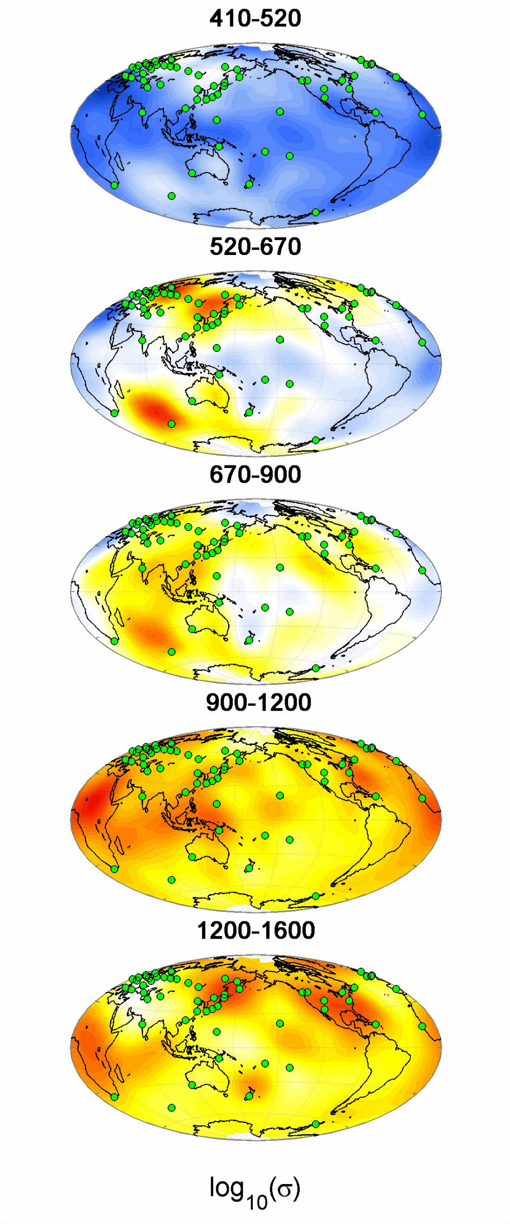

Figure 2: Regularized degree and order 9 inverse electrical conductivity solution, based on the C responses from the mid-latitude subset of the global observatory data set of Fujii and Schultz (2002). This data set has been corrected for the near-surface effects as described by Kuvshinov et al. (2002). The 59 data locations are denoted by green dots; the depths from the Earth's surface are indicated in km. The RMS misfit of this model with the C ratios is 1.14. Regions of poor spatial resolving power have been identified in Kelbert et al. (2008) for the specified observatory distribution and frequency range. These include most of Africa and the Indian Ocean, Southern Pacific and the South America.