The evolution of a continent: Thirteen years of EarthScope Magnetotelluric Three-Dimensional Imaging of the United States

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For the past fifteen years, the US National Science Foundation EarthScope Program has systematically mapped the three-dimensional structure and dynamics of the Continental United States by deploying seismic, geodetic and magnetotelluric stations on a continental scale. Incorporated Research Institutions for Seismology (IRIS), a prime award recipient of NSF EarthScope funding has supported Oregon State University (OSU) as the lead institution in executing the EarthScope Magnetotelluric Transportable Array (MT TA). For the past thirteen years, OSU has operated a large MT instrument facility (currently ~100 long-period and wideband MT instruments), and it has directed the mapping of 3-D electrical conductivity structure of the US crust and mantle on a grid of MT stations spaced ~70 km apart. Approximately 1100 MT TA stations have been completed to-date. The US Geological Survey has also contributed 47 long-period MT stations in key regions, and the University of Alberta in Canada has made its long-period MT stations available to EarthScope as well.

The 70-km MT TA grid is instrumented by temporary arrays of long-period MT instruments (Narod Geophysics NIMS systems) that are used to generate MT response functions over the frequency band of $\sim 10^{-4}$ Hz $< f < 10^{-1}$ Hz, providing information on electrical conductivity structure from mid-crust (~10 km) to upper mantle (~300 km) depths. The original timeseries data are processed into MT tensor impedances and induction vectors (“tippers”). After quality control review, timeseries are archived in miniSEED format, and impedances and tippers are archived in EDI and XML formats. All data reside on internet-accessible servers within the IRIS Data Management System. From the beginning of the EarthScope Program, all MT (and other EarthScope data) have been available to anyone to use without restriction and free of cost. The current status of the EarthScope MT array is seen in the figure below.

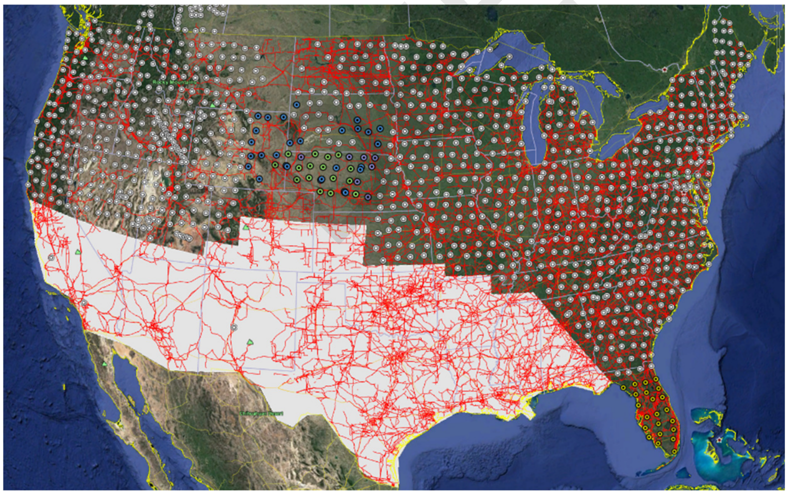

Figure 1. The status of the EarthScope MT TA station grid as of summer 2018. White circles are MT TA stations installed and completed during 2006-2017. Colored circles represent MT TA stations installed in 2018 (as of July 2018); station installations have continued through the summer and into the autumn, with the goal of filling in the MT TA station grid in the northern Great Plains so the large western and eastern arrays are joined completely and a continuous array from the Pacific to Atlantic oceans will be achieved. The white area is planned for completion after the end of the EarthScope Program.

The EarthScope Program has officially ended on September 30, 2018, although MT activities are continuing past that date. At the conclusion of EarthScope, the MT TA array spanned 2/3 of the area of the conterminous USA, with the southern tier of states not yet instrumented. Plans are currently underway for continuing the MT TA using funds from a number of different Federal agencies, with the goal of completing the 70-km MT station grid within the next ~5 years.

In addition to the MT TA station grid, the NSF EarthScope and related programs such as GeoPRISMS have supported higher-resolution long-period and wideband MT array installations to obtain additional information in areas where geophysical targets of interest have been identified by analysis of the MT TA array data. Specific projects include the largest amphibious (seafloor and land-based) MT array ever undertaken, along the Oregon continental margin (the MOCHA Project); a very high resolution wideband MT and active/passive seismic project in the southern Washington Cascade volcanic arc designed to image the sources of melt beneath the major volcanoes (the iMUSH Project); detailed wideband MT studies of Yellowstone supervolcano; and a novel MT study in the interior of Alaska combining a large synchronously operating array of MT instruments operating underneath the footprint of an ionospheric imaging incoherent scattering radar system.

Some of the key findings of analysis of the MT TA data, as well as of the more focused studies just indicated will be presented. These studies have revealed the impact of previously undiscovered deep crustal igneous intrusive bodies (batholiths) on the migration of deep melt and the location of surface volcanic features in the Cascade volcanic arc, as well as the relationship between metasedimentary bands left over from crustal accretion events and the path of melt migration and enhanced seismicity. Images of the electrical conductivity variations immediately above the subducting Juan de Fuca-Gorda plates have been used to infer the fluid content at the plate-mantle wedge interface, and studies are underway to understand the relationship between lubrication of the boundary by such fluids and plate locking in this great megathrust seismic zone. MT data have shown evidence for the trace of an ancient (1.1 Ga) deep mantle plume as the source of melt during the incipient continental rifting event that formed the Mid-Continent Rift system, and which is linked to the formation of economically important banded iron formations. The MT TA data set, as well as recently acquired wideband MT data are more clearly illuminating the relationship between deep crustal melt sources that shallow up from the Snake River Plain and serve as the source of melt beneath Yellowstone caldera, and the well-known surface hydrothermal features that are located there. Important new information on the evolution of eastern North America has also been revealed by analysis of MT TA data.

In addition to important results of direct relevance to solid Earth geoscience questions, EarthScope MT TA data have become an important element of research efforts to understand and potentially to mitigate damage to the electric power grid due to the effects of geomagnetically induced currents arising from space weather events, such as the 1989 Hydro-Québec wide-area power failure, or the mid-19th century Carrington Event that badly impacted the global telegraph network. Researchers around the world have made use of MT TA data to study and more accurately model the ground level electric fields that result from geomagnetic disturbances, and how these fields couple into the high-voltage power transmission network. While not originally envisioned as a component of the EarthScope Science Plan, this recent application of EarthScope MT data has perhaps some of the most immediate and high-impact relevance to the practical needs of society. This illustrates that free and open availability of data such as the MT TA timeseries and impedance data may have unanticipated benefits to a wider audience than may have originally been anticipated, thus multiplying the value of efforts such as this to improve the lives of all members of society, as well as to serve the purposes of fundamental scientific inquiry.