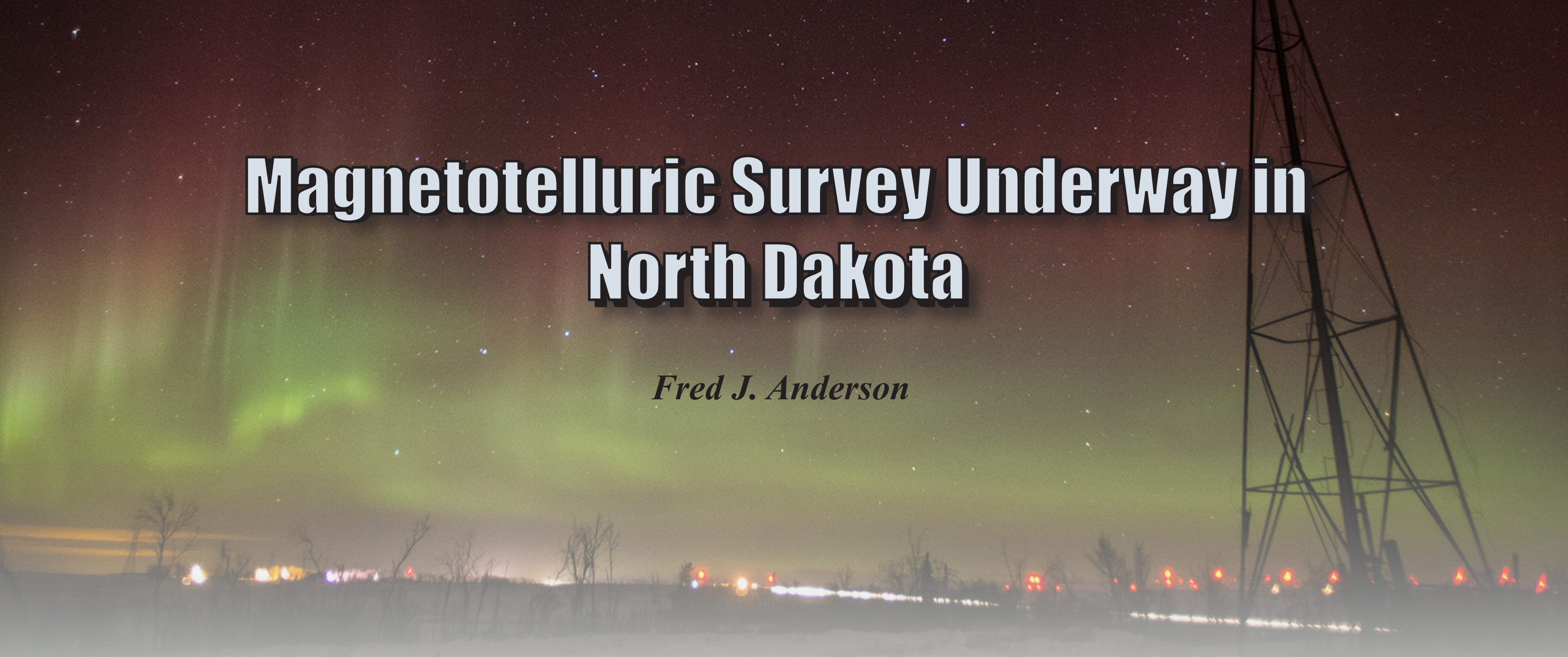

Magnetotelluric Survey Underway in North Dakota

Fred J. Anderson

EarthScope is back in North Dakota! Deep-earth sounding stations of the National Science Foundation's (NSF) EarthScope project's Magnetotelluric Array (MT Array) are currently being deployed across North Dakota by researchers from the National Geoelectromagnetic Facility at Oregon State University in an approximate 40 mile grid (array) in order to perform a geophysical survey of Earth's crust and upper mantle. As many as 38 MT Array stations could be installed by the summer of 2018 (fig. 1). Each station collects induced electromagnetic field data from within the earth for about three weeks. The work being conducted in North Dakota is part of a larger Northern Great Plains (NGP) study that includes locations in South Dakota, Nebraska, and northern Kansas (EarthScope, 2017).

MT surveying is one of the few geophysical methods that can be used to examine Earth's crust down to the depths of the mantle (Park, 2004), which is about 30 miles in North Dakota. Conducting this type of geophysical investigation across North Dakota will help to unravel the underlying architecture of the rocks, geotectonic structures, and ancient continental boundaries that may be found at depths significantly greater than those of the Williston Basin, North Dakota's largest structural geologic feature (fig. 2).

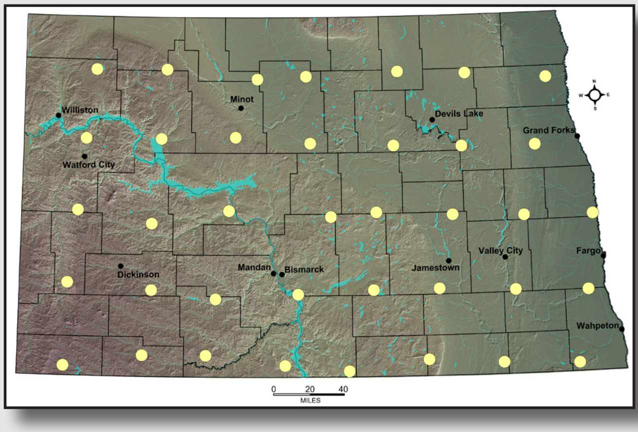

Figure 1. Planned locations of MT Array sounding stations being deployed across North Dakota as a component of the National Science Foundation sponsored EarthScope investigation of the geomagnetic and geoelectric properties of Earth's crust across the U.S.

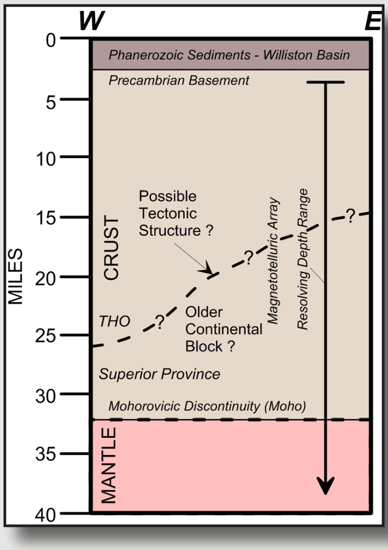

Figure 2. Schematic cross-section segment of Earth above the mantle beneath the Williston Basin in North Dakota as modeled from recent EarthScope continental seismological investigations highlights the depth range "window" that the EarthScope MT Array can investigate and the potential geotectonic structures present at these depths (after Anderson, 2016; Nelson et al., 1993), THO = Trans-Hudson Orogen.

Again, it is important to note that the current configuration of the MT Array (i.e. station spacing and sensor frequency selection) permits geophysical resolution of depths greater than about six miles and down into the upper mantle. In order to investigate within the shallower depths of the Williston Basin a tighter station array grid, coupled with higher frequency instruments, would be needed.

The MT Array project is complimentary to the larger EarthScope US Array project, a decade-long continental geophysical survey of the U.S. from west to the east (and Alaska) with the ultimate goal of surveying and imaging the underlying geologic and tectonic structure of the entire country using seismological and other geophysical methods like magnetotellurics.

The seismological component of the EarthScope project has just reached full deployment in Alaska and will remain operational there through 2019. EarthScope's seismometers began their traverse of North Dakota nearly a decade ago in 2008, with the in-

Background Image Credit: Lyndon Anderson – prairiejournal.com stallation of broadband seismic monitoring stations on a similar style grid in the western part of the state and ended in 2012 with the planned removal of the seismometers located in the Red River Valley (Anderson, 2010).

EarthScope scientists are conducting the NGP MT study in order to fill the gap and tie together previously completed MT Array surveys, with similar station spacings, across the western and eastern U.S. (EarthScope, 2017). For North Dakota, the NGP study is expected to provide several new insights into deep-earth structure beneath the state leading to new interpretations of geotectonic boundaries, continental assemblage, and the mineralogical and petrological character of Earth far below the depths of the Williston Basin.

The magnetotelluric (MT) method is considered a passive source geophysical method, rather than an active source method like explosives or vibratory, in that the source energy used originates from naturally occurring external sources, dominantly space weather phenomena (such as coronal mass ejections) that originate from our sun and regional electrical storm activity. Both of these phenomena induce geoelectric currents (and create our spectacular Northern Lights) that generate magnetic fields in the earth which can be measured and used to determine the electrical conductivity structure (or inversely the resistivity) of Earth's rocks and fluids layers at depth. Of course, the "magneto" portion of the term magnetotelluric refers to the measurement of the resultant magnetic fields created by the earth-induced electrical currents, and "telluric" from the Latin *tellus* meaning earth.

Historically, the development of the MT method is credited to two European scientists: Andrey Tikhonov of Russia and Louis Cagniard of France (Oilfield Review, 1990), along with Japanese scientist, Tsuneji Rikitake, who recognized its applicability to deep-earth exploration (Chave and Jones, 2012). Deep geological surveying using the MT technique was conducted heavily in Russia in the latter half of the twentieth century in the search for previously unexplored sedimentary basins. At that time, this method was primarily employed as a reconnaissance technique (Dobrin, 1976).

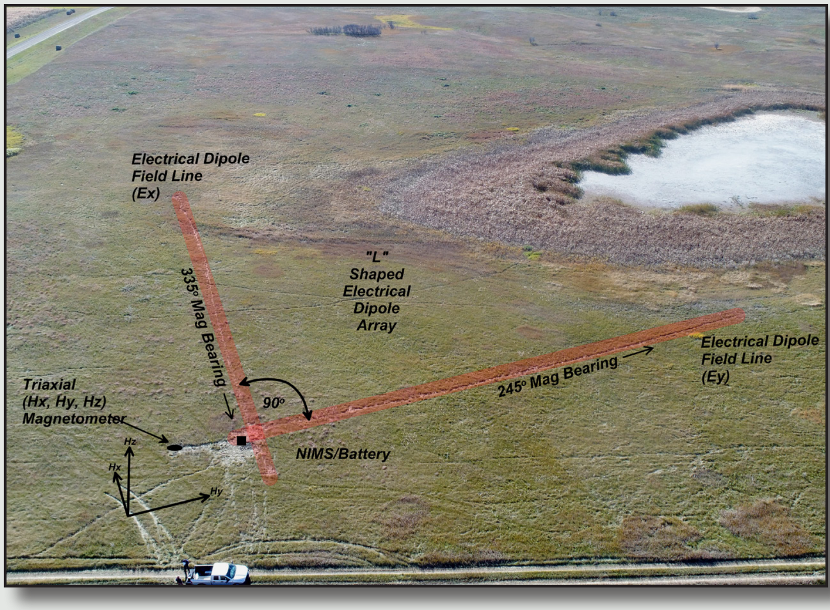

Figure 4. Layout of MT Array station NDD29, just north of Pettibone, as captured from the NDGS's Phantom 4 Pro Quad-Copter Drone. The reversed "L" shaped layout of the electric field dipole lines, which measure the induced electrical fields are highlighted in red. The location of the magnetometer that measures the resultant magnetic fields is depicted in the foreground at left. View is to the south.

Figure 3. At both ends of the electrical dipole lines are Pb-PbCl_2 gel-type electrodes (built by OSU researchers) like this which are buried directly into the ground in a shallow hole containing a kaolinite mud. The kaolinite (aluminum silicate) based mud ensures a strong electrical connection between the earth and the electrical dipole line.

At an MT Array station, an electrical wireline array is constructed with two orthogonally oriented horizontal electrical dipole lines (fig. 3) along with a shallowly buried magnetometer. The magnetometer is wired into a Narod Intelligent Magnetotelluric System (NIMS) receiver powered by two buried 12-V DC batteries. Measured electrical and magnetic field data is collected and stored within the receiver and is extracted upon removal of the station. Each leg of the electrical wireline array dipole lines can be as long as a football field and are commonly arranged in "L" or "+" shaped configurations (fig. 4).

Commonly, the two induced horizontal electrical field components (mathematically noted as Ex and Ey) are measured and the resultant two horizontal and one vertical magnetic field components (mathematically noted as Hx, Hy, and Hz) are measured.

The type of magnetometer installed at each of the MT Array stations is a custom-designed triaxial fluxgate magnetometer which simultaneously measures an induced magnetic field in three directions as opposed to using three separately oriented single magnetometers (figs. 5 and 6). A fluxgate magnetometer measures the difference between a known time-varying instrumented magnetic field and an external magnetic field imposed upon it.

In addition to enhancing our understanding of the geologic properties and deep-earth geologic structure beneath the state, an additional benefit of this investigation will be an enhanced and comprehensive continent-wide understanding of the potential geohazard effects of large-scale geomagnetically induced currents. These geomagnetically induced currents are triggered by coronal mass ejections buffeting Earth's magnetic field, causing it to "rattle" back and forth. This rapid movement of the magnetic field creates induced currents that can flow through conductive infrastructure like rail lines, pipelines and power grids (NASA, 2016). Recent work by Love and others (2016) has suggested a high susceptibility to this type of geohazard in northwestern Minnesota and has shown the potential to disrupt and disable regional and national scale electrical power grids, such as the 1989 event that blacked out a portion of the Quebec power grid.

Figure 5. Triaxial fluxgate magnetometer installed at an MT Array station just southwest of McClusky. This truly unique custom-made magnetometer measures the magnetic fields resultant from induced telluric currents in three directions.

Figure 6. The magnetometer is buried into the ground within a moisture barrier bag and is oriented with respect to magnetic north and properly leveled.

At the time of this writing about one-third of the MT Array stations planned for North Dakota have completed their data collection runs.

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