Magnetic observatories and transportable magnetotelluric observatory arrays: imaging the Earth's interior on planetary, continental and local scales

Adam Schultz
College of Earth, Ocean and Atmospheric Sciences,
Oregon State University, Corvallis, OR 97331-5503, USA

Magnetic observatories represent the longest continuously operating, coordinated global system of geophysical observations. Carl Friedrich Gauss, in conjunction with Wilhelm Weber, constructed the Göttingen magnetic observatory in Germany in 1833. By forming an association (the Göttingen Magnetischer Verein) to coordinate continuous observations at fixed times across a network extending from Holland to Italy, Gauss and the members of the association were able to publish the first set of coordinated magnetic observatory records for the period 1836 – 1839. Alexander von Humboldt enlisted the help of the Royal Society in Britain (northern Germany was under the control of Britain at that time), as well as the Russian Czar, to spread the system of coordinated magnetic observatories all over the world. By 1841 a global system was essentially complete, with 53 operating observatories. Magnetic observatories have operated on substantially the same principles since that time.

In Japan, the first magnetic observatory operating on established international principles was established in Tokyo in 1883. A modernized magnetic observatory was set up, also in Tokyo in 1897. The prevalence of magnetic field noise related to DC railways led to the relocation of that observatory to Kakioka in 1913, an event we are commemorating today.

The founders of the global magnetic observatory network were motivated by fundamental scientific studies of magnetism, but also by interests on the part of governments to obtain charts of magnetic field changes over time, to assist in navigation both for commercial and military purposes. Later, in more recent times, magnetic observatories have played a role in ionospheric and magnetospheric studies, particularly during and in the period after the International Geophysical Year of 1957-1958.

It would probably be unimaginable to the founders of the global magnetic observatory network that the data they had collected, and that is still being collected by dedicated magnetic observatory staff all over the world, would have unanticipated importance to a different branch of the geosciences. Today I will present results obtained from the analysis of years and decades of magnetic observatory data. Specifically I will show images of the variation in the electrical conductivity of the Earth's mantle, globally, that can be inferred from how magnetic fields at the Earth's surface diffuse into the Earth's interior, and through the process of electromagnetic induction, cause electric and magnetic fields to be set up within the Earth and oceans.

Since the 1950's, a technique known as the magnetotelluric (MT) method, pioneered by Tikhonov in the Soviet Union and Cagniard in France, has been steadily advancing. The MT method extends the idea of using magnetic observatory data to image the electrical conductivity variations in the Earth's interior, but it also includes information on the electric field as well as the magnetic field. The use of electric fields allows one to employ this method to image shallower structure than the methods developed for magnetic field data from magnetic observatories. For the MT method, as well as the Geomagnetic Depth Sounding (GDS) method used for magnetic observatory data, there is a proportionality between the depth of investigation beneath the Earth's surface and the time period it is necessary to make field recordings. Thus using a network of transportable magnetic and electric field observatories, one may use the MT method to more rapidly cover a network of more finely spaced stations than would be the case for GDS investigations using magnetic observatory data.

Today I will describe how GDS investigations have provided an initial 3D view of the influence of subducting tectonic plates on the water content of the upper mantle through the mid-mantle transition zone. We will then turn our focus from such global-scale phenomena to a continental-scale investigation of electrical conductivity structure from analysis of MT data collected over a large portion of the continental United States, as a result of the National Science Foundation supported EarthScope MT program. I will highlight some EarthScope results that show a remarkable conductivity anomaly associated with the Yellowstone supervolcano/Snake River Plain region of the northwestern US. I will then conclude with a description of several regional and local scale MT projects currently underway, including studies of fluid emitted from subducting plates, an investigation of the magmatic roots of arc volcanic systems, and efforts to monitor fluids injected into an Enhanced Geothermal System.