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# FORUM

## Ultralow-Frequency Magnetic Fields Preceding Large Earthquakes



The Great Alaska Earthquake (*M* 9.2) of 27 March 1964 was the largest earthquake ever to strike the United States in modern times and one of the largest ever recorded anywhere. Later that year, *Moore* [1964], in a surprisingly rarely cited paper, reported the occurrence of strong ultralow-frequency (ULF; ≤10 hertz) magnetic field disturbances at Kodiak, Alaska, in the 1–2 hours before the earthquake. That report has since been followed by others [*Fraser-Smith et al.*, 1990; *Kopytenko et al.*, 1993; *Hayakawa et al.,* 1996; see also *Molchanov et al.*, 1992] similarly describing the occurrence of large-amplitude ULF magnetic field fluctuations before other large earthquakes ("large" describes earthquakes with magnitudes *M* ~ 7 or greater). These reports involving four separate, large earthquakes were made by four different groups and the results were published in well-known, refereed scientific journals, so there is no doubt that there is evidence for the existence of comparatively large ULF magnetic field fluctuations preceding large earthquakes.

My immediate response to these reports is conservative, even clichéd: I would like to see additional measurements made to verify the evidence. It is therefore of some concern, particularly given the potential significance of these magnetic fields for the issuance of earthquake warnings, that there is no federal program in the Earth sciences to obtain these additional measurements using equipment appropriately located (i.e., at a substantial number of locations where large earthquakes are anticipated) and of appropriate sensitivity and frequency response.

This concern regarding the lack of a federal program of measurements goes beyond its implications for earthquakes. There is an even more significant loss for the Earth sciences: Given that the earthquake measurements suggest that ULF magnetic signals can emerge from within the Earth under certain circumstances, there is a possibility that ULF magnetic signals may be emerging from the Earth from more general processes than those involving earthquakes and that their measurement could provide new information about these processes and about the interior of the Earth.

To cite further experimental results, in 1994 I reported ULF magnetic field measurements made in connection with the 17 January 1994 Northridge earthquake in California [*Fraser-Smith et al.*, 1994]; the measurements were made with two identical measurement systems at two separate locations in southern California, and the data, covering the frequency range 0.01–10 hertz, were shown for the entire month of January 1994. As is often done with these types of measurements (in an Earth sciences context), to gain the greatest sensitivity to potential earthquake-related ULF magnetic field fluctuations, I subtracted the (half-hourly) amplitude measurements made by the more distant system from the corresponding measurements made at the system closest to the earthquake. This has the effect of removing most, and perhaps all, of the fluctuations originating in the upper atmosphere, which, coming from extended sources, tend to be uniform over extended distances on the surface. No earthquake-related signals were detected (the earthquake had a magnitude of less than 7), but for the entire month there were residual ULF signals remaining, some of moderately large amplitude, in all of the nine frequency bands studied within the overall range 0.01–10 hertz.

At the time, I assumed these residual signals were due to incomplete cancellation of the upper atmosphere signals. But they could just as well have been ULF magnetic fluctuations unrelated to earthquakes but generated in the Earth by other processes. This could be a fascinating and productive new area of research, and in that context as well as in the earthquake context, measurements with superconducting instrumentation could dramatically increase the sensitivity of the measurements [*Fraser-Smith*, 1999].

It is now more than 400 years since William Gilbert published his *De Magnete, Magneticisque Corporibus, et de Magno Magnete Tellure* ("On the Magnet and Magnetic Bodies, and on That Great Magnet the Earth"), in which he concluded that the magnetism of the Earth was a planetary property and that "it proceeded from within" [see *Chapman and Bartels*, 1940]. Several decades later, in 1635, Henry Gellibrand's measurements of declination showed that there was a secular variation of the Earth's magnetic field [*Chapman and Bartels*, 1940]. In other words, converting to modern terminology, by 1635 it was known that a ULF magnetic signal was emerging from the Earth. After all these years, the earthquake measurements I have cited strongly suggest that there are still new and exciting things to be learned about these magnetic signals from inside the Earth—if we make the measurements.

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*References*

Chapman, S., and J. Bartels (1940), *Geomagnetism*, vol. 2, Oxford Univ. Press, London.

Fraser-Smith, A. C. (1999), Cancellation of natural geomagnetic field fluctuations: An opportunity for new discoveries in the Earth sciences using superconducting magnetic field gradiometers, *Final Tech. Rep. A416–1* (for the U.S. Geological Survey), Space, Telecommun. and Radiosci. Lab., Stanford Univ., Stanford, Calif., Feb.

Fraser-Smith, A. C., A. Bernardi, P. R. McGill, M. E. Ladd, R. A. Helliwell, and O. G. Villard Jr. (1990), Low-frequency magnetic field measurements near the epicenter of the $M_s$ 7.1 Loma Prieta earthquake, *Geophys. Res. Lett., 17*(9), 1465–1468.

Fraser-Smith, A. C., P. R. McGill, R. A. Helliwell, and O. G. Villard Jr. (1994), Ultra-low frequency magnetic field measurements in southern California during the Northridge earthquake of 17 January 1994, *Geophys. Res. Lett., 21*(20), 2195–2198.

Hayakawa, M., R. Kawate, O. A. Molchanov, and K. Yumoto (1996), Results of ultra-low-frequency magnetic field measurements during the Guam earthquake of 8 August 1993, *Geophys. Res. Lett., 23*(3), 241–244.

Kopytenko, Y. A., T. G. Matiashvili, P. M. Voronov, E. A. Kopytenko, and O. A. Molchanov (1993), Detection of ultra-low-frequency emissions connected with the Spitak earthquake and its aftershock activity, based on geomagnetic pulsations data at Dusheti and Vardzia observatories, *Phys. Earth Planet. Int., 77,* 85–95.

Molchanov, O. A., Y. A. Kopytenko, P. M. Voronov, E. A. Kopytenko, T. Matiashvili, A. C. Fraser-Smith, and A. Bernardi (1992), Results of ULF magnetic field measurements near the epicenters of the Spitak ($M_s$ = 6.9) and the Loma Prieta ($M_s$ = 7.1) earthquakes: Comparative analysis, *Geophys. Res. Lett., 19*(14), 1495–1498.

Moore, G. W. (1964), Magnetic disturbances preceding the 1964 Alaska earthquake, *Nature, 203,* 508–509.

—Antony C. Fraser-Smith, Departments of Electrical Engineering and Geophysics, Stanford University, Stanford, Calif.; E-mail: acfs@stanford.edu

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