Seismologists can't do it alone

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The recent string of powerful and deadly earthquakes reminds us of the dangers that lurk deep below. Prominent seismologists [1] have stated categorically "Earthquakes cannot be predicted". This pessimistic assessment remains the prevailing view in the seismology community today.

Unpredictability, however, cannot be the last word. Instead of using past events to statistically predict future events, it stands to reason to try to understand *in real time* the processes that evolve during the build-up of stress deep in the Earth's crust **before** a catastrophic rupture unleashes the awesome power of major earthquakes. Monitoring signals due to stress-induced processes may lead to a better assessment of earthquake risks and to a narrowing of the uncertainty windows.

There have been innumerable observations of pre-earthquake signals, often fleeting and subtle, occasionally distinct and strong. Some reports date back over 2000 years as delightfully recounted in Tributsch's classic book "When the Snakes Awake" [2]. Others draw on modern ground-based and satellite-based technology. Here is a partial list:

(i) Low to ultralow frequency electromagnetic emissions from the ground,
(ii) Luminous phenomena, often called earthquake lights, prior to many seismic events,
(iii) Enhanced infrared emission from the epicentral region as seen in satellite images,
(iv) Changes in the atmosphere above the epicentral region,
(v) Perturbations in the ionosphere 100-600 km above the Earth's surface,
(vi) Changes in the water chemistry,
(vii) Unusual animal behavior, etc.

The pessimism about the unpredictability of earthquakes comes from the fact that nobody had been able to formulate a physical process, or sequence of processes, capable of explaining the diversity of the pre-earthquake signals. Nobody knew how such signals might be generated deep in the Earth's crust or at the Earth's surface or transmitted upward into the ionosphere.

This state of ignorance has now been largely overcome.

The sea change was brought about by the discovery that essentially all rocks contain a certain type of electronic charge carriers, which had been overlooked or ignored by generations of geoscientists. These charge carriers exist in an electrically inactive form. They are dormant but become activated when rocks are subjected to mechanical stress [3]. Their activation turns the stressed rock volume into a battery, from where electric currents flow out [4,5,6]. The outflow currents are carried by defect electrons, also known as positive holes. The positive holes stream out of the stressed volume into the surrounding unstressed rocks. They travel fast and far, meters in laboratory experiments, probably kilometers, maybe even hundreds of kilometers in the field. Under a certain set of conditions the electric currents can flow continuously. Under other conditions they will pulsate, leading to low to ultralow frequency electromagnetic emissions.

Positive holes flow not only through solid rock but also through sand and soil. They reach the Earth surface and can cause a range secondary reactions. For instance, at the surface, pairs of positive holes can recombine leading to vibrationally highly excited states, which de-excite by emitting infrared photons [7]. This unusual form of infrared emission may be responsible for the widely reported pre-earthquake "thermal anomalies" captured in night-time infrared satellite images of the areas around future epicenters [8,9,10,11]. The arrival of positive holes at the Earth's surface leads to the build up of distinct surface/subsurface charges. Such surface charges in turn lead to microscopic electric fields, strong enough to ionize the air and create massive amounts of airborne ions [12]. The same surface charges can cause corona discharges accompanied by visible light [3,13] and by noise in the radiofrequency range, which can interfere with telecommunications [14].

Air laden with positive ions is expected to expand upward, causing condensation of water droplets in the atmosphere, causing haze and clouds. Drifting further up, the ionized air will carry along the Earth's ground potential to stratospheric heights and affect the ionosphere. This may be the cause for the well-documented pre-earthquake ionospheric perturbations [15,16,17] and for distinct changes in the transmission of radiowaves [18,19].

The medical community has known for a long time that positive ions in the air to cause nausea and headaches in humans [20]. They increase the level of serotonin, a stress hormone, in humans and animals [21]. The generation of massive amounts of positive airborne ions at the ground-to-air interface and changes in water chemistry at the ground-to-water interface may allow us to understand why animals reportedly exhibit anomalous behavior before major earthquakes [22, 23].

The discovery of the stress-activated electronic charge carriers in rocks and their astounding physical properties can help us decipher the mystery of pre-earthquake signals. It is too late for the many who died, unforewarned, in so many recent earthquakes, but it is not too late to re-evaluate the distribution of public and private funds dedicated to earthquake research.

Over the course of decades hundreds of millions, even billion of dollars have been spent by the US government and governments around the world to find an answer to the pressing economic and humanitarian question: Can we recognize the approach of the next major earthquake? Can we forewarn those who will be most affected by its deadly force?

Despite seismology's great achievements in unraveling the structures of Earth's hidden interior, seismologists are not well placed when it comes to earthquake forecasting. The reason is that seismology has been built around the study of seismic waves, which reveal the hidden structures of the Earth and provide important information about rupture processes in the Earth's crust that lead to earthquakes. Using insight gained from past earthquakes, seismologists calculate the probability of future events. As a result seismological earthquake prediction models come with wide uncertainty margins – years to decades. They are useful for civil engineers and city planners but useless for alerting governments and the population of an approaching major seismic event.

If seismologists can't do it alone, alliances have to be forged among all disciplines who are able to contribute in a meaningful way to the momentous task in front of us: How to understand the subtle, often fleeting signals that the Earth sends out weeks, days and hours before major seismic events. To encourage this interdisciplinary collaboration, governmental and non-governmental funding organizations have to re-assess their priorities in the area of earthquake-related research.

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