

ICES 1-page summary of work

Earthquakes – Deadliest of all Natural Hazards

Earth is this wonderful blue sphere, floating serenely through the blackness of space, seemingly so quiet except for white clouds drifting over its surface.

For us, who live on this pale blue dot in space, the environment is often very dynamic.

Earthquakes are the deadliest of all natural disasters. They are feared because they appear to strike suddenly, unannounced. The Holy Grail of earthquake science is to identify signals, which would precede the approach of large seismic events.

Many different types of precursory signals have been reported ranging from earthquake lights to unusual animal behavior to ionospheric perturbations. However, none of these pre-earthquake signals has been accepted by the mainstream geophysics community. All have been called anecdotal or products of wishful thinking. Prominent seismologists¹ have declared with great authority: “Earthquakes cannot be predicted”, and (almost) everybody believes it.

But let’s have a look at the energies involved. An earthquake of Richter magnitude 8 unleashes an energy equivalent to 1 Gigaton TNT, equal to the energy of about 66,000 Hiroshima-class atomic bombs. In the case of magnitude 9 earthquakes, the energy equivalence is to more than 2,000,000 Hiroshima-class atomic bombs. From a physics perspective it is inconceivable that the Earth would not produce some form of signals, when many thousand cubic kilometers of rocks are being stressed to the breaking point deep below.

A small discovery, has provided crucial insight. It all started with a study some 35 years ago where my coworkers and I showed^{2,3} that the oxygen anions in oxide crystals and silicate minerals are not fixed in their valence state 2-. Instead some O²⁻ convert to the higher oxidation state 1-. This change in the valence of oxygens involves traces of water, H₂O, incorporated in the form of hydroxyls, OH⁻, as “impurity” in the crystal structures. As the hydroxyl oxygen anions change their valence from 2- to 1- the hydroxyl protons, H⁺, change their valence from 1+ to 0, leading to the formation of H₂ molecules in the crystal matrix⁴. Chemists call such a process a redox reaction. Over the following 10-15 years we presented evidence^{5,6} that traces of “water” in silicate minerals are subject to the same redox conversion.

All this surely sounds a bit academic, but the practical consequences are enormous. Just take earthquakes and the signals that the Earth gives off before a catastrophic rupture. An O⁻ in a matrix of O²⁻ represents a defect electron, a mobile electronic charge carrier like the “holes” of semiconductor fame in any transistor. In minerals we call these defect electrons “positive holes”.

A breakthrough came with the recognition that any volume of rock, when stressed, turns into a battery from where electric currents can flow out. The outflowing charge carriers are positive holes. They can travel fast and far, with phase velocities up to about 200 m/sec and over distances on the order of meters in the laboratory and surely kilometers to tens of kilometers in the field. As the positive holes flow, they constitute an electric current. Like any electric current they generate a magnetic field. If and when a current fluctuates, it will radiate electromagnetic (EM) waves. If these EM waves fall into the ultralow frequency (ULF) range, they are only weakly attenuated in the Earth's crust. Hence they travel to the Earth's surface from tens of kilometers below.

All of a sudden we saw an opportunity how to explain the fleeting ULF signals, sometimes powerful, sometimes weak, which have been recorded prior to many major earthquakes. Obviously such ULF signals look like coming from battery currents, which flow transiently in the Earth's crust when rocks deep below undergo intense stressing.

The discovery of positive hole currents provided us with insight why the pre-earthquake ULF signals are reportedly so fickle and "unreliable" as a tool for predicting seismic events. The reason is surprisingly simple: Battery currents can flow in a sustained manner only when the electric circuit is closed. In other words, the outflow of positive holes from a stressed rock volume must be balanced by an equally large outflow of electrons or an inflow of positive charges. These conditions, however, cannot be easily achieved in the Earth's crust.

The positive holes are capable of doing much more "mischief", once they are activated by stress. For instance, as they flow through the Earth's crust and enter water, they oxidize water to hydrogen peroxide. This is onto itself an interesting observation that leads to many ideas yet to be explored.

When positive holes arrive at the surface of the Earth, they can also recombine, giving rise to a special form of infrared radiation, called the "thermal infrared" (TIR) anomaly. TIR anomalies have been seen for over 20 years in night-time images of satellites equipped with infrared sensors. Their true nature is only now emerging as we begin to understand how positive holes behave at the Earth surface.

In addition, when positive holes arrive at the surface of the Earth, they build up very steep electric fields – often so steep that air molecules become ionized on a massive scale above the epicenter of a future earthquake. At first, only positive airborne ions form. As they enter the atmosphere they will expand upward and rise to stratosphere, carrying along the positive electrical potential that exists at the surface of the Earth. This effect is expected to lead to a response in the ionosphere, the plasma region which begins at about 100 km altitude and extends far into space. Ionospheric perturbations a few days before major earthquakes have been widely documented. They are marked by an increase in the number density of electrons at the lower edge of the ionosphere – something that seems to be in-line with the upwelling of air laden with positive ions that are injected at the ground-to-air interface above areas of high stress deep in the Earth's crust.

When positive holes arrive at the surface of the Earth in even larger numbers, laboratory experiments have shown that the electric fields at the ground-to-air interface can become so steep that they fire up corona discharges. These corona discharges lead to increased radiofrequency noise – an effect that has been widely reported prior to earthquakes.

In summary, even without addressing the issue of unusual animal behavior, the discovery of stress-activated positive hole charge carriers in rocks has already helped us decipher some open questions regarding the alleged unpredictability of the most frightening of all natural disasters.