meter (Hitachi model-U3210, Japan). The absorbance values obtained at $\lambda_{\max}$ = 570 nm were compared with the standard calibration curve for fluoride concentration. Finally, an attempt has been made to indicate the extent of fluoride contamination.

There are unpublished reports of high fluoride content in underground mine water and open-well water from some coal seams of the Raniganj Coalfield, where the maximum reported fluoride content is up to 3.2 ppm. The results of the present study have been summarized below:

1. Dilution of fluoride content was observed in the post-monsoon water sample from all sources. The pH value of water also reduced sympathetically.
2. In general, fluoride content in water was higher in the Raniganj Formation than the basement areas in the south. Even within Raniganj Formation, fluoride content of groundwater was higher in the western block (study area I) than in the area to the east (study area II), where the sediments are rich in finer clastics and iron cement. Fluoride content (pre-monsoon) in the eastern part ranged from 0.63 ppm (Pabra) to 1.03 ppm (Tapasi) and that in the western part from 0.81 ppm (Sarbari) to 1.22 ppm (Gobag, Perbelia). Similarly, the post-monsoon fluoride values ranged from 0.27 ppm (Jemua) to 0.52 ppm (Ballavpur) in the east, and 0.34 ppm (Belijhupa) to 0.81 ppm (Gobag) in the west.
3. High fluoride content in water has been found associated with relatively high TDS, HCO_3^- and TH.
4. In both the study areas, iron content of the water samples was less during the post-monsoon period than the pre-monsoon period, which indicates that iron does not get into groundwater through percolation from the vadose zone (Table 1).
5. Fluoride content increases from east to west even within the Raniganj Formation, in spite of dilution effect during post-monsoon.
6. It is evident that water from all sources in the study area of the Raniganj Coalfield has fluoride locally higher than the WHO[6] limit of 1.0 ppm. It would be worthwhile to undertake a systematic geological formation-wise monitoring of fluoride content in the Raniganj Coalfield area, starting from the east of Durgapur to Kumardhubi.

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Earthquake probabilities and pre-earthquake signals

In his recent letter to *Current Science*, Bapat[1] has drawn attention to the concept of 'probability'[1] and argues that when applied to earthquake science, it makes little sense. To underline his point, Bapat presents a table, published in a recent report submitted by the Director, Geological Survey of India (GSI) to the Government of Uttarakhand, Dehradun about the vulnerability of different districts of this northern part of India to destructive earthquakes. This table lists the probabilities of occurrence of such earthquakes between 81.6% and 98.3%. The same GSI report contains a statement that 'earthquakes cannot be predicted'. What does prediction mean and how is it to be judged?[2].

Seismology has done an admirable job over the past 100 years, unravelling the hidden structures deep in the earth. Using earthquakes as 'flashlights', seismologists have developed powerful tools to create three-dimensional images of the interior of the earth. They can reconstruct with second resolution how catastrophic ruptures propagate along faults and radiate-off seismic waves, which unleashes their destructive power as soon as they reach the surface of the earth. This impressive body of work has put the seismologists firmly in control of earthquake science. Nobody knows more about earthquakes than the seismologists.

However, there is a snag. Everyone who lives in a seismically active region of the world would like to know when an earthquake will occur. But earthquakes are notorious for striking suddenly. They cause death and devastation apparently without warning. Tens of thousands of lives could be saved, if early warnings are available. The damage to structures and infrastructures, often reaching hundreds of billions of dollars, a sizeable fraction of the GNP even for wealthy nations, could be reduced. Yet, famous seismologists have been quoted as saying categorically[3]: 'earthquakes cannot be predicted'.

In a certain way, this statement is true: if the only tools in the scientific toolbox are those of seismology, earthquakes can indeed not be predicted[4].

What are these tools? Seismologists have long determined where the tectonically active faults lie. They have mapped most of them. They also know how the tectonic plates move relative to each other, whether they collide in a thrust-like fashion or rub past each other in a strike-slip fashion. Seismologists can measure the speed of relative plate motions with astounding precision. They can look at past seismic events, small and large, using seismograph data that go back at least a century. For large events they can extend the timeline back by thousands of years, studying the scars which past earthquakes may have left in the geological records. Using such massive amount of data seismologists have constructed probability models for the next major earthquake to occur along a given fault. They often refine these probability models by taking into account that each time an earthquake happens along a section of a fault, tectonic stresses will be transferred onto the adjacent sections of the same fault or onto other faults in the neighbourhood, making them more likely or less likely to rupture in the near or not-so-near future.

However, all the data that go into seismological models are retrospective: the knowledge accrued through past events is used to forecast future events. Bluntly speaking, it is a statistical game, akin to what life insurance companies do when they calculate the life expectancies of different groups of people, taking into account their characteristic lifestyle, occupational risks and environmental factors, which might shorten or lengthen their average life spans. Statistical models always work well for large numbers, but fail miserably when it comes to individual cases. The same holds true for seismological earthquake forecasting: even the most elaborate model is inadequate because it is not based on information that might become available in real time about a specific earthquake that looms ahead. The reason for the failure is that the tools which seismologists use are retrospective like the death statistics crucial to the life insurance industry, relying on past events to calculate the probability of future tremors.

But unpredictability cannot be the last word. There must be other ways to learn ahead of time, when stresses deep in the earth reach dangerously high levels. When rocks are stressed, they undergo deformation. This deformation might become detectable at the earth's surface in the form of bulging, measurable by geodesic techniques. Alternatively, with increasing stress, rocks at depth may fracture on small scales. This could lead to acoustic emissions or to minor events called foreshocks. Unfortunately, as seismologists will acknowledge, geodesic deformations at the surface of the earth and foreshocks are both unreliable indicators of impending earthquake activity[5]. In particular, in the case of foreshock activity, the recognition that a given minor event was a foreshock can only come retrospectively, after the major seismic event has occurred.

Clearly, we have to move away from just seismology and geodesy. We have to formulate our questions in a different way: (i) Are there other signals that rocks produce when subjected to ever increasing stress? (ii) If such signals are produced at depth, can they be transmitted or somehow carried from the seismogenic region to the surface of the earth?

There have been countless reports of non-geodesic, non-seismic pre-earthquake signals. Some date back over 2000 years, as delightfully recounted in Tributsch's classic book[6]; others are based on modern technology and on information provided by satellites[7]. The following is a partial list of non-geodesic, non-seismic pre-earthquake signals which deserve consideration.

(i) Low to ultralow frequency electromagnetic emissions recorded all around the globe.

(ii) Local magnetic field variations over a wide range of timescales.

(iii) Luminous phenomena, often called earthquake lights, prior or during seismic events.

(iv) Enhanced infrared emission from the epicentral region seen in satellite images.

(v) Changes in the atmosphere near the ground and at altitudes up to about 1000 m.

(vi) Perturbations in the ionosphere 100–300 km above the ground.

(vii) Unusual animal behaviour, etc.

The scientific community has been deeply divided over these signals and whether or not they are indeed pre-earthquake indicators. What had been sorely lacking until now was a physical process or a set of physical processes that could explain the multitude signals, processes that could outline how these signals may be generated deep below or at the earth's surface in response to the build-up of pre-earthquake stresses in the seismogenic zone, and how they may be interrelated.

Many seismologists have taken a hard-line position, pointing out that the origin of these signals is not properly explained. They draw attention of the fact – and correctly so – that these signals do not always occur before all major earthquakes. They tend to label the reports of such signals as anecdotal, or express doubts whether the signals are even real.

On the other hand, those who have vested an enormous amount of effort into capturing these alleged pre-earthquake signals, scientists and lay persons alike, have struggled to make sense of their observations. Many ideas have been floated as to how the often subtle manifestations of a build-up of high levels of stress deep below could lead to signals at the surface of the earth and how they could be explained. In spite of valiant efforts, no consensus has emerged.

The situation has changed over the course of the past few years. The remainder of this correspondence will focus on this new development.

Key is the discovery that, when igneous or high-grade metamorphic rocks are subjected to deviatoric stress, electronic charge carriers are activated[8]. The charge carriers consist of electrons and a specific kind of defect electrons, known as positive holes or pholes for short. They exist in the rocks in a dormant, electrically inactive form. When stresses are applied and dislocations begin to move through the crystal structure of the individual mineral grains, the electrons and pholes 'wake up' and become available in the stressed rock volume as mobile electronic charge carriers. The pholes have an unusual property that they can stream out of the stressed rock volume into the adjacent unstressed rocks. They can travel far, over distances of metres in laboratory experiments, and probably over distances of kilometres or tens of kilometres in the field. These charge carriers had previously not been recognized. They cause the stressed rock volume to turn into a battery, in fact a new form of battery never before described[9,10]. Every cubic kilometre of stressed rock can deliver up to 10,000–100,000 A for extended periods of time, provided the battery circuit can close. If the circuit closes, large current pulses can be expected to flow. They will lead to low to ultralow frequency electromagnetic emissions.

What is further special about the pholes is that they can flow not only through solid rock, but also through sand and soil. As in the case of rocks, they can travel over distances of metres in laboratory experiments and probably over distances on the order of kilometres or tens of kilometres in the field. Their interaction with water is complex and still under intense investigation.

The same phole charge carriers cause the surface of the rocks – presumably also the surface of the earth – to become positively charged. This charge can be strong enough to affect the ionosphere, leading to the well-documented, pre-earthquake ionospheric perturbations[7,11] and to changes in the transmission of radiowaves[12,13]. At the surface of the earth, the charge carriers generate locally steep electric fields, strong enough to ionize the air and to form positive ions[14]. Positive ions in the air are known to the medical community to cause nausea and headache in humans[15]. They may be the reason why animals tend to behave strangely before major earthquakes. The same airborne ions can cause condensation of water droplets in the lower atmosphere and hence haze or cloud formation. At higher electric fields on the earth's surface corona discharges are expected to occur accompanied by emission of visible light[8,16]. Widely distributed corona discharges can be expected to emit electromagnetic noise in the radiofrequency range and hence cause other forms of interference with telecommunication as mentioned by Arun Bapat[1].

When the charge carriers recombine at the earth's surface, they form vibrationally highly excited states which de-excite by emitting mid-infrared photons[17]. This non-thermal infrared emission may be responsible for the widely reported but poorly understood pre-earthquake 'thermal anomalies'[18,19] captured in night-time infrared satellite images.

Although mainstream science, and in particular seismology, has not yet caught up with the rapid development at the scientific front, it appears that the discovery of the stress-activated electronic charge carriers in rocks, and their multifaceted and in part surprising properties, will help us unravel the mystery of pre-earthquake signals[20,21].

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