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Earthquake prediction using extinct monogenetic volcanoes: A possible new research strategy

Alexandru Szakács *

Dept. of Environmental Sciences, Sapientia University, Cluj-Napoca, Romania
Institute of Geodynamics, Romanian Academy, Bucharest, Romania

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ABSTRACT

Volcanoes are extremely effective transmitters of matter, energy and information from the deep Earth towards its surface. Their capacities as information carriers are far to be fully exploited so far. Volcanic conduits can be viewed in general as rod-like or sheet-like vertical features with relatively homogenous composition and structure crosscutting geological structures of far more complexity and compositional heterogeneity. Information-carrying signals such as earthquake precursor signals originating deep below the Earth surface are transmitted with much less loss of information through homogenous vertically extended structures than through the horizontally segmented heterogeneous lithosphere or crust. Volcanic conduits can thus be viewed as upside-down "antennas" or waveguides which can be used as privileged pathways of any possible earthquake precursor signal. In particular, conduits of monogenetic volcanoes are promising transmitters of deep Earth information to be received and decoded at surface monitoring stations because the expected more homogenous nature of their rock-fill as compared to polygenetic volcanoes. Among monogenetic volcanoes those with dominantly effusive activity appear as the best candidates for privileged earthquake monitoring sites. In more details, effusive monogenetic volcanic conduits filled with rocks of primitive parental magma composition indicating direct ascent from sub-lithospheric magma-generating areas are the most suitable. Further selection criteria may include age of the volcanism considered and the presence of mantle xenoliths in surface volcanic products indicating direct and straightforward link between the deep lithospheric mantle and surface through the conduit. Innovative earthquake prediction research strategies can be based and developed on these grounds by considering conduits of selected extinct monogenetic volcanoes and deep trans-crustal fractures as privileged emplacement sites of seismic monitoring stations using an assemblage of physical, chemical and biological sensors devised to detect precursory signals. Earthquake prediction systems can be built up based on the concept of a signal emission–transmission–reception system, in which volcanic conduits and/or deep fractures play the role of the most effective signal transmission paths through the lithosphere. Unique "precursory fingerprints" of individual seismic structures are expected to be pointed out as an outcome of target-oriented strategic prediction research. Intelligent pattern-recognition systems are to be included for evaluation of the signal assemblages recorded by complex sensor arrays. Such strategies are expected however to be limited to intermediate-depth and deep seismic structures. Due to its particular features and geotectonic setting, the Vrancea seismic structure in Romania appears to be an excellent experimental target for prediction research.

1. Introduction

"Current earthquake prediction methods may need to be revised in the wake of the recent Haiti and Asian earthquakes and tsunami", University of Queensland researcher Dr. Huilin Xing said (http://www.uq.edu.au/news/index.html?article=20408). "We cannot predict earthquakes in the way the public would like us to predict earthquakes," Thomas Jordan, director of the Southern California Earthquake Center, said (http://www.cbsnews.com/stories/2010/01/16/eveningnews/main6105412.shtml). Such media excerpts clearly show the current public sensitivity related to earthquake-related research.

As recent earthquake-related disasters, such as the 12 January 2010 M_w 7.0 Haiti event with >200,000 fatalities, and the 27 February 2010 M_w 8.8 Chile earthquake show, seismic prediction is still an unsolved challenge for science.

Scientific approaches to the issue of earthquake prediction span from extremely skeptical, i.e. earthquake prediction is impossible in principle (e.g. Geller, 1991; Geller et al., 1996) or in practice (Matthews, 1997; Kagan, 1997) to optimistic, including claims of

* Dept. of Environmental Sciences, Sapientia University, Cluj-Napoca, Romania.
E-mail address: szakacs@sapientia.ro.

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successful predictions ("a few correct predictions have been made (…); some were accurate to days and allowed preparatory actions", Wyss, 2001). The recent unpredicted earthquake disasters seem to shift the balance towards the skeptical party, as Geller (1997) stated: "Earthquake prediction research has been conducted for over 100 years with no obvious successes". However, science always was challenged by problems which at the time seemed to be unsolvable. The "impossibility" of flying with objects heavier than air is just one of them. Hence, the unsuccessful story of short-term deterministic earthquake prediction attempts should not discourage the scientific community from investing further effort, intelligence and money in seismic prediction research. "As a physical phenomenon, earthquakes must be predictable to a certain degree" (Wyss, 2001). Even the most skeptical acknowledges that "Precursor research is plagued by poor methodology" (Geller, http://www.eps.s.u-tokyo.ac.jp). What is actually missing is a sound research strategy based on innovative ideas and concepts. Since Frank Press (1968) addressed the issue, no further attempts to devise a long-term seismic prediction strategy has been published (e.g. "No real program for earthquake prediction research exists in the United States", Wyss, 2001). This contribution intends to provide a new concept which might be incorporated in a consistent science-based seismic prediction research strategy. The concept basically is that locations on the Earth surface are not equivalent in terms of precursory signal reception or, in other words, there are privileged spots where earthquake precursory signals can better be received (i.e. with an enhanced signal/noise ratio) than in other spots on Earth surface. Volcanic conduits extending vertically through Earth crust/lithosphere to the surface are such sites.

2. Earthquake precursory signals

The basic problem in seismic prediction is not the inexistence of precursory phenomena. Even skeptical researchers admit that in the earthquake focal area stress accumulates within the seismogenic structure or rock volume prior to failure and onset of the seismic event. Stress buildup itself and all related processes can be considered, in principle, precursory phenomena. However, only those processes which occur closely before the moment of rupture, when the evolution of the seismic structure toward rupture is inevitable, can be seen as precursory processes and their signals used for prediction purposes. Anyway, the existence of precursory phenomena can be postulated.

If precursory activity actually exists in the earthquake foci, then precursory signals also exist. And they are detectable in principle. Therefore, seismic prediction basically means detection and correct interpretation of precursory signals in terms of location, time and size of the predicted event. This paper addresses only the problem of signal detection. Precursory seismicity on which earthquake prediction studies are frequently based is not considered here in particular, apart of any other possible signals of physical nature.

We define seismic precursory signal as any decodable information, of whatever nature, originating in the seismic focus which propagates across the lithosphere and arrives at Earth surface in advance with respect to the seismic waves. At a theoretical level, precursory signals can tentatively be classified in primary (having their origin in the hypocenter) and secondary or induced (a precursory phenomenon, such as a chemical or biological process, triggered "on-way" by a primary, e.g. physical, precursory phenomenon originating from the hypocenter). As for their nature, precursory signals can be systematized in physical, chemical and biological precursors. One special type of physical precursors, which is largely studied and used for predictive purposes, includes the seismic precursors (i.e. change of seismic pattern of a known seismogenic structure before a high-magnitude earthquake). A promising avenue of prediction research using seismic precursory patterns considers SOC-based approaches, e.g. in Sammis and Sornette (2002) where positive feedback mechanisms are discussed as accounting for singular behavior associated with accelerated seismic release in large earthquakes.

Another type is related to the changes in the electromagnetic field in the crust preceding a seismic event (e.g. those used by the "VAN method", Varotsos et al., 1986). Recently, significant changes in shear-wave splitting have been reported before large earthquakes (Gao and Crampin, 2008). Examples of chemical signals are changes of radon concentration levels in spring water (e.g. Crockett et al., 2006) or changes in chemical composition of mineral waters. Biological signals are those recorded in the behaviour of living creatures. Chemical and biological signals are induced, while physical signals can be both primary and induced (e.g. magnetic). In conclusion, while addressing the issue of seismic prediction, one must take into account a multitude of precursory signals of different nature. Probably, there is no unique, universal precursor to be detected. Each seismic structure and, maybe, each particular seismic event of the same seismogenic structure, may produce different precursory signals. The precursory signals are thus site-specific. This concept can be expressed as the uniqueness of seismogenic structures: each seismogenic structure has its own particular assemblage of features and, as a consequence, produces a particular assemblage of precursory signals.

3. Seismic prediction seen as a signal emission–reception problem

If precursory activity and related precursory signals do actually exist, then the whole problematics of earthquake prediction can be reduced to a signal emission–reception system whose parts (subsystems) are: signal emission, signal transmission and signal reception (Fig. 1). This is one possible valid starting point premise, which will be used in the proposed approach.

The seismogenic structure whose part is ruptured during an actual earthquake (seismic source) can be viewed as an emitter of precursory signals. In some cases the emitter is well-known. The Vrancea seismic area in Romania is an example of well-known seismogenic structure, i.e. the seismogenic rock volume is identified and its position in space accurately determined. Another example is the San Andreas fault system in California, US. Other seismogenic structures (i.e. precursory signal emitters) are less well determined. Some others are actually unknown and they manifest themselves only during strong earthquakes with epicenters located in areas not considered for seismic hazard.

Precursory signals are intended to be detected using purposefully devised sensors placed at the Earth's surface or in near-surface locations such as abandoned mines or boreholes. A large spectrum of sensors has been experimented for seismic monitoring and in prediction studies. Most of them are based on physical phenomena recording modifications of a certain physical field (magnetic, acoustic, electromagnetic, electric, gravity, etc.) attributable to earthquake-related processes. Others detect vibrations transmitted through the rocks or variations in level of surfaces (e.g. of phreatic groundwater or topographic surfaces). Methods and instruments designed to point out changes in chemical composition of fluids (air and water or melts) due to seismic activity can also be viewed as sensors (i.e. chemical sensors). Radon monitoring techniques are just one research method using chemical sensors. Finally, one may further consider biological sensors represented by living creatures which may react and show alteration of their common behavior under earthquake-related changes in their physical or chemical environment. Different types of sensors are used to detect precursory signals of different nature.

Whatever sensors earthquake prediction studies use, a crucial problem is the precursory signal transmission through Earth materials. Since seismic foci are located in the crust or upper mantle, any precursory signal, as the seismic waves themselves, propagate through rocks as the signal transmission medium. Earth's lithosphere through which signals originating from most seismic foci have to propagate represents a highly heterogeneous transmission medium,