History of earthquake prediction researches (*)(**)

G. MARTINELLI (***)
Regione Emilia-Romagna, Servizio Cartografico e Geologico, Viale Silvani 4/3 - 40122 Bologna, Italy

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Summary. — In the last 25 centuries a great amount of data regarding precursory phenomena of seismic events have been gathered and recorded by observers, whether professional, casual or indirect. Such data have been better systematized in the last 120 years and have become the object of systematical applied research in the last 30 years in coincidence with a better understanding of physical and chemical phenomena which accompany earthquake occurrence. Rare-gases geochemistry played a fundamental role in earthquakes physics knowledge and in seismic prediction-oriented researches. The main procedures of diffusion of knowledge on earthquake prediction researches in space and time have been reconstructed. Scientific and economic constraint factors that caused difficulties or accelerations in seismic precursors researches have been investigated and commented.

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PACS 91.30.Px – Phenomena related to earthquake prediction.
PACS 01.65 – History of science.
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1. – Introduction

By earthquake prediction we mean the establishment in advance of a certain number of parameters which define a seismic event in time and space, as well as in its physical dimensions: the position of its epicentre, the time when it commences, and its magnitude. The seismic phenomena which are the subject of examination and research cover a historical span of about 25 centuries. The essential characteristics of the main lines of past research on earthquake prediction can be found in two different approaches to the problem: statistical prediction and deterministic prediction. By statistical prediction we mean the calculation of the probability that an earthquake of a certain magnitude will occur in a given zone within a certain period of time. If

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(**) The authors of this paper have agreed to not receive the proofs for correction.
(***) E-mail: g.martinelli@mo.nettuno.it

assessments of this kind are to produce tangible results, it is necessary not only to study the historical seismicity of the area under investigation, but also to evaluate geological factors on a regional and local scale (Keilis-Borok, 1990). Such an approach is particularly useful for seismic zoning studies and for assessing seismic hazard. Deterministic prediction, on the other hand, is based on the understanding of deterministic physical laws which relate the measurement of those physical parameters believed to be precursors to the actual occurrence of a seismic event.

2. – The diffusion of knowledge

Earthquake prediction studies began in the Mediterranean area and spread into Central Europe, the Euro-Asian Continent, the Far East and America in ways and at times which are parallel to those found in the history of earthquake theories and seismic instruments.

An early example worth mentioning is that of Pherecydes, who is thought to have been a teacher of Pythagoras. Cicero mentions the case in his *De divinatione*: "...Pherecydes, that famous teacher of Pythagoras who predicted an earthquake when he saw that the water from a well which was usually well filled had disappeared" should be regarded as a diviner rather than a physicist (Schinche, 1875). Current research on water level changes in aquifers before earthquakes shows that Pherecydes had identified a phenomenon which still seems to play a useful part in earthquake prediction studies (Roeloffs, 1988). Later on, and indeed throughout the Middle Ages, philosophers and scholars turned their attention to investigate the causes of earthquakes rather than trying to predict them. The predominant theory throughout the Middle Ages was that put forward by Aristotle, according to whom earthquakes were generated by air pressure which gave rise to subterranean winds.

In Renaissance times, the direct observation of natural phenomena became very important, and a new attitude is found in historical sources. A. J. Buoni, a doctor from Ferrara, refers to bubbling gas and the clouding of water in wells before and during the earthquake of 1570 in Ferrara. This piece of evidence is recorded in his treatise *Del terremoto* (Buoni, 1571), which contains a good deal of information of an observational and historical type, including a reference to Nicolò Cardano's observation of similar phenomena. In this connection it is worth remembering that anomalous gas emissions and the occurrence of geophysical and geochemical anomalies in subterranean water are currently the subject of intense research activity (Barsukov *et al.*, 1984; Wakita *et al.*, 1988). In the 16th and 17th centuries the circulation of scientific theories became more intensive and influential, partly as a result of printing ability and the abandonment of the Aristotelian theory of earthquakes; and historical records of earthquakes reflect this more favourable cultural situation. These features allowed the computation of the first catalogue of pre-seismic and co-seismic phenomena recorded in Italy in the last centuries (Martinelli, 1997).

In this connection it is worth noting that the 17th century saw a substantial exchange of scientific information between the Jesuit fathers and China, of particular importance being Father Matteo Ricci's journey there for cultural and scientific purposes. He established a good diplomatic relationship with the Chinese authorities, and initiated cultural exchanges. He designated as his successor Father Nicola Longobardo, whose name was adapted by the Chinese to Long Huamin. Longobardo was a native of Caltagirone in Sicily, and in 1597 arrived in Peking, where he died in

1655. His work on *The Interpretation of Earthquakes* was published there in 1626 (Longobardo [1626], translated into Italian by Matteucig, 1988). In it he sets out clearly the precursors of which he was aware, such as anomalous emissions of gas from the earth, the clouding of water in wells, and a change in the taste of water before earthquakes—phenomena which are now considered to be indicators of geochemical changes in ground fluids. He also mentioned the occurrence of exceptionally high tides, which are now considered to be indicators of possible crustal deformations. Father Longobardo attributes the appearance of precursory phenomena to subterranean gas pressure, and he also considers certain meteorological conditions and the appearance of certain cloud formations to be seismic precursors, stressing the importance of the work of Aristotle, especially the *Meteorologica* (Louis, 1982). Another historical source printed in China in 1663 and known as the "Longde County Annals", quoted by Ma Zonjin *et al.* (1990) reports the description of precursory phenomena almost exactly as described by Longobardo in 1626. This feature could be interpreted as a confirmation of the presence of the Greek thought in the Chinese cultural environment. All the phenomena he lists are the subject of modern earthquake prediction research (Rikitake, 1982). It is also remarkable that modern Chinese earthquake prediction research considers the observation of meteorological phenomena to be important (Lu Dajiong, 1988). Lu Dajiong's work clearly demonstrates the survival of traces of Aristotelian thought, as brought to China with great effect by the Jesuit missions.

3. – The beginning of scientific methods and systematic observations

In the 1870s, an Italian chemist, Demetrio Lorenzini, published detailed information and careful measurements concerning the behaviour of water in a well which he used (Albarello *et al.*, 1991). His aim was to devise an observational system that could be used for predicting earthquakes, as is also clear from his correspondence with M. S. de Rossi (fig. 2).

Moreover, in the 19th century we can find the scientific achievements of many outstanding scholars, like Robert Mallet (1810-1881), Michele Stefano de Rossi (1834-1898) (fig. 3), Timoteo Bertelli (1826-1905), Giuseppe Mercalli (1850-1914), John Milne (1850-1913) etc. Such authors observed and catalogued many phenomena that were considered precursors of earthquakes (*e.g.*, de Rossi, 1879). An anomalous behaviour of a compass was observed in central Italy in 1873 (Serpieri, 1873). Many similar observations were reported as precursory phenomena of geomagnetic type (Taramelli and Mercalli, 1888; Galli, 1906, 1910; Baratta 1979; Ferrari, 1991).

In the early 20th century, partly as a result of the Messina earthquake of 1909, research activity on the subject became more intense. Mondello (1909) reported about successful experiments in detecting self-potential anomalies before the occurrence of some earthquakes. In 1909 Father A. Maccioni published the first impressive results of experiments to predict earthquakes using slightly modified versions of the "coherer" (Alfani 1909; Maccioni, 1909). At roughly the same period, researches of a similar nature were carried out in Japan, involving a network of observatories for monitoring electromagnetic emissions. Of particular importance was the founding of the Japanese Seismological Society after the Yokohama earthquake of 1880. British interest in this kind of research was "exported" to Japan, since that country had more to offer for experiments. The man responsible for this cultural transfer was John Milne. From 1876 to 1895 he worked in Japan, actively supporting earthquake precursor research (Milne, 1890). Almost at the same time Giuseppe Mercalli carried out researches on variations in electric and magnetic parameters that precede earthquakes (Taramelli and Mercalli, 1888; Mercalli, 1980). The interest all over Europe in the study and verification of electromagnetic phenomena can be testified by the activity of geophysical observatories provided with equipment for a continuous monitoring of such phenomena (Chapman, 1930). Similar investigations are in progress today as part of modern research projects (Fraser-Smith *et al.*, 1990, Bella *et al.*, 1994). After the Mino Owari earthquake of 1891 the Imperial Earthquake Investigation Committee was set up to investigate seismic and volcanic phenomena and to limit their effects. In 1927, Shiratoi first detected radon changes in hot springs in Japan before some earthquakes (Shiratoi, 1927), while Imbò (1939) first recognized the role of gas carriers in induction of radon anomalies in thermal waters. Reports on fluid monitoring of seismic precursor parameters also appeared in the 1940s and 1950s (Imamura, 1947; Hatuda, 1953; Okabe, 1956). Japanese technological interest in this topic increased after the publication of a comprehensive report on earthquake prediction by Tsuboi *et al.* (1962), commonly called the "blueprint". The "blueprint" described the guidelines of a research activity program oriented to earthquake prediction in the territory of Japan. The program started some years later giving priority to detection of crustal movements, detection of seismic activity, identification of possible seismic gaps (*e.g.*, Mogi, 1979) geomagnetic monitoring and laboratory rock mechanics (Rikitake, 1966). Scarce attention to fluid monitoring was paid in the first steps of the Japanese program. Intense research activity in this field began in the late 1970s with the institution of the Laboratory for Earthquake Chemistry where remarkable scientific results were reached (*e.g.*, Wakita, *et al.* 1980).

The need of a multidisciplinary approach to earthquake prediction studies was firstly stressed by Russian prince B.B. Galitzin who drafted in 1911 a complete research program for the prediction of earthquakes (Galitzin, 1960), which implied:

1) the study of frequency and magnitude of seismic events and of the features of the recording of seismic oscillations;
2) the study of the propagation rate of seismic waves in order to evaluate the state of tension in seismically active areas;
3) geodetic measurements aimed at discovering slow deformations in the earth's crust;
4) gravimetric measurements;
5) study of the condition of springs and of wells, and study of composition of the gases in the earth's crust.

B. B. Galitzin's attention to the behaviour of fluids in the earth's crust may be due to his direct observations; anyway, his researches were certainly influenced by the remarkable correspondence he had with many European geophysicists.

4. – Research starting in modern and contemporary ages

In Uzbekistan after the Tashkent earthquake in 1966 a test area was equipped in order to predict seismic events. In 1956, Y. Muminov had already started to record chemical parameters including radon in the waters of local springs to check variations in the composition of thermomineral waters with a therapeutic purpose. The research unit led by A. N. Sultankhodjaev carried out further research on geochemical precursors in Uzbezkistan reaching interesting results (Sultankhodzhaev, 1984). After the earthquake of Aschabad in 1948 a test area devoted to earthquake prediction researches was equipped in Garm (Tadjikistan). As a result of the observations carried out in the Garm area it was reported that before large earthquakes the velocity of seismic waves passing nearby the epicentral region changed markedly. In particular the V_p/V_s ratio between the velocity V_p of longitudinal waves and the velocity V_s of transverse waves decreases by 10 to 15% from the normal value of 1.75 and a large seismic event occurs when the ratio has recovered to the normal value (Semyenov, 1969).

Given the quality and number of publications, it is possible to state that most of the research into geochemical and geophysical earthquake precursors that have been carried out in many nations has certainly been inspired by the pioneer research carried out in Central Asia in the Sixties, Seventies and Eighties (Abdullabekov, 1991; Kissin *et al.*, 1993; Gokhberg *et al.*, 1995). It is in the last ten years that the most encouraging results in this topics have been obtained and confirmed after a validation procedure (Wyss, 1991).

All present earthquake prediction research projects are based on the dilatancy theory worked out by Scholz *et al.* (1973), or on modified versions of it (Mjachkin *et al.*, 1975). These theories try to provide an organic explanation of the contemporaneous occurrence of a number of different precursory phenomena. Characteristic of the former Soviet Union's research on earthquake prediction is the strong and qualified multidisciplinary approach. In fact, the entire Academy of Sciences of the USSR has been actively involved in this topic and active cooperation still characterizes the findings of geophysicists, geochemicists, mathematicians, seismologists etc. These peculiarities were previously stressed by Carapezza *et al.* (1980) and by Dall'Aglio (1995). Signs of the European scientific thought can also be found in China, where a massive earthquake prediction research programme was launched in the 1960s and has produced encouraging results. The main guidelines of the Chinese research program came from the Uzbek approach. The local peculiarity is the particular attention paid to the empirical observation of a number of natural phenomena, including some of a macroscopic kind, such as animal behaviour and meteorological phenomena which are thought to be earthquake precursors. Alongside this there is the automatic instrumental measurement of a variety of parameters, using advanced technology (Wan Dikun, 1993).

Earthquake prediction studies began in the United States in the second half of the 1960s. Certain test areas, such as Parkfield in California, have recently been provided with sophisticated equipment for monitoring precursory phenomena (Bakun, 1990). The scientific method is very similar to the one proposed by Galitzin in 1911. As a multidisciplinary approach it can be considered as a recovery of the working tradition of the Geophysical Observatories Network in Europe during the 19th century.

As far as the European and Mediterranean areas are concerned, important results have been obtained in Turkey, where an earthquake prediction project has been carried out jointly by Turkish and German research institutes. The basic characteristic of this joint project was its multi-parameter approach, involving the simultaneous observation and analysis of multiple precursors. This feature, too, goes back to the working tradition of Geophysical Obsevatories of the 19th century (see also Schlinder *et al.*, 1993).

Since the second half of the Eighties, the scientific debate concerning earthquake prediction has been strongly affected by the advancement obtained in Greece, Japan, France (Varotsos and Kulhànek, 1993) about deterministic earthquake prediction through the study of precursory phenomena of electric type. Seismologists, as a scientific class, accepted that approach to the problem in a sceptical way (see also Geller, 1996) drawing the attention to the apparent fortuitousness of the predictions which were actually guessed by researchers on precursors of electric type. The total denial of the validity of this type of research may, however, cancel previous analogous research, which on the other hand proved to be univocally shared and representative of a consolidated state of the art (Sobolev, 1975; Caputo, 1995).

5. – Present-age difficulties in developing earthquake prediction research

In the second half of the 20th century a strong specialization of experiences and methodologies asserted itself between seismometric seismology and geophysics applied to the study of non-seismometric phenomena; that has been involving so many seismologists and geophysicists from the scientific community of the present generations.

Convincing evidences show that such a stretching apart was due to the need of mutual seismic monitoring which the superpowers had to face after World War II. During the Cold War and the negotiations on nuclear-weapons control, the mutual seismic monitoring has proved to be of great importance to distinguish between subterranean nuclear explosions and actual earthquakes. If the efficiency of know-how transfer from the research sector to the sector of engineering applied to buildings is regarded as a scientific indicator, some considerations can be drawn about the trends of effective impact on the actual organization of research on seismic-event prediction. Modern engineering has found an answer to the problems connected with earthquakes for a long time: in economically highly developed and seismically active countries like California and Japan research on earthquake prediction does not have any priority character. In those countries, protection from earthquakes is entrusted to an advanced engineering know-how, as the only prediction of each single event does not seem profitable.

Such considerations can be valid for countries with an advanced economical level, but not for the developing countries, where it is possible to foresee potential applications of research on earthquake prediction just owing to the excessive cost of the buildings that are suitable for resisting to seismic events.

6. – Conclusions

If the scientific publications regarding seismic-events precursors are carefully examined, one might consider the process of scientific growth as a chronologically coherent course. In fact, it was not: intense discussions have always been following research into earthquake prediction. Thus the scientific environment of geophysics has distinctly been split into two parts: seismologists on the one hand, and geophysicists and geochemists concerned in non-seismometrical observations on the other one. Beyond the normal scientific dynamics resulting from the fact that one may belong to one “school” rather than to another, economics do play a role on such occasions: insurance companies have a part in this field (Freeman, 1932). The assessments of probability of seismic occurrence are carried out on the basis of catalogues of events seismometrically recorded. However, nowhere in the world has research on earthquake prediction ever reached outcomes so good as to assert itself upon other methodologies for an approach to the question of defence against earthquakes. Yet, up to now only a small amount of money has been assigned to this research, compared to other disciplines. The present shrinkage in the expenses assigned to research, which characterizes a certain number of advanced nations, may lead to assume scarce possibilities for research on earthquake prediction in the immediate future. A new, expanding economic cycle like the one that characterized the Sixties will probably be necessary to reverse the present trend.

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