PROGRESS IN EARTHQUAKE RESEARCH AND HAZARD ASSESSMENT

by

Andreas Vogel
Institut für Geophysikalische Wissenschaften
Freie Universität Berlin

During the recent years we have been witnessing a considerable change in earthquake research. Seismology in the sense of earthquake research is no longer exclusively a matter of earthquake recording and the analysis of seismograms. The progress in understanding the sources of earthquakes, the capability of new measuring techniques, the improvements of computational methods and last not least the call for disaster prevention programs have increased the efforts to investigate the processes of earthquake generation and to find criteria for earthquake prediction. The study of precursory strain, of temporal change of rock properties in the earthquake source region and of the seismo-tectonic pattern requires a multidisciplinary approach in earthquake prediction research which is systematically summarized in Fig. 1. The interdisciplinary approach requires a broad cooperation between *geophysicists, geodesists and geologists. The experimental approach to earth*quake generation and prediction follows three lines according to Fig. 1:

The first one is concerned with the observation of surface deformations and displacements as an indicator of changing stresses and strain. A continuous survey in the earthquake source region requires high-precision recording instruments of sufficient long-term stability. Recording tiltmeters, strainmeters, gravity meters, sea-level recorders in coastal areas and groundwater level recorders in wells have already reached the accuracy to detect precursory strain events.

Long-term changes of strain associated with earthquake activity are investigated by repeated ground surveys such as triangulation, trilateration and levellings, which are combined or in the future to a certain extent may be replaced by precise gravity surveys.

Space geodetic techniques have reached an accuracy to study position changes with an accuracy of a few centimeters over hundreds and thousands of kilometers. Earthquake activity is intimately related to the large-scale motion of tectonic plates. Space geodetic techniques such as very long baseline interferometry (VLBI) and laser ranging seem most appropriate for establishing a world wide geodynamic reference system of plate motion. Highly mobile systems are developed to be operated for rapid measurements of strain changes in earthquake zones.

The second main line of techniques in earthquake prediction research is concerned with the physical state and processes in the earthquake source region. Knowledge of the physical parameters as revealed by conventional geophysical surveys is important.

More closely related to earthquake generation and of special concern in earthquake prediction research are changes of the physical state and rock properties preceeding earthquakes. Premonitory changes of seismic wave velocities, magneto- and electromechanical phenomena, radon emission and others have been observed associated with dilatancy.

Stress is a key factor in earthquake prediction research. Measurements of the overall stress distribution in earthquake-prone areas is extremely useful. For measurements of changes of the stress field as an indicator of impending earthquakes the capability of stress measuring techniques is still unsufficient.

The last main line of earthquake prediction research concerns seismotectonics. Seismological research in the conventional way is one part. It comprises studies ot the temporal and spatial distribution of earthquakes as well as focal mechanisms in the past and the information involved as to future earthquakes. Another part of seismotectonics are neotectonic studies by geological ground surveys, aerial photography and satellite imagery and investigations of neotectonics as related to seismicity and focal mechanisms.

More detailed information about the present capabilities of terrestrial and space techniques in earthquake prediction research can be found in the proceedings of a workshop organized by the working group Geodynamic Techniques of the European Seismological Commission (Vogel, A. (Editor) 1979).

Earthquake prediction research is hardly successful if the information obtained from each of these various observational techniques is considered separately. Models of earthquake generation are required. For the modelling of the processes which are going on in the earthquake source region the complexity of observations is needed. Models of earthquake generating processes even speculative ones are required quite from the beginning. A working hypothesis should be followed when establishing survey networks and recording stations in areas of potential earthquake risk. Models constraint by the complexity of observational data may help to rearrange and improve the observational network and finally to find criteria for earthquake prediction. Fig. 2 summarizes various interpretation and modelling techniques according to the various experimental techniques in Fig. 1. Interpretation of the surface strain pattern as obtained rrom recording stations, ground and space geodetic surveys leads to a model of the tectonic processes above in the scheme of Fig. 1. The analysis of geophysical field surveys, of changing physical fields and wave propagation and of stress observations results in a model of the chemophysical constitution and changing physical state and rock properties in the earthquake source region in the middle of Fig. 1. From seismicity statistics, focal mechanism studies and neotectonics below in the scheme of Fig. 1 a seismotectonic model is resulting. The three modelling procedures are brought together and unified into a complex model of earthquake generation. This final model should be supported by laboratory experiments and basic theory of earthquake generation.

Models of earthquake generation constrained by the complexity of observations provide criteria for seismic risk estimation and prediction. One has to realize that this final goal of earth science research should be considered in a wider sense. In the near future prospects are small of predicting time and place of occurrence, mechanism and energy release of earthquakes.

To begin with we have to deal with earthquake prediction in a wider sense trying to acquire all kind of information that may be helpful to minimize damage from further earthquakes. Support of measures such as proper land use planning and design of earthquake resistant structures in earthquake engineering according to the scheme in Fig. 2 is today a realistic contribution to earthquake damage reduction. Earthquake prediction research is still far away from establishing earthquake warning systems.

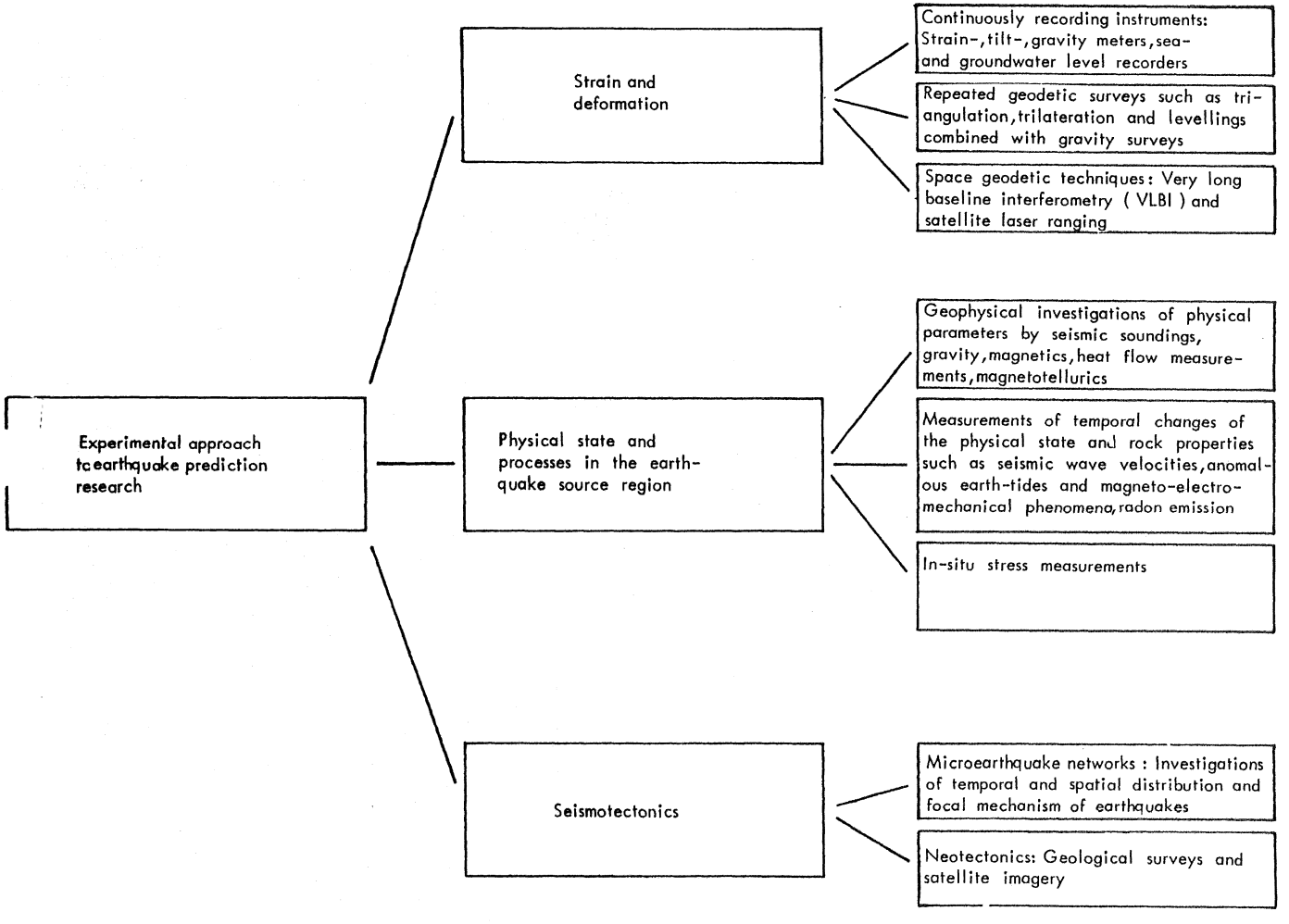
In earthquake prediction research most progresses have been made in Japan, USA, China and Sovjet Union. In Europe research is going on in various countries of potential earthquake risk. The European Seismological Commission is now planning to extend activities into the broader aspects of earthquake generation and prediction. The Council of Europe and the European Space Agency have organized two workshops in order to define a European earthquake prediction programme (European Space Agency 1979, 1980). Test sites for intensified research have been proposed in Turkey, Greece, Italy and the Iberian Peninsula.

In the North Anatolian Fault Zone in Turkey is a well-defined zone of high earthquake risk. Recently an international conference was held in Istanbul where experts from all over the world met to discuss present research and to plan a multidisciplinary programme for earthquake prediction research in the North Anatolian Fault Zone. The proceedings of this conference are published by Friedr. Vieweg, Wiesbaden, Western Germany (Isikara, A.M. et al. 1980).

Vogel, A. (Editor), 1979: Terrestrial and Space Techniques in Earthquake Prediction Research. Vieweg, Braunschweig - Wiesbaden

Isikara, A.M. et al., 1980: A Multidisciplinary Approach to Earthquake Prediction. Proceedings of an Interdisciplinary Conference on Earthquake Prediction Research in the North Anatolian Fault Zone. Vieweg, Braunschweig - Wiesbaden

European Space Agency 1979, 1980: Earthquake Prediction. ESA SP - 149, SP - 156, Paris


Experimental approach to earthquake prediction research
Strain and deformation
Physical state and processes in the earthquake source region
Seismotectonics
Continuously recording instruments: Strain-, tilt-, gravity meters, sea- and groundwater level recorders
Repeated geodetic surveys such as triangulation, trilateration and levellings combined with gravity surveys
Space geodetic techniques: Very long baseline interferometry (VLBI) and satellite laser ranging
Geophysical investigations of physical parameters by seismic soundings, gravity, magnetics, heat flow measurements, magnetotellurics
Measurements of temporal changes of the physical state and rock properties such as seismic wave velocities, anomalous earth-tides and magneto-electro-mechanical phenomena, radon emission
In-situ stress measurements
Microearthquake networks : Investigations of temporal and spatial distribution and focal mechanism of earthquakes
Neotectonics: Geological surveys and satellite imagery

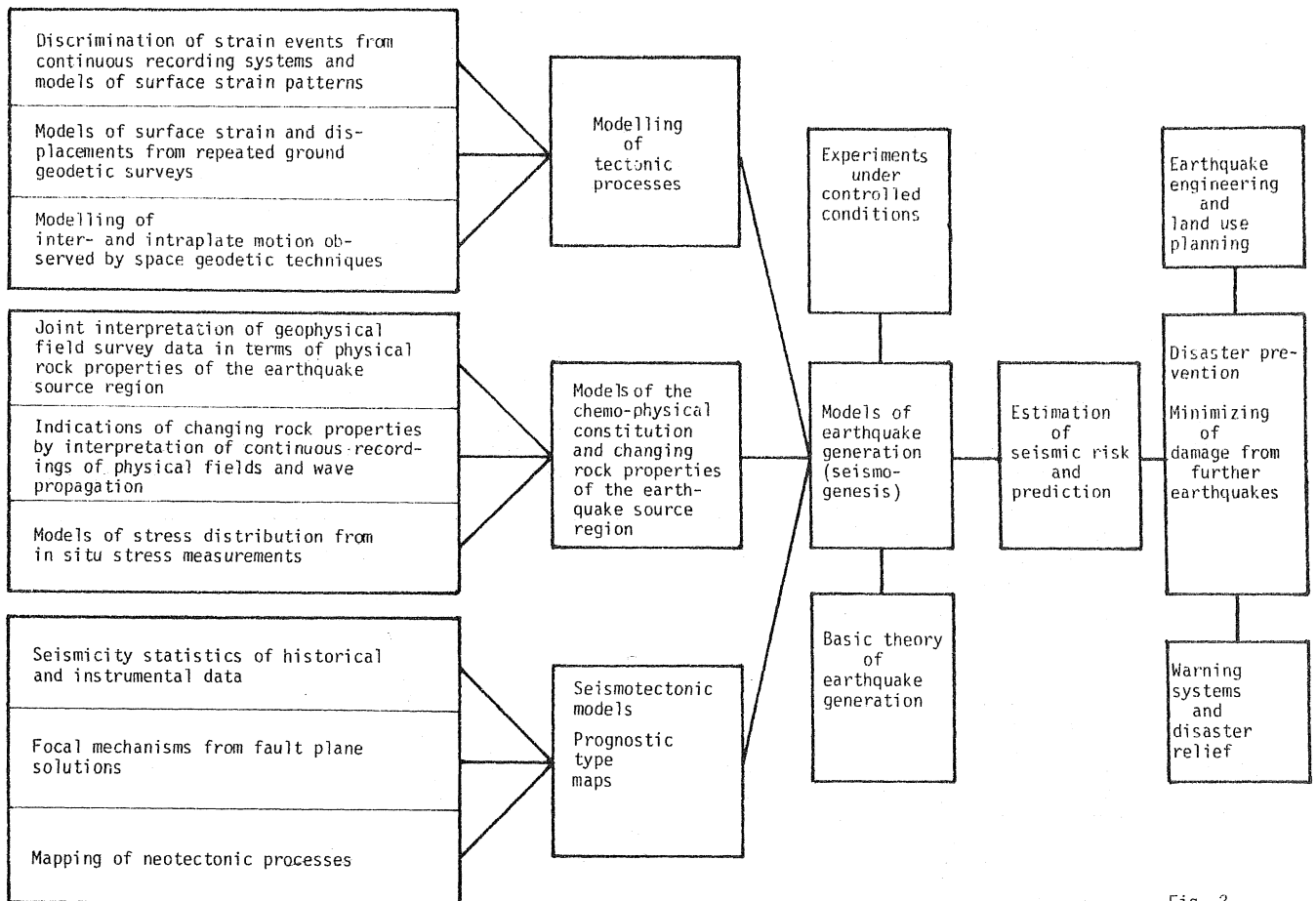

Discrimination of strain events from continuous recording systems and models of surface strain patterns
Models of surface strain and displacements from repeated ground geodetic surveys
Modelling of inter- and intraplate motion observed by space geodetic techniques
Joint interpretation of geophysical field survey data in terms of physical rock properties of the earthquake source region
Indications of changing rock properties by interpretation of continuous recordings of physical fields and wave propagation
Models of stress distribution from in situ stress measurements
Seismicity statistics of historical and instrumental data
Focal mechanisms from fault plane solutions
Mapping of neotectonic processes
Modelling of tectonic processes
Models of the chemo-physical constitution and changing rock properties of the earthquake source region
Seismotectonic models
Prognostic type maps
Experiments under controlled conditions
Models of earthquake generation (seismogenesis)
Basic theory of earthquake generation
Estimation of seismic risk and prediction
Earthquake engineering and land use planning
Disaster prevention
Minimizing of damage from further earthquakes
Warning systems and disaster relief

Fig. 2