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Second Round of Evaluations of Proposed Earthquake Precursors

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Abstract—This review summarizes the result of the second round of nominations for the IASPEI Preliminary List of Significant Precursors. Currently this List contains five cases of precursors: (1) foreshocks, (2) preshocks, (3) seismic quiescence before major aftershocks, (4) radon decrease in ground water, and (5) ground water level increase. A list of four cases that could not be accepted nor rejected by the panels reviewing them contains three on crustal deformations and one on seismic quiescence. In the second round 10 nominations were evaluated, nine new ones and one which had been considered previously. Two were accepted for the List, two were placed in the category of undecided cases. To date, a total of 40 nominations have been evaluated by IASPEI. For 37 of these the nominations, the mail reviews, the panel opinions, and, where supplied, the author's reply were published. This evaluation process remains active throughout the International Decade for Natural Hazards Reduction. Additional nominations are invited.

The IASPEI Sub-commission on Earthquake Prediction does not guarantee that precursors accepted for the List can be used for earthquake prediction, nor does rejection of a nomination mean that the particular method could never become useful for prediction. However, the List, as well as the interchanges between authors and reviewers, allow us to gauge the state-of-the-art in earthquake prediction research. It is clear that we do not have an earthquake prediction capability, because the manner in which to use the few precursors on the List for predictions is not known. It also appears that many of the results thought to be conclusive by the authors, may not command the respect of the seismological research community at large. A more quantitative approach to data analysis, the use of rigorous statistical techniques, and high quality, long-term data sets are needed to make progress in earthquake prediction research.

Background

The idea of starting a Preliminary List of Significant Precursors was put forward at the 25th General Assembly of the International Association of Seismology and Physics of the Earth's Interior (IASPEI) in Istanbul. The Sub-commission on Earthquake Prediction proposed that such a list should be developed during the International Decade of Natural Hazards Reduction (IDNDR). The attribute "preliminary" was chosen, because there will never be a final list. As we learn more about the physical processes leading to failure of faults, as we design more sophisticated and insightful ways to recognize precursory patterns, as we deploy more and better instruments, and as we may be lucky enough to participate in some

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of Nature's own experiments in crustal rupture, we are likely to expand the Preliminary List. On the other hand, the Preliminary List may be shortened, because precursors, once thought to be "significant," may turn out to be unrelated to earthquakes, after further scrutiny.

By using the attribute "significant," the IASPEI membership wanted to express the need for some kind of screening. The List of Precursors was not simply developed as an enumeration of all conceivable phenomena, possibly related to the preparation process of rupture in earthquakes. Although not preferred by all, the expression "significant" won over other words emphasizing the strength of the evidence for a true precursor, in a vote taken in Istanbul at the Sub-commission bi-annual meeting. It was felt that, for a precursor to be placed on the List, the data had to be strong, the association with the earthquake plausible, alternative explanations for the anomaly had to be ruled out with a high probability, and the analysis procedure had to be mature. For a nomination to be accepted, even critics of that particular approach to earthquake prediction had to be convinced that the case had merit, and that continued testing of the hypothesis over the years could lead to general acceptance of the proposed precursor. However, some enthusiastic researchers are very much taken by their own hypothesis or data, and fail to see how others may want more and stronger evidence before accepting a precursor for the List.

Thus, the scene was set for a vigorous dialog between proponents of precursors and critics. Proponents of new ideas have the tendency to believe in their idea, no matter what objections others may raise. This stubbornness is a necessary quality in a researcher's mind set. Without it, scientists would quickly abandon all new ideas, because at the mere mention of a new idea objections are immediately raised: "We have never heard of this before. This cannot possibly be correct." With the evaluation process of the proposed precursors, the Sub-commission has attempted to channel this dialog in a constructive direction. We have issued a "Call for Nominations" (Appendix A) in which we tried to outline guidelines necessary for proponents of a precursor hypothesis to follow, to convince critics. Further, "Validation Criteria" (Appendix A) were formulated to give skeptics a chance to indicate their general areas of concern, and to guide proponents in their efforts to improve the maturity of their research.

The results of the first round of nominations were published in a monograph (WYSS, 1991), containing for each case the nomination material, the anonymous reviewer's comments, and the IASPEI panel opinion, as well as an author's reply, if available. This dialog gives some insight into the attitudes of proponents and skeptics. Remarkable about this interchange was the proponents' casual approach. Many of the proponents thought it was enough to submit a short abstract or published papers. However, most reviewers and panelists requested exhaustive presentations of the complete data sets and extensive quantitative analysis. While the formulation of a precursor hypothesis, backed by a preliminary data set, might

Table 1

IASPEI Preliminary List of Significant Precursors, March, 1994

No.	Author	Precursor	Earthquake
		A. Seismicity Patterns	
1	K.-T. Wu, M.-S. Yue, H.-Y. Wu, S.-L. Chao, H.-T. Chen, W.-Q. Huang K.-Y. Tien, and S.-D. Lu	Foreshocks (hours to months)	4 Feb. 1975, *M* 7.3 Haicheng, China
2	J. R. Bowman	Preshocks (months to years)	22 Jan. 1988, *M* 6.7 Tennant Creek, Australia
3	R. S. Matsu'ura	Seismic quiescence before strong aftershocks	Several cases in Japan
		B. Ground Water Properties	
4	H. Wakita, Y. Nakamura, K. Notsu, M. Nogutchi, and T. Asada	Radon concentration and temperature decrease in ground water	14 Jan. 1978, *M* 7.0 Izu-Oshima-kinkai
		C. Crustal Deformation	
5	E. Roeloffs and E. G. Quilty	Ground water rise	4 Aug. 1985, *M* 6.1 Kettleman Hills, California

make a research article acceptable for a professional journal, a hypothesis must be tested, at least to some degree, before it can be included in the List, or the evidence in a single case history, must be overwhelmingly strong. Only about 10% of the nominations were accepted in the first round (WYSS, 1991). In the current, second round, 20% have been accepted, but the mix of nominations, those prepared in a casual or in a detailed way, persisted.

The Current Preliminary List of Significant Precursors

Five precursors are on the List, after this second round of evaluations (Table 1). Three of these are seismicity patterns. One is based on ground water chemistry and temperature, and one is a measurement of crustal deformation by ground water levels. The limitations of the usefulness of such a list and of the uncertainties of panel decisions on nominations for the List will not be discussed here, because they were discussed by WYSS (1991), except that it should be emphasized again that inclusion in the List does not make a precursor "true," and exclusion does not necessarily make it "false." The List is simply a collection of phenomena that have a better-than-average chance of becoming useful in earthquake prediction.

There is, of course, no question that foreshocks occur before some mainshocks, and that these are a part of the preparation process to the mainshocks rupture. In the case of the Haicheng (M 7.3) 1975 earthquake, the population was actually warned as a result of the foreshocks, and therefore the nomination by WU *et al.* (1991) was accepted for the List. However, we must admit that we do not know how to recognize foreshocks and how to use them for prediction. Nevertheless, the existence of foreshocks proves that failure of faults in major earthquakes sometimes is preceded by a preparation process. It may be that other measurable crustal parameters change during the preparation period, and that they could be used for identifying foreshocks. The existence of foreshocks is a major reason for which I think that the study of the physics of the fault failure process may eventually lead to an earthquake prediction capability.

"Preshocks" is an expression I would like to use for the seismicity that started about one year before the mainshock at Tennant Creek, Australia, and was proposed as a precursor by BOWMAN (this issue). This precursor was accepted for the List essentially for the same reason the foreshocks were accepted. The fact that a rich earthquake swarm in a stable continental shield, where no earthquakes had been recorded for a prolonged period, was followed by major earthquakes in the same source volume within a year, makes it almost impossible to believe that these events were unrelated. Therefore, the preparation process must in this case have lasted for about a year instead of the usual foreshock duration of a few days. The choice of a different word, preshocks, for the Tennant Creek events implies a process different from that generating foreshocks. However, that may not be so. One could imagine that the same process leading eventually to rupture, could have different time constants along a well-developed fault with a short recurrence time, and in a stable continent with ultra-long recurrence times. One might speculate that the following observation is not due to chance: The ratio of 4 days of typical foreshock duration to 100 years recurrence time in the case of plate boundary ruptures is the same as that of 400 days of preshocks to a 10,000 year assumed recurrence time in Australia. In any event, the usefulness of preshocks for prediction is very limited at present, because the p value is not always characteristic. There exist examples of preshock sequences with normal p values, followed by a mainshock, as well as examples of relatively low p-value swarms not followed by a mainshock, both in stable continents.

The seismic quiescence observed by MATSU'URA (1986, 1991) before major aftershocks is a special case of prediction. Although not as valuable as the prediction of mainshocks, it is also useful. However, this is another parameter we do not really know how to use yet. Although some time has passed since the phenomenon was discovered and measured, no progress has been made to identify it quantitatively in real time and to use it for actual predictions.

The two precursors on the List that were based on ground water observations have in common that data from very long observation periods were presented

Table 2

Second round nominations for the IASPEI List of Significant Precursors

No.	Authors	Title
1	E. A. Roeloffs and E. G. Quilty	Water level changes preceding the 1985 Kettleman Hills earthquake
2	J. R. Bowman	A seismicity precursor to a sequence of M_s 6.3–6.7 midplate earthquakes in Australia
3	M. Wyss	Precursory seismic quiescence
4	H. Sato	The Tonankai 1944 precursory tilt revisited
5	Y. Fujii and K. Nakane	Reevaluation of anomalous vertical crustal movement associated with the 1964 Niigata, Japan, earthquake
6	A. Zavyalov and R. E. Habermann	Application of the concentration parameter of seismoactive faults to Southern California
7	Anonymous	Withdrawn
8	T. Yoshino	Electromagnetic emissions possibly related to earthquakes in Japan
9	Qiang Zu-ji, Xu Xiu-deng, and Dian Chang-gong	Thermal infrared anomaly precursor of impending earthquakes
10	Zhao Yulin and Fuye Qian	The relationship between georesistivity precursors and crustal deformation

(WAKITA *et al.*, 1988, 1991; ROELOFFS and QUILTY, this volume). The measurements in both data sets seemed to have been carried out with great care and consistency, and noise sources that could have created the anomalies seemed to have been eliminated. The detailed documentation of careful and consistent measurements was the main element that elevated these nominations into a class above most nominations that were not accepted for the List. A common shortcoming of these two cases is that they are based on a single example. Clearly it will be necessary to document many additional cases of the same precursor before we can firmly accept them as valid. An additional problem with the decrease in Radon concentration reported by WAKITA *et al.* is that there is no plausible physical explanation for the connection to the mainshock. In the case of the water level rise (ROELOFFS and QUILTY, this volume) the mechanism proposed is reasonable, although not unique. However, in this case again we do not know, how exactly to use the phenomenon for prediction. For example, how will we estimate the location and the size of the expected event if a similar anomaly reappears?

Some people are of the opinion that none of these precursors should have been accepted for the List, because they are either untested, or are not understood to a point where they could be used for prediction. The reason for their inclusion on the List is that a majority of reviewers and panelists felt that, although imperfect, these cases likely represented real precursors, and would remain on the List over the years, becoming more accepted as additional case histories may be documented. In future reviews of these phenomena the IASPEI Sub-commission on Earthquake

Table 3

Nominations for the IASPEI LIST for which no decision was reached, March 1994

No.	Authors	Precursor	Earthquake
1	Y. Fujii and K. Nakane	strain	1 Sept 1923, *M* 7.9, Kanto
2	Hiroshi Sato	tilt	7 Dec 1944, *M* 8.1, Tonanki
3a	H. Ishii, S. Miura, and A. Takagi	crustal movement	26 May 1983, *M* 7.7, Japan Sea
3b	A.T. Linde, K. Suyehiro, S. Miura, I. S. Sacks, and A. Takagi	strain	26 May 1983, *M* 7.7, Japan Sea
3c	S. Miura, S. Nakao, T. Sato, K. Tachibana, M. Mishina, H. Ishii, and A. Takagi	strain and tilt	26 May 1983, *M* 7.7, Japan Sea
4	M. Wyss	seismic quiescence	many cases

Prediction will reevaluate the status of these precursors, to determine whether additional evidence supports them or whether they should be removed from the List.

The Second Round of Nominations for the List

In the second round, ten nominations were considered by panels, mostly at the 27th IASPEI assembly (Table 2). Two of these were accepted for the List (see above, and Table 1), two were placed in the category of undecided cases (Table 3), and six were not accepted. This means that the failure rate in the second round (66%) was smaller than in the first round (75%). It is hoped that this trend will continue with high quality nominations dominating in the third round. The nomination by SATO (1991) had been placed in a category of undecided cases in the first round (WYSS, 1991), because not all information available for this case had been presented. It was thought that the category of undecided cases was only a temporary holding place for cases that could later be placed into the category of accepted or unaccepted cases, depending on further evidence. However, in the case of the proposed tilt precursor to the 1944 Tonankai (*M* 8.1) earthquake, promoted by SATO (1991, and this volume), the additional evidence was not strong enough to convince the reviewers and the panel. Thus, the category of undecided cases has become permanent (Table 3). Three other cases in this category, placed there in the first round, also remained there. Nobody championed their cause in the second round, to promote them into the category of accepted cases.

The hypothesis of seismic quiescence before mainshocks, considered in this second round, is also in the category of undecided cases (WYSS, this volume). One of the reasons for this is that it has not been tested as rigorously as the hypothesis of precursory swarms was tested by EVISON and RHOADES (1993). Their statistical

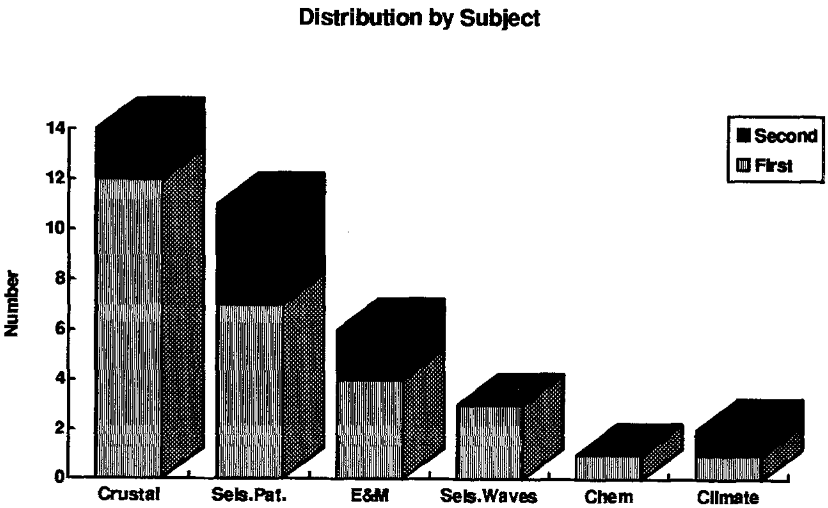

Figure 1
Distribution of nominations as a function of subject. First and second rounds of nominations are differentiated.

analysis, which lead to the rejection of their hypothesis, is exemplary and should be applied to other proposed precursors as well.

The cases for the nominations that were not accepted were not made very vigorously in this second round. This was different from the first round, where some cases were supported, as well as criticized, in detailed articles (e.g., JIN and AKI, 1991; SATO, 1991; CRAMPIN *et al.*, 1991). In these cases the state of knowledge was advanced through these debates, although the proposed precursors could not be accepted yet for the List. The clear messages that reviewers and panelists of the

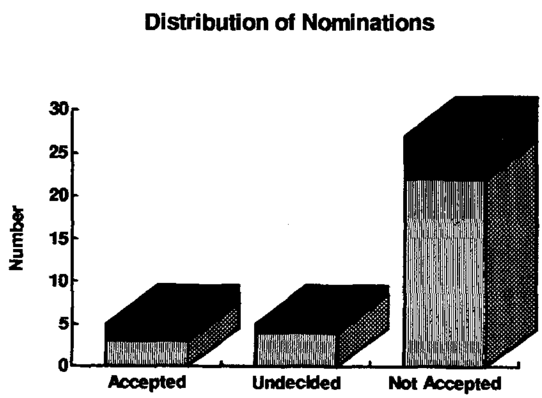

Figure 2
Distribution of nominations in the classes of accepted, undecided, and not accepted for the IASPEI Preliminary List of Significant Precursors. Nominations received in the first and second round of evaluations are differentiated.

second round sent again to nominators were: (1) The probability that the anomaly and mainshock coincided by chance must be evaluated quantitatively. (2) The case for a connection between the anomaly and the mainshock must be plausible. (3) The data have to be excellent.

The distribution by subject matter in the second round was similar to that in the first. Of the 37 total cases reviewed (28 first round, 9 new ones in the second) crustal deformation cases dominate (38%), closely followed by nominations of seismicity patterns (30%) (Figure 1). Electromagnetic precursors lead the seismic wave propagation, climate and geochemical nominations, which, collectively, comprise one third of the entries. Considering all the cases reviewed to date, the majority, 73%, was not accepted, whereas about 14% each was placed in the accepted and the undecided categories (Figure 2). This demonstrates that the proponents of precursors still have considerable work to accomplish to convince the skeptics of the merit of the precursor hypotheses and case histories proposed.

The Review Process of Nominations

Nominations are invited and will be processed at any time (Appendix A). Authors are strongly encouraged to write very detailed nomination papers in which all existing data are shown, all assumptions and error sources are explicitly discussed, where the hypothesis is clearly formulated and at least a tentative physical model is presented to explain the observations, where the probability of chance correlation of anomalies with the mainshocks is evaluated, where the false alarm and failure rates are estimated to the extent possible, and where tests of the hypothesis are presented. Although it is understood that not every nomination can furnish all of the aforementioned elements, each author should endeavor to present in detail as many of them as possible. Scientific journals exert pressure on authors to be brief. With good reason. However, in working toward a Preliminary List of Significant Precursors we are not in the business of communicating new ideas and new methods as briefly as possible to others. We are, however, dedicated to exploring all possible pitfalls to insure that we are not deceiving ourselves, and ultimately the users of the prediction method we wish to develop, into believing, possibly erroneously, that a particular parameter may be used as a precursor. We cannot afford to announce to the public that we have a method for predicting earthquakes, and later retract it as a mistake after several failures. For this reason, nomination papers should be far more explicit than journal articles, and they cannot be first proposals of a hypothesis. The hypothesis should have passed some tests.

Reviewers are asked to give their appraisal, and they may do so anonymously. We are aiming, but not always succeeding, at getting about four reviews. The reviewers are selected for their expertise in the specific field of the nomination. The

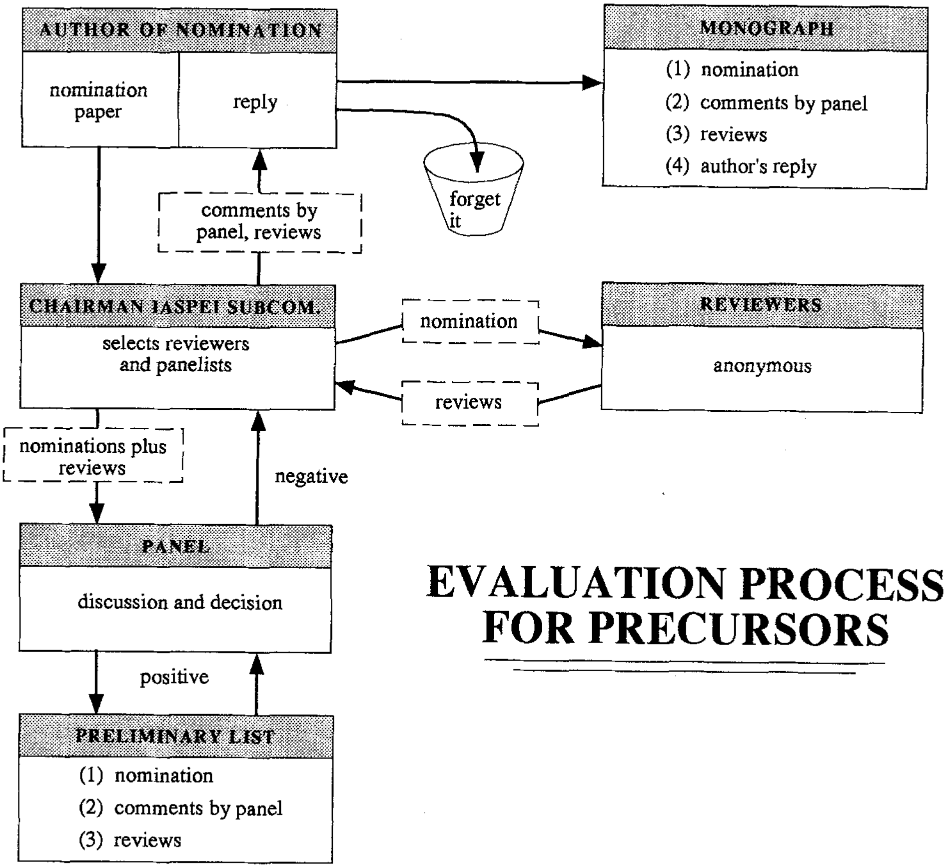

Figure 3
Review process used by the IASPEI Sub-commission on Earthquake Prediction to evaluate nominations for the IASPEI Preliminary List of Significant Precursors.

panels of about five members will then consider the nomination together with the reviews, and discuss the merits of the case. For the discussion, the panels must meet. This introduces delay in processing the nominations because there are no funds available to bring panel members together. We have been using the assistance of Sub-committee members and other senior scientists attending international meetings. Panel decisions usually are unanimous. If not, a vote is taken, and a minority opinion may be formulated.

The panel decision, whether or not to accept a nomination for the List, is then communicated to the nominator, together with the reasons for the decision, and with the anonymous mail reviews. The authors may reply to the reviewers and the panel. We finally publish the entire interchange: nomination paper, mail reviews, panel opinion, and author's reply. Authors have the option to withdraw at any time. However, if reviewers have put forth considerable effort, as they often do, the exchange should be published, because the interchange can be very informative and may move earthquake prediction research forward. The review process is graphically summarized in Figure 3.

Nominations may also be resubmitted. After becoming aware of the skeptic's concerns, authors may be able to improve their work, answering the questions. It is quite conceivable that an improved nomination may be accepted for the List. This is the reason for the discussion of proposals of precursors that have not been included on the List at a workshop planned for the IUGG meeting 1995 (see below).

Future Reviews of Proposed Precursors

The call for nominations is still in effect (Appendix A). The IASPEI Sub-commission on Earthquake Prediction will continue to accept and process nominations of precursors. However, it is not expected that many new cases will be proposed, because earthquake prediction research is not progressing very fast, due to the infrequent opportunity for gathering new data sets. Nevertheless, it is of strong interest to the Sub-commission to review the progress of research. A workshop will be held for this purpose at the IUGG meeting in Boulder, Colorado, where proponents and critics alike will be invited to present their latest views on proposed precursors on the List, as well as those not yet on the List. The subjects that will be discussed in Boulder contain the precursors currently on the List, those in the category of undecided cases, and those that seemed to be the most advanced and mature methods among the cases not accepted. By continuing the dialog on the merits of the methods during the IDNDR, we hope to keep a close tab on developments in earthquake prediction research, and to foster advances in the methods and data quality.

Conclusions

(1) Data sets must have very high quality and long duration to be acceptable to reviewers and panelists for placing precursor nominations on the List. Unless funding is provided for long-term observations, years to decades, and unless great care is exercised in data gathering, an earthquake prediction capability cannot be achieved.

(2) Authors of precursor work and their critics are still deeply divided over what constitutes solid research that can be placed on the List. Some nominators of precursors seemingly fail to realize that placing a result on the List means that we as seismologists are saying to scientists in other fields (physicists, mathematicians, chemists, biologists, etc.): This is the cream of the crop of the work we are doing.

(3) Progress in earthquake prediction research is being made. Two more case histories of precursors have been accepted for the IASPEI Preliminary List of Significant Precursors.

Acknowledgments

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Appendix A

Call for Nominations of Precursors for the IASPEI Preliminary List of Significant Precursors and Guidelines for Submission of Earthquake Precursor Candidates

Call for Nominations (Submissions can be made at any time)

Researchers are invited to nominate outstanding examples of geophysical precursors for inclusion in the list of potentially reliable precursors which the sub-commission has started. The purpose of preparing such a list is to reach a consensus on (a) the quality criteria which a case history has to meet to be considered well substantiated, and (b) which case histories are well substantiated. It is important to identify precursors as either reliable or insufficiently well defined for testing physical models for the earthquake preparation process.

Researchers who propose a particular case for inclusion in the list are assumed to be advocates of the case and are expected to supply supporting evidence. The evidence should address the criteria detailed in the Validation Criteria. The nomination package consists of: (1) a summary defining the nomination and summarizing its strong and weak points, and explaining why this case or method should be included in the list of significant precursors (if possible include an ASCII file of the summary on a floppy disk), (2) published papers on the case history or method in question, (3) unpublished details and supporting evidence.

The facts and interpretations of each case will be reviewed by a panel with the help of anonymous outside reviewers. The reviews, together with the panel evaluation, will be transmitted to the advocate. The advocate has the option of responding to the criticism, or to withdraw the nomination.

Documentation of the absence of a precursor near mainshocks is also invited. In these cases, an explanation of the circumstances whereby a precursor was expected is necessary.

The Sub-commission will not consider predictions of pending earthquakes, only case histories of past events. A report will be issued on all evaluations except for cases withdrawn by the advocates.

Please send your nominations with 10 copies of all supporting material to the chairman of the IASPEI Sub-commission, on Earthquake Prediction.

Guidelines for Submission of Earthquake Precursor Candidates

Validation criteria. Proposed precursors should satisfy the following criteria: (a) The observed anomaly should have a relation to stress, strain, or some mechanism leading to earthquakes. Evidence of a relationship between the observed anomaly and the mainshock should be presented. (b) The anomaly should be simultaneously observed on more than one instrument, or at more than one site. (c) The amplitude of the observed anomaly should bear a relation to the distance from the eventual mainshock. If negative observations exist closer to the mainshock hypocenter than to the positive observations, some independent evidence of the sensitivity of the observation sites should be provided. For instance, if the anomaly is observed at a site that appears particularly sensitive to precursory strain, it should also be more sensitive to tidal and other strains. (d) The ratio of the size (in time and space) of the dangerous zone to the total region monitored shall be discussed to evaluate the usefulness of the method.

Data. Data submitted to support a candidate precursor must include the exact location of all relevant observation sites, the time when the anomaly was observed, and the location, time, magnitude, and focal mechanism of the mainshock associated with the precursor. Details of instrument installation and operating conditions shall be provided. Relevant records of environmental conditions at recording sites such as temperatures, atmospheric pressure, and rainfall shall be provided. There should be a persuasive demonstration that the calibration of the instrument is known and that the instrument is measuring a tectonic signal. This might be done, for example, by comparing recordings of identical or related instruments installed close to each other. Reduced or original data showing the claimed anomalies shall be provided in detail, including figures and tables. Original instrumental recordings or copies of them shall be provided if requested. Data processing steps shall be explicitly explained. Such steps would include removing signals due to installation, changes in instrument properties, and environmental conditions. The possibility of errors introduced inadvertently during data gathering and analysis should be evaluated in detail. All data gaps should be explained, and data editing criteria should be described in detail. It is necessary to provide a long-term record of data so that the long-term signal and noise characteristics can be evaluated.

Anomaly detection. Anomaly definitions shall be precisely stated so that any other suitable data set can be evaluated for such an anomaly. It should be shown how normal values of data during a time interval are established. The difference between anomalous and normal values shall be expressed quantitatively, with an explicit discussion of noise sources and signal-to-noise ratio. Negative evidence (such as failure to observe the anomaly at other sites nearer the earthquake hypocenter) should be reported and discussed.

Association of anomalies with subsequent earthquakes. The rules and reasons for associating a given anomaly with a given earthquake shall be stated precisely. The definition of an anomaly and the association rule should be derived from a data set other than the one for which a precursory anomaly is claimed. Alternatively, a physical theory may be used to define an anomaly and association rule. The probability of the "predicted" earthquake to occur by chance and to match up with the precursory anomaly shall be evaluated. The frequency of false alarms (similar anomalies not followed by a mainshock) and of surprises (similar size mainshocks not preceded by an anomaly) should be discussed. The possibility that anomalies are related to prior earthquakes instead of future earthquakes should also be discussed. The size of any precursory anomalies should be compared with the size of any coseismic anomaly and the relative sizes should be explained. A complete listing of significant earthquakes near the recording instrument is necessary so that possible association with other shocks can be assessed.

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