The Future

In 1992, experts at the National Science Foundation Workshop titled "Low-Frequency Electrical Precursors to Earthquakes: Fact or Fiction?" concluded that "seismic electric signals observed in Greece are generated in the Earth, and the apparent correlation with earthquakes is promising" [*Park*, 1992]. On March 5 and 26, 1993, strong earthquakes hit Pirgos City, Greece. Despite heavy damage, there was no loss of life because the citizens were prepared due to VAN predictions. In 1995, all of the three destructive M:6-class events were predicted and two important international meetings on the subject were held. One was titled "A Critical Review of VAN," held jointly by the International Council of Scientific Union's Scientific Committee for IDNDR and the Royal Society of London, of which the Proceedings is *Lighthill* [1996]. The other was a workshop, "Low Frequency Electromagnetic and Resistivity Precursors to Earthquakes," organized by H. F. Morrison at the University of California at Berkeley. In late 1997, when large earthquakes occurred after the 2.5-year quiescence, quite a few scientists inquired about whether VAN had predicted them. The answer has been given earlier in this article. Thus interest in VAN seems to be growing steadily in the geoscience community.

In Japan, signals highly suspect of being precursors have been observed [*Lighthill*, 1996] and we have embarked on a project to clarify the physics of crustal electromagnetic phenomena, covering a wide frequency range from DC to MHZ. The VAN method is one of the main targets of the project. Inland earthquakes can cause enormous devastation relative to their magnitude, especially when the epicenter is close to a major city. The electromagnetic methods seem to be effective for predicting this type of earthquake with a relatively small number of stations, and therefore at small cost. Objective fundamental scientific research on the electromagnetic phenomena seems indispensable for the future.

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VAN Method Lacks Validity

PAGES 573, 579

Varotsos and colleagues (the VAN group) claim to have successfully predicted many earthquakes in Greece. Several authors have refuted these claims, as reported in the May 27, 1996, special issue of *Geophysical Research Letters* and a recent book, *A Critical Review of VAN* [*Lighthill*, 1996]. Nevertheless, the myth persists. Here we summarize why the VAN group's claims lack validity.

No Physics

The VAN group observes electrical potential differences that they call "seismic electric signals" (SES) weeks before and hundreds of kilometers away from some earthquakes, claiming that SES are somehow premonitory. This would require that increases in stress or decreases in strength cause the electrical variations, or that some regional process first causes the electrical signals and then helps trigger the earthquakes. Here we adopt their notation SES to refer to the electrical variations, without accepting any link to the quakes.

The SES are supposedly observed only at special sensitive spots depending on the epicenters. The spots might be far from the quake, while no observations of SES may be made at nearer sites. Furthermore, the SES are reported only as precursors, not at the times of the quakes themselves when the greatest stress changes occur. No other seismic, geodetic, or geophysical changes regularly accompany the SES.

Laboratory observations show that stresses can stimulate electric fields in dielectric materials. However, this piezoelectric effect is very weak; it would require huge stresses, or extreme sensitivity, and a remarkable conductivity structure for electric signals to be detectable hundreds of kilometers away. The fact that the electrical variations are not observed at sites closer to the earthquakes requires significant conductivity variations.

In several papers the VAN group discusses physical mechanisms by which preseismic stress changes might produce observable piezoelectric effects. But no model explains the quantitative relationship, even to within orders of magnitude, between possible pre-earthquake stresses, SES, and their frequency content. No model explains the sensitive spots (and nonsensitive spots) quantitatively. If, as the VAN group contends, sensitivity were related to spatial variations in conductivity, such variations would be readily detectable using magnetotelluric or other observations. However, no evidence of such variable conductivity has resulted from independent observations.

No Science

Published works by the VAN group lack documentation, adequate formulation of hypotheses, and testing. Because the motivation for VAN's claims is empirical, support for this idea must come from an empirical demonstration that SES predict earthquakes better than chance [*Kagan and Jackson*, 1996]. But VAN's claims of successful predictions for larger quakes in Greece collapse under scrutiny. VAN's hypothesis is ill-posed, and the many published descriptions of it are incomplete and inconsistent [*Kagan and Jackson*, 1996]. Not only are VAN's "predictions" absurdly vague, but VAN also sometimes claim "successful predictions" that violate their own stated criteria and common sense.

No Prediction

Earthquake prediction requires prior specification of times, locations, and magnitudes within stated bounds. Unless these requirements are met, a prediction method cannot be tested or used. A beginning and ending time should be given; the location should be within a closed area or volume; and the magnitude should be defined by upper and lower limits using a particular magnitude scale. The VAN group's "predictions" are much too vague to qualify. Here is an example, quoted verbatim from *Varotsos and Lazaridou* [1991]: "Significant electrical activity was recorded at IOA-station on August 31 1988 epicenter at N.W. 300 or W. 240 with magnitudes 5,3 and 5,8." No limits are given. Instead, they must be inferred from examples of earthquakes the VAN group claims to have predicted.

The vagueness of the predictions has grown steadily with time. *Geller* [1996] provides an exhaustive history with direct quotations from the VAN group. *Varotsos et al.* [1981] claimed that earthquakes followed one type of electrical variation within a few minutes and another type within about 7 hours. In 1984 the VAN group reported several types of electrical variation with interval times of 6-13.5 hr, 43-60 hr, 24-36 hr, and 60-115 hr. In 1991 claims were made for "isolated events" with a warning time of 7 hr to 11 days, "electrical activity" with a warning time of "around 22 days," and "gradual variation of electric field" with a precursor time of "a few weeks." In 1993 successes were claimed within 11 days for "single SES," "order of one month" for "electrical activity," and "a few weeks" for "gradual variation of the electric field." *Varotsos et al.* [1994] claimed success for an earthquake on June 13, 1993, which occurred over 2 months after the prediction was issued. Another earthquake on April 16, 1994, occurred 47 days after its "prediction."

Predicted locations are equally vague. The telegram quoted above implicitly specifies two alternate locations—300 km NW or 240 km W of Athens, respectively—but refers to no closed area or volume. The VAN group has published some "sensitivity maps." However, the sensitivity maps have evolved with time, there is no comprehensive collection, and they have not been used in any attempted significance tests by friends or foes of the VAN hypothesis. Instead, many authors (see May 27, 1996, special issue of *Geophysical*

Research Letters) define for testing purposes a closed region within a circle about the proposed epicenter, assuming that NW means N45W, etc. The size of the "prediction" region was not specified in advance, so the prospective testers had to infer it from the claimed successes.

The VAN group now claims that earthquakes within about ± 0.7 magnitude units of the values given in the telegrams are successful predictions. The magnitude most often cited by the VAN group is M_{SA} (surface wave magnitude determined by Athens observatory), which is determined by adding 0.5 units to the Athens local magnitude. Earthquakes with $M_{SA} = 5.0$ have average global surface wave (M_S) magnitudes of 4.1 [*Wyss*, 1996]. Thus, a "prediction" of an $M_{SA} = 5.7$ earthquake could be satisfied by an earthquake with $M_S = 4.1$ (or even less, if the "about ± 0.7" criterion is stretched, as it sometimes is). The global rate of earthquakes exceeding magnitude 4.1 is about 37 times that for $M_S \geq 5.7$.

No Success

E. Dologlou [1993] claims that the VAN group successfully predicted 21 earthquakes between January 1987 and September 1989, out of 37 earthquakes with $M_{SA} \geq 5.0$. Dologlou, who is a member of Varotsos' department at Athens, lists 32 telegrams that include 51 separate predictions covering the most seismically active parts of Greece. Thus, many successes could be expected by chance, but the actual number is difficult to evaluate because of the VAN group's vagueness. The 67 VAN "predictions" during the years 1987-1995 are listed in Table 1 of *Varotsos et al.* [1996]. However, 27 of these were double "predictions," so VAN predicted 94 earthquakes during this period. Given that such "predictions" are considered open for up to 2 months, much of the 8-year period was covered. Thus, "success" by chance is likely, especially since alarms were preferentially issued during heightened seismic activity [*Kagan and Jackson*, 1996]. *Kagan* [1996] showed that a simple scheme based on recent seismicity outperforms the VAN method. Thus, the reported SES in themselves have no predictive power, even if the VAN group's "success" record is taken at face value.

However, the successes claimed by *Dologlou* [1993] stretch the facts. *Geller* [1996] examines each claim. Of the claimed 21 successes, 14 fall outside the time, space, or magnitude windows which Dologlou herself adopts. Four are aftershocks or members of swarms and three are insufficiently documented. There are no unqualified successes!

Varotsos et al. [1996, Table 3] claim that VAN successfully predicted 10 of 14 events in Greece with $M_{SA} \geq 5.8$ from January 1987 through June 15, 1995. *Geller* [1996, Tables 6, 7 and Section 8.5.3] examined the 13 of these events for which he could obtain the text of VAN's "predictions." Only 3 of the 13 events nominally met the prediction criteria, even if "about a month" allows a time window of more than 40 days, etc. Of the three nominal successes, one lacked sufficient documentation, another was predicted during an intense earthquake swarm, and the third was delayed more than 31 days. The earthquake not analyzed by *Geller* [1996] occurred on June 13, 1993. According to Table 2 of *Varotsos et al.* [1994], a "prediction" was issued on April 12, 1993; that is, more than 2 months before the earthquake.

Several recent moderate (moment magnitude $M_w \geq 5.5$) shallow earthquakes have occurred in or near Greece.

1) October 13, 1997, 36.10°N, 22.04°E, $M_0 = 4.95 \times 10^{25}$, $M_w = 6.5$;

2) November 5, 1997, 38.11°N, 22.49°E, $M_0 = 2.81 \times 10^{24}$, $M_w = 5.6$;

3) November 18, 1997, 37.33°N, 20.84°E, $M_0 = 9.01 \times 10^{25}$, $M_w, = 6.6$;

4) January 10, 1998, 37.21°N, 20.84°E, $M_0 = 1.86 \times 10^{24}$, $M_w = 5.5$.

The locations and scalar seismic moment (M_0 measured in dyne x cm) of these events are from the Harvard CMT catalog. In the companion article S. Uyeda proposes a different list using PDE mb as a criterion, although Varotsos and colleagues now accept M_w as their threshold. There are several slightly different formulas for calculating the moment magnitude. We use $M_w = (\log_{10} M_0 - 16)/1.5$ above.

As far as we know (H. Kanamori and R. Geller, personal communications, 1998), no prediction was issued before event 1). In his companion article, S. Uyeda claims that "two of the three new events in 1997 were predicted remarkably well" in three 1997 manuscripts. They were submitted on October 15, November 9, and November 20; that is, right after earthquakes 1), 2), and 3) in the list above (see the references in the companion paper). The text of the first paper and the drafts (faxed to us by S. Uyeda) do not report earthquake predictions. Instead, each suggests that previously stated criteria and assumptions should be retroactively relaxed or modified so that credit should be allowed for a past earthquake, while suggesting that observed SES might also indicate a future event somewhere. Thus, the VAN group attempts to reserve credit for future earthquakes without risking false alarms.

Shouldn't near misses count as successes, especially since all measurements have experimental uncertainties? The VAN group neglects acceptable ways of treating uncertainties in statistical tests. One such method explicitly expands the prediction windows beforehand to allow for uncertainties. A second method states predictions in terms of a probability density function, which need not be discontinuous at the edge of a window in time, space, or magnitude. But the criteria for success must be stated unequivocally and unalterably before the test begins. Expanding the windows a posteriori to include near misses precludes objective testing.

No Way

Could there be any connection between electrical variations and subsequent earthquakes? Perhaps, but the VAN group's publications have failed to demonstrate one. The VAN hypothesis badly violates physical intuition, it is too vague to test, and its proponents' claims of successful prediction are greatly exaggerated.

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FALL MEETING PREVIEW

AGU Job Center to Offer Services to Candidates and Employees at Fall Meeting

PAGE 575

AGU's Committee on Education and Human Resources (CEHR) went before the AGU Council at the 1998 Spring Meeting last May in Boston and successfully argued for funding of an ambitious Human Resources Program. This new program will fund a number of exciting activities including further development of the AGU Job Center at Fall and Spring meetings, surveying recent Ph.D. graduates on employment trends, and a career brochure designed for students at the eighth grade level.

I would like to highlight AGU's Job Center, bringing to your attention a number of opportunities for this Fall AGU Meeting in San Francisco. AGU has operated its Job Center since the 1981 Spring Meeting, and is one of the few societies to offer such services for free to both candidates and employers. Growth of the Job Center has been rapid in recent years under the direction of Jennifer Giesler, recently given responsibilities as AGU's Career Services Manager. The 1997 Fall Meeting Job Center, in fact, marked a record for the number of jobs registered, and we hope to see this trend continue. Jobs can be preregistered on the AGU Web site and candidates may preview these positions the week before the Fall Meeting.

Growth of the Fall Meeting Job Center also now provides members with a Graduate Forum, a Career Fair, informal Roundtable discussions with professionals, a Career Planning and Placement Workshop, a career search library, information on undergraduate internships, and results from the AGU/AGI Survey of Employment Experiences of Recent Doctoral Graduates in Earth and Space Sciences. Some of the services are targeted for undergraduates and master's students. For example, the Graduate Forum will provide university departments a venue for recruiting undergraduate and master's students for their Ph.D. programs.

This year eight departments are participating—Cornell University, New Mexico Tech, Oregon State University, University of California at Riverside, University of South Carolina, University of Texas at El Paso, Virginia Poly-Technic Institute, and Yale University. The Job Center will also highlight internships for undergraduates. For students of all levels, a number of activities will offer career search assistance.

First, Employment Roundtable Discussions will be available on Sunday, the first day of the meeting. This will give candidates a chance to speak informally with professionals employed in geophysics. Second, a Career Planning and Placement Workshop will be offered on Wednesday. This workshop will concentrate on job-hunting skills and strategies, identifying career goals, researching the job market, and career alternatives. Third, a number of books are available through the Job Center that highlight job search methods. Also, AGU will sponsor a Geoscience Career Fair for recent Ph.D. graduates and early career professionals. The Geoscience Career Fair will provide government and industry organizations the opportunity to recruit candidates with a strong geophysical background. Currently, Koch Industries will be participating in this event. In addition, the results of the employment trends survey of recent Ph.D. graduates will be available for review to interested students.

On behalf of CEHR, I invite you to learn more about the services provided by the Job Center by dropping by its booth in the Exhibit Hall at the Fall Meeting.

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