titatively explained the anomalous crustal deformations associated with the 1989 activities. A plate model of the Kanto–Tokai region which is the scene of extensive seismic activity has also been constructed. These are only a few examples among many achievements. To accelerate the progress of earthquake prediction technology it is essential to increase the number of case studies using more intensified observation systems.

Geller's claim that there should be "external review" for the choice of research directions in the JEPP is reasonable. Not only do the formalities of an external review process need to be set up but there must also be a change in the general attitude of scientists. Careful consideration and discussion among scientists are important to solve these issues.

KAZUO HAMADA
National Research Institute for Earth Science and Disaster Prevention, Science and Technology Agency, Tennodai 3-1, Tsukuba-Shi 305, Japan

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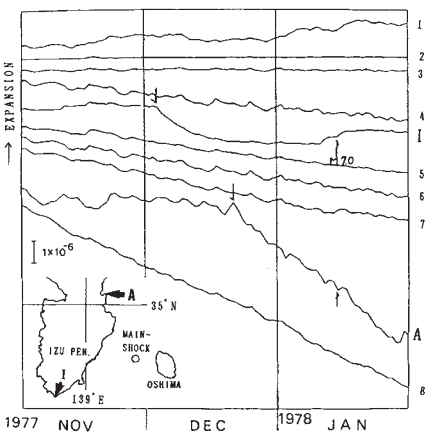
GELLER REPLIES — Hamada's claim that a "short-term prediction for the *M*7.0 Izu–Oshima earthquake of 14 January 1978 was issued by the Japan Meteorological Agency (JMA) 1.5 hours before the event" is at variance with the facts.

The 1978 Izu–Oshima earthquake occurred in an area noted for earthquake swarms. Following 18 felt earthquakes (M_{max}4.9) in a 3-hour period, the JMA issued the following statement[1] (my translation): "The present swarm events, which are somewhat larger than typical swarm events, are the largest since events in 1964 that caused a small amount of damage. Because there is a possibility that the present swarm earthquake(s) may cause some damage, you might consider taking precautions". The *M*7.0 earthquake occurred about 90 min after this statement. However, the JMA statement, which merely cautioned that the earthquake swarm might continue, is not a 'short-term prediction', as it places bounds on neither the hypocentre, the time nor the magnitude[2]. Indeed, neither the JMA nor other advocates of earthquake prediction in Japan have claimed the 1978 event as a successful prediction[1].



Volumetric strain records at 10 sites on the Pacific coast of Japan, near Tokyo. Ajiro (A) and Irozaki (I), shown on the inset map, are about 34 and 41 km from the epicentre, respectively. The other stations are at distances from about 60–200 km. The arrows in early December (Irozaki) and mid-December (Ajiro) indicate the beginning of alleged precursors. The arrows on 14 Jan indicate the time of the *M*7.0 earthquake. This figure (including the arrows exactly as drawn) is taken from the JMA data published shortly after the 1978 event.

Hamada's claim of more than 10 different types of precursors for the 1978 Izu–Oshima event is apparently based on data summarized by Sekiya[3]. The volumetric strain recordings at Ajiro and Irozaki (see figure) are considered the best examples of precursors[4], but no quantitative studies have shown these signals to be causally related to the *M*7.0 earthquake. The amplitude of the December–January signal (the alleged precursor) at Irozaki is an order of magnitude larger than the strain change for the *M*7.0 Izu–Oshima earthquake at Irozaki (which cannot be seen clearly in the figure, but can be seen clearly in data presented by Sacks *et al.*[5]). Because near-field strain dies off as r^{-3}, this suggests that the alleged precursor at Irozaki is the result of a source in the immediate vicinity of Irozaki, rather than a precursory source near the epicentre of the *M*7.0 earthquake, as otherwise a similar signal would have been observed on at least some of the other strain records in the figure. This argument also seems to apply to the Ajiro record.

The existence of many other precursors (water levels, radon and so on) for the *M*7.0 earthquake has also been claimed. However, Shimazaki[6] concluded that some of the apparent precursors are artefacts, and that reports of a similar pattern of temporal variation of different types of observations at different sites were groundless. Also, Turcotte[7] has noted the absence of compelling physical arguments for viewing temporal changes of such phenomena as earthquake precursors.

Notwithstanding Hamada's comments, short-term prediction in Tokai is possible only if precursors occur, are observed, identified, and can be reliably analysed to constrain the parameters of the predicted earthquake. Turcotte noted that "large earthquakes . . . occur without systematic precursory phenomena"[7]: Hamada concedes that "precursors . . . do not always occur". No short-term seismic or strain precursors were observed before the *M*7.1 Loma Prieta, California, earthquake in 1989, despite extensive observational networks[8].

Hamada claims that the present empirically oriented earthquake prediction programme has led to "significant progress . . . in earthquake research in general", but I think there would have been much more progress in the past 25 years if "earthquake prediction and basic research in seismology and other related fields [were] strongly linked"[2].

Hamada claims there is a "clear consensus that . . . short-term prediction for the Tokai earthquake can probably be made using the present instrumental networks". However, the spirited discussion and standing-room attendance at a recent special session "What do earthquake precursors signify?" at the Japan Earth and Planetary Science joint meeting in April demonstrated both a lack of consensus and an intense interest on the part of the scientific community.

Excepting my Commentary article, none of the references cited by Hamada appeared in a refereed journal. This epitomizes the closed nature of Japan's present earthquake-prediction programme and further underscores the need for an open review.

ROBERT J. GELLER
Department of Earth and Planetary Physics, Faculty of Science, Tokyo University, Tokyo 113, Japan

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Scientific Correspondence

Scientific Correspondence is intended to provide a forum in which readers may raise points of a scientific character. They need not arise out of anything published in *Nature*. In any case, priority will ge given to letters of fewer than 500 words and five references. □