Hydrogeochemical Anomalies and the 1995 Kobe Earthquake

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Earthquake precursors are notably difficult to "catch"; so far, most destructive earthquakes in several countries have been in areas without intensive geophysical and geochemical monitoring. The magnitude 7.2 Kobe earthquake on 17 January 1995 was no exception; it occurred far away from the densely instrumented area in and around Tokyo. However, Igarashi *et al.* (*1*) were fortunate enough to have set up a ground-water radon monitor near Kobe a few months before the Kobe earthquake and were able to record some clear pre-earthquake anomalies. Their results are published in this issue of *Science*, together with a paper by Tsunogai and Wakita (*2*), who have observed another pre-earthquake hydrogeochemical anomaly at a different site using an ingenious and inexpensive method: collecting and analyzing commercially bottled and dated drinking water that has been extracted before and after the earthquake. Additional hydrogeochemical data have been obtained by researchers at Kyoto University (*3*).

The Kyoto group monitored water temperature, pressure, and chemical content at three wells (labeled YSO, YDN, and CSN in Fig. 1). Coseismic changes were observed at the time of the Kobe earthquake as well as during two earlier large earthquakes in and near northern Japan (magnitude 8.1 on 4 October 1994 and magnitude 7.5 on 28 December 1994, both more than 1000 km away). Figure 2 shows the recorded water temperature at YDN, water pressure at YSO, and chloride-ion content at CSN, together with atmospheric pressure, temperature, and rainfall data recorded at a nearby meteorological station, HMJ. The water flow at CSN stopped at the time of the Kobe earthquake.

Figure 1 shows also the location of other wells and springs near Kobe that were found in a preliminary questionnaire survey to have shown coseismic changes in either water level or discharge rate. Most sites that showed increases are located in a quadrant compressed by the Kobe earthquake. However, there are also a number of hot and mineral springs in the same area that showed no changes before or after the earthquake.

No significant premonitory changes in strain were recorded at nine crustal-movement monitoring stations, except at Rokko, which is located closest to the epicenter (25 km), as mentioned by Tsunogai and Wakita (*2*). However, coseismic and postseismic changes in strain were recorded at most of these sites. The local seismic networks recorded four foreshocks about 12 and 6 hours before the earthquake. No electromagnetic instrument was deployed before the Kobe earthquake because of the relatively high artificial noise in Kobe city.

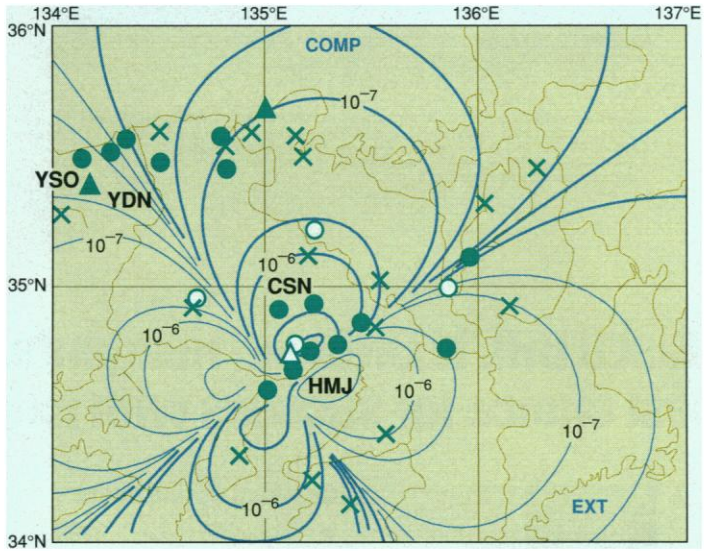

Fig. 1. Location of three water wells used for geochemical observation (YSO, YDN, and CSN), Himeji meteorological station (open triangle, HMJ), and the epicenter of Kobe earthquake (origin of strain-change quadrants). Also shown are the locations of wells and springs that showed postearthquake water-level, pressure, or discharge increase (solid circle), decrease (open circle), increase and stoppage (two wells, solid triangle), and no changes (cross). The contour lines (thick, postseismic compression; thin, extension) indicate coseismic volumetric strain changes calculated from a fault model (*6*).

The fact that several large earthquakes occurred in a broad region within a relatively short period of time is not unusual. Also, the occurrence of the pre-earthquake hydrogeochemical anomalies reported in (*1*) and (*2*) is consistent in pattern with that observed elsewhere, notably in China and the former Soviet Union (*4*): Anomalies may occur a few days to many months before a large earthquake at some "sensitive" locations (within several earthquake-source dimensions from the epicenter). Both the anomalies and the earthquakes may result from some broad-scale but small incremental stress changes in an inhomogeneous crust. Under such circumstances, only fault segments that have been stressed to near critical levels will rupture (*5*), and only aquifers located in structurally precarious zones will respond to the stress increment. In the cases reported in (*1*) and (*2*), it is possible that the pre-earthquake anomalies were triggered by the passage of seismic waves generated by the large earthquakes in late 1994. Even so, these anomalies may still be considered precursory to the Kobe earthquake because the fact that they continued to increase in amplitude after the earthquakes suggests that the monitored aquifers in the Kobe area had been stressed to a critical level before the Kobe earthquake.

There were some anecdotal reports of anomalous phenomena visually observed the day before the earthquake. They include (i) the normally transparent seawater in the epicentral area turned a dirty black-tea color, (ii) a huge number of small fish that had never been seen before were floating on the water, enough that the local Fishermen Association organized 20 to 30 boats to harvest them, and (iii) a number of instances of abnormal animal behavior were observed on Awaji Island. These included the disappearance of the normally common rats from a sunflower seed storage room on a ranch that was later severely damaged by the earthquake. The mechanisms for these phenomena, if precursory, are not known.

The existence of hydrogeochemical and other kinds of earthquake precursors has been regarded with skepticism by many earthquake researchers, particularly in the United States. The primary reason is that in many previously reported cases the data were inadequately documented or causes unrelated to earthquakes were not carefully ruled out. To overcome such skepticism, the monitoring efforts of (*1*) and (*2*) should be continued and, if possible, expanded. Additional data will show background variations for longer periods and will help better assess the significance of the anomalies. Such efforts may also encounter more earthquakes and anomalies, providing a

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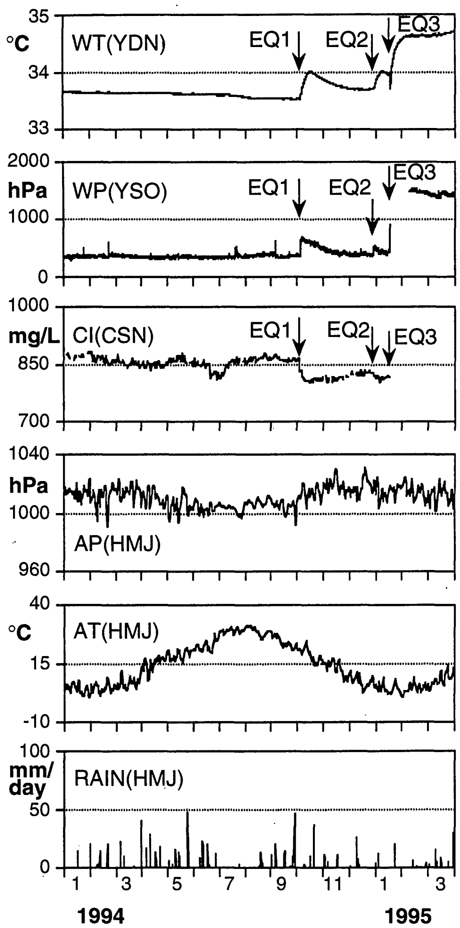

Fig. 2. Temporal variations of water temperature recorded at YDN, water pressure at YSO, chloride-ion content at CSN, and atmospheric pressure, temperature, and rainfall at HMJ. Earthquakes 1, 2, and 3 occurred on 4 October 1994, 28 December 1994, and 17 January 1995 (Kobe), respectively.

better opportunity to study statistically their correlation. Only when a sufficient number of robust cases have been observed in Kobe and elsewhere may we conclude whether a geochemical or geophysical method is useful for prediction. Also, because of the complexity of Earth's crust, it is unlikely that any single method will be useful everywhere. Thus, a multidisciplinary approach for prediction is needed, along with other measures for earthquake-hazard mitigation.

References and Notes

1. G. Igarashi *et al.*, *Science* **269**, 60 (1995).
2. U. Tsunogai and H. Wakita, *ibid.*, p. 61.
3. Disaster Prevention Research Institute of Kyoto University Newsletter (special issue, February 1995).
4. See a review paper by C.-Y. King, *J. Geophys. Res.* **91**, 12269 (1986).
5. C.-Y. King, *Pure Appl. Geophys.* **143**, 457 (1994).
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7. We thank E. Roeloffs and M. J. Johnston for helpful comments.

The Complexities of Conception

R. John Aitken

At insemination, some 200 million spermatozoa are released into the female reproductive tract. Their task: to find just one other cell—the egg. After their journey "upstream" to the Fallopian tubes, the first contact between male and female gametes appears to be a disconcertingly random affair. But, once made, contact is maintained by an exquisitely tuned cell-specific recognition process that results in the tenacious binding of the spermatozoon to an extracellular shell surrounding the oocyte, the zona pellucida (see figure). After the spermatozoon has become tightly bound to the zona pellucida, it is induced to undergo the acrosome reaction, a secretory event that facilitates the spermatozoon's passage through the zona pellucida and its subsequent fusion with the vitelline membrane of the oocyte (see figure). In this week's issue of *Science*, two reports consider the molecular basis of this process. However, the conclusions that they reach are very different.

The molecule on the surface of the ovum responsible for binding and activating spermatozoa is a major glycoprotein constituent of the zona pellucida, ZP3 (*1*). However the nature of the complementary receptors on the sperm surface that bind ZP3, and the biochemistry of the subsequent signal tranduction events, are still open to question. One class of molecule that could account for both ZP3 recognition and signal transduction is a receptor tyrosine kinase (*2*). Exposure of both mouse and human spermatozoa to ZP3 results in the rapid autophosphorylation of tyrosine residues on a putative zona receptor kinase (ZRK) of 95 kilodaltons. In one of the reports in this issue, Burks and coworkers (*3*) used a monoclonal antibody directed against this molecule to screen a human testicular complementary DNA (cDNA) library and isolate a full-length clone predicting a 600–amino acid receptor that contains a unique cysteine-rich extracellular domain. Peptides from the extracellular domain of this molecule suppress sperm-zona binding, suggesting a role for ZRK in gamete recognition as well as signal transduction.

Tyrosine phosphorylation is an important component of the signal transduction cascade used by mammalian spermatozoa with agonists such as progesterone and PAF (*4, 5*), as well as ZP3. However, a central role for tyrosine kinases in sperm-egg recognition is more difficult to understand. This difficulty arises because tyrosine kinase receptors are generally targeted by proteinaceous ligands, and yet there is abundant evidence to suggest that it is the oligosaccharide side chains of ZP3 that mediate the first contact between the sperm plasma membrane and the zona surface. In this context, mouse spermatozoa appear to possess a particular affinity for terminal galactose residues on one class of O-linked oligosaccharides on ZP3 (*6*). Removal or modification of this sugar residue results in a loss of sperm-binding activity. The use of cross-linking and affinity chromatography strategies has demonstrated that this class of oligosaccharide binds to a single lectin-like molecule, localized on the sperm head, with a molecular mass of 56 kilodaltons (sp56) (*7*). In the second report in this issue, Bookbinder *et al.* describe the cloning and sequencing of a full-length cDNA for this molecule (*8*). The cDNA encodes a 547–amino acid peripheral membrane protein with no transmembrane domain and no obvious sequence homology to other galactose-binding proteins such as the rat liver asialoglycoprotein receptor (RHL 2/3). However, this protein is homologous to members of a superfamily of protein receptors of which the most closely related appears to be the α subunit of the complement 4B binding protein.

Evidence that sp56 is a ZP3 receptor in the mouse is convincing, although it is not the only candidate for this role. A sperm-associated galactosyltransferase has also been nominated; this enzyme targets terminal *N*-acetylglucosamine residues on the zona pellucida oligosaccharide side chains, rather than the galactose residues bound by sp56 (*9*). Moreover, aggregation of this receptor induces the acrosome reaction through the activation of a $G_i\alpha$-containing heterotrimeric complex (*10*), providing an alternative signal transduction mechanism to the tyrosine kinase pathway suggested by Burks *et al.* (*3*). Lectins have also been implicated in the binding of human spermatozoa to ZP3, although in this case the sugar involved is neither galactose nor *N*-acetylglucosamine, but mannose (*11*). Human spermatozoa are devoid of both sp56 and significant galactosyltransferase activity but do possess a D-mannosidase activity, which

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