crypt and decrypt with the new codes for this sort of application to be practical. In electronic mail, long messages must be very rapidly transmitted. Brian Schanning of Mitre and Thomas McPherson of Digital Communications, however, explain that their firms are experimenting with a hybrid system that incorporates the best features of a new and more traditional code.

The more traditional code being used is the Data Encryption Standard (DES), a sophisticated system developed by the National Bureau of Standards. Although encryption is fast with the DES, the problem with using the DES alone for electronic mail is that each recipient of a message must be sent a decoding key in advance. The key must be sent through secure channels such as registered mail or a private courier. The sending of the key, then, can be cumbersome, time-consuming, and infeasible for any large-scale mail system.

At Mitre and at Digital Communications, the idea has been to encode DES keys with one of the new codes and then transmit the keys electronically. A user could make public his encryption key but keep his decryption key secret. Then anyone could send him an encoded DES key in advance of a DES-encoded message but only he could decrypt the key and thus the message.

The relatively low speed of encryption with the new codes is a consequence in part of their very novelty. At present, computers, such as microprocessors, must be used to encrypt, rather than special-purpose microelectronic chips, which would be much faster. Ronald Rivest of the Massachusetts Institute of Technology explains that, with a microprocessor, only a few hundred bits of information per second can be encrypted. The DES, which is available commercially as a single chip, can encrypt more than 10^6 bits per second. Rivest and his associates are now putting a new code that they designed on a single chip. A prototype of the chip should be available in June or July, Rivest says, and it should encode more than 10^3 bits per second. And it should be possible to make chips that encode 10^4 bits per second. Rivest speculates that when the new codes are available on single chips, they will be much more widely implemented. Quite a few companies have been asking him when the chips will be available.

Simmons points out, however, that there is another reason people have been slow to use the new codes. They are waiting for some sort of seal of approval from the National Security Agency (NSA), which has already certified that the DES is secure.

The American National Standards Committee has convened a subcommittee to try to decide on a secure version of one of the new codes. This version would then be submitted to the NSA so that it could be officially deemed "not insecure."

For now, implementation of the new codes is still proceeding slowly. But in the future, Amundson predicts, "The applications will only be limited by the needs of the users."

—GINA BARI KOLATA

Quake Prediction by Animals Gaining Respect

The popular idea that animals can sense coming earthquakes is getting a boost from some of the first U.S. studies

> Some instances noted at this time [before the earthquake] were of snakes being found frozen on the road, . . . geese flying, chickens refusing to enter their coop, pigs rooting at their fence, cows breaking their halters and escaping, and goats as well as cows being unusually restless. Rats appeared to behave as though drunk. Three well-trained police dogs howled, refused to obey commands, and kept their noses close to the ground as though sniffing.—HAICHENG EARTHQUAKE STUDY DELEGATION*

Although rarely more than anecdotes, the sheer volume of reports of unusual animal behavior preceding Chinese earthquakes has had a considerable impact in the United States. Reports in the daily press of apparently anomalous animal behavior before an earthquake can upstage the earthquake itself. Even the highly skeptical U.S. scientific community has had to concede that there might be something to it after all. Now, preliminary results from modest U.S. studies suggest that some animals may indeed sense phenomena related to a coming earthquake, but only sometimes. In many cases, it appears that the connection between unusual animal behavior and the subsequent earthquake is only in the mind of the human observer. Unlike Chinese specialists, American researchers are anxious to identify any geophysical link between earthquakes and animals, an interesting prospect being low-frequency sound generated by foreshocks too small to be recognized by standard seismic networks.

Disappointingly, the highly publicized accounts of strange animal behavior, such as those reported from Marine World/Africa USA after the Coyote Lake, California, quake of last summer, have added little acceptable support for the hypothesis that animals can predict earthquakes. "If it's true, it doesn't smack you in the face," says Leon Otis of SRI International in Menlo Park. Otis and William Kautz of SRI run a network of observers that includes people who work in the animal park. The network's 1200 volunteer observers, who are spread over several earthquake-prone areas of California, are instructed to report immediately on a toll-free line any unusual animal behavior.

The trouble, Otis explains, was that most people called after rather than before the magnitude 5.7 Coyote Lake earthquake (*Science*, 2 November 1979, p. 542), which fell on the fringe of the network and 70 kilometers from Marine World/Africa USA. There was no significant increase in calls before the quake, but "as soon as it happened, we got a whole flock of calls," Otis recalls. Most were what the researchers term "I goofed" calls—the observer immediately apologizes for not reporting it when it happened, but their dog or horse or cat certainly was acting strangely soon before the earthquake. Such calls, even those reporting numerous cases of unusual behavior as at Marine World/Africa USA, are dropped from consideration in the study as invalid. The problem may simply be one of training, Otis says, or perhaps people tend to attach special significance to unusual behavior that coincidentally preceeds an earthquake.

*C. B. Raleigh *et al.*, *Eos* **58** (No. 5), 236 (1977).

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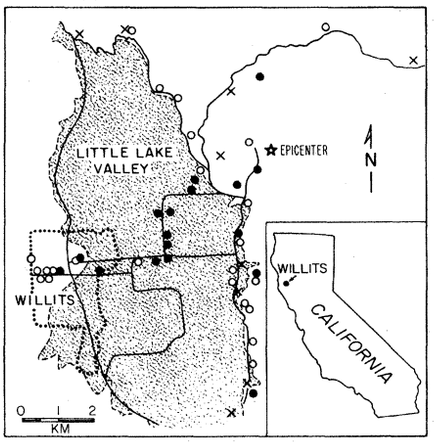
Much of the behavior at Marine World/Africa USA that was reported in hindsight as unusual can be better explained by causes unrelated to the Coyote Lake earthquake, according to Dale Lott, Benjamin Hart, Kenneth Verosub, and Mary Howell of the University of California at Davis. By interviewing the handlers most familiar with a particular animal, they found, for example, that the seemingly unusual clustering of field animals strictly according to species is a common occurrence. The lunging of a shark halfway out of the water, which was reported as unprecedented, happens about once a week, according to its most experienced keeper. And the cougar that became cranky a few days before the quake was found to be still cranky afterward, most probably because of a recurring abdominal problem. These results and those of Otis and Kautz lend credence to the widely held idea that many of the postearthquake reports of unusual animal behavior are the ordinary, everyday quirks of animals seen in a new light after the earthquake.

In spite of the possible pitfalls, the Davis group has been able to use postearthquake reports from untrained observers to substantiate one case in which animals seem to have anticipated an earthquake. In two other cases, animals seemed no better than humans at earthquake prediction. By applying strictly designed interviewing procedures, they found that persons in only 4 out of 51 households in the vicinity of the Coyote Lake earthquake recalled that the behavior of their animals was in any way out of the ordinary before the quake. Only 1 out of 17 households in Ovando, Montana, near a magnitude 4.9 shock in 1977, reported anomalous animal behavior before that quake. The Davis researchers now consider that such sporadic positive reports represent the everyday level of unusual behavior in animals.

By contrast, 17 of 50 households near the Willits, California, quake of 1977 reported unusual behavior such as a nervous Arabian gelding kicking the sides of its stall, a cat pacing and fidgeting during his usual nap time, and a Doberman pinscher alternately whining excitedly and passively putting her head on her owner's lap. None of the behavior was bizarre, the researchers note, but in many instances it was unusual enough to be commented upon before the quake. Even so, most animals, such as the other horses in stalls near the gelding, behaved normally throughout the few hours before the quake, during which most of the reported anomalous behavior occurred.

Exactly what it is that could upset some animals before an earthquake remains unknown, but the few researchers who have shown an interest in the question believe that they have narrowed the possibilities. Ruth Buskirk, Cliff Frohlich, and Gary Latham of the University of Texas Marine Science Institute in Galveston have compared the known geophysical phenomena associated with earthquakes and the known sensory capabilities of animals. They found three possibilities that are consistent with the observed behavior—low-frequency sound, electrical phenomena, and odors. The latter is a neglected possibility, according to the Texas group. Some species, especially fish, are particularly sensitive to electrical field changes but measurements preceding earthquakes are scarce.



Distribution of reports of unusual animal behavior associated with the 1977 Willits, California, earthquake. Solid circles are positive reports, open circles are negative reports, and crosses indicate an inadequate opportunity to observe. [*Source: American Geophysical Union*]

Perhaps the best documented of the three possibilities is low booming sounds that seismologists often hear associated with the aftershocks of major quakes. In 1975, David Hill of the U.S. Geological Survey in Menlo Park found that nearby aftershocks of magnitude 2 to 2.5 shook the ground beneath him enough to produce a low, rumbling boom with a frequency of 50 to 70 hertz, which is similar to that of thunder. Buskirk points out that some species, such as pigeons and kangaroo rats, are far better at hearing sounds of about 50 hertz and below than humans. According to Hill's calculations, even humans may be able to hear booms from quakes as small as magnitude 0 to −1, although neither humans nor animals can feel the ground vibration of quakes with a magnitude of much less than 2. Such small earthquakes could be detected by a seismometer in the vicinity, but they would go unrecorded by even the dense networks in California, according to Hill, because a quake must be recorded by more than one instrument in order to be retained during subsequent data manipulation.

Chance observations of earthquake booms last year in the Mojave Desert by Donald Stierman of the University of California at Riverside illustrate how much better an earthquake detector an animal can be than a human. In camp after setting up portable seismometers in the aftershock zone of a moderate quake, Stierman and his colleagues heard numerous earthquake booms that they initially mistook for the sound of distant artillery practice. Lying in his sleeping bag, Stierman noticed that the booms came 4 to 10 seconds after he felt the shock and that virtually every boom set off a brief chorus of barking from a pair of dogs about 200 meters away. Many of the aftershocks that activated the seismometer beside him could not be felt, but they still produced a boom that incited the usual barking. On several occasions, the seismograph whirred into operation as it recorded another shock, the dogs barked, but Stierman did not feel the shock or hear a boom. He suggests that some earthquakes may have no detectable foreshocks, as was the case at Willits, but still be preceded by very small shocks that provoke obvious anxiety and strange behavior in particularly sensitive animals.

Evidence supporting the anticipation of some earthquakes by animals is being accepted by a growing segment of the scientific community, but researchers do not seem inclined to do much about it. Total federal support for animal behavior studies has been limited to less than $200,000 per year for two or three projects. The low level of research activity is due to the limited number and quality of proposals rather than to a lack of available funds, according to Jack Evernden of the U.S. Geological Survey. "There just haven't been any more credible proposals," he says. Research activity is not expected to increase in the coming year in spite of a conference in the fall of 1979 intended to stimulate greater interest. Some researchers are reportedly concerned that their colleagues still do not consider such studies to be professionally legitimate. In addition, animals, it seems, are less appealing to physical scientists than the more reliable and easily understood machine. If it is ever shown that their machines have been missing some clue on how to predict earthquakes, there will probably be no lack of geophysicists who will try to measure it.—RICHARD A. KERR