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BASELINE STUDIES OF THE FEASIBILITY AND RELIABILITY OF USING ANIMAL BEHAVIOR AS A COMPONENT IN THE PREDICTION OF EARTHQUAKES

Open-file report
(United States.
Geological Survey)

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BASELINE STUDIES OF THE FEASIBILITY AND RELIABILITY OF USING ANIMAL BEHAVIOR AS A COMPONENT IN THE PREDICTION OF EARTHQUAKES

TECHNICAL REPORT

Grant 14-08-0001-G-482
and
Contract 91622

Dale F. Lott
Wildlife and Fisheries Biology

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TECHNICAL REPORT

Grant 14-08-0001-G-482 and Contract 91622

Baseline Studies of the Feasibility and Reliability of Using Animal Behavior as a Component in the Prediction of Earthquakes

INTRODUCTION

This project was established to determine if it were possible to advance the state of the art in earthquake prediction by learning more about claims that unusual animal behavior was an earthquake precursor. We used intensive post-earthquake interview surveys to gather objective reports both of instances of unusual animal behavior as an earthquake precursor and of instances in which animals behaved normally prior to a moderate or large earthquake. We prepared briefing volumes describing the cultural significance and interpretation of seismicity for cultures other than our own with which we were likely to have contact. This information helped us assess the impact of cultural expectations on our data set. These briefing volumes are one of the work products of our project and are included in this final report.

Since our goal was to increase the ability to predict earthquakes, we avoided study of earthquakes with known foreshocks since in those cases the unusual animal behavior might have resulted simply from the foreshocks. Our data indicates that unusual animal behavior occurs a few hours to a few days before some, but not most, earthquakes that do not have known foreshocks.

Our studies of earthquake folklore support the same conclusion (pp 121-144 of this report). Even when unusual animal behavior is a precursor to a particular earthquake, most individual animals behave normally. This creates a signal to noise ratio that will reduce the potential for direct use of unusual animal behavior in earthquake prediction, but the analysis of some animals

reactions might help to identify physical precursors to at least some earthquakes.

Each phase of this research program has produced one or more completed work products. These products, which follow, compose our final report.

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Mary Howell

1978

Introduction

The High Cultures of ancient Mexico originated in the central highlands and along the valleys and coastal plains of south-central Mexico. From that central geographic province, began a stream of emigration to the south and east, extending as far as the lands that today are Guatemala, El Salvador and Nicaragua. Together with the Maya-speakers already present in these new lands, the Mexican emigrants, although of differing linguistic stocks and cultural achievements, were similar in a great many respects and formed what has been called "a great geographical culture province" (Seler, 1960). Mexico and Guatemala are particularly represented in the historical record by the Maya, Aztecs, and other groups such as the Zapotecs, Mixtecs, and Huastecs. Groups such as these are generally considered to have developed a relatively greater complexity in religious beliefs and ritual activity than other groups of Mexico and Central America. Thus, south-central Mexican and Guatemalan culture traits are more closely related, and of a different nature than those found in most other far south and eastern regions of Central America. Additionally, Mexico and Guatemala now share a common basis in the relatively greater population density and variety of cultural practices than do their neighbors to the far south and east (Foster, 1950). It is important to realize, however, that <u>while cultural details vary in assemblage, pattern or emphasis from settlement to settlement, a single cultural tradition appears to exist throughout the highlands of Guatemala and Mexico.</u>

Maya-speakers today inhabit areas of south-central Mexico (especially Chiapas), Guatemala and Belize. They are largely found in the central highlands of Chiapas and Guatemala, lowlands of Yucatan, parts of Belize, Tabasco,

Campeche, Vera Cruz and San Luis Potosi (Vogt, 1969b). Of the remaining indigenous peoples of the New World, Maya-speakers rank high in population size and distribution, second only to the Quechua-speakers of South America (Vogt, 1969b). Much of the land which is now occupied by Maya-speakers lies in an area of high seismic activity. This region extends diagonally from the highlands plateau of Chiapas through the highland of Guatemala, north to nearby mountainous parts of Honduras, and South-east through El Salvador and Nicaragua. Although most strong earthquakes have had epicenters located just off the continental shelf in the depths of the Pacific Ocean basin, the occurrence of strong earthquakes in the above regions of Central America is certainly well documented (ESSA 1970). Therefore the discussion of ethnographic information in this paper will restrict itself to these areas.

In the Mexican state of Chiapas lies a region occupied primarily by the Tzotzil, Tzeltal, and Tojobal peoples, about 167,000 Maya-speakers. These Indian groups largely populate the Chiapas plateau in widely scattered settlements and share the area with Ladinos in towns and villages, occasionally interspersed with fincas (plantations) and cattle ranches (Vogt, 1969b). The Guatemala highlands, with the greatest predominance of Indian populations, forms the second great realm of Maya speakers, and may be roughly subdivided into three major regions:

(1) the northwest highlands--located around the Cuchumatanes mountains are found primarily in the departments of Huehuetenango and San Marcos. Here reside the Mam, Aguacatec, Ixil, Kahobalan, Jacaltec, Solomec, and Chuh peoples totalling approximately 278,000 Maya-speakers.

(2) the midwest highlands--located around Lake Atitlan, are largely in the departments of Solola, El Quiche, Chimaltenango, and Quetzaltenango. The

predominant Indian groups include the Quiche, Cakchiquel, Tzutuhil, Rabinal, and Uspantec, about 573,000 Maya-speakers.

(3) the eastern highlands--located east of Guatemala City are found in several departments including Jalapa and El Progreso. There is a considerably smaller Indian poplation in this region, consisting mostly of the Pokomam and Chorti, about 23,000 Maya speakers (Vogt, 1969b). In addition to the Indian population of each of these regions, there also exists a significant although smaller population of Ladinos.

The continental divide runs through the central highlands of Guatemala. The mountains of the highlands range in altitude up to 10,000 feet, averaging at about 4,000 feet. The Western highlands, where the greatest numbers of Indians reside begin just to the west of Guatemala City and extend westward into Chiapas. This western mountainous region represents approximately one-fourth of the area of Guatemala (Nash, 1969).

Some general statements can be made about the Chiapas and Guatemala highland areas: climate is predominantly cool and deep deposits of volcanic ash are present. The dominant vegetation includes "grassland and trees, sedge, and meadows for sheep" (Nash, 1969). The midwestern highlands being generally better suited to subsistence Indian agriculture rather than the European form, is generally "a stronghold of Indian settlement" (Nash, 1969). Thus one would also expect fewer Ladinos and less ladinoization. Likewise in regions where European agriculture is dominant, one would expect to find other European traits and a greater degree of ladinoization.

A second and useful classification system of agricltural zones can be applied to these areas we are examining:

(1) <u>tierra fria</u> - land above 1600 m. Usually characterized by one dry

season, one rainy season, this region produces one crop of maize per year. This zone may have pockets of humid or arid conditions which influence agricultural production.

(2) tierra templada - 800-1600 m. Generally more humid than the tierra fria, this region has one rainy season and one dry season; two maize crops per year is usual. In these elevations, European crops such as coffee, citrus, and sugar cane have been successfully introduced. This agricultural pattern may have demographic implications, i.e., Ladino populations might be expected in greater numbers in these regions.

(3) tierra caliente - sea level - 800 mm. This region has one short dry season and a regular rainy season with abundant precipitation. In this elevation, mean annual temperatures and rainfall assures two annual maize crops (Palerm, 1967). These lowland areas generally do not correlate well with the regions of Guatemala and Mexico which experience great earthquake activity. Most of the central highlands are tierra fria lands, however in the areas bordering these highland regions, mountainous terrain may have interdigitating belts of all three climate types, depending on altitude (Palerm,1967). This situation is found both in the Guatemala and Chiapas highlands, which are similar in many respects including vegetation, geology and topographical features (Vogt, 1969b).

According to Nash's map of the geographic provinces of Guatemala, it appears that the earthquake of February 22, 1978 was felt in the Upper and Lower Pacific Piedmont regions (Nash, 1969). Nueva Concepcion, the site of the reported epicenter of the 5.6 earthquake (February 1978) is located in the Department of Esquitia. Located on the coastal plain at the southwestern base of the Sierra Madre range, Tiquisate, a Municipo of the area, appears to be a crossroads for

several transportation routes. The close proximity of these areas allows one to make some cautions assumptions of cultural similarity among peoples of this geographic region.

Because of the epicenter's close proximity to predominantly Quiche-speaking peoples, Quiche may also be encountered in regions affected by the earthquake, in addition to Mam ean languages (Mam, Aquacatec, and Ixil) (Nash, 1969). It is interesting to note (and may have significance in the use of field interpreters) that Indians apparently feel no socio-cultural unity based on "linguistic affiliation beyond the municipal level". Neither do they identify themselves as Quiche or Mam for example, nor do they distinguish themselves from other Indians on the basis of the language they speak. Where different Maya languages abut, speakers do not necessarily understand each other; such is the case with Mam and Quiche (Nash, 1969).

SOCIAL AND POLITICAL ORGANIZATION

A common socio-political form of organization occurs throughout much of the highland regions of Chiapas and Guatemala. Largest in scope is the department, similar in function to a state. Each department comprises usually several municipios (small cities or towns) each having a pueblo or cabecera (capital) of the same name. The cabecera forms the central hub of economic, political and religious activity; larger cabeceras may be subdivided into barrios, calpules, or secciones each having distinguishing socio-cultural traits or activities. Municipios may be further subdivided into units termed aldeas, cantones, congregaciones, or caserios. Probably the most common of these sub-divisions is the aldea, which generally connotes an Indian settlement and is found in areas surrounding the pueblo (Wisdom, 1940; Camara, 1952). The typical highland

(Indian) population resides in a village or rural area around a central town. The town proper (cabecera or pueblo) takes on the significance of a "common civic and religious center" to which residents of the community feel a sense of belonging (Redfield and Tax, 1952). In this community center, public office holders perform their duties, markets are held, churches and homes are present. The term "vacant town" is used to describe towns or pueblos which have no permanent Indian residents. In these towns, Indian families reside in the surrounding countryside working and living on their farms. These people may live in either nuclear or extended family situations. Then on market days, fiesta and church days, people come in from their country homes and live in their town houses, using them as "headquarters" during these times. This type of settlement pattern is typified by the municipio of Chichicastenango. A variation of the "vacant town" municipio occurs when Ladinos are present as permanent residents of the pueblo in addition to the "oscillating" Indian population. Such is the case in Totonicapan, where Ladino residents are found in the pueblo at all times and Indian populations tend to be interspersed about the periphery. In these instances, it is probably common that Indians become attracted to employment opportunities offered by Ladinos, and in doing so may tend toward becoming more permanent residents themselves. A third type of settlement pattern, like many communities of Lake Atitlan, is that of the "town nucleus", where most of the Indians are permanent residents of the pueblo. In this case, most residents are to be found in neighborhoods along fairly well-defined streets. Plots of land used in agriculture are still located in the surrounding countryside, however men leave early in the morning to work the land, leaving women and children to perform their tasks in the municipio (Tax and Hinshaw, 1969). Variations in settlement patterns such as these must be

taken into account when respondents are chosen and contacted.

Municipios are important ethnic units of social organization. Residents make distinctions between themselves and those of other municipios. Each municipio is characterized by a unique set of culture traits: habits, speech accent, rules of etiquette, methods of producing goods, and ways of dressing to name only a few. However "culturally distinct", the strong sense of group affiliation with one's own municipio does not preclude contact with people from other municipios at markets and through other commercial, political and social events (Tax, 1953, and Camara, 1952). One of the chief marks of identifying a specific municipio is that of the economic specialty it produces. This type of specialization arises from a variety of environmental "determinants". Economic production may vary with altitude which limits uniformity of crop zones and the types of domestic animals which may be raised. Access to resources such as availability of water, arable and grazing land may determine the types of crops and livestock which can be raised, (Tax, 1952). Thus resource distribution such as this may influence the choice of interviewing sites in order to obtain observations of animal behavior.

As mentioned above, political activity within a municipio is generally organized around a central building or cluster of buildings. Office-holders form a hierarchy which is generally recognized as an affiliate of the national state government. However, in addition to political activities, these officials also often serve as functionaries of the religious hierarchy providing leadership in local religious activities and during other festive occasions (Redfield and Tax, 1952). These politico-religious leaders are usually a few older and experienced men of the community known as principales, pasados, or cabildos, alcaldes, jueces, gobernadores or jefes. These men are obeyed and

highly respected largely because of the economic success they have attained, their ability as leaders, because they are learned and wise or because they have great knowledge of religious and political ritual (Camara, 1952). In Indian municipios, the principales constitute an "informal Indian power structure" which generally makes decisions on which persons will fill administrative offices. The alcalde fulfills the role of mayor and justice of the peace; local grievances are heard at the municipio town hall, the juzgado (Hirshberg, 1958). Often the high-backed sandals, and a long black ceremonial robe are signs of authority worn by municipio officials. Additionally, most officials carry a staff of some kind which marks their status (Vogt, 1969c). It is interesting to note out that while formation of socio-economic classes is atypical in Indian society, it is very characteristic of Ladino culture. Leadership in Indian groups is considered as a community service obligation, whereas Ladinos generally consider office-holding as a measurement of success; therefore those positions are competitive and highly sought after.

ETHNIC RELATIONS

In spite of the strong inclination toward the peculiarities of one's own municipio, a general attitude of neutral acknowledgment of cultural differences of other municipios predominates, at least in western Guatemala Indian populations (Tax, 1953). Thus it appears that there is very little prejudice in Indian-Indian relationships. Such is not the case, however, in Indian-Ladino relationships. The term "Indian" may be used by some to indicate socio-economic status, however the term most often is a cultural one. The basis for identifying the Indian lies in a cultural definition, thus the distinction between people of Guatemala and Chiapas is an ethnic one rather than a racial

one. A man is considered an Indian if he adheres to Indian customs, beliefs, occupations, dress, and if he speaks a non-Spanish language (Salz, 1953). Indian mannerisms may commonly be viewed as "backward", "inferior" or "vulgar" by Ladinos, especially urban Ladinos (De la Fuente, 1952). There seems to be a fairly strong tendency for Indians to adopt Ladino (or westernized) traits in order to gain social status. The process of "ladinoization", as this transition is often called, is accompanied by adopting Spanish as the primary language, withdrawal from Indian life styles, the division of religious and political activities into two domains, and adopting European customs (western dress, high values of money and manufactured goods, among others) (Camara, 1952). There is also disparity in more basic attitudes between Ladinos and Indians. Within Indian families, the husband is "officially dominant"; however in a practical sense a reciprocal division of labor and decision-making occurs. The position or status of Indian women is relatively high. Women and men make joint decisions on family financial matters. The advice of an old woman is valued as highly as that of an old man (for example when both are relatives). In addition, politico-religious posts may occasionally be held by women, although most offices are held by a couple (Guiteras-Holmes, 1952). The machismo or masculine dominance ideal is less present among Indians. On the other hand, among Ladinos, machismo is much more obvious. The woman assumes a less assertive role and is not readily accepted as a participator in politics and business. The Ladino marriage is essentially a "contract between families as well as individuals, and tends to be calculated with heavy attention to the social status of the prospective spouses, a feature which does not occur among Indians" (Gillin, 1952). Although accessibility to respondents may vary from group to group and among individuals, the above points should probably be

recognized in the course of fieldwork and dealt with appropriately.

Ladino-Indian and Ladino-Ladino tensions seem to arise from a variety of circumstances: (1) reciprocal prejudice between agrarians and non-agrarians, (2) prestige of having Caucasian features (especially light complexions), (3) wealth-status levels (Humphrey, 1953). (Note: Although this passage refers to field-work in Jalisco, Mexico, by Humphrey, the statement is essentially applicable to most areas of Central America). Indian-Indian conflict is not serious in political, occupational, or in religious spheres. However, there may be greater conflict among Indians in response to economic competition and access to land, than among Indians and Ladinos (De la Fuente, 1952).

"Indians exhibit some prejudice against unknown Ladinos and resent regional Ladinos, traditionally dominant as well as those (generally governmental employees) who exercise political and general dominance. Regional Ladinos exhibit suspicion of Indians of particular villages." (De la Fuente, 1952).

The intrusion of Ladinos into, and plundering of Indian territory has resulted in great hostility toward Ladinos on the part of Indians. Apparently that hostility is returned by Ladinos in certain regions. Conflict also occurs in places where formerly peaceful Ladino-Indian relations have deteriorated into a situation of "double conflict". Indian resentment and fear of Ladinos (as a result of recent plundering, destruction and usurpation of Indian property) has sometimes been "directed toward Ladino authorities" charging that they are protecting the Ladino exploiters. Ladinos, "in turn, resent the relatively greater favor accorded the Indians in the regional [political] organization" (De la Fuente, 1952). These facts suggest some features the field worker must

consider in finding appropriate and culturally acceptable interpreters, or persons introducing them to each of the types of communities they wish to study.

WORLD VIEW

For the Indian, the universe is confined for all practical purposes to the limits of the local community. While some Indians may indeed travel and experience contact with regions outside their community, the contact is not perceived as a part of their "structured life experience". The Ladino typically has a more expanded view of the universe. Socio-economic and political ties connect Ladinos with other communities (Gillin, 1952). Thus for both groups, the degree of contact with other people and ideas, particularly those of Western orientation, may in turn influence their thinking about certain issues, such as the causal mechanisms of earthquakes, for example.

Ladino culture maintains a strong interest in its European heritage, its ancestors its history. Indian culture, on the other hand, does not extend temporally out of the present. There is very little "collective memory" concerning the past, and little or no projecting into the future (Gillin, 1952). Thus, the perceptions of the two groups concerning past and future personal events may also "spill over" into conceptions of natural events (such as earthquakes) resulting in distorted answers, although this statement largely refers to events occurring in the long-ago past.

Ladinos and Indians also differ fundamentally in the way they picture the world in relationship to themselves. The Indian will try to adapt him- or herself to a peaceful coexistence with the universe. A basic Indian belief is that man must learn to act in such a way as to reap the greatest reward and least misfortune as possible from a universe which is inevitably controlled by

supernatural forces. The Ladino, on the other hand, wishes to control the environment and assumes that both the natural and the supernatural realms can be manipulated by man (Gillin, 1952). It is quite likely that these fundamental distinctions in worldview will color attitudes and beliefs about cause-and-effect relationships between events in the natural world.

Another factor which may influence answers during interviews involves the status the respondent acquires by participating in the interview. Among Indians, the individual *per se* is less important than the group as a whole. The Ladino, however, accords the individual a great deal of status (Gillin, 1952). These factors may or may not affect the validity of responses given in interviews; however they should nevertheless be kept in mind during fieldwork.

For Indians, continuous practice of traditions is greatly valued. In contrast, Ladino practices and values change through time to a much greater degree (Gillin, 1952). There is a general inclination for Ladinos and individuals becoming ladinoized, as a group, to overtly ridicule the magico-religious aspects of Indian traditions. This derision may in part be the result of newly acquired Western "ethical and moral values". (1) On an individual basis, the Ladino may still perform activities peculiar to Indian traditions; however he does so only when this participation will provide personal benefit. (2) In addition, this small acceptance of Indian ways is done so, covertly or through rationalization or justification of the activity (Gillin, 1952). (3) There does not appear to be ridicule of Ladino beliefs by Indians *per se*, however, Indians who are trying to imitate Ladinos for social benefit are considered to be disloyal or "putting on airs" by other Indians. Thus, field interviewers may be likely to find Indian respondents emphasizing the supernatural quality of earthquakes and other natural phenomena, while

unusual behavior reported here was much less than that reported before the Willits earthquake, where 17 of 41 interviews yielded positive reports. Moreover the reports that we did get from Coyote Lake make much less sense biologically than the reports obtained at Willits.

We believe, based on our experience with animals and their owners, that the rate of unusual animal behavior at Coyote Lake was not greater than the rate that would be observed on any ordinary day.

It is worth noting that most of the people giving these negative reports believe that animals behave strangely before earthquakes. An opinion on this issue was obtained from 31 of the people who reported no unusual behavior either at the time of the P wave or earlier. Twenty-four of them definitely believed that animals behave strangely before earthquakes, four thought it possible and only three thought it was not true. At the same time they were sure that the animals they knew about had not done so before this one. The day after the earthquake the news media reported that there were many instances of unusual animal behavior at a commercial wild animal park 70 km north of the epicenter. The park welcomed our request to visit the site and arranged for us to interview the people most closely involved with the animals.

On the basis of 27 interviews focused on unusual animal behavior we concluded that nearly all the instances of unusual animal behavior reported were better accounted for in other ways and that not enough remained to represent an increase over what

we supposed would be the base rate. One report involved a tiger cub that became irritable and difficult to manage 2 days before the earthquake. When we visited 2 days after the earthquake he was still in the same foul temper. The behavior was unusual but it was not temporally related to the occurrence of earthquake precursors. A second case involved leopard sharks reported by one person to be lunging nearly out of the water hours before the earthquake, behavior the person had never seen before. However, another caretaker who spent much more time with the sharks reported that he saw that behavior frequently. The behavior was not really unusual.

In summary, we searched for evidence of unusual animal behavior as a precursor wherever we had reason to suppose it might exist and we believe that we found none. Thus our findings in animal behavior conform to those of investigators in the geophysical sciences, pointing to an absence of detectable precursors to the Coyote Lake earthquake.

IS UNUSUAL ANIMAL BEHAVIOR OBSERVED BEFORE EARTHQUAKES? YES AND NO

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Abstract. Following two moderate earthquakes, reports of the behavior of animals prior to the earthquakes were gathered using a standardized interview schedule. This schedule was developed to maximize the reliability and validity of the reports through the application of accepted social science methodology. Interviews with 50 households near Willits, California, produced 17 reports of unusual animal behavior prior to that earthquake. Only one of thirty-five interviewees who experienced a similar earthquake near Ovando, Montana, reported unusual animal behavior prior to the earthquake. This difference in the frequency of positive reports and the content of the positive reports from Willits support the inference that a number of animals at Willits were responding to physical precursors which were absent at Ovando. The behavior reported at Willits was unusual in the sense that there was no immediate explanation for it, but it was not bizarre. On the contrary, it was always behavior typical of that species when motivated by generalized anxiety. Unusual behavior was often reported in only one or a few animals at a particular location so that even at Willits most animals were described as having behaved normally.

Introduction

It has been said for centuries that strange, unusual, bizarre or unexpected animal reactions have occurred prior to many earthquakes. In fact, abnormal animal behavior is the oldest and most consistently reported earthquake precursor [*Lee et al.*, 1976]. Chinese claims that animal behavior reports had a role in the successful prediction of the Haicheng earthquake of 1975 stimulated both popular and scientific interest in this phenomenon. But virtually all of the reports of abnormal animal behavior are retrospective, i.e., the recollections of human observers subject to the excitement and emotional strain caused by an earthquake. The doubts raised by this circumstance have been reinforced by recent investigations which did not find any evidence of unusual animal behavior prior to particular earthquakes [*Toksoz et al.*, 1977; *Wallace et al.*, 1977]. These conflicting viewpoints prompted us to ask whether these disparities resulted (1) from investigators using widely varying methodologies, or (2) from precursory stimuli unique to any given earthquake. In an effort to address this issue we developed an interviewing strategy designed to obtain unbiased, reliable and valid reports of animal behavior as it occurred before an earthquake. We applied this uniform methodology to two post-earthquake investigations and obtained different results. One earthquake was preceded by several cases of unusual animal behavior while the other earthquake produced only one account of abnormal animal behavior.

The two earthquakes studied had several characteristics in common. Both earthquakes occurred near semi-rural communities where most households owned livestock and pets. Both communities are situated in alluvial valleys, and the earthquakes studied at each site were of similar magnitudes. A magnitude 4.7 earthquake occurred at Willits, California, on 22 November 1977 at 1:16 PM (PST); on 23 April 1978 a magnitude 4.9 earthquake occurred at Ovando, Montana, at 4:24 PM (MST). The Modified Mercalli intensities clustered around V at both sites; no foreshocks were detected before the main shocks at either site.

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Data Collection

Our interview schedule has seven goals which we pursued in the following sequence:

1. establish rapport and convince the interviewee that the interviewer does not have preferred answers to his questions: implemented through verbal application of the Modified Mercalli scale of perceived intensity. (Since application of this scale always involves asking if effects greater than those perceived occurred, the interviewee learns that he or she is giving useful information when he or she answers a particular questions by saying "no".)
2. introduce the subject of precursors in general: implemented with a short neutral question "did you notice any changes before the earthquake?"
3. raise the question of unusual animal behavior without creating pressure to answer: implemented by a question that gives the respondent a graceful way to acknowledge being unaware of the behavior of his or her animals "someone as busy as you might not have the chance to notice what their animals were doing before the earthquake, but did you happen to?"
4. obtain an objective description of the animal's actions to be interpreted by the animal behaviorists on the project and learn if these actions occurrred in other contexts: implemented by questioning by the behaviorist.
5. check the internal consistency of the report: implemented by a repetition of critical points of the interview.
6. check the external support for a report of unusual animal behavior: implemented by viewing the animal, observing the sites of the reported behavior, examining damage caused by the animal's behavior, inquiring if the behavior caused the informant to discuss it with someone before the earthquake.
7. find out if the respondent believes that animals behave abnormally before earthquakes: implemented by asking the respondent's opinion of reports that animals behave abnormally before earthquakes.

This survey was first used in Willits and again in Ovando approximately six months later. Each interview was conducted by a behaviorist and a research assistant. The assistant took notes and conducted the internal consistency checks. Interviews were openly but inconspicuously tape recorded.

After each interview, the two interviewers independently rated the interviewee's credibility on a scale from one to five, where five is highest credibility. With the exception of one case for each earthquake, the behavior of the subjects and internal consistency of their reports convinced us that they were faithfully reporting their recollection of the event. The consistency of their reports with known behavioral phenomena convinced us that their recollections accurately reflected the behavior of the animals.

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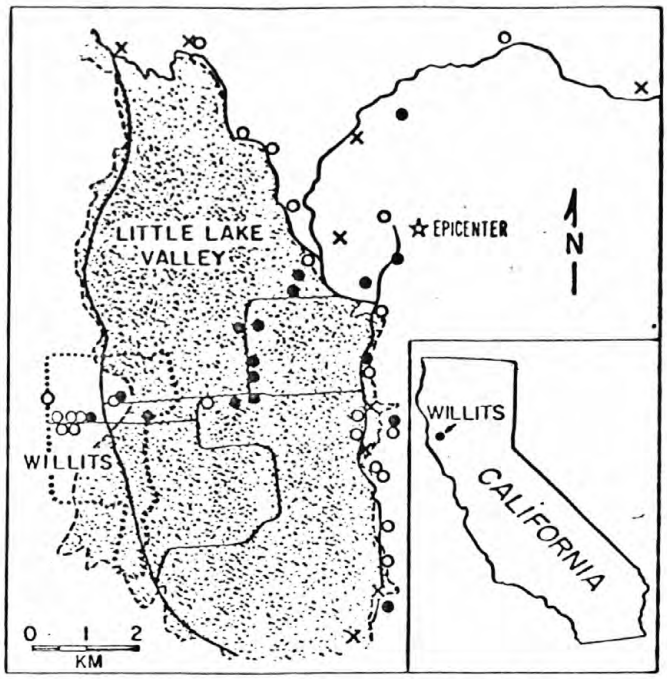

Fig. 1. Distribution of reports of unusual animal behavior in the vicinity of Willits, California, associated with the earthquake of 22 November 1977: Positive reports (solid circles), negative reports (open circles), inadequate opportunity to observe (crosses). City limits are indicated by a dotted line, principal roads by solid lines. Shaded area represents alluvial valley.

Data Analysis

Those interviewees who were home for any part of the five hours preceding the earthquake were categorized as having had an adequate opportunity to observe their animals. This excluded those who had arisen in the morning, put out food for their animals and gone to work with little or no awareness of the state of their animals. Overall, this criterion undoubtedly inflated the number of negative reports. Several respondents said they were at home but would not have noticed unusual behavior in their animals if it had occurred, yet these reports were categorized as negative. Moreover, unusual animal behavior might have gone unnoticed by people who thought they were well aware of their animals.

A report was judged positive if at least one animal at the residence exhibited unusual behavior at least 5 minutes before the shock. Reports of behavior less than 5 minutes before the earthquake were not scored as positive to avoid scoring responses to the P wave. Although the P wave would have arrived only seconds before the main shaking, the five minute criterion was adopted to allow for error in the judgement of time by the respondents. Two reports (from Willits) that were otherwise positive were classed as negative through the application of this rule.

Our first set of data consisted of interviews with 50 households near Willits, California, which produced 17 positive and 24 negative reports of unusual behavior prior to the earthquake. The relationship of positive and negative reports to the epicenter of the Willits earthquake is presented in Figure 1. The positive reports tend to be clustered in a small region to the southwest of the epicenter. Most of the positive reports were in response to the general question about earthquake precursors, which preceded any mention of animal behavior by the interviewers.

It is possible that the positive reports from Willits reflect merely some chance level of reports of unusual animal behavior and might be obtained at the same frequency in the absence of any seismic event. The fact that there was only one positive and 31 negative reports among 35 interviews following the Ovando earthquake has enabled us to reject this possibility (Figure 2).

This earthquake occurred on a Sunday at 4:24 PM (MST); consequently fewer people in Ovando (3) than in Willits (9) lacked the opportunity to observe their animals. In contrast to those from Willits, no positive reports from Ovando were reclassified to negative status through application of the five minute criterion. Therefore the difference in the number of positive reports between Ovando and Willits was in spite of rather than because of the classification scheme.

The near zero rate of positive reports from Ovando may be taken as a baseline level of positive reports, at least for comparative purposes. Willits and Ovando both are semi-rural communities which experienced earthquakes of similar magnitude. Therefore the data from Ovando provided a better comparison (control) for the data from Willits than would the results from interviews in a randomly selected community which had experienced no earthquake. The ratio of positive to negative reports from Willits is reliably higher than the same ratio from Ovando ($\chi^2 = 12.23$, $df = 1$, $p < .001$). This difference supports the inference that a number of animals at Willits were responding to physical precursors which were absent at Ovando. The possibility of such a difference between earthquakes is supported by Toksoz who obtained reports of abnormal behavior in dogs after a recent earthquake (M. N. Toksoz, personal communication, 1979) in contrast to the negative reports obtained after an earlier earthquake [*Toksoz et al.*, 1977]. An alternative interpretation is that the positive reports at Willits were generated by the expectations of the interviewees rather than by unusual behavior of the animals. If this were so, the differences in the rate of positive reports between Willits and Ovando would reflect merely the differences in the belief systems of the respondents in the two areas.

We examined this possibility by analyzing the relationship between the occurrence of positive reports and the belief that abnormal animal behavior is an earthquake precursor. This data was available on 12 positive and 12 negative reports from Willits. Nine of the 12 positive reports were given by respondents who believed that animals behave abnormally before earthquakes as were 7 of the 12 negative reports. The same data was available on 1 positive and 16 negative reports from Ovando. The one respondent giving a positive report believed that animals behave abnormally before earthquakes. Fourteen of the 16 negative reports were by respondents who also believed that; the two remaining negative reports were by respondents who did not believe it. These data are subject to a number of interpretations, but they are not compatible with the hypothesis that people who believe abnormal animal behavior is an earthquake precursor report its occurrence, while those who believe otherwise report its absence.

Discussion

Contrary to some published reports of very strange behavior [*Lee et al.*, 1976], the behavior reported to us at Willits was unusual because there was no immediate explanation for it, but it was not bizarre. The same behavior had often been observed at other times

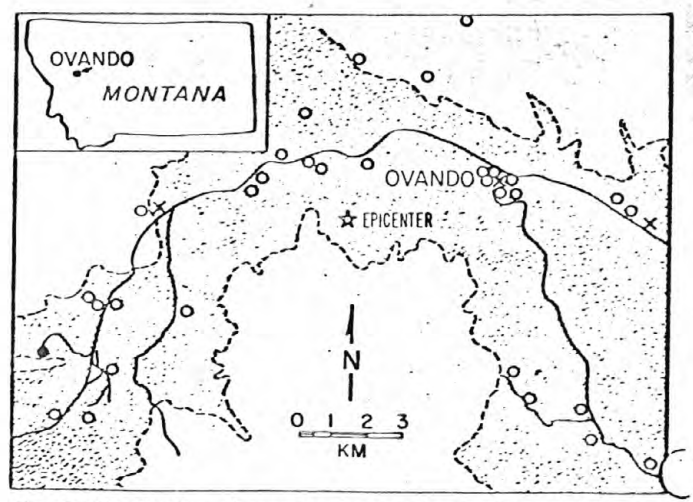

Fig. 2. Distribution of reports of unusual animal behavior in the vicinity of Ovando, Montana, associated with the earthquake of 23 April 1978: For explanation of symbols see Figure 1.

under various circumstances that one would expect to make animals anxious or nervous. The specific behavior varied from species to species but was always behavior typical of that species when motivated by generalized anxiety. This outcome has been predicted on theoretical grounds [*Lott*, 1976]. Natural selection is not likely to have produced animals with a specific response to earthquake precursors but may well have produced animals which are made anxious by unfamiliar stimuli.

The following instances of species-specific anxiety reactions are among the reports of unusual behavior recorded at Willits. A normally calm Arabian gelding was found kicking at the sides of its box stall approximately 3 hours before the earthquake. After attempting to quiet the horse, the owner released it into a paddock where it continued to move about nervously; horses in the neighboring stalls were calm the whole time. A cat that normally entered the house about 7:30 in the morning to eat and find his place to sleep, continually paced and repeatedly entered and left the house that morning: behavior so unusual for this cat that the owners discussed it hours before the shock. A two-year old Doberman Pinscher, which normally ran about indoors or slept during the morning, remained in her owner's presence almost continually from 8 AM until the earthquake, sometimes whining, pacing, and acting nervous and excited, at other times resting her head in her owner's lap. The owner wondered aloud to her husband if she should give the dog a tranquilizer.

These three cases illustrate one form of external verification of the report; namely that the unusual behavior of the animal produced a change in the behavior of the observer, such as discussing the unusual behavior or making some adjustment to it prior to the earthquake. Since the positive reports from Willits conform to scientifically documented species-specific anxiety reactions, the likelihood of their validity is enhanced.

Three other points emerged from our analysis of the Willits interviews. (1) Unusual behavior was generally first observed a few hours prior to the Willits earthquake. (2) Unusual behavior was often reported in only one or a few animals at a particular location. Even in the area where the positive reports clustered, most animals were described as having behaved normally. (3) Several owners reported that the behavior seen before the earthquake had also been seen before storms.

Conclusion

The data from these two earthquakes are consistent with the notion that some but not all earthquakes are preceded by unusual animal behavior. The occurrence of such behavior before an earthquake may depend on one or a combination of factors such as distance from the epicenter, nature of underlying geology, type of faulting, and physical precursors such as foreshocks. For instance, the Willits and Ovando earthquakes differed in two ways: (1) the hypocenter of the Willits earthquake had a depth of 5 km while the hypocenter at Ovando had a depth of 20 km, and (2) the Willits earthquake occurred along a strike-slip fault while the Ovando earthquake probably occurred along a normal fault.

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Psychological Value as a Determinant of Earthquake Portents in Two Peruvian Communities*

Beverly Crane suggested that a folk narrative that persists through time and space within a culture implies a psychological value commonly felt by members of the community. This exclamation might also be appropriate concerning the persistence of a specific folk belief: that impending earthquakes are foreshadowed by portents. The great contrast in the nature of portents of death and of earthquakes between the bodies of folk belief in Cuzco and the Sacred Valley of the Incas in Peru is a particularly compelling example of this phenomenon.

Cuzco lies high in the Andes Mountains; until 1531 it was the seat of government of the Inca empire. Following the downfall of Inca rule, Cuzco continued to be the politically and economically dominant center of the region up to present times. Situated on the Urubamba River, the Sacred Valley of the Incas lies some ~~twenty airline miles away and 3,000 feet lower~~ Thirty kilometer away and 1,000 meters lower than Cuzco. From earliest times in the history of the Inca empire, the Sacred Valley has been a major source of food for Cuzco. These economic and political linkages have produced substantial cultural interchange; most features of the culture reflect this long-standing association.

Auled: Should be metric!

Nevertheless, there are very striking contrasts between the two communities with respect to portents of events as a function of their local significance. The two areas share a common folklore of death portents. People in both communities generally feel that death can be predicted from the behavior of animals, and these portents of death are the same. There are three most common portents of death.

The first two are common to many cultures, perhaps because they generally occur in the dark of night, and thus are easily connected with frightening things.

(1) The howling of dogs as a portent of death usually takes place at night and may involve the dogs belonging to the doomed person(s) or all the dogs in town (especially if the doomed person is important in the community). The barking and howling of dogs before a death—usually at night—is a belief widely encountered throughout Europe and the Americas.

(2) When the call of the owl is a death portent, it usually occurs while the owl is perched on the roof of the doomed person's house or on a nearby tree.

(3) A third common portent of death appears to be far less widespread than the previous two. The fact that this portent is fully shared by Cuzco and ~~and~~ the Sacred Valley illustrates the close cultural contact between them. The central element of this portent is an individual cat which assumes the role of a corpse in a cat burial or funeral. The other cats may merely gather aruond this one as it lies on the ground, but more commonly two or four of them pick up the "corpse" and carry it like people bearing a corpse to its grave. Wayland Hand attests to the rarity of this belief, but in the same breath has told the authors that cats have been reported to have their special conventicles, in Hungary and elsewhere, where they assemble in a large field from all over the country. This belief parallels, of course, the witches' sabbaths, and is perhaps derivative from the more widespread notion. As witch's familiars, cats are considered somewhat more "human" than dogs.

The general content of these portents is the same in both communities, although the details may vary from individual to individual. (For example, the dogs may begin to howl as little as a day or two or as much as seven years in advance of a death. Or, the cats enacting the funeral may cry mournfully over the cat which acts as the "corpse," or they may be silent. But none of these variations seems more typical of one of these regions than another). The similarity in portents of death stands in sharp contrast to the marked difference in portents of earthquakes between the two areas.

Cuzco is located on an active fault and has a long history of devastating earthquakes, the most recent large earthquake having been in 1950. There is a rich fund of portents pertaining to earthquakes in Cuzco. Strong winds or abrupt changes in the weather are said to be earthquake portents, as are changes in the illumination of the moon, or the appearance of rainbows around the rising or setting moon. Dust rising from within a volcano is another earthquake portent. In Cuzco, animal portents of earthquakes include dogs howling, cats conducting a funeral, and roosters crowing in the afternoon or evening (less frequently this can also portend death). In one case tadpoles whistling was reported as a portent of earthquakes (the informant in this case was a *paq*, roughly equivalent to a witch or sorcerer).

Many of these earthquake portents overlap with those relating to death. It is said that dogs howl before a death because they see the spirit of the doomed person abroad at night. In some cases they howl before natural disasters because they see the spirit of someone who will be killed. Thus some portents relate to both death in general and to death caused specifically by

The earthquakes which have repeatedly shattered Cuzco have barely been perceptible twenty miles away in the Sacred Valley. The residents of the Sacred Valley believe that the Urubamba River (also called the Sacred River) absorbs the force of the earthquakes and so protects the valley from harm. Consequently, they believe that earthquakes will never be of any real danger to the valley, and therefore also believe that earthquake prediction is of no value to them. In contrast to folk beliefs found in Cuzco, the folklore of the Sacred Valley appears to contain no portents of earthquakes. In fact, many people there assert that it is not now, and never will be, possible to predict earthquakes.

This remarkable distinction between the two communities, despite their strong cultural affinities and proximity to each other, demonstrates the power that a psychologically valuable belief has on its own entry into a belief system and its persistence through time. This effect is especially striking in this case since portents of death are shared by the two communities, while earthquake portents which are common in Cuzco have not been preserved or perhaps never developed in the Sacred Valley of the Incas.

Residents of the Sacred Valley feel protected by the river; they apparently suffer no damage or injury due to the effects of earthquakes, therefore they have no use for earthquake portents. On the other hand, residents of Cuzco experience great damage and feel very vulnerable to the disastrous effects of earthquakes. They may feel safer if they believe they possess some means of predicting an impending earthquake. In the absence of signs of a coming earthquake they could assume there is no imminent danger. That assumption would give the residents of Cuzco psychological security; this sense of security (value) would explain the persistence of these beliefs.

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[5] Wayland Hand, 1979, personal communication.

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Animal Behavior and Earthquake Prediction

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Summary: Unusual or abnormal animal behavior is the oldest and most consistently reported earthquake precursor. Yet, even the recent scientific literature is fraught with contradictory evidence related to this phenomenon. We recently completed studies of eight earthquakes in North, Central and South America, none of which were known to have had foreshocks. Our data indicates that unusual animal behavior occurs a few hours before some, but not most, such earthquakes. Studies of earthquake folklore support the same conclusion. Animal behavior seems unlikely to be of much direct value in earthquake prediction, but it is possible that analysis of some animal reactions could point the way to identification of physical precursors common to at least some earthquakes.

Successful earthquake prediction involves two steps, the identification of areas likely to experience earthquakes over a long period of time and an approximation of the time and place an earthquake will occur, within a day or two. Short term prediction such as this requires at least one short term precursor. Abnormal animal behavior is the oldest and most consistently reported short-term precursor and it contributed to the successful prediction of the Haicheng earthquake in 1975 (1). If abnormal animal behavior consistently occurs prior to earthquakes, it could contribute directly to prediction as a part of a predictive system, or indirectly, by leading to the discovery of a physical precursor that can be monitored by instruments.

Within the scientific literature, there is conflicting evidence of the occurrence of unusual animal behavior as an earthquake precursor. Some investigations have documented reports of unusual animal behavior before earthquakes (1, 2, 3, 4, 5, 6, 7, 8, 9, 10) while others have not (11, 5). Different investigators employ different methods for data gathering, a factor that may contribute to these discrepancies. The nature and timing of reported behavior varies widely and is sometimes puzzling. The behavior reported spans a broad spectrum, ranging from mild excitement to bizarre behavior exemplified by a panda holding its head and screaming, and a yak refusing to eat and rolling over two hours before the quake (12). Most reported changes in behavior occur within a day or two of the earthquake, but there are also reports of snakes coming out of hibernation 1.5 months before an earthquake (13) and changes in fish harvests several weeks before earthquakes (14, 15).

Biological principles provide a means of evaluating the validity of these reports. For the most part the behavior of animals is an evolutionary adaptation; thus we expect that accurate reports of behavior will reveal an

adaptive property of the animal. Earthquakes have never been biologically significant to more than a few individuals in an occasional generation of any vertebrate species. Consequently, it is unlikely that any species has evolved a special detection-response system to physical stimuli such as liberation of radon gas, changes in electrical or magnetic fields, ultra sounds, sub sounds, or foreshocks emmanating from the future origin (16). However, it is possible that earthquake precursors may stimulate a response through a mechanism evolved for some other function. Unfamiliar stimuli may cause generalized anxiety, making the animals more alert or predisposing them to respond more intensely to other stimuli not related to the earthquake (16). Animals also have species-specific generalized anxiety responses: some flee, some freeze, some warn their conspecifics. Thus responses one might expect would not be bizzare, but would be normal behavior occurring outside its usual context (17).

A RETROSPECTIVE STUDY OF EIGHT EARTHQUAKES

Methodology

Given the great diversity of investigative approaches and the contradictory views expressed in the literature, we attempted to apply a systematic, uniform approach to the retrospective study of several moderate to large earthquakes.

We selected earthquakes for study according to the following criteria: 1) the absence of detected foreshocks (because of their potential for producing a generalized anxiety response in animals), 2) proximity of the epicenter to a large population of livestock or pets, 3) occurrence of the earthquake during a time when most people would have been able to observe animals for several hours beforehand, and 4) generation of a magnitude great

enough to make it likely that the earthquake had physical precursors detectable by animals.

We obtained our data through post-earthquake interviews. Each interview was conducted by a behaviorist and a research assistant who took notes and conducted internal consistency checks. At each site, a number of households (R = 35 - 115), located as close as possible to initial estimates of the epicenter, were questioned according to our standardized interview schedule. After each interview, the two members of the team independently rated the respondent's credibility on a scale of one to five, with five designated highest credibility.

Our information was taken directly from the recollections of human observers. Consequently we had to take into account factors which might affect the accuracy of those recollections. Memory falls off gradually; with the passage of time the true details of an event may unconsciously be replaced with fictitious detail in small increments (18). On the other hand details of particularly important or impressive events are often remembered more accurately, a phenomenon that has been called the "flashbulb effect" (19). We expected the recall of detail after an earthquake to be reasonably accurate for several weeks. Even so, we attempted to maximize the accuracy of recollections by visiting each of our study sites as soon as possible and never more than six weeks after the event.

Strong cultural expectations may affect the accuracy of recollections by either facilitating the recognition of expected events that truly occur, or conversely, may distort the reports of events which are not expected. To help us recognize possible cultural expectations on the reports we obtained, we prepared summaries of cultural elements which might potentially influence the gathering and interpreting of reports of unusual animal behavior in each

of the cultures in which we anticipated working.

For each of the eight earthquakes we investigated, we used an interview schedule designed to minimize possible distortions of the data induced by data collection. Our interview schedule has seven goals which we pursued in the following sequence:

1. Establish rapport with the respondent and convince him that the interviewer does not have preferred answers to his questions (20).
2. Introduce the subject of precursors in general.
3. Raise the question of unusual animal behavior without creating pressure to answer affirmatively.
4. Obtain an objective description of the animal's actions.
5. Check the internal consistency of the report.
6. Determine if there is external support for the report of unusual animal behavior.
7. Determine if the respondent expects animals to behave abnormally before earthquakes.

The reports we scored as cases of unusual animal behavior conformed to our expectations of behavioral reactions to novel or frightening stimuli and could not be accounted for by other circumstances. Almost all the respondents were judged to be highly credible. We deleted the few reports that were not internally consistent, or had low credibility. We also excluded cases in which unusual behavior began and ended before the earthquake, and cases in which the unusual behavior began before the earthquake and continued unchanged for a long time after the shock. We also excluded a number of positive reports which could have been in response to

the P wave. This wave often precedes the surface wave by a few seconds to a minute and manifests itself as a sound wave audible to most animals and often to man. Responses attributed to the P wave would be of no value in earthquake prediction, so reports of unusual animal behavior occurring a few seconds to a few minutes before the earthquake were not scored as positive.

Results

The eight earthquakes we studied occurred from November 1977 through October 1979. Figure 1 depicts each study site and indicates the location of reports of unusual animal behavior. Households whose members were not aware of the behavior of their animals are not plotted. Table 1 presents the occurrence of unusual animal behavior by species at each study site, as a fraction of the total number of animals of each species whose behavior was under observation by our respondents prior to the earthquake. Animals owned by the respondents but not under observation prior to the earthquake are excluded from Table 1.

Note that we obtained at least one credible report of unusual animal behavior before each of the earthquakes. Presumably, there is some probability than any animal might behave unusually on any given day; therefore, our interviews should reveal a "baseline" frequency of such reports. We believe that the small number of reports obtained at all sites except Willits reflects that base line probability. The number of reports of unusual animal behavior was much greater at Willits than at any of the other earthquake sites. We interpret this to mean that the rate of unusual animal behavior at Willits was increased by the presence of one or more physical precursors to the earthquake. We believe there was no increase in unusual behavior before the earthquakes at Ovando, Mexicali, Landers and Coyote Lake

(21). The results of our studies of the other earthquakes at Oaxaca, Punto Flamenco and Tiquisate seem inconclusive (22). We do not believe that unusual animal behavior increased before these earthquakes, but subsequent to our interviews the epicenters of these earthquakes were revised to locations some distance from our interview site (Fig. 1). Therefore, unusual animal behavior might have been observed nearer the epicenter.

The unusual behavior recorded at Willits is the kind one would expect in response to physical precursors that evoke fear or escape reactions. Three examples will illustrate this point.

About sunrise the morning of the earthquake, a retired couple in their sixties were awakened by the noise of two horses running in a nearby pasture. Although these horses always grazed quietly in the mornings, the unusual disturbance of the horses prompted the husband and wife to watch the horses with binoculars at about 10 a.m. The behavior continued for another 30 minutes. Afterwards, the horses did not resume grazing but continued to act nervous the rest of the morning.

Another resident of Willits reported a one year old steer galloping about its pasture, from one fence to another, as though he were frightened and trying to escape. This behavior was first observed an hour and fifteen minutes before the earthquake and continued for at least an hour. The steer had never behaved this way during the year since it was first purchased. The owner wondered if it might be sick or bothered by insects, but biting insects are absent in winter, and the steer was calm after the earthquake.

The wife of a Willits veterinarian reported their three dogs tried to climb into bed with them about eight hours before the earthquake, and all morning long tried to stay in the house contrary to their usual habit of wanting to go out for the day at 5:00 a.m. While in the house the dogs

followed the owners from room to room, sitting near and gazing at them.

As Table 1 indicates, unusual behavior was reported in higher percentages of some domestic species than others. This result may be partly due to variable domestication effects on the different species. Many domestic species have been bred for a lack of response to strange or even threatening stimuli which makes them easier to raise or work with. Selective breeding of cattle and sheep generally emphasizes a phlegmatic temperament. But in other species, artificial selection has often preserved or even enhanced ancestral reactivity as in "high-strung" horse and dog breeds (23).

The data on wild birds should be interpreted a little differently from that on other species. Wild birds were generally observed in flocks; members of such flocks are subject to very strong social facilitation effects. A single alarmed member of the flock normally alarms the other flock members. Consequently, a reaction to an uninterpretable stimulus by one member of a flock is likely to produce unusual behavior in a dozen or even a hundred other birds (24).

An alternative explanation of the high frequency of unusual behavior at Willits is that the animals did not behave any differently than on ordinary days, but rather that our respondents recalled the behavior of their animals in a way consistent with their cultural expectations that animals behave unusually prior to earthquakes. We examined this possibility by analyzing the relationship between the occurrence of positive reports and the belief that abnormal animal behavior is an earthquake precursor. This data was available on twelve positive and twelve negative reports from Willits. Nine of the twelve positive reports were given by respondents who believed that animals behave abnormally before earthquakes as were seven of the twelve negative reports.

This relationship was also deterimined on eight positive and eighty-two negative reports from the four additional earthquakes where our studies seemed conclusive (Ovando, Landers, Mexicali and Coyote Lake). Six of the eight positive reports were by people who believed that animals behave abnormally before earthquakes and two were by people who did not believe that. Sixty-nine of the eighty-two negative reports were by people who also believed that; the remaining thirteen were by people who did not believe it. These data are subject to a number of interpretations, but they are not compatible with the hypothesis that people who believe abnormal animal behavior is an earthquake precursor report its occurrence, while those who believe otherwise report its absence. We believe these data support our final conclusion that there was an elevated rate of unusual animal behavior prior only to the Willits earthquake, but not before the earthquakes at Landers, Mexicali, Coyote Lake and Ovando.

Discussion

We evaluated evidence for unusual animal behavior as an earthquake precursor by very conservative standards, but these standards did not preclude finding precursory animal behavior at Willits.

The Willits earthquake was like three of the other earthquakes in several potentially important dimensions. Like the earthquakes occurring at Mexicali, Coyote lake, and Landers, the Willits earthquake had a shallow epicenter in a strike-slip fault. All four earthquakes occurred in a semi-rural community with a substantial animal population living very near the epicenter. The magnitude of the Willits earthquake (MB = 5.2) was similar to that of Landers (MB = 5.5), and Coyote Lake (MB = 5.4) and substantially smaller than the Mexicali earthquake (MS = 6.9).

Yet of the four earthquakes, only that at Willits produced an impressive number of cases of precursory animal behavior. It is possible that physical events leading to or accompanying the earthquake at Willits produced different precursors. Alternatively, the precursors of the other three earthquakes may have been so attenuated by the medium through which they passed that they were rendered incapable of generating unusual animal behavior. Finally, it is possible that undetected foreshocks occurred prior to the main shock at Willits and that the unusual animal behavior arose from undetected foreshocks rather than from precursory phenomena. Certain foreshocks that register poorly on seismographs produce ground vibration and sub sounds that might be detectable by some animals (25). Since we do not know what special circumstances caused the large number of reports of unusual animal behavior at the Willits earthquake and not before the other three, we cannot postulate a stimulus-response mechanism for the generation of unusual animal behavior prior to earthquakes.

Our conclusion that precursory animal behavior did not occur before the majority of earthquakes we studied contrasts with some published reports (6, 7, 1, 2, 3). This difference may be due to the criteria we used in selecting earthquakes for study, together with our methods of evaluating reports of animal behavior. The net effect of these methods is to reduce the number of reports we considered to be valid accounts of precursory unusual behavior. We chose, for example, to study only those earthquakes with no known foreshocks, since foreshocks may stimulate unusual animal behavior. In fact, much of the unusual animal behavior reported before the Haicheng earthquake may have resulted from the many foreshocks which preceded that earthquake.

Aside from the issue of foreshocks, we rejected some reports because the behavior did not conform to our expectations of animal reactions to novel

stimuli, or the behavior was not temporally correlated with the occurrence of the earthquake. We also rejected the few reports made by a person who was given a low credibility rating.

ANIMAL BEHAVIOR PRECURSORS IN EARTHQUAKE FOLKLORE

In many instances unusual animal behavior as an earthquake precursor has been integrated into traditional cosmologies and folklore (1, 26, 27). Since accurate observations are frequently incorporated into folklore, the apparent frequency of such reports lends credence to the possibility that unusual animal behavior is an earthquake precursor. If unusual animal behavior were a consistent precursor in an earthquake affected culture, it would be likely to appear in the form of predictive folk knowledge. Alternatively it might be transformed into a cause of earthquakes in the cosmology of the culture; such was the case the pre-scientific cosmology of Japan. Earthquakes were believed to be caused by the movements of a catfish-god residing under the earth's surface. It is probably no coincidence that abnormal behavior of fishes has long been reported as a precursor of earthquakes, and still continues to be reported frequently in Japan (4). With these concepts in mind, the comparative study of earthquake folklore constituted a second approach in our research.

A person studying a given culture is more likely to note and report the presence rather than the absence of a link between animal behavior and earthquakes than its absence. Consequently, there is a general expectation that an association between animal behavior and earthquakes is present among all people living in seismically active areas. However, this impression is not borne out by the results of our examination of both the traditional and modern folklore of Peru, Guatemala, Mexico, Hawaii and Alaska. Many

connections between animals and earthquakes are reported in the ethnographic literature of Latin America (27, 28, 29, 30); however, an equally extensive search of the folklore literature of both Hawaii and Alaska revealed very few associations between animals and earthquakes. Of the few connections observed, none were of a predictive or cause-and-effect nature as are those of many other cultures (26, 31). This is true despite frequent earthquakes, the economic importance of animals, and the belief that animal behavior portends other events.

Additionally, belief in animal behavior as an earthquake precursor may be incorporated into a local folklore, without becoming universal in that culture. For example, the city of Cuzco, Peru, rests on a major fault and has experienced many severe earthquakes. A brief survey conducted there yielded evidence of numerous portents which included animals portending earthquakes. Yet in the Valley of the Incas only 30 km away, the residents believe that earthquakes cannot be predicted by unusual animal behavior or in any other way although they do believe that animal behavior portends other events including death, changes of weather and changes of season (32).

It is also possible that animal precursors are present in the folk cultures of Hawaii and Alaska but have not yet been detected or reported by ethnographers. To test this hypothesis, we consulted specialists in Hawaiian folklore and conducted interviews with several residents on the island of Hawaii. The specialists agreed that traditional and modern Hawaiian folklore contains very few associations of abnormal behavior and the coming of an earthquake. No reliable reports of unusual animal behavior prior to earthquakes were obtained in a survey there. This study also serves to increase our confidence in our analysis of Alaskan earthquake-lore. We conclude that in Hawaii, and probably in Alaska, the native population has

experienced numerous earthquakes for hundreds of years without animal behavior becoming significantly incorporated into the folklore as an earthquake precursor. We suspect that earthquakes and animal behavior are not linked in the folklore because they are not linked in the experience of the people.

Thus our ethnographic studies support the same general conclusion as our post-earthquake interviews: unusual animal behavior is a precursor to some earthquakes but not others.

Conclusion

Our interview data suggest that unusual animal behavior is not normally a precursor of earthquakes that lack foreshocks. Even when unusual animal behavior does precede an earthquake, it might be difficult to use as the basis for earthquake prediction if the percentage of animals exhibiting precursory behavior were as low as it was at Willits. However, it is still possible that unusual animal behavior could point the way toward the identification of a physical precursor common to certain types of earthquakes, and thus contribute to their prediction.

FOOTNOTES

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20. Goal one was implemented through verbal application of the Modified Mercali scale of perceived intensity. (Since our application of this

scale always involves asking if effects greater than those perceived occurred, the respondent learns that (s)he is giving useful information when (s)he answers a particular question by saying "no"). Goal two was implemented with a short neutral question, "Did you notice any changes before the earthquake?". Goal three was implemented by a question that gives the respondent a graceful way to acknowledge being unaware of the behavior of his or her animals, "someone as busy as you might not have the chance to notice what their animals were doing before the earthquake, but did you happen to?". Goal four was implemented by detailed questioning. Goal five was implemented by a repetition of critical points of the interview. Goal six was implemented by asking to see the animal, observing the sites of reported behavior, examining damage caused by the animal's behavior, or inquiring if the behavior caused the respondent to discuss it with someone before the earthquake. Goal seven was implemented by asking the respondent's opinion of reports that animals behave abnormally before earthquakes.

21. The day following the Coyote Lake Earthquake, the news media reported many instances of unusual animal behavior at a commercial wild animal park 70 km north of the epicenter. The park welcomed our request to visit the site and arranged for us to interview the people most closely involved with the maintenance and care of the animals and were in a position to have made the closest observations.

We conducted 27 interviews focusing on the news reports of unusual animal behavior. In nearly all the cases of unusual animal behavior

reported were better accounted for in ways not related to the earthquake. The animal care people either felt the animals were normal or that other factors, such as ill health, or disturbance from new personnel, were the most likely cause of the behavior. Because of the great distance between this site and the epicenter, as well as the special nature of the interviews, these data are not included in Figure 1 or Table 1.

22. It was common in parts of Latin America to get reports that roosters had crowed more before an earthquake. We regard these reports as very weak evidence of precursory unusual animal behavior. Roosters are expected to portend calamities in these communities. Since the change in behavior recalled is a change in the frequency of behavior that occurs at all times every day it would be very subject to slight memory distortions guided by strong cultural expectations.

23. Moreover, general anxiety does not make roosters crow more. For these reasons we have excluded "rooster stories" from Figure one and Table one. Such reports were given in four households in Guatemala, thirteen in Oaxaca and eighteen in Chile.

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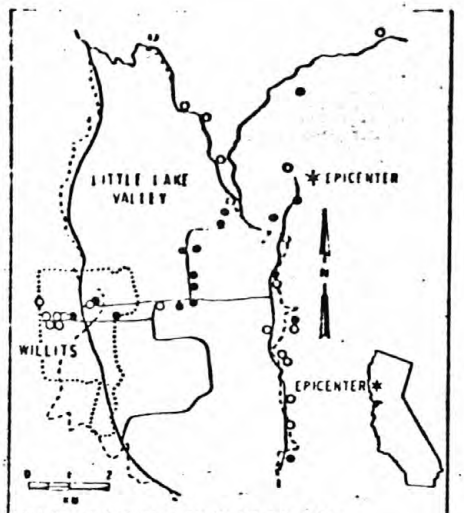
33. This research was supported by grant 14-08-0001-G-482 and contract 91622 from the US Geological Survey. K. L. Verosub has provided a geological and geophysical perspective throughout the project. R. M. Murphy pointed out the potential fruitfulness of a comparative study of earthquake folklore. J. Vohs and E. Loftus gave us invaluable consultation on the conduct and interpretation of interviews. W. . Hand helped us study and understand earthquake folklore.

The project would not have been possible without the help of literally dozens of fellow scientists, government officials and interpreters. But it was most dependent on the kindness of the hundreds of people who took the time to answer our questions.

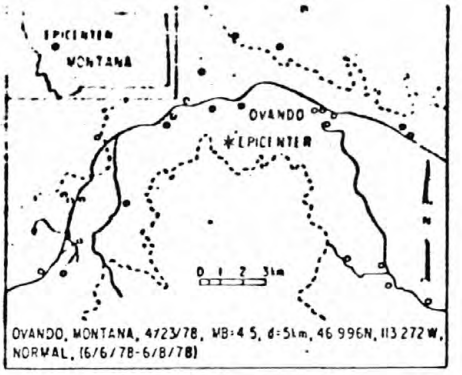
Fig. 7. Distribution of reports of unusual animal behavior obtained during interviews following each of eight earthquakes. Positive reports (solid circles) and negative reports (open circles) indicate individual households on the maps of all sites except Oaxaca and Punto Flamenco. On these latter maps, the number of households which yielded usable interviews in each community are shown as positive reports (+) and negative reports (−) alongside the point that indicates a particular town located a considerable distance from the epicenter. The legend on each map reports in sequence for each earthquake: common name and general location; date of occurrence; magnitude of main body wave (MB) or Main surface wave (MS); depth of origin; epicenter latitude and longitude; type of fault along which motion occurred; (dates of interview study).

Table 1. The figures appearing as a fraction denote the proportion of the number of individual animals behaving unusually before the earthquake (numerator) to the total number of that species sampled at each site (denominator).

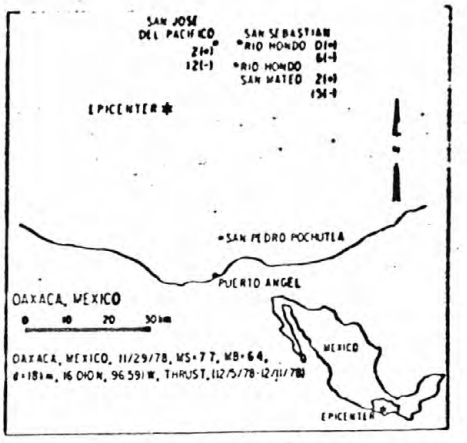
	EARTHQUAKE SITES							
SPECIES	Willits	Ovando	Landers	Mexicali	Coyote Lake	Tiquisate	Oaxaca	Punto Flamenco
Dog	16/53	0/44	0/66	1/102	4/70	9/122	0/26	10/92
Cat	13/26	0/16	0/12	0/30	1/42	0/49	0/4	0/38
Cattle and Ox	33/155	4/1096	0/0	0/524	0/924	2/328	2/15	0/1
Goat	4/12	0/1	0/15	0/53	2/7	0/0	0/2	0/8
Sheep	0/76	0/1023	0/0	0/0	0/21	0/0	0/0	0/3
Pig	0/4	0/0	0/0	0/334	0/16	3/108	0/28	0/13
Horse	66/87	2/129	0/3	0/19	4/86	1/12	0/3	0/0
Donkey and Mule	0/0	1/3	1/1	0/0	0/0	0/0	3/22	0/2
Wild or Exotic Birds	387/390	0/12	6/13	4/160	0/42	12/12	0/4	4/12
Duck, Goose, Turkey and Guinea Fowl	0/18	0/0	0/2	0/153	0/38	11/91	2/20	3/54
Chicken	10/155	0/5	0/10	20/1008	0/46	59/1115	2/80	4/317
Miscellaneous	6/9	0/34	0/58	0/9	0/34	0/2	0/0	0/23



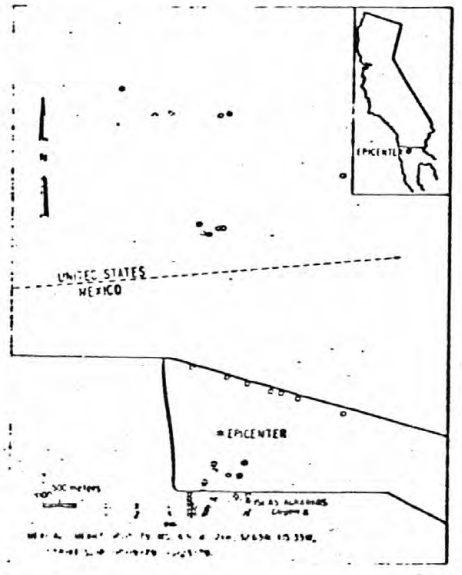
WILLITS, CALIFORNIA, 11/22/77, MB=5.2, d=5km; 39.448N, 123.259W, STRIKE SLIP, (12/19/77, 1/6/78-1/7/78)

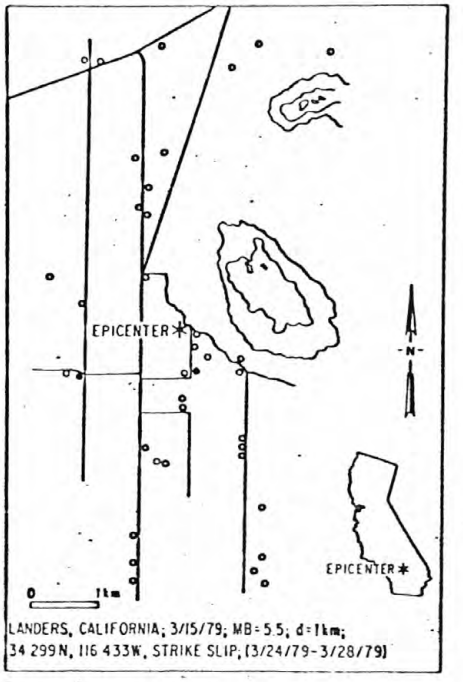


OVANDO, MONTANA, 4/23/78, MB=4.5, d=5km, 46.996N, 113.272W, NORMAL, (6/6/78-6/8/78)

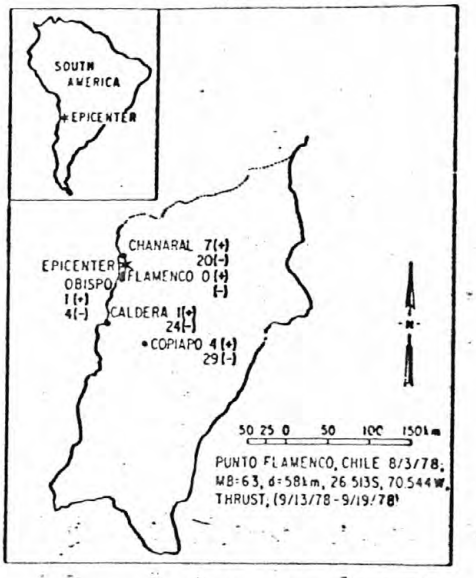


OAXACA, MEXICO, 11/29/78, MS=7.7, MB=6.4, d=18km, 16.0ON, 96.591W, THRUST, (12/5/78-12/11/78)

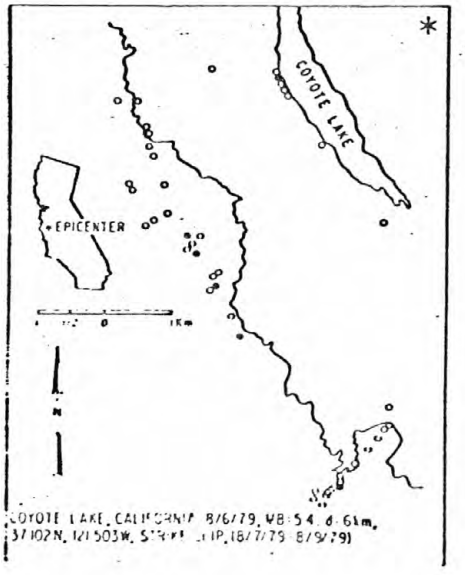




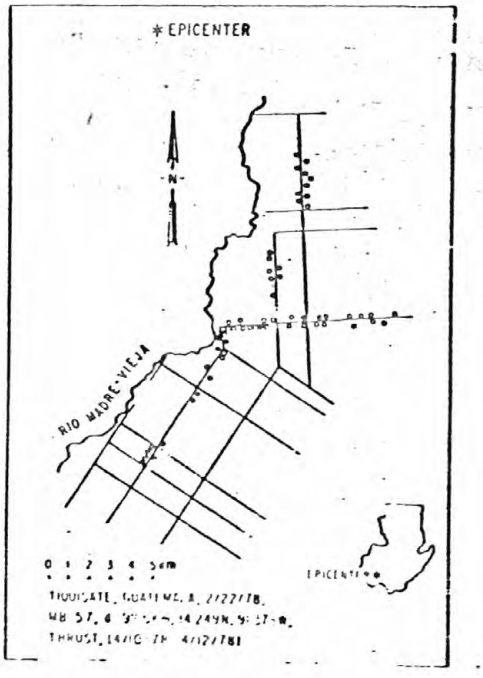
LANDERS, CALIFORNIA; 3/15/79; MB=5.5; d=1km; 34.299N, 116.433W, STRIKE SLIP, (3/24/79-3/28/79)



PUNTO FLAMENCO, CHILE 8/3/78; MB=6.3, d=58km, 26.513S, 70.544W, THRUST, (9/13/78-9/19/78)



COYOTE LAKE, CALIFORNIA 8/6/79, MB=5.4, d=6km, 37.102N, 121.503W, STRIKE SLIP, (8/7/79-8/9/79)



TIQUICATE, GUATEMALA, 2/27/78, MB=5.7, d=[illegible], 14.249N, 9[illegible]W, THRUST, (4/10/78-4/12/78)

ANIMAL BEHAVIOR SOCIETY

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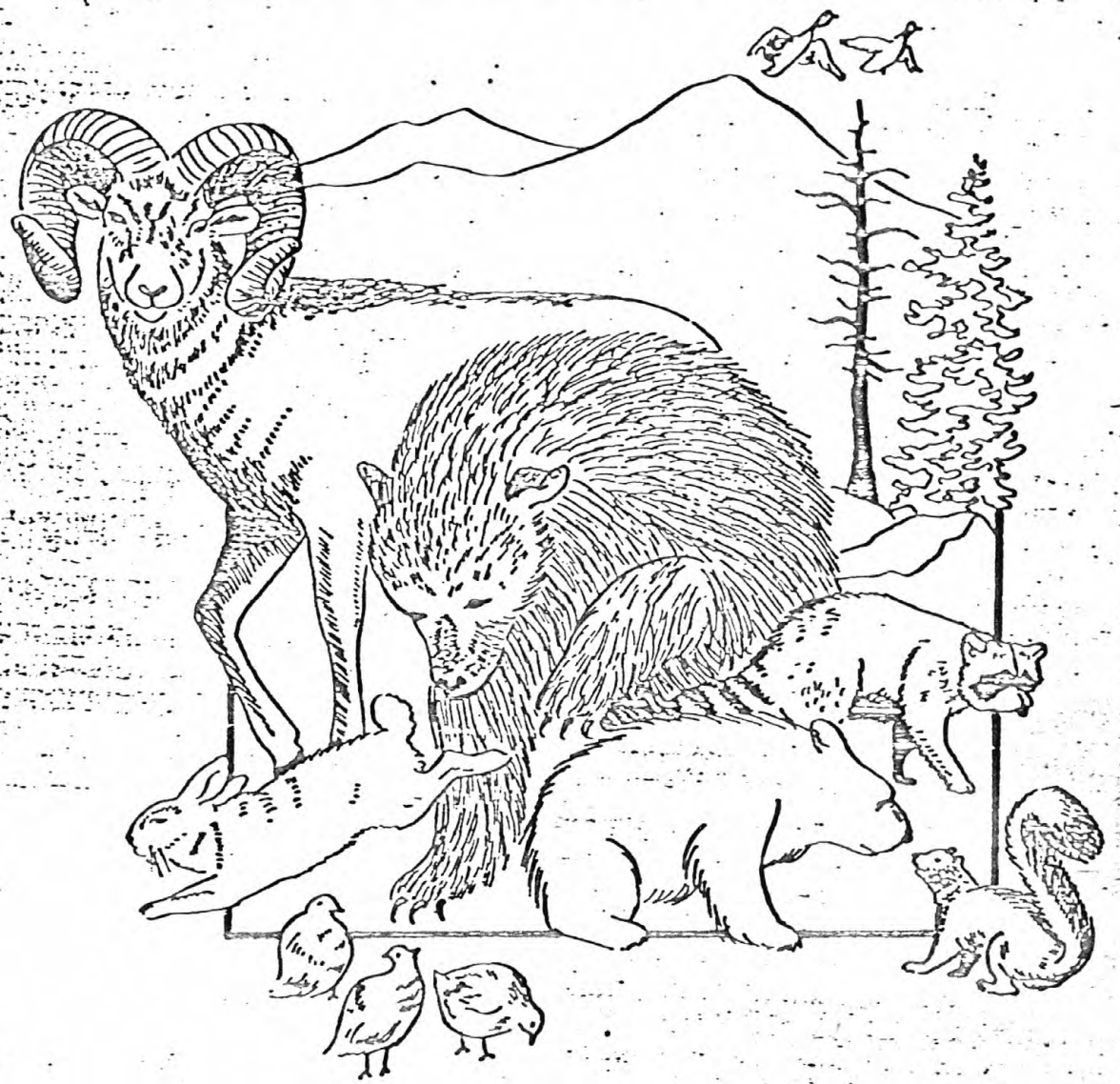

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SOCIAL STATUS AND THE DISTRIBUTION OF URINATIONS IN CAPTIVE COYOTES

Fred H. Harrington, Mount Saint Vincent University, Nova Scotia

In many species which utilize urine-marking in communication, the frequency and/or distribution of urinations is dependent on social status. Generally, high status individuals urinate frequently, void relatively little urine at each urination, and distribute their marks widely, whereas low status individuals void larger amounts of urine infrequently and often at relatively restricted locations within their home range. In an observational study of captive coyotes (Canis latrans), similar patterns were noted. Urinations were more frequent and of shorter duration in high status animals. Also, even within their relatively confined enclosure, differences in the distribution of urinations were noted, particularly involving the substrate preferred for urination. High status individuals urinated over solid ground, whereas low status individuals often, and sometimes exclusively, urinated in water. Such patterns suggest that low status individuals may be attempting to "cover up" their urinations to avoid detection.

UNUSUAL ANIMAL BEHAVIOR PRIOR TO EARTHQUAKES: A RETROSPECTIVE STUDY OF EIGHT EARTHQUAKES

Benjamin L. Hart, Dale F. Lott and Mary W. Howell
University of California, Davis

For centuries it has been reported that strange, unusual, bizarre or unexpected animal reactions have occurred prior to many earthquakes. In fact, abnormal animal behavior is the oldest and most consistently reported earthquake precursor. Chinese claims that animal behavior reports had a role in the successful prediction of the Haicheng earthquake of 1975 stimulated both popular and scientific interest in this phenomenon. Recognizing the pitfalls of relying upon the recollections of human observors, we developed an interviewing strategy designed to obtain unbiased, reliable and valid reports of animal behavior as it occurred before an earthquake. We applied this uniform methodology to eight post-earthquake investigations and obtained different results. Two earthquakes were preceded by several cases of unusual animal behavior while the other earthquakes produced only very few accounts of abnormal animal behavior. The data are consistent with the notion that some, but not all, earthquakes, are preceded by unusual animal behavior.

PRESENTING AND COPULATORY BEHAVIOR DURING THE MENSTRUAL CYCLE FOR COLONY LIVING STUMPTAIL MACAQUES (Macaca arctoides)

Nancy C. Harvey, Rutgers University

Duration of menstrual cycle for the females ranged from 26-32 days, with a mean of 28.6 days (±1.90 SD). The cycles were plotted from day 1 of menstruation and midcycle was defined as days 11-15 of the cycle. Female spontaneous presents showed a rise during the follicular phase which peaked around midcycle, followed by a depression in the midluteal phase. Induced presents occured throughout the cycle, with a distinct peak at midcycle. Copulatory behavior likewise occurred throughout the cycle, with complete copulation showing a peak at midcycle, followed by a second peak in the late luteal phase. Effects of the dominant male switching from related females at midcycle to his preferred female influenced the occurance of copulation during the midluteal phase. In the stumptails, male and female sexual behaviors flucuate with phases of the cycle when the animals are living in a social group.

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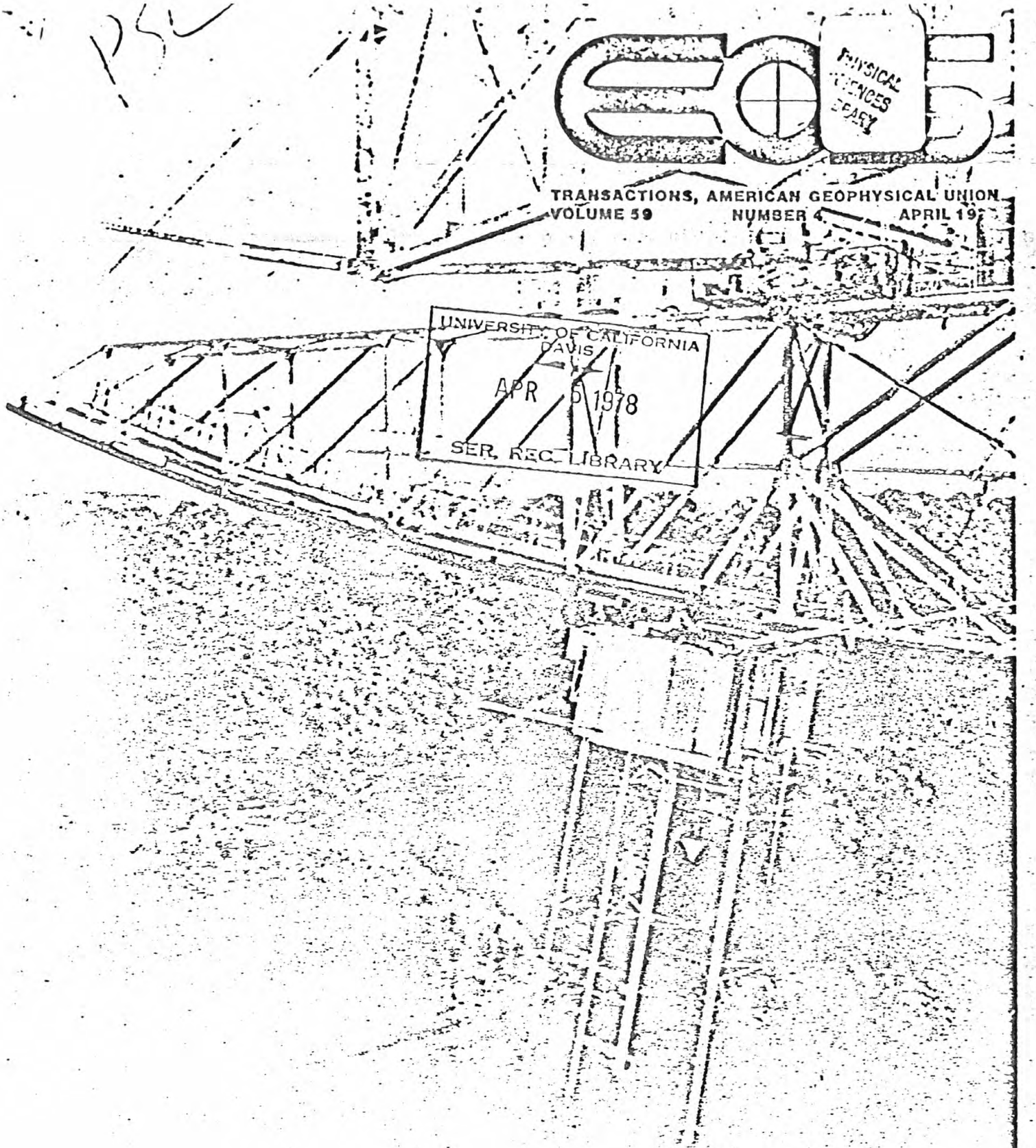

...ntal crustal sample is in progress.

...significant travel time change de-
...ing the period 1967-1977 was at sta-
...km from the epicenter of the Nov.,
...) Kalapana earthquake (A.C. John-
...ience, in press, 1978). The 0.2 sec
...in 1972, and returned to normal in
... It was not observed at other sta-
...the Hawaii network. If this one ex-
...excluded, arrival times at all stations
...nt is time to within the reading ac-
...-.1 sec). In addition, no detectable
...rred that correlate with any vol-
...ity, although absolute travel time
...are early for summit stations and late
...stations.

...oral stability of arrival times re-
...to the Hawaii network (except WHA) pro-
...ort for a causal relationship between
...lav and the preparatory phase of the
...earthquake. This was Hawaii's largest
...in this century - it appears that
...associated with smaller scale ac-
...ould not be resolved by this technique.

...TIVITY MEASUREMENTS ACROSS THE SAN
...ULT NEAR PALMDALE: A PROGRESS REPORT

...A. Fuehle
...ation
...Jackson (all at: Department of Earth
...Sciences, University of California,
...geles, CA 90024)

...ear, a continuing sequence of galvanic
...ity measurements was begun across the
...Fault near Lake Hughes to monitor
...changes in the deep electrical resis-
...possible precursory phenomena to
...ntivity. We have currently accumu-
...r 1 year of measurements from a
...ole array with a dipole separation
... The mean apparent resistivity ob-
...r the last year is approximately 314
... Error bars on individual measurements
...ly about 0.5%, but may increase to 1%
...tually active days. Variations between
...ts of less than 1% are observed but do
...to be correlated with rainfall, water
...the intervening lakes, or seismicity.
...apparent resistivity variation larger
... correlates well with the first heavy
...of the season. No correlation with
...mic swarm activity has been found.

...TION OF GAS FROM ROCK SAMPLES
...TO STRESS IN THE LABORATORY

...Caspero (General Electric
...h and Development Center,
...ady, NY 12301)

...ments were performed in the labo-
...to investigate the characteristics
...s of gas released from rock
...jected to uniaxial stress.
...s of granodiorite were cut in
...of cylinders (7mm in diameter
...) and pressure was applied
... to the point of rock col-
... Kb). The main results are:

...gas release was typically 0.4
...at STP per cm^3 of rock, but
...8 cm^3 has been observed.

...nt of gas released prior
...ranges from about 10% to 50%
...amount and depends on the
...ied stress.

...vapor is present, N_2, O_2 and
...each measured to consti-
...of the remaining gas.

...usually released at an ir-
...as a function of applied
...continues to be emitted
...minutes of either stop-
...easing the applied stress.

...origin of the released
...the relevance of these
...to earthquake prediction
...discussed.

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EARTHQUAKE ASSOCIATED RADON ANOMALIES
--POSSIBLE MECHANISMS

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W.F. Libby (Both at: Institute of Geophysics and Planetary Physics, Univ. of California, Los Angeles, Los Angeles, CA 90024)

Apparently anomalous radon activity has been observed in Track Etch" measurements of gas phase radon in shallow soil holes along the San Jacinto Fault zone in Southern Calif Radon activity increased systematically at ten sites close to a M4.3 earthquake several weeks prior to it. It was followed by very low activity for several months. Low radon values have occured with these events because their small magnitude and short precursor times superimposed the effects producing high and low radon activities resulting in the dominant effect, lowered activity, being observed. Gas flow transports radon. Measured radon activity decreases dramatically when air flows into the ground and increases when gas flows out of the ground. When rapid degassing is produced before moderate or large earthquakes a large positive radon anomaly will be produced. When pore space increases and the water table lowers low radon values will occur. For several months up to January 1978 extremely high radon values have been observed which may be a continuation of unusual activity beginning in April 1977.

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UNUSUAL ANIMAL BEHAVIOR PRIOR TO THE WILLETS, CA. EARTHQUAKE OF NOVEMBER 22, 1977

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Ben L. Hart (School of Veterinary Medicine, Univ. of Calif.-Davis)
Mary Howell (Dept. of Wildlife and Fisheries Biology, Univ. of Calif.-Davis)
Kenneth L. Verosub (Dept. of Geology, Univ. of Calif.-Davis)

On November 22, 1977 an earthquake of magnitude 5.0 occurred near Willets, California, a semi-rural area in which it is customary for households to have some livestock and companion animals. Observations of unusual animal behavior, by people living in the affected area, were studied by a multi-disciplinary team consisting of a geologist, two animal behaviorists and an anthropologist. Over fifty households in the general area of and surrounding the reported epicenter were visited by experienced interviewers who used an interview approach designed to avoid encouraging false reports. The interviews yielded several cases of reports of unusual behavior in at least one of the animals owned by the respondents. The unusual animal behavior reported was not bizarre but was in fact of a form that had been observed in other circumstances. It was defined as unusual because it was inappropriate to the circumstances in which it was manifested. When the positive and negative reports were plotted on a map of the area, there seemed to be a distinct geographic pattern to their distribution. This study demonstrates that in at least one earthquake it has been possible to find very reliable reports of unusual animal behavior prior to an earthquake.

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'EARTHQUAKE LIGHTS' - A POTENTIAL AID IN EARTHQUAKE FORECASTING

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T.R.Viswanathan (University of South Carolina, Union, S.C. 29379

Observations of 'strange lights' near the earth's surface and in the sky have been reported in different parts of the world in the past. These are sometimes referred to as 'earthquake lights' as they have often been associated with earthquakes. A list of well documented 'light occurrences' in the United States was compiled. The locations of these lights were plotted on a map. This map was then compared with the seismo-cyclic map of the United States, which was prepared previously and independently by the co-author. In this seismo-cyclic map earthquakes were plotted symbolically, each symbol representing a specific interval of time in the lunar anomalistic cycle (in which individual earthquakes have occurred.) Thus, the seismo-cyclic map adds the dimension of time to the seismic map. A comparison of the 'lights' map and the seismo-cyclic map showed that 'lights' have been observed mostly in zones or areas in which past earthquakes have occurred predominantly when moon was travelling from its perigee to its apogee, that is when the tidal force was decreasing. This spatial correlation between 'lights' and earthquakes (of one type) is seen as a potential aid to the understanding of the regional tectonics and prediction of earthquakes.

Earthquake Prediction, 2
Napoleon 2 (D), Friday 1315h
S. S. Alexander (Pennsylvania State University) and
M. Caputo (Istituto Nazionale Geofisica), Presiding

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SEISMICITY-TIME SERIES ANALYSIS

F.T. WU
W.J. Wu (both at: Department of Geological Sciences, State University of New York at Binghamton, Binghamton, New York 13901)

Under the reasonable assumption that the regional tectonic strain rate remain steady on a time scale of 10-1000 years, the seismicity-time series for a region would be stationary and can be used for the purpose of long term earthquake prediction.

We have used the technique of Wiener predictive filtering for one and more channels of seismicity-time series and found that prediction of highs and lows in seismicity can be achieved. The data used in this study are (1) seismicity of Feng-wei region of Northern China from 504-1973 (Chang et al, 1974), and (2) seismicity of Ryukyu, Taiwan, Northern Luzon and the Philippines from 1901-1974, with data for each area treated as one channel. The success of prediction is measured by our ability to match actual data points when we cut off the time series at certain time and try to "predict" the series beyond the cut off.

The multichannel analysis method can be used to incorporate, in addition to seismicity-time series, other precursory data. It has the capability to "learn" as time goes on.

Chang et al, Probability of time of earthquake occurrence (II), ACTA GEOPHYSICA SINICA, 17, 200-208, 1974.

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DEPENDENCE OF SEISMICITY ON DEPTH

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L. Knopoff (both at: Institute of Geophysics and Planetary Physics, UCLA, Los Angeles, CA 90024

Space and time patterns of earthquake occurrence have been studied for the worldwide earthquake catalog (NOAA) 1965-1975, with $m_b \geq 5.3$. The total number of earthquakes is nearly 7,000. The time clustering of earthquakes at different depths was studied by modeling the earthquake sequences by a multidimensional stochastic point process. A sudden change of the rate of earthquake clustering is found around 60-70 km depth in

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SEISMIC ACTIVITY ASSOCIATED WITH THE AUGUST 6, 1979 COYOTE LAKE EARTHQUAKE

W. H. Bakun (U.S. Geological Survey, Menlo Park, CA 94025)

The M_L 5.9 (BRK) Coyote Lake earthquake occurred on a creeping section of the Calaveras fault about 10 km NNE of Gilroy, California. Epicenters of early (first 15 days) aftershocks lie primarily along a 16-km-long, relatively continuous segment of the fault trace. The main shock was located near a right-stepping offset in the fault trace that terminates the segment on the northwest. Aftershocks concentrate near a mapped complication in the trace near the center of the segment and at a right-stepping offset at the southeast end of the segment. Although the Coyote Lake sequence was not preceded by prominent foreshock activity, a preliminary analysis of seismic activity on the Calaveras fault near the Coyote Lake earthquakes shows that cumulative seismic slip in the decade before the sequence was concentrated near the right-stepping fault trace offsets at the ends of the segment. There also appears to be persistent seismic activity near the fault trace complication near the center of the segment. Similar correlations of fault-trace discontinuities with seismic activity have been observed for moderate-size mainshocks occurring on the creeping section of the San Andreas fault in central California.

S130

HISTORIC SEISMIC ACTIVITY AND THE 1979 COYOTE LAKE SEQUENCE

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Four earthquakes (1911, 1949, 1955, 1979) with M_L greater than 5 have occurred on the southern half of the Calaveras fault system since 1910. S-P times at Mount Hamilton and Berkeley are sufficient to locate aftershocks of the 1911 shock if the epicenters are constrained to the trace of the Calaveras fault. Published times imply a 20-km-long aftershock zone for the 1911 shock from near Mount Hamilton southeast to the epicenter of the August 6, 1979 M_L 5.9 Coyote Lake main shock. The similar lengths of the 1911 and 1979 aftershock zones and the similarity of the felt reports suggest that the 1911 and 1979 shocks were comparable events on abutting sections of the Calaveras fault. The M_L 5.2 1949 shock was located on the southeast part of the 1979 Coyote Lake aftershock zone. The 1955 M_L 5.5 shock occurred about 10 km northwest of Mount Hamilton. Activity on the Calaveras fault in the year before the 1979 Coyote Lake earthquake was concentrated southeast of the 1955 shock near the inferred northwest end of the 1911 aftershock zone.

S131

MICROEARTHQUAKE CLUSTERING PRECEDING THE COYOTE LAKE EARTHQUAKE

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Microearthquake clustering occurring along a 45-km-segment of the Calaveras fault centered on the 15-km-long aftershock zone of the 6 August 1979 earthquake was examined for the 10-year period prior to the event. During those 10 years all earthquakes within this region above catalog completeness level of M 1.5 were tested for clustering defined by 1) focal separation of no more than 1 km greater than the sum of their hypocentral standard errors, and 2) temporal separation less than 5 days. During the 10-year period, microearthquake clusters were observed to exhibit a distinct pattern with respect to the 6 August 1979 earthquake mainshock-aftershock zone: clusters were concentrated in a 6-km zone (3 clusters/km) just to the north of the main shock; cluster density decreased to a single cluster along the northern 4-km of the rupture zone; and cluster density slowly increased to a maximum of 4 clusters/km just south of the southernmost aftershocks. Clustering was low (less than 0.5 clusters/km) at the extreme north and south ends of the study area. The clustering process appears to have been stable during the 10-year period, and no distinct changes either in space or time were noted before the 6 August earthquake. These results suggest that the fault has distinct, long-term mechanical properties revealed by microearthquake occurrence patterns, and that these properties influence the location of a large rupture.

S132

THE SOURCE CHARACTERIZATION OF THE COYOTE LAKE EARTHQUAKE OF AUGUST 6, 1979 FROM SYNTHESIS OF TELESEISMIC BODY WAVES

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We present a preliminary source analysis of the August 6, 1979 Coyote Lake earthquake. The source parameters are obtained by matching of waveforms of the teleseismic body waves with theoretical seismograms. The theoretical seismograms are computed by a numerical integration of point sources distributed along the fault surface. The size and depth determined from the distribution of aftershocks are used as a starting model. Near field seismograms are used to establish the direction of propagation and duration of the rupture.

S133

TEMPORAL VARIATIONS IN TELESEISMIC P TRAVEL TIMES TO STATIONS NEAR THE AUGUST 6, 1979, COYOTE LAKE EARTHQUAKE

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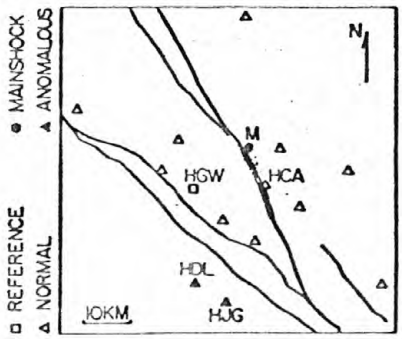
Teleseismic P-wave travel-time residuals were measured for the period Jan. 1 to Aug. 11, 1979 at 14 stations within 41 km of the Coyote Lake earthquake to look for premonitory variations. All but 6 of the 35 events were in the distance range of 71 to 83 degrees from the reference station (HGW) and have azimuths between 227 and 237 degrees. The scatter in residuals at individual stations is between ± 0.05 and ± 0.10 s. Medians of observations in four 60-day intervals were computed for each station. For all but two of the stations (HDL and HGJ), the variations in these medians were less than 0.05 s. HCA, in the middle of the aftershock zone, falls into this category. Residuals at HDL and HJG increased by 0.10 s in 1979. The spatial extent of this anomaly is poorly defined, but it is not coincident with the aftershock zone (shaded in figure) of the earthquake.



S134

PRESEISMIC AND CO-SEISMIC MAGNETIC FIELD MEASUREMENTS NEAR THE COYOTE, CALIFORNIA EARTHQUAKE OF AUGUST 6, 1979

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The epicenter of the Coyote earthquake (M_L = 5.5) of August 6, 1979 is located within an array of recording magnetometers which has been in operation since 1974. The nearest instrument COY was installed in October 1978 and, subsequently, was within 4 km of the earthquake epicenter. It is located on alluvium, but basalt outcrops with magnetization of 0.1 A/m occur nearby. Although some longer term variations have occurred at this site early in 1979 with respect to other sites in the area, no anomalous changes within the previous two months have occurred outside the present measurement uncertainty. We conclude that, in contrast to the 2 nT change observed prior to a previous M 5.2 earthquake (Smith and Johnston, 1976) no demonstrable tectonomagnetic effect was detected. A reasonable tectonomagnetic model of the earthquake indicates that if the mean stress change on the fault is 10 bars, the average magnetization must be less than implied by the basalt outcrop. This conclusion can be tested by precise surveying and modelling of the magnetic structure.

S135

MAGNETIC MONITORING IN THE AFTERSHOCK ZONE OF THE COYOTE RESERVOIR EARTHQUAKE

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R. Mueller (National Center for Earthquake Research, U.S. Geological Survey, Menlo Park, CA. 94025).

Within four days of the Coyote Reservoir earthquake, three temporary continuously recording magnetometers were installed in the aftershock zone to supplement the permanent U.S.G.S. recording magnetometer at Coyote Reservoir. This array of magnetometers recorded for approximately one month. Furthermore, eight magnetic surveys were completed during this period at each of 30 survey points having a separation of one mile. The majority of differences between the total magnetic field at the survey points and one of the continuously recording magnetometers remained constant, to within one nanotesla throughout the survey period. No effects larger than four nanotesla were observed. Records from the continuously recording magnetometers are being analyzed for aftershock-related magnetic perturbations.

S136

SOIL-GAS RADON-CONCENTRATION DATA RECORDED AT THE TIME OF THE COYOTE LAKE EARTHQUAKE OF AUGUST 6, 1979

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Radon concentration of subsurface soil gas has been monitored since 1975 at an extensive network of stations deployed along several major faults in Central California. The recorded data are examined to see whether radon concentration showed any changes at or before the time of the magnitude 5.7 earthquake which occurred on August 6, 1979 on the Hayward-Calaveras fault near Coyote Lake. Preliminary results indicate that, while no significant changes were recorded at two stations which are closest to the earthquake epicenter, the radon concentration showed a broad-scale increase elsewhere on the Hayward-Calaveras fault between San Jose and Hollister and along the Hayward fault and its northern extension between Santa Rosa and San Jose, during a period of several months before the earthquake. This episode of increased radon concentration is comparable in duration, amplitude and spatial extent to several earlier episodes, which was previously found to be correlated with local earthquakes of magnitude 4.0 to 4.3.

S137

A SEARCH FOR REPORTS OF UNUSUAL ANIMAL BEHAVIOR PRIOR TO THE COYOTE LAKE EARTHQUAKE OF 6 AUGUST 1979

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On 7 August 1979, one day after the magnitude 5.9 Coyote Lake earthquake, two teams of investigators went to the epicentral region to sample the level of observations of unusual animal behavior prior to the earthquake. Using a standard interview schedule, we conducted interviews at 51 households within 6 km of the epicenter. Each interviewee had been able to observe the behavior of domestic animals prior

to the earthquake. Except for 4 cases, the animal behavior which was reported to us was not unusual in any way. We have concluded that the rate of positive reports associated with the Coyote Lake earthquake represents the expected rate of occurrence of unusual animal behavior on any "random" day. Thus the Coyote Lake earthquake does not appear to be associated with the types of precursory stimuli which produce a high percentage of reports of unusual animal behavior.

In addition to our work in the epicentral area, we also investigated a publicized cluster of reports of unusual animal behavior occurring at a wild animal park about 70 km from the epicenter. In-depth interviews with individuals responsible for the maintenance and handling of these animals indicates that in most cases the behavior attributed to the earthquake by the news media is better explained by other factors not associated with the earthquake.

Project ROSE and LOPEZ Island Intercomparison Experiment

Gold Rush (HI)
Wednesday 1330 h
G. Sutton (Univ. of Hawaii) and *Brian T. R. Lewis* (Univ. of Washington), Presiding

S138 INVITED PAPER

SEISMICITY OF THE OROZCO FRACTURE ZONE DURING PROJECT ROSE

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Approximately 250 microearthquakes were recorded in the vicinity of the Orozco Fracture Zone by ten Texas OBS stations during a 2-week period as part of Project ROSE. The magnitudes of all but [illegible] of these events are so small that they were [illegible]rded by a single station only. Both spatial [illegible] temporal variations in seismicity were large during the experiment. Average activity levels at the various stations ranged between 0 and 20 events/day. The epicenters of the events that are large enough to be located are distributed along the east-west trending fracture zone with highest concentrations near the two intersections with the East Pacific Rise. The western center of activity appears to be shifted northward into the spreading center itself, but this conclusion is tentative pending completion of a more precise bathymetric map for the experiment zone.

S139

SEISMICITY OF THE OROZCO FRACTURE ZONE: ROSE MICROEARTHQUAKES AND TELESEISMIC HISTORY

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We present a preliminary analysis of earthquakes recorded by two M.I.T. ocean bottom seismometers and 8 W.H.O.I. ocean bottom hydrophones during the ROSE expedition to the Orozco Fracture Zone in March, 1979. We have located 16 events using P arrival times from the OBH and P and S arrival times from the OBS. Interesting spatial and temporal patterns emerge from this study which suggest a complex tectonic environment. Although all events are located within what we expect to be the active transform zone, they seem to separate into two groups. Events in the first group are all shallow (0-6 km) and define a narrow zone of activity striking east-west. First motion polarity is consistent with strike-slip transform motion. The events in the second group define a broad zone of activity striking approximately north-south and yield depths which ra[illegible] 0 km to greater than 15 km. The te[illegible] distribution of this activity suggests a [illegible] of small events with occasional larger shocks rather than a foreshock-mainshock-aftershock sequence.

We have also examined the teleseismic history of the Orozco Fracture Zone. Although latitudinal control is poor, most events are aligned along the active portion of the transform. The fault plane solution of the largest recent earthquake is consistent with transform motion. The seismicity of the transform since 1961 as documented by the WWSSN suggests a cyclic release of stress with a period of about 10 years. Peaks in activity marked by events with m_b>5.0 occurred in 1975 and 1966. Large (M_s>6) events were also recorded in 1955 and 1931.

S140

MEASUREMENT AND INTERPRETATION OF THE SHEAR WAVE VELOCITY IN NEAR-SURFACE BASALT

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(Sponsor: Peter Vogt)

The reflection coefficient from the water-basalt interface was measured in the frequency range, 15-30 hz, at a thinly-sedimented site at the East Pacific Rise in conjunction with Project Rose. The measurements were made with a 14 element mid-ocean hydrophone array and 240m SUS charges deployed to yield approximately 1 shot per degree grazing angle. The resultant data yields a measure of the shear wave velocity in near-surface basalt, which is in reasonable agreement with previously reported inferences of the interfacial shear wave velocity at the East Pacific Rise from reflectivity measurements (Diachok, J. Acoust. Soc. Am. 65, Suppl 1, 15) and from OBS measurements (McLain and Lewis, U. Wash. Contribution 1090). These data, together with previously reported low frequency measurements by Spudich and by Helmberger and Morris, are correlated with Christensen's high frequency determinations of shear wave velocity vs geologic age in small solid-basalt samples, through an analytical model of the velocity of sound in a randomly disordered two phase medium, in which neither phase acts as the host or matrix material (Budiansky, Mech. Phys. Solids, 13, 223-227, 1965). This theory, which appears to be qualitatively consistent with Hyndman's heuristic description of the ratio of solid rock to sediment/water in near-surface basalt, offers a plausible quantitative account of the observed relationship between the high and low frequency measurements, and a working hypothesis for the development of a geoacoustic model of the upper crust.

S141 INVITED PAPER

LOPEZ ISLAND OBS INTERCOMPARISON EXPERIMENT--ROSE EXPERIMENT

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P. Pomeroy
G. Sutton (at Hawaii Institute of Geophysics, Univ. of Hawaii, Honolulu, HI 96822)
and other Friends of Lopez Island

Between June 13 and 30, 1978 a field intercomparison of several ocean bottom seismograph systems was conducted in Shoal Bay, Lopez Island (Puget Sound), Washington. The two main reasons for the field test were: (1) to compare the responses of the instruments, having quite varied mechanical configurations, when coupled to the earth through soft sediments comparable to those of the ocean floor; and (2) to determine the susceptibility of the instruments to noise induced by near-bottom ocean currents. In addition to 12 operational OBS's, supplied by 10 different research organizations, three sets of three-component (T_0=1 sec) seismometers and a hydrophone were included to provide standards for comparison: a "spike standard" was pushed firmly into the bottom; a "plate standard" was mounted on a large, flat, circular plate resting on the sediments and had a smooth hemispherical superstructure; a "neutral density standard" had a roughly spherical shape and was floated within the uppermost sediment. All of the instruments were placed within a few meters of each other and connected by cable to a digital recording system on shore. Four current meters were installed around the array of instruments to monitor water circulation in the bay. Signals from mechanical transients applied directly to the OBS's and to the standard instruments, in addition to seismic signals from an air gun, blasting caps, and various levels of background noise were recorded.

S142

BOTTOM SEISMOMETER OBSERVATIONS VS. THEORETICAL AIRGUN SIGNAL AT LOPEZ ISLAND COMPARISON EXPERIMENT

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One of the tests during the OBS comparison experiment in Shoal Bay, Lopez Island, Washington, made extensive use of an airgun source. Digitally recorded signals were examined to study the fidelity with which different types of ocean bottom geophones detect vertical ground motion. To minimize effects of horizontal motion, only that portion of the wave train preceding a large shear-wave phase from the most distant airgun shots was analyzed. Results show in general a spectrum centered around a well-defined frequency peak. This is in good agreement with that computed from a theoretical airgun waveform although differences in wave shapes exist between signals recorded by individual instruments.

S143 INVITED PAPER

A COMPARISON OF OBS COUPLING AND CROSS COUPLING RESULTS BETWEEN LOPEZ ISLAND AND DEEP WATER DATA

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The Lopez Island OBS Calibration Experiment showed that most OBS designs show varying degrees of cross coupling of horizontal motion into vertical motion, thereby distorting the waveforms and making seismogram interpretations difficult. Similar results are seen in the University of Washington tripod OBS data in the ROSE Experiment, and off the Washington Coast, from S and P-S arrivals. The amount of cross coupling is dependent on the configuration of the OBS. Waveform distortion of near vertical incidence P waves appears to be much less dependent on OBS configuration. The cause of the cross is not presently well understood; it appears that rocking is not the cause as this would result in vertical frequencies one-half of the horizontal forcing function frequency.

S144

ESTIMATION OF BOTTOM-TO-OBS TRANSFER FUNCTION USING MECHANICAL TRANSIENT LIFT TESTS (LOPEZ/ROSE EXPERIMENT)

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Comparison of time functions and spectra resulting from mechanical transient lift tests applied to OBS's resting on a soft bottom in shallow water with signals recorded from blasting caps, air gun, earthquakes and background noise indicate that such tests provide useful information for estimating the Bottom-to-OBS transfer function. The transfer function is dependent upon the rigidity and density of the bottom sediments and upon the mass, density and configuration of the OBS. A relatively simple theory for bottom coupling response along with results from the Lopez Island OBS intercomparison experiment and other data provide valuable guidelines for future OBS development.

S145

COMPARISON OF AMBIENT BACKGROUND NOISE TO SURFACE WAVES GENERATED BY EXPLOSIVE SOURCES

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The OBS Intercomparison Field Test conducted

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