CAN ANIMALS PREDICT EARTHQUAKES?
A SEARCH FOR CORRELATIONS BETWEEN CHANGES IN ACTIVITY PATTERNS OF TWO FOSSORIAL RODENTS AND SUBSEQUENT SEISMIC EVENTS

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I. INTRODUCTION

A. Objectives

The purpose of this investigation is to answer the following questions:

1. Can certain animals anticipate seismic events? If so,
2. To what extent is their ability to anticipate seismic events useful for earthquake prediction?
3. How does an animal anticipate a seismic event?
4. Do any biological systems provide useful models for human technology?

Clearly, none of the above questions can be completely isolated from the others. However, unless Question 1 can be answered positively the remaining concerns are meaningless. The unequivocal demonstration that even a few individuals of a single species could anticipate earthquakes would constitute a major breakthrough. Therefore, our current investigation is directed primarily toward answering the first question. Specific objectives are:

1. to establish animal monitoring facilities within seismically active regions;
2. to continuously monitor (a) the daily and long term activity of small rodents under controlled conditions of light and temperature and (b) the daily and seasonal activity of small rodents in artificial burrow systems buried in the ground and exposed to the natural environment;
3. to determine whether any correlations exist between changes or anomalies in the activity of these animals and subsequent seismic events;
4. to record baseline patterns of animal activity in the absence of seismic events: and to determine whether correlations exist between changes or anomalies in the activity patterns and changes in non-earthquake related environmental parameters such as temperature, rainfall, humidity, insolation, barometric pressure, and atmospheric electrostatic fields.

B. Rationale

It is now well known that there exist numerous reports of unusual animal behavior immediately prior to moderate and strong earthquakes. Unfortunately, with but a few possible exceptions (Hatai and Abe 1932, Kraemer, Smith, and Levine 1976, Kenagy and Enright 1980, Skiles, Lindberg, and Hayden 1980), these reports are entirely anecdotal and retrospective. Although there is yet no conclusive scientific evidence to the effect that any animal can in any sense 'predict' earthquakes, the number, variety, and world-wide origin of the reports, together with the well documented sensitivities of numerous animals to extremely subtle mechanical, chemical, and electromagnetic stimuli, do not permit arbitrary dismissal of all such reports as simply imagined or coincidental. Indeed, observations of unusual animal behavior apparently form an integral part of the Chinese earthquake prediction effort. Moreover, the U.S.G.S. sponsored Conferences on Abnormal Animal Behavior Prior to Earthquakes of October 1976 and 1979 led many skeptical U.S. biologists and geophysicists to reassess their views and to conclude that the question deserves serious scientific study.

C. Past History of Contract

The study was initiated in FY 1977 with installation of indoor and outdoor monitoring facilities at the Big Morongo Wildlife Reserve adjacent to the town of Morongo Valley, San Bernardino County, California. In FY 1980,a second outdoor monitoring station was installed in Stone Canyon near Hollister, California. Both locations are seismically active. An earthquake swarm centered around the town of Landers, San Bernardino County, California commenced about 1218 hrs. PST on 15 March 1979 and continued for many weeks. The epicenter of the swarm was located about 30 km NNE of the Morongo study site. Changes in animal activity patterns were observed in both the indoor and outdoor facilities during the days immediately preceding and following commencement of the Landers' earthquake swarm. However, changes in factors not associated with earthquake (i.e.air temperature, on-set of seasonal behavior, and maintenance procedures) were coincident with the activity anomalies observed and thus preclude a conclusion that we intercepted an event of unusual animal behavior precipitated by an impending earthquake.

II. TECHNICAL APPROACH

The methods of implementing this study have been fully reported in the Annual Technical Report for this contract dated 31 October 1979, as well as the U.S.G.S. Open File Report #80-453 dealing with abnormal animal behavior prior to earthquakes. The approach is being used at both the Morongo and Stone Canyon sites and is abstracted below.

A. Animal Activity Monitoring

The behavioral parameter we are monitoring is gross motor activity as manifested by the use of a running wheel or passage of an animal through a switch gate. These activity data can be recorded continuously without interfering with the normal behavior of the experimental animals. Because they are recorded electronically, the data are objective and the presence of a human observer is not required. Furthermore, under known natural or laboratory environmental conditions, these activity data exhibit fairly regular and predictable patterns which are amenable to both qualitative and quantitative analyses.

Indoor Animal Facility (Morongo)

Located indoors is an array of 20 plywood boxes, each of which contains a 9 in. diameter plexiglass running wheel mounted within an 11.5 in. cubical plexiglass box with a wire mesh top. Each revolution of the running wheel closes a microswitch and the event is recorded on magnetic tape via a single channel of an event recorder. The plywood boxes are light-proof and contain baffled openings on the front and back which permit the passage of air through each box. Each box also contains two low wattage lamps. One provides the caged animal with constant dim light of less than 1 lux intensity. The other provides a light intensity of approximately 20 lux and can be turned on and off by a timing switch to provide a 24 hour light cycle (LD cycle).

Fresh air is forced through the boxes by a fan mounted in a plenum chamber on the back of the array. The temperature in each box is held constant within 1^{o} or $2^{o}F$ throughout the year, despite outdoor temperatures ranging from 15^{o} to 115^{o}.

Each running wheel box houses a single kangaroo rat (*Dipodomys merriami*).

The animals are trapped in the wild, usually on the Big Morongo Reserve. Recently, 8 Kangaroo Rats were replaced with a large species of Pocket Mouse, *Perognathus fallax*. These animals are good wheel runners and appear to have longer life expectancies than the Kangaroo Rats. During the past year, the animals have been divided into two groups subjected to different light conditions. Sixteen boxes have been continually maintained on a 24 hour light cycle of 12 hours of 20 lux intensity from 0600 to 1800 PST, and 12 hours of less than 1 lux intensity from 1800 to 0600 PST (LD 12:12 [L 0600-1800]). The remaining four boxes have been maintained on a 24 hour LD cycle 180^o out of phase with former (LD 12:12 [L 1800-0600]).

Because these animals are nocturnal, they generally make frequent use of the running wheel during the dim portion (D) of an LD cycle and little or no use of the wheel during the bright (L) part of the cycle, regardless of the relation of the artificial LD cycle to the local natural LD cycle.

Outdoor Animal Facility

The outdoor monitoring facilities are similar at Morongo and Stone Canyon. All monitoring equipment is operated by 12VDC power supplies in parallel with a 12V battery so that data collection can continue uninterrupted during intermittent AC power failures.

We are currently monitoring kangaroo rats (*D. merriami*) and pocket mice (*Perognathus longimembris*). Each animal is housed individually in an artificial burrow system which is intended to simulate a natural burrow. Each burrow system contains three activity boxes (10 in x 15 in x 4 in high for pocket mice: 13 in x 18 in x 5 in high for kangaroo rats). One box is at ground level and exposed to the natural LD cycle; one is buried just below the surface; and one is buried at a depth of about 76 cm. The boxes are connected by PVC pipe so that each animal has free choice of the box it occupies. Each box is divided into three sections and contains three activity gates triggered by the passage of an animal. The animal must pass through an activity gate to enter or leave a box or to pass from one section of a box to another. One channel of a counting event recorder is dedicated to each box, so that we obtain a record of where and how active each animal is throughout each 24 hour day. Because kangaroo rats and pocket mice are considered nocturnal, we expect to find reduced activity in the top boxes during the hours of daylight. Thus, most of the activity takes place below ground. Hence the advantages of the monitoring system over one which relies on human observers are obvious.

Bee Activity

A bee hive has been positioned near the indoor facility at Morongo and instrumented to score the time and number of bees leaving the hive during the day. The data are collected on an available channel of the indoor animal monitoring system and processed by computer.

B. Environmental Parameters

Along with animal activity we are monitoring several environmental parameters. In the indoor temperature controlled facility at Morongo we are continuously recording temperature and humidity. Out of doors we continuously record air temperature, humidity, rainfall, and, at Morongo, the atmospheric electrostatic field. In addition, soil temperatures are obtained manually from three thermistor temperature probes buried at depths of 76 cm, 35 cm, and 4 cm. Seismic data are obtained from the U.S.G.S. seismic networks.

C. Data Recording and Processing

The data are processed and printed out by computer in a format which gives both a quantitative and graphic display of the data (Fig.4). Total activity for the 24 hr period (ACTOT); number of sampling intervals in the 24 hr period in which activity occurs (NIO); average number of counts for each interval during which any activity was recorded (SUM/N); duration of activity (HRACT); and the time interval of the arithmetic median of activity (ACRO), are derived and displayed on the printout.

These five quantities were chosen because they provide useful and reliable numerical indices of the distribution, duration, and intensity of recorded activity. Their daily values can be visually scanned to determine whether obvious departures from their usual day to day variations exist. In addition, the overall pattern of activity, without regard for numbers, can be examined for evidence of abnormal activity.

III. STONE CANYON STUDY SITE

A. General Description

In November 1979 we began monitoring animal activity at an outdoor facility in Stone Canyon, San Benito County, California. The site is located at approximately 36°38'N, 121°15'W on the southern slope of Stone Canyon within 2km of the San Andreas Fault (Fig.1).

As it is well within the boundaries of the 101 Ranch, the site is not accessible to the general public, although two private hunt clubs do have access to the area. To date we have suffered only one minor incident of unwanted human intrusion (during the deer hunting season) which resulted in the theft of a rain gauge, a small animal trap, and a battery, and minor damage to the electric fence when it was hit by a high powered rifle bullet fired at close range.

Cattle also graze in the area at certain times of year, so the site is protected by a 4ft. high barbed wire fence. In addition, an 18in. high chicken wire fence topped by a 1000 VAC electric shock wire (a standard electric livestock containment device) prevents ground squirrels, foxes, and the like, from entering the facility and damaging the equipment.

AC power is delivered to the site via approximately 2km of twin spiral 4 cables. These carry 220 VAC which is converted to 110 VAC at the site. The monitoring equipment is powered by a 12 VDC power supply in parallel with a 90 amp hour rechargeable 12V battery which protects against AC power failure of up to four days duration.

Weather data (temperature, wind speed, precipitation) are recorded approximately 2km from the site at a U.S.G.S. maintained weather station. We also have a rain gauge at the site which is read approximately once a week when the site is visited to feed the animals and check the equipment.

The Stone Canyon monitoring equipment is similar in all essential respects to that of the outdoor facility at Morongo Valley which has been described in detail in previous reports. Data are recorded on magnetic tape (Fig.2) from ten three-level burrow system cage arrays (Fig.3). Six of these arrays, each containing a single 'little pocket mouse' (*Perognathus longimembris*), have been operational since November 1979. The remaining four arrays, each housing a large pocket mouse (*Perognathus californicus*), became operational in mid-May 1980. For each species equal numbers of males and females are used.

The individuals of *P. californicus* were trapped in Stone Canyon. To our knowledge, *Perognathus longimembris* is not native to the region and individuals of that species were trapped in southern California where we obtain animals for the Morongo Canyon facility. Because it has been an exceptionally hardy and manageable experimemtal animal at Morongo Valley and in many laboratory experiments we decided to use *P. longimembris* in Stone Canyon. The major difference between the Stone Canyon and Morongo Valley environments is the greater winter precipitation on Stone Canyon, but this should be of little consequence to the animals owing to our choice of a well drained site. All *P. longimembris* survived the winter (Fig.s 7 & 8) and showed no signs of ill health until mid-May when the three males suddenly and inexplicably died, apparently within a single week.

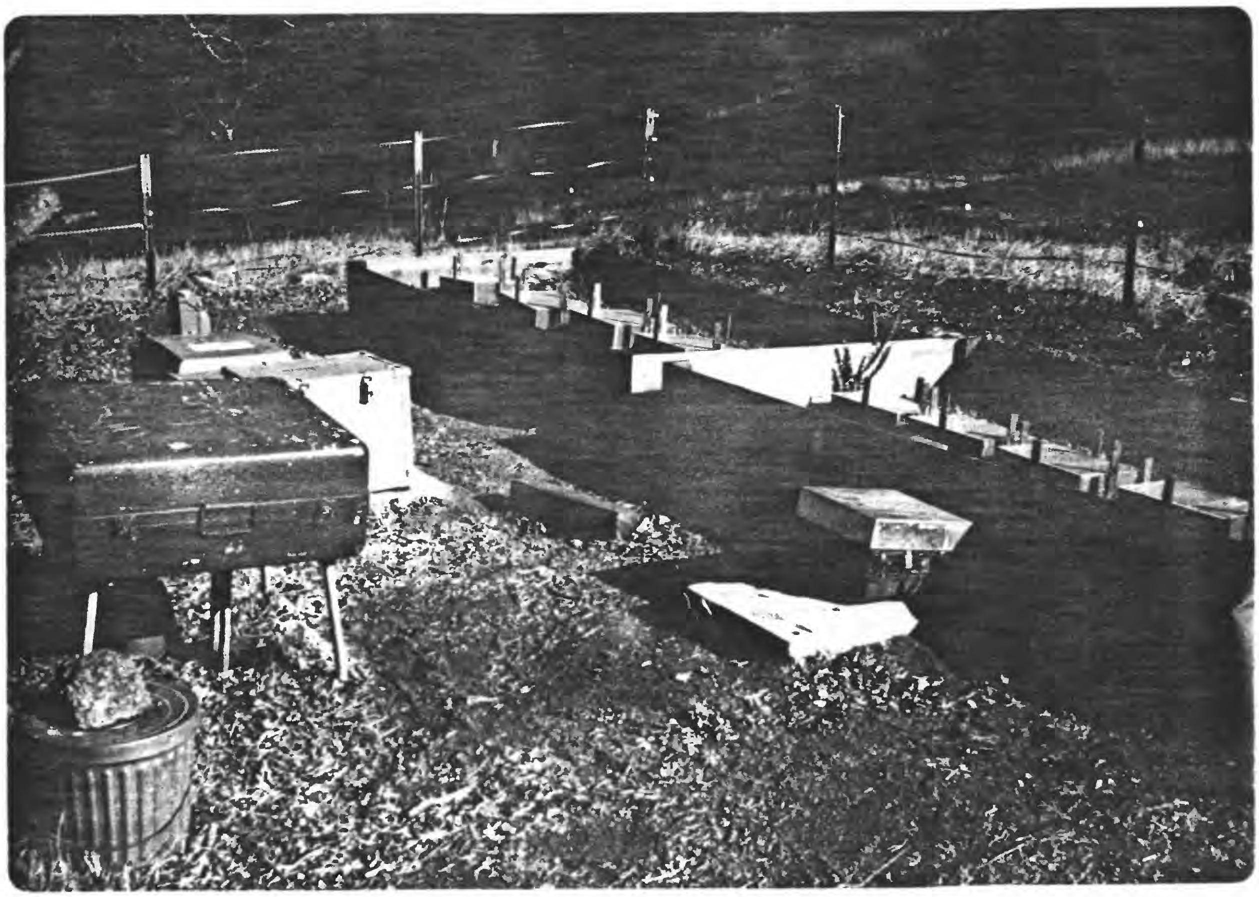

Figure 1. Stone Canyon experimental facility. Data recorder is in weatherproof box at left, animal cage arrays at right and above center.

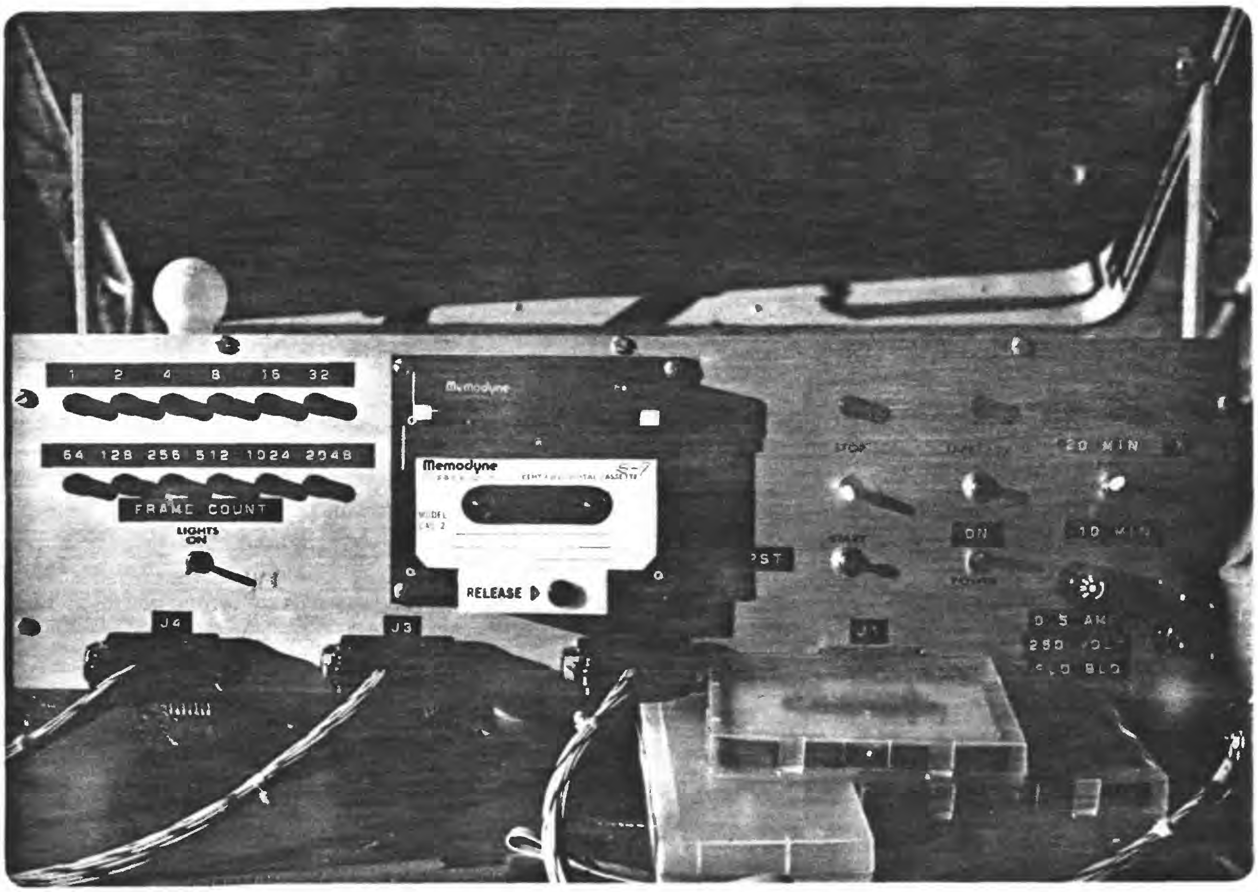

Figure 2. Closeup view of magnetic tape cassette data recorder.

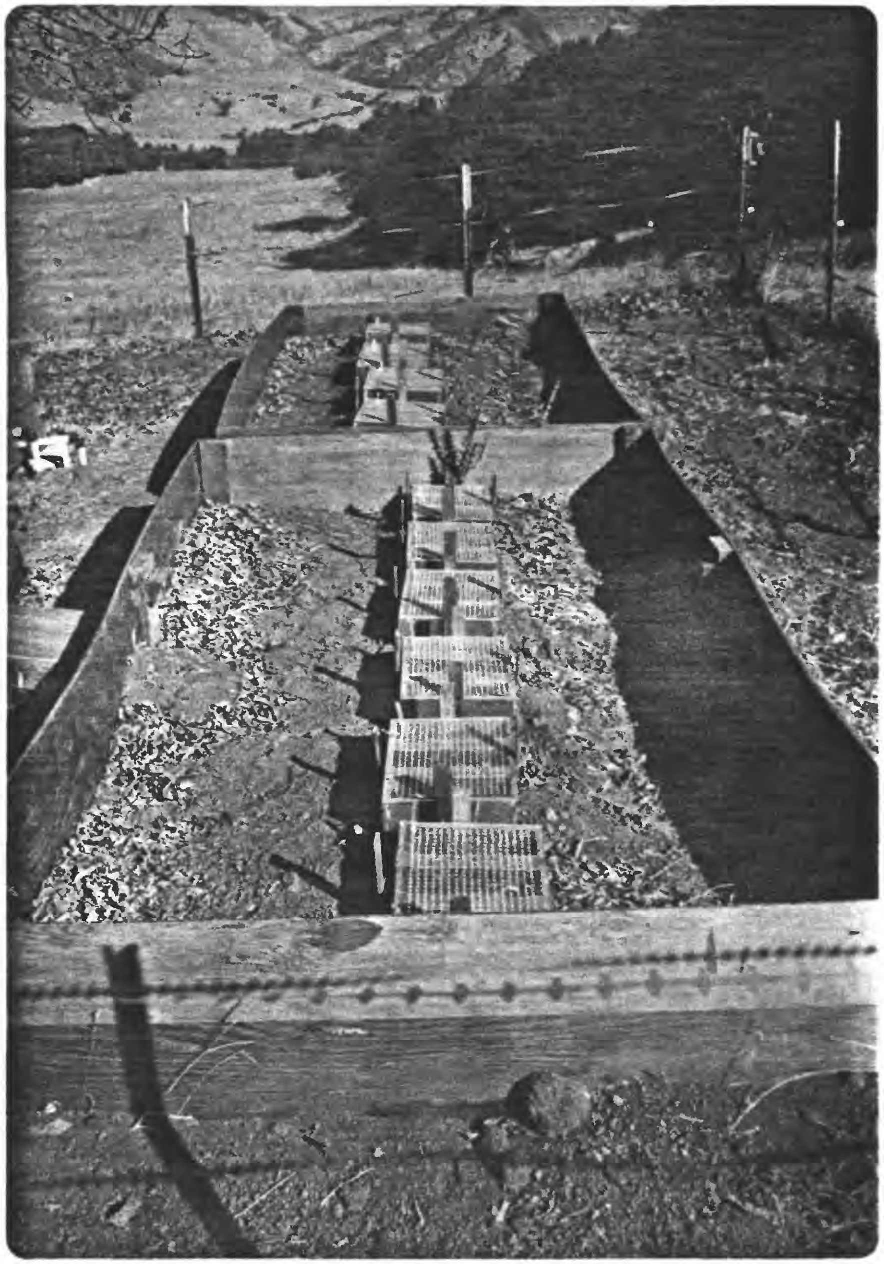

Figure 3. Experimental animal cage arrays in place and recording animal activity. Perognathus longimembris cages in foreground, larger P. californicus cages in background.

USGS EQ PREDICT OUTDOOR

STONE CANYON
ANIMAL PC-3

DAYS/YEAR 240/80 - 261/80
ACTIVITY BOX TOP

TIME PST	261	260	259	258	257	256	255	254	253	252	251	250	249	248	247	246	245	244	243	242	241	240	TIME PST	
											DAY OF YEAR													
1200																							1200	1
1220																							1220	2
1240																							1240	3
1300			7																				1300	4
1320			19																				1320	5
1340			35																				1340	6
1400			17																				1400	7
1420			3																				1420	8
1440																							1440	9
1500																							1500	10
1520																							1520	11
1540																							1540	12
1600																							1600	13
1620																							1620	14
1640																							1640	15
1700																					3		1700	16
1720																					1		1720	17
1740															3			4					1740	18
1800	3	8			6	3	5	4										2					1800	19
1820	3	21		16			1			11	4		4	4	5		5		2	3	5		1820	20
1840			11	3	6			6	12			8				13		2	1	1			1840	21
1900	5	9	4	8	10	4	10	4	15	9	7	1	5	4	8	15	7	4	6	8	5		1900	22
1920	7	4	16	3		10		13	3	10	9	14	5	10	3	4	5	5	14	5	7	18	1920	23
1940	22	12	16	4		1	5	4	20	10	21	18		10	19	10	3		16	8	10	10	1940	24
2000	28	11		9		10	7	18	22	15	11	14	9	13	23	15	15	14	12	11	15	7	2000	25
2020	14	12					8	23	10	6	18	12	6	19	12	8	13	16	11	11	18		2020	26
2040	19	19	1	3			17	5	3	3	14	13		18	7	15	12	17	19	26	26	7	2040	27
2100	9	1	4	15		5	31			1	35	2	1	16	3	19	21	3	9	20		7	2100	28
2120	16	3					13	8	5	15	20	18	6	11	21		11	14	2	22	5	13	2120	29
2140	11	5	6			11	4	8	2	13	5	8	15		29		16	23	9	17	21	7	2140	30
2200	3	12	3	13		3		5	8		23	2	16	3	13	20	19	13	19	8	18	7	2200	31
2220	13	29	12	13		7	6	21	5	6	42	1	27	3	28	7	5	19	9	3	5		2220	32
2240	15	25	17	5	14	21	13	28	11	9	18	5	15	17		10	6	16	6		10		2240	33
2300	22	1	23		6	7	13	26	9	10		12	18	10	5	17	20	4	13	16	6		2300	34
2320	16	24	12	3	5		15	17		42	21	15	18	13	13	14	10		19	18		13	2320	35
2340	16	11	9	4	5	5	15	1			30	1	8	15	15	28	9	9	14	4			2340	36
0	26	24	23	5		10			25		21	10		12		6	6	5	1		5		0	37
20	3	16	15	11		11	2	12	32	7	15	12		7				5		4	15		20	38
40	3	22	2	3		24	15	25	25	10	13		21		8	6	3		9	6		4	40	39
100	22	22		7		12		11	11	13	5	5	15	3	13	12	7	5	5	9			100	40
120	11	5				12		16	13	12	7	15	5	13	13		13	24	23	5			120	41
140	15	11				18	8		28	24	16	19	16	12	16	9			13	13	8	8	140	42
200	26	16	8			15	12		8	11	6	8	1	6	8	4			9	9			200	43
220	19	4	16			12	31	6	2	14	10	31	10	16	5	12	14	9	18	8	7	15	220	44
240	16	2	4			18	10	10		6	16	19	40					10	17	9		7	240	45
300	16					10	5		11		8	17	20	14			14		10	4	6	3	300	46
320	7					36	14		9				12		9		5			4			320	47
340						10			3				8		7		10	7					340	48
400		7								7	7	7						14					400	49
420									6			7	4	2							2		420	50
440	6																		4		9	4	440	51
500												4				6							500	52
520							3					6						2					520	53
540															1					1		1	540	54
600											4					1	3			1			600	55
620														5					1	1		2	620	56
640																2						2	640	57
700	1						4			2								3					700	58
720																							720	59
740																							740	60
800										1		1											800	61
820																							820	62
840													5										840	63
900	6							6			6					18				4			900	64
920	1	10						5									5						920	65
940	5								4														940	66
1000			7						4														1000	67
1020																							1020	68
1040																							1040	69
1100																							1100	70
1120																							1120	71
1140																							1140	72

	262	261	260	259	258	257	256	255	254	253	252	251	250	249	248	247	246	245	244	243	242	241	MEAN	SD
ACTOT	5.6	4.8	4.0	1.7	.7	3.8	3.7	3.9	4.3	3.7	5.7	4.2	4.3	3.6	4.0	3.8	3.6	3.5	4.0	3.6	2.9	1.9	3.7	1.1
N20	33.0	28.0	25.0	17.0	7.0	24.0	25.0	24.0	27.0	25.0	28.0	30.0	26.0	25.0	25.0	24.0	26.0	26.0	28.0	30.0	22.0	18.0	24.7	5.2
SUM/N	12.3	12.4	11.6	7.4	7.4	11.5	10.7	11.8	11.3	10.7	14.7	10.2	11.9	10.2	11.5	11.3	9.9	9.6	10.4	8.6	9.4	7.5	10.6	1.7
HRACT	16.0	15.7	21.3	7.0	6.0	10.0	13.3	15.7	15.7	14.0	15.0	13.7	14.7	12.3	12.3	14.7	15.3	13.7	12.3	15.0	12.0	11.7	13.5	3.1
ACRO	35.7	34.0	26.3	29.5	28.5	38.6	35.2	33.9	35.6	34.5	34.0	36.3	37.7	33.8	32.7	34.5	34.2	34.0	34.4	33.3	31.3	33.8	33.7	2.7

Figure 4a. Twenty-two day activity record from the top cage for *Perognathus californicus*. Individual PC-3.

USGS EQ PREDICT OUTDOOR

STONE CANYON — DAYS/YEAR 240/80 - 261/80

ANIMAL PC-3 — ACTIVITY BOX SUB.

TIME PST	DAY OF YEAR 261	260	259	258	257	256	255	254	253	252	251	250	249	248	247	246	245	244	243	242	241	240	TIME PST	
1200	4					2	2			7			2										1200	1
1220						2																	1220	2
1240																	2	2					1240	3
1300			10				2			11													1300	4
1320			46			2					3												1320	5
1340	2		32		10						1		6			4	1	12	3				1340	6
1400	5	9	47		1	4	7					11		5	7		8	8	9				1400	7
1420			59	7				4	4		3				1		3			12	6		1420	8
1440		2	38					5	4		28									1	5		1440	9
1500			15		2					6	1		2						2				1500	10
1520					3							2				2							1520	11
1540		3							2			3	2		4	9					2		1540	12
1600		3				13		5	1			1	4	7							1		1600	13
1620	6	9	1			1							3			3	1		2	7	13		1620	14
1640	4	1	4				5		1		8							1	1	1	2		1640	15
1700				7					3			4			5		3	5	7	2	5	4	1700	16
1720	2				7				2	4			1		3		2	2	2		6	4	1720	17
1740				2	3	3	2			5	3	6		9	4	2	2	5		6			1740	18
1800	11	19	2	5	17	8	11	12		2	8		9			8	5	3	5		3		1800	19
1820	3	17	3	8	1		6		5	5	4	3	8	7	4		4	5	7	4	5	25	1820	20
1840	5	3	5	4	8	7	3	6	15	2	1	5	1	7	3	11	1	6	4	2	1	43	1840	21
1900	2	4	8	4	49	1	3	5	15	8	4	3	8	3	3	12	5	4	5	8	7	9	1900	22
1920	2	1		13	12	2	4	3	1	2	3	5	3	7	3	3		3	4		4	11	1920	23
1940			9	4	1		9		9	3		1		2	3		4			4	1		1940	24
2000	10	3	12	4	1	4	3	3	3		2		4		6	3	3	3	2	3	6	2	2000	25
2020	3	5	9	2	2	2		5	1	2	2	3	1	2	2	4	2	1	3		1	2	2020	26
2040			2	4			4	2	2	1	3	3	1	8	8	3	2	2	2	3	5	10	2040	27
2100	5	1	2	6	3	6	10			2	6	2	4	2	5	4	5	1	2	5			2100	28
2120	2	4		2	1		2	5	3	2	1	2	4	1	7	1	2	2	4	2	2	9	2120	29
2140	2		2	4	1	7				2	2	1	2		7	2	5	3	3	1	7	7	2140	30
2200	3	6	4	6	3			5	3		6	1	2	2	3	5	2	4	5	3	4	1	2200	31
2220	4	5	2	9	11	4	7	4		2	4	4	2	4	5	2	1	5	3	2	1		2220	32
2240		3	2	7	18	6	2	3	7	4	1	3	4	4		3	6	5	7		7	1	2240	33
2300	4	1	9	1	47	2	6	8	2	6			7	4	2	2	4	1	2	10	3	6	2300	34
2320	1	6	7	2	16		3	6		7	1	4	8	1	3	8	4	2	3	6		5	2320	35
2340	5	9	3	6	16	6	4	4			4		2	6	4	8	4	8	2		1	2	2340	36
0	5	6	6	6	2	6		2	10		2	4		7	3	1	1			1	3		0	37
20		4	9	4	9		3	4	5	1	4			1					1	3	5		20	38
40	4	3		9	9	3	8	6	4	2	2		7		5	5	4	6	5	6		3	40	39
100	9	5		9	19	6		5	6	6	3	4	2	6	4	5	3	2	5	2			100	40
120	2	3		6	25	7		13	5	4	1	3	4	9	4		6	9	16	5	2	2	120	41
140	6	3		6		8	8	3	10	8	9	2	1	5	8	7	1		5	8	4	4	140	42
200	3	3	13			3	12	10	13	5	4		2	3	1	6	1	1	3	5		2	200	43
220	5	1	16			5	12	14	17	6	4	8	5	8	1	3	8	1	11	2	3	5	220	44
240	4	2	25		15	9	6	6		3	7	2	9	1		4	2	3	13	2		1	240	45
300			6		4	1	8	20	4		4	2	7	7	2	5	8		2	3	4	21	300	46
320	18		44			13	11	5	3				7		18		2			13			320	47
340			14	2		4			3	2		2	8		2		3	6					340	48
400		3		8						7	3	2		3				3					400	49
420	2	7							7				17	3							2		420	50
440	3				2	5		3								1	3		4			5	440	51
500							5	2				10				5				3			500	52
520		4	3						3			4	4					6			7		520	53
540														2	35		3				11		540	54
600				2							12				15		39				6		600	55
620						8			2	4			2	28		3			6	2		5	620	56
640					2				2				2	4		15				23		9	640	57
700	15			2	4		31	5		2						2		21		29			700	58
720			1	5	2		51										2	14		11			720	59
740			2		2	4						3			5				5		3		740	60
800		4			3	3				48	5	26										1	800	61
820					2					2			3	9								1	820	62
840					1	6	5		2		3		30					5			4		840	63
900	5				2	3	2	23	2		17			6	3	33		3	9	6			900	64
920	2	23		5	4			8					7		4	2	23	1	4	3		3	920	65
940	9	1	1	5	3	4			10		3	18	5									4	940	66
1000			4				8		3	5											4		1000	67
1020				8							6		7					2				1	1020	68
1040						2											15						1040	69
1100																	3						1100	70
1120					4						6			4					4				1120	71
1140					2						17		2			14	2						1140	72

	262	261	260	259	258	257	256	255	254	253	252	251	250	249	248	247	246	245	244	243	242	241	MEAN	SD
ACTOT	2.5	2.6	6.6	2.6	4.8	2.5	3.7	3.0	2.7	2.6	2.9	2.2	3.1	2.6	2.8	2.9	2.9	2.4	2.5	2.9	2.2	2.9	3.0	1.0
N20	36.0	36.0	38.0	35.0	43.0	38.0	34.0	33.0	38.0	35.0	42.0	34.0	44.0	35.0	37.0	37.0	44.0	39.0	39.9	37.0	37.0	31.0	37.4	3.4
SUM/N	4.9	5.2	12.6	5.3	8.1	4.8	7.8	6.5	5.1	5.4	5.0	4.6	5.0	5.3	5.5	5.7	4.8	4.5	4.7	5.6	4.2	6.7	5.8	1.8
HRACT	22.0	20.0	21.3	20.8	22.3	23.0	22.3	19.3	20.0	22.3	22.7	20.0	24.0	21.7	19.7	22.3	23.8	22.0	22.0	19.3	20.0	17.7	21.3	1.6
ACRO	36.3	33.6	22.4	35.0	33.4	36.8	42.3	39.3	36.2	38.7	38.8	40.3	41.4	39.1	38.4	40.9	43.0	36.2	35.9	40.6	32.3	32.3	37.0	4.4

Figure 4b. Record from the subsurface box for PC-3.

USGS EQ PREDICT OUTDOOR

STONE CANYON — DAYS/YEAR 240/80 - 261/80

ANIMAL PC-3 — ACTIVITY BOX DEEP

TIME PST	261	260	259	258	257	256	255	254	253	252	251	250	249	248	247	246	245	244	243	242	241	240	TIME PST	
											DAY OF YEAR													
1200										3													1200	1
1220																							1220	2
1240																							1240	3
1300										1													1300	4
1320																							1320	5
1340																							1340	6
1400																							1400	7
1420																							1420	8
1440																							1440	9
1500																							1500	10
1520																							1520	11
1540																							1540	12
1600																							1600	13
1620																							1620	14
1640																							1640	15
1700																							1700	16
1720																							1720	17
1740																							1740	18
1800																							1800	19
1820																							1820	20
1840																							1840	21
1900																							1900	22
1920																							1920	23
1940																							1940	24
2000																							2000	25
2020		3																					2020	26
2040																					4		2040	27
2100				4																			2100	28
2120																						2	2120	29
2140																							2140	30
2200																							2200	31
2220			4	2															2				2220	32
2240									3								2				2		2240	33
2300			4		4											2				2			2300	34
2320					12			3											2				2320	35
2340			3		22													2					2340	36
0	2		1		80																1		0	37
20			1	3	65																4		20	38
40		3	4	4	65		3												3				40	39
100		2		5	12					3						2				2			100	40
120		2		46	6	3			4								3		2		2		120	41
140		23		31						2										2	2		140	42
200		6	1						5	3											2		200	43
220		2	3		2				3		3	5				2				3	2	6	220	44
240	10	1	10		4			2		8	2	6				1				4		14	240	45
300	3		28		2		3	9	2		1	6				2			1	1	2	5	300	46
320	3		11				17	3	1								4			1			320	47
340			5	2		1			3	1		1			5		2						340	48
400		2		3						3	2	1						3					400	49
420	2	2							2			2									3	2	420	50
440	2				1	2		2								1	2		4		3	2	440	51
500							2	4				3				1				2			500	52
520		4	2				2		2			1						7			3		520	53
540											1				1		2				40		540	54
600				2							1				1		3				25		600	55
620						4			2	2						2			6	2		3	620	56
640									2				4	1		5				1		1	640	57
700	3			2			1	8		14						1		1		1			700	58
720	1		1	2			1										4	1		2			720	59
740		2	1			1						2			4				4		2		740	60
800		2								1	2	2	2									1	800	61
820										1			1	3							1	3	820	62
840							1		1		1		1			2	2	1			1		840	63
900	3						3	1	1		1			1	1	1			1	3			900	64
920	1	1		4				2					1				1					1	920	65
940	1		1	1					1		4	1									1		940	66
1000							1			3													1000	67
1020				1							2												1020	68
1040																	2						1040	69
1100																							1100	70
1120											2												1120	71
1140											5												1140	72

	262	261	260	259	258	257	256	255	254	253	252	251	250	249	248	247	246	245	244	243	242	241	MEAN	SD
ACTOT	.4	.8	1.1	1.6	3.8	.2	.5	.5	.4	.6	.4	.4	.1	.1	.2	.3	.4	.2	.3	.4	1.4	.6	.7	.8
N20	11.0	14.0	16.0	15.0	12.0	5.0	10.0	9.0	14.0	13.0	13.0	11.0	5.0	8.0	5.0	12.0	11.0	6.0	9.0	13.0	18.0	11.0	10.7	3.9
SUM/N	2.8	8.9	5.0	7.5	22.9	2.2	3.4	3.8	2.3	3.5	2.1	2.7	1.8	1.7	2.4	1.8	2.5	2.5	2.8	2.0	5.6	3.6	4.0	4.3
HRACT	10.0	13.3	11.7	13.7	6.0	6.7	9.7	10.3	11.3	22.3	9.7	7.7	3.0	2.7	5.7	10.3	12.3	9.3	11.0	10.3	18.8	12.3	10.1	4.0
ACRO	50.4	44.2	44.6	43.0	38.0	50.6	50.1	50.5	47.4	47.6	60.2	49.3	60.0	61.4	54.4	51.0	52.3	51.3	48.9	49.2	51.0	48.0	50.2	5.4

Figure 4c. Record form the deep box for PC-3.

As of the date of writing this report, the females are still doing well and we are therefore preparing to add three new males to the system.

We have experienced no problems with P. californicus. As Figure 4 shows, that species is providing excellent activity records.

B. Seismic Data

Seismic data are presently obtained from the Seismograph Station at the University of California, Berkeley. The Berkeley net has three instruments near Stone Canyon: SAO, approximately 22.5km NW; LLA approximately 28km E; and PRS, approximately 36.5km SSW of our site. All events of magnitude 2.5 or greater are routinely cataloged at the station and we have used them as our seismic data base.

Figures 5 and 6 show all events of preliminary magnitude 2.5 and above whose preliminary epicenters were located within 50km of the Stone Canyon site from 1 December 1979 through 8 June 1980. Figure 9 shows similar data for 27 August to 25 September 1980. A few events with magnitude less than 2.5 are shown because they were associated with swarms. Events whose epicentral distance d from the site is given by $0 \leq d \leq 10$km are indicated by an X, by $10 < d \leq 25$km by a circle, and by $25 < d \leq 50$km by a dot.

C. Animal Activity

We begin by noting that much to our dismay, owing to a succession of equipment failures and the failure of our local help to recognize some of those failures, the majority of the data from 9 June to 27 August 1980 were lost. The equipment problems have been remedied and the help reeducated so that we presume the situation will not recur.

Figures 5 and 6 show the total activity (surface box + subsurface box + deep box) for the six P. longimembris during the first seven months of the reporting period together with the nearby seismic events. Figures 7 and 8 show the activity of individual animals.

As expected, the animals were relatively inactive during the coldest months, December and January. Part of the reason for the decreased activity is that the animals did not visit the surface during this period. Nevertheless, the intensity of activity was seldom zero, and significant intensity fluctuation occurred. In February, as air temperature increased and winter rains abated, the intensity of activity increased and the animals slowly began to visit the surface again. The beginning of surface activity for each animal is indicated by an arrow in Figures 5 through 8.

D. Animal Activity versus Seismic Activity

Let us begin with some general remarks. First, excepting the period of depressed winter activity, there is considerable scatter in the activity data. Second, seismic events are rather frequent and rather evenly distributed throughout the reporting period. Third, none of the earthquake magnitudes was particularly large.

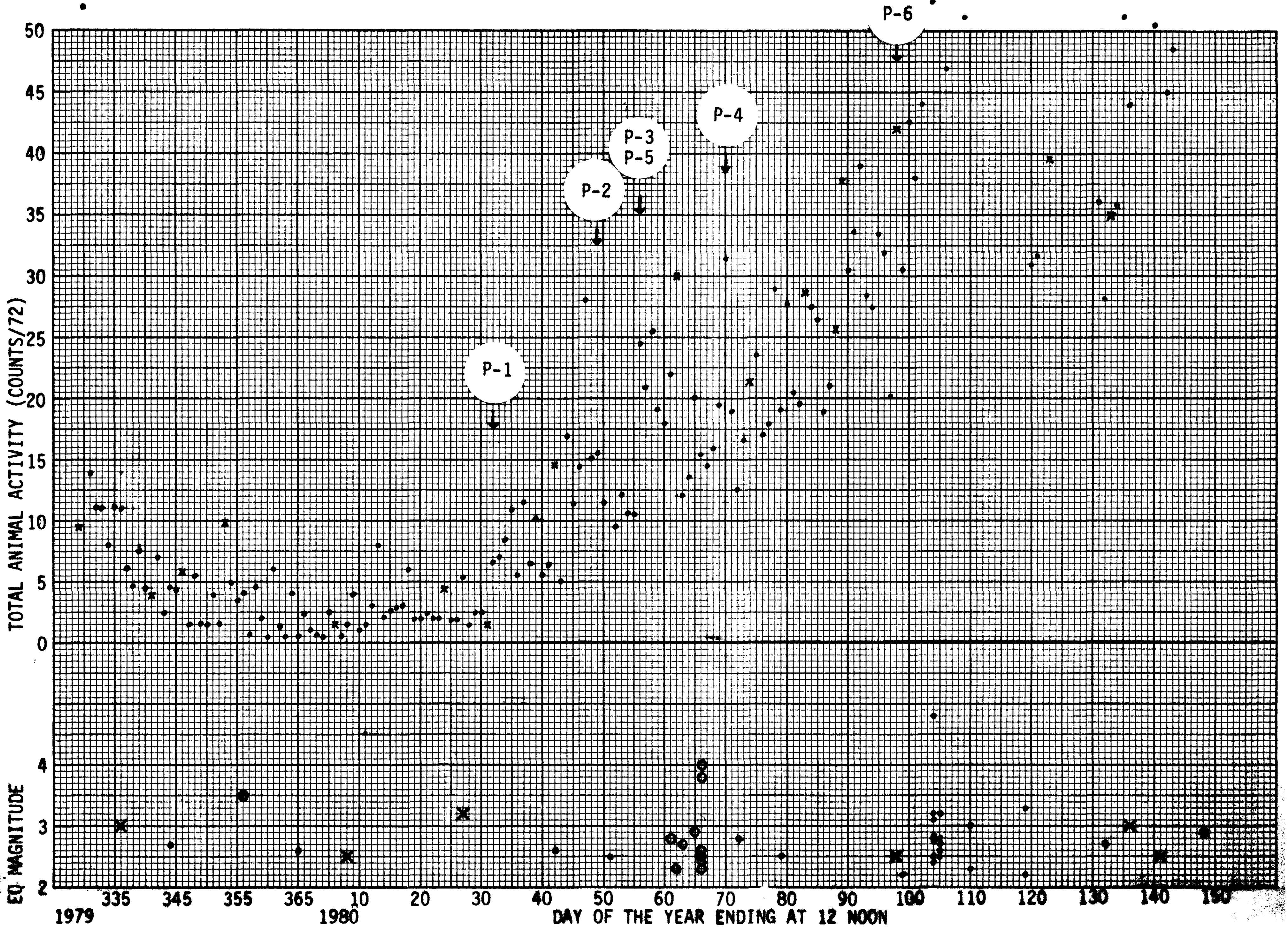

Figure 5. ABOVE: Total activity for six Perognathus longimembris at Stone Canyon. Arrows indicate first day of renewed surface activity by individual animals. BELOW: Seismic activity near Stone Canyon. Epicentral distances d from the study site are indicated: X, 0<u><</u>d<u><</u>10 km; o, 10<u><</u>d<u><</u>25 km; ·, 25<u><</u>d<u><</u>50 km.

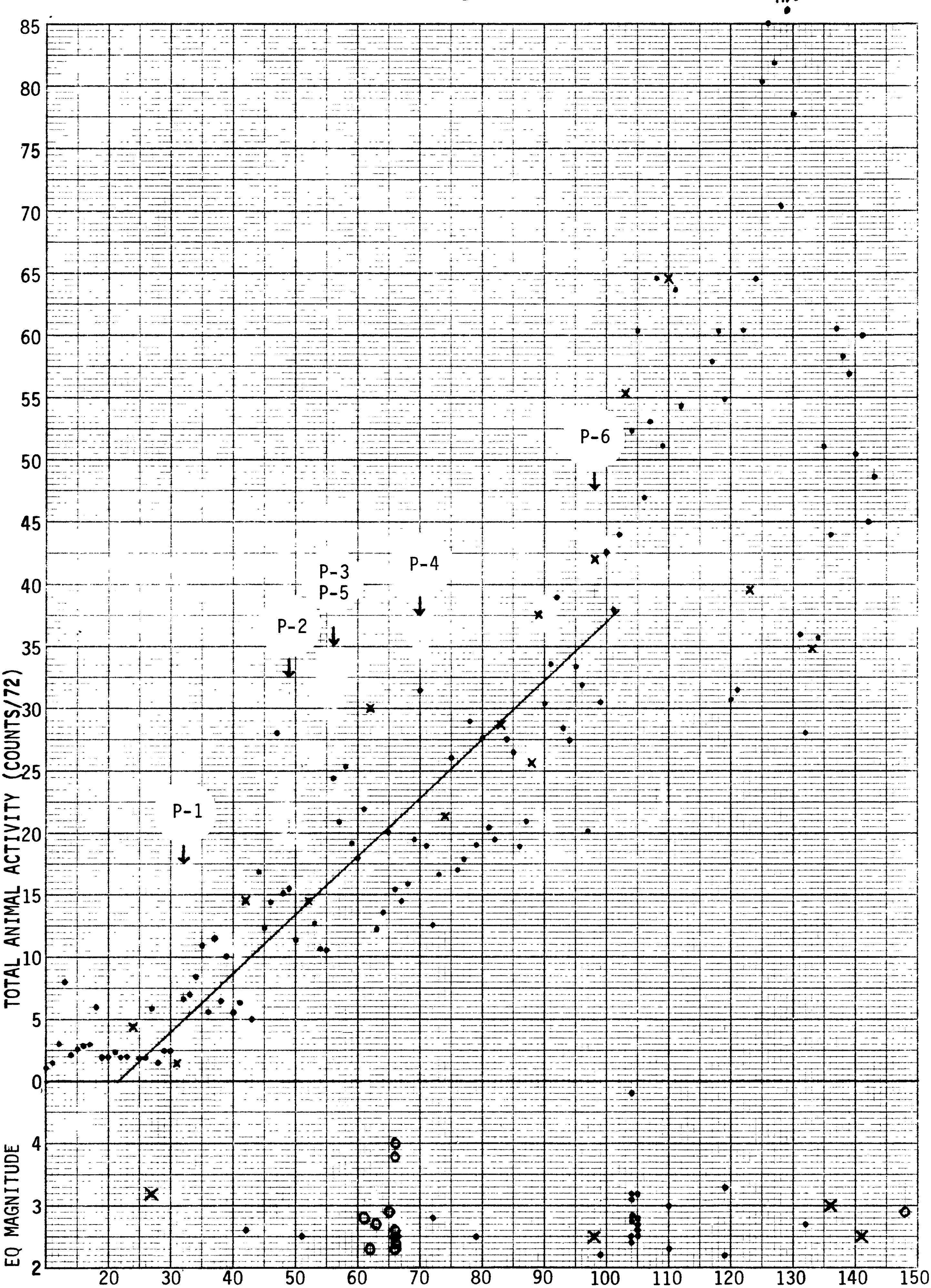

Figure 6. Same as Fig. 5, but showing linear regression for days 10-102.

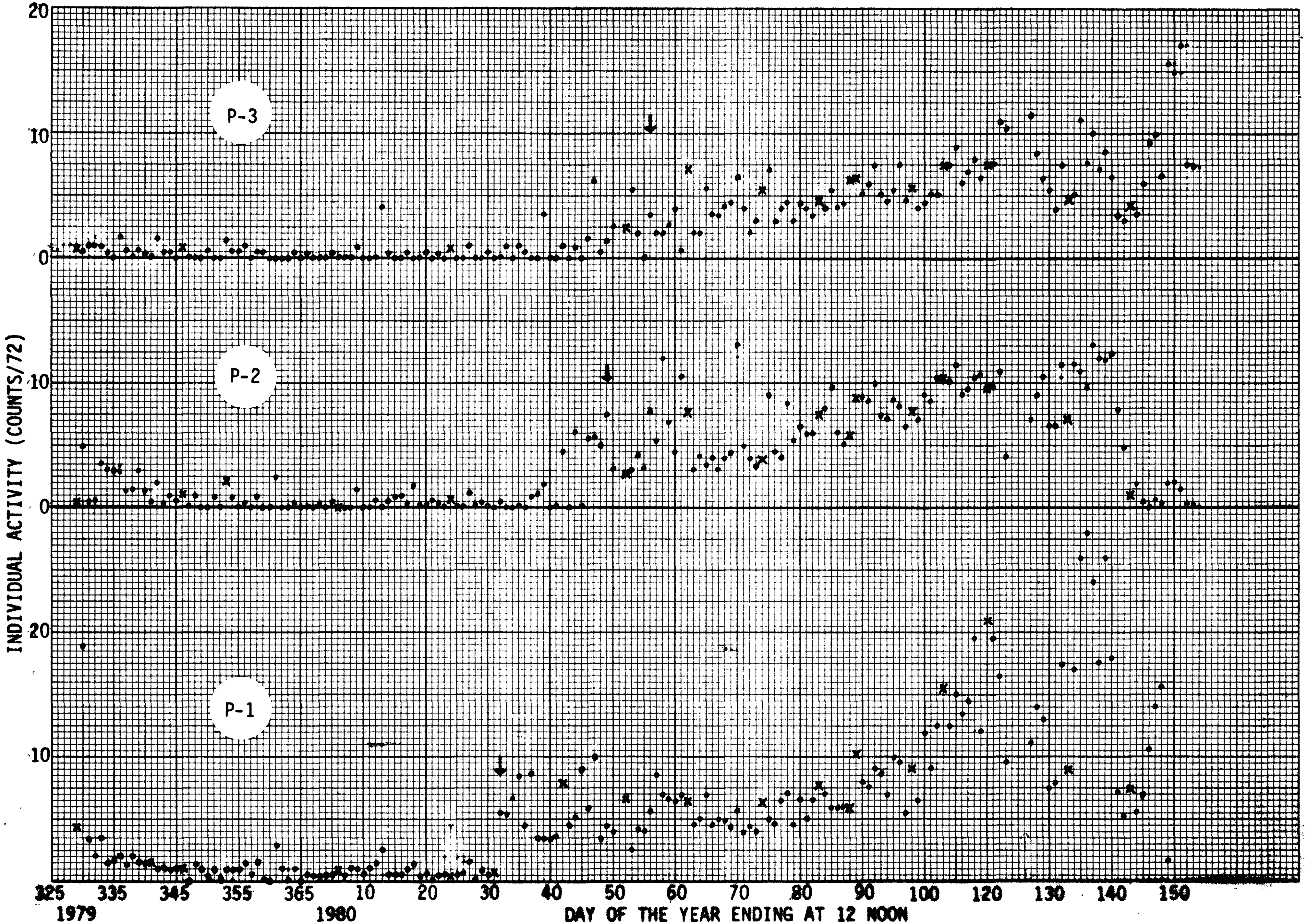

Figure 7. Total activity for individual *Perognathus longimembris* P-1, P-2, P-3 from Stone Canyon. Arrows indicate first day of renewed surface activity.

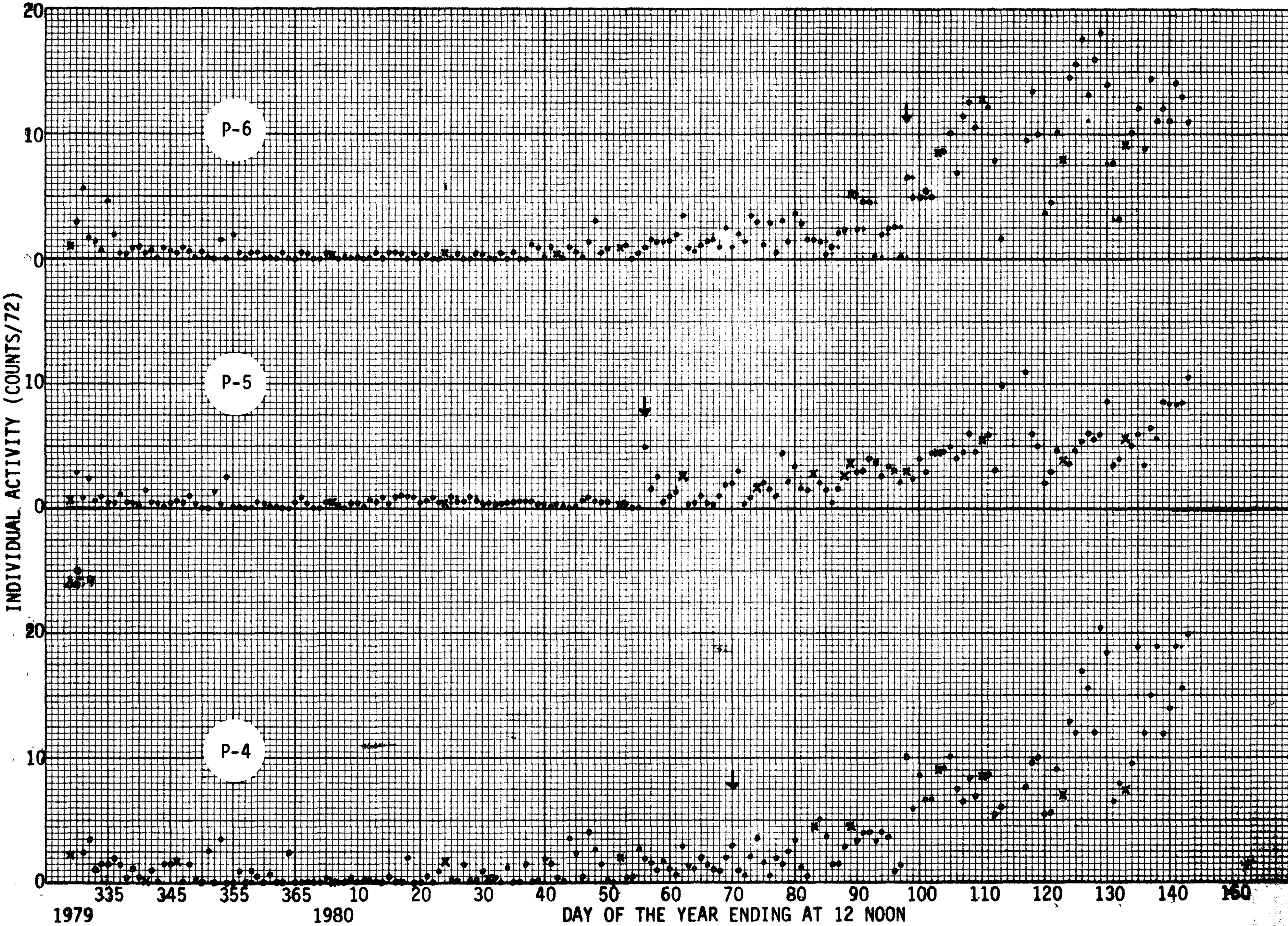

Figure 8. Same as Figure 7 for <u>Perognathus longimembris</u> P-4, P-5, P-6.

The largest event (M=4.8, on 12 April 1980, day 104) was part of the Fremont Peak sequence and was located about 30km from the site. Perhaps the most significant events were magnitude 3.8 and 4.0 events occurring on day 66 (1980) only 13 and 11.5km, respectively, from the site. These were the major events in a small swarm centered northwest of Stone Canyon and spanning days 61 to 66.

Each of these factors, and their combined effect in particular, should render the presence of any earthquake related activity anomalies less obvious. Despite the scatter in the data, dramatic departures from the general trends and day to day variations are rare. We shall first examine a few of the more obvious departures and then examine the records around the times of particular earthquakes.

Perhaps the most dramatic change in intensity of activity in the accelerating increase beginning around day 100 (Fig.s 5 & 6), followed by a sudden and persisting decrease beginning on day 131. It is tempting to relate the sudden decrease to the two earthquakes which occurred near the site on days 136 and 141. However, the decrease is primarily due to a sudden decrease in the activity of the three males which died shortly thereafter.

However, even if the activity of the ailing animals is removed, there is a dramatic decrease in the activity of the remaining animals on days 131 to 134 just prior to the two earthquakes. It is therefore possible that this represents an earthquake related anomaly. Unfortunately, the evidence is at best equivocal since the enhanced activity from day 135 onward is quite possibly due to our working in the area and disturbing the animals. On days 135 to 139 we were excavating immediately adjacent to the six *P. longimembris* cage arrays in order to install the four *P. californicus* cages.

We should therefore enquire whether any other dramatic activity decrease occurred and whether they were closely followed by seismic activity. The most notable drops in activity for *P. longimembris* occurred on day 97 and days 120-122 (Fig. 6) and on days 255 and 258 (Fig. 9). Table 1 shows the seismic activity most closely following these days.

Table 1. Earthquakes of magnitude M at distance d $\leq$20km from Stone Canyon site following N days after a day D of dramatically decreased activity in *P. longimembris*.

D (1980)	M(Day)	d	N
97	2.5 (98)	10km	1
120	3.0 (136)	1.5km	16
121	3.0 (136)	1.5km	15
123	"	"	13
131	"	"	5
132	"	"	4
133	"	"	3
134	"	"	2
255	3.3 (257)	10km	2
258	2.5 (262)	9.5km	4

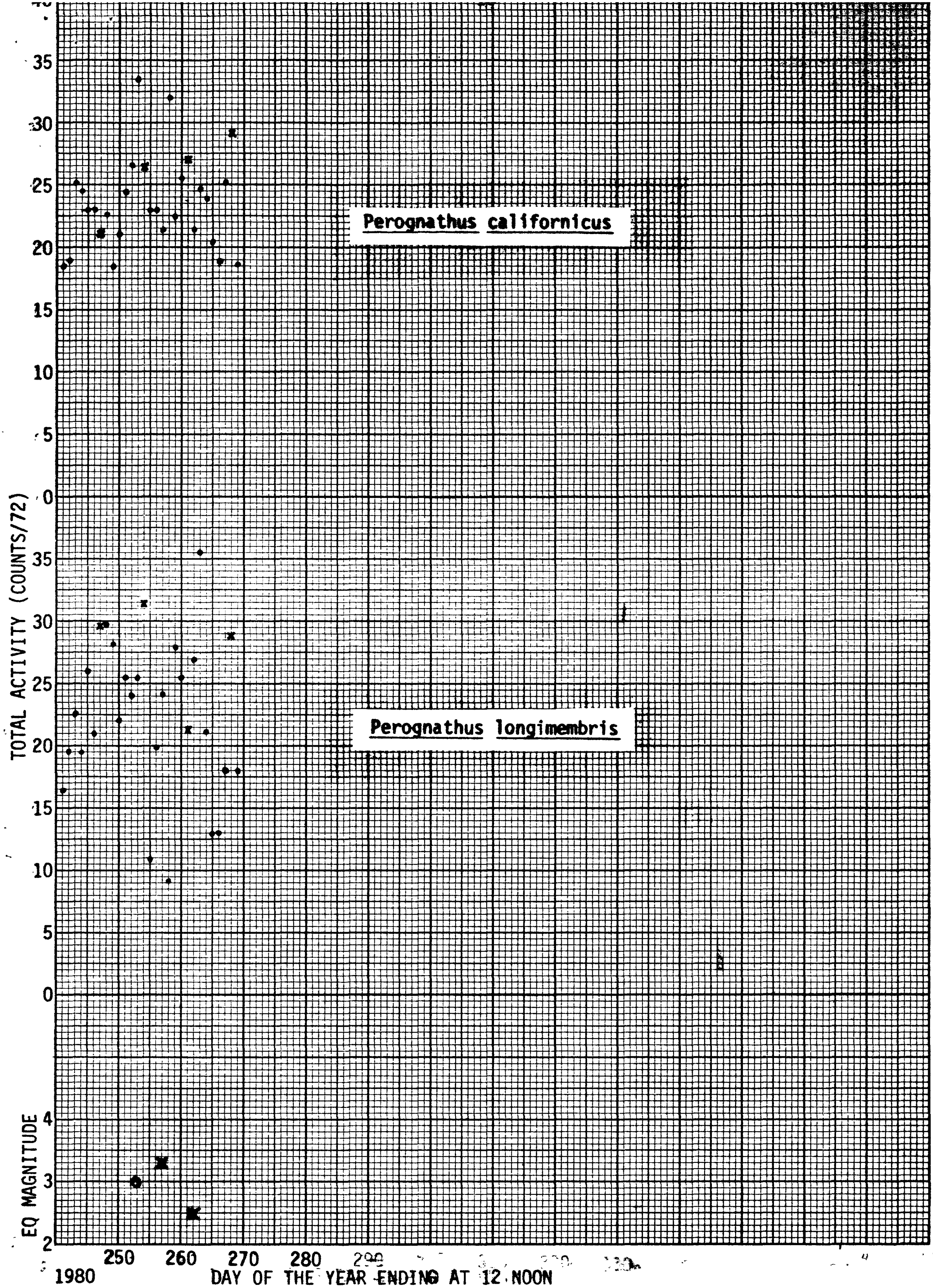

Figure 9. Same as Figure 5, days 240-269 1980, for P. longimembris P-4, P-5, P-6, and P. californicus PC-1, PC-2, PC-3, PC-4.

It is clear from Table 1 that with the exception of days 131-134 sustained dramatic activity decreases did not precede any earthquake. Furthermore, the most dramatic decrease (days 120,121,123) did not immediately precede an earthquake. Hence, at best these data provide only weak support for the premise that earthquakes are preceded by decreased animal activity.

A swarm of earthquakes occurred near (d=11.5 - 19km) Stone Canyon on days 61-66 (Fig.6) and comprises some of the most significant seismic activity to occur near the site during the reporting period. Figure 6 shows a clear increase in activity, relative to the days immediately preceding and following for days 56-62. Day 62 was a feeding day (denoted by an X) and hence the increased activity for that day may be due to increased activity for the purpose of collecting the food from the surface box and storing it underground.

As Figure 6 shows, the increased activity during this period coincides with the initiation of above ground activity by P-2, P-3, and P-5. However, only in the case of P-5 did initiation of surface activity actually coincide with the animals initial increase in activity (Fig.8). P-2 and P-3 became more active prior to their initial surface activity (Fig. 7). Hence, the most obvious explanation for enhanced activity prior to the earthquake swarm is coincidence - the animals increased their activity not because of the impending earthquake,but because winter had ended and weather conditions were conducive to resumption of surface activity. Nevertheless, this obvious explanation does not completely explain the behavior of P-2; the activity on days 56-62 is significantly above the mean activity immediately preceding and following those days.

Figure 10 provides a closer look at the period (days 40-80) surrounding the earthquake swarm. Because the animal activity continually increases during this period, we computed the linear regression for the data from day 10 to day 101. Figure 6 shows that linear regression line and Figure 10 shows the activity data relative to the linear regression. The mean activity on days 56-62 lies well above the regression line while that immediately preceding (days 50-55) and following (days 63-69) lies well below the line. However, the day to day variation throughout the forty days shown in Figure 10 is considerable, so that the enhanced activity immediately prior to the swarm may not be significant.

Figure 9 shows the data obtained after our equipment problems were corrected. Included are data for the recently installed *P. californicus* burrow system. Prior to the earthquakes indicated in Figure 9, seismic activity exceding magnitude 2.5 had not occurred since day 215. Hence, the animals had enjoyed a period of relative seismic calm.

Figures 11 and 12, respectively, show the total activity of all *P. longimembris* and all *P. californicus* relative to their respective mean activities during days 241 to 269. It is unfortunate that we did not obtain more data during the period of seismic calm. Therefore, we rather cautiously note the following: for both species of pocket mouse the activity became much more variable and the maxima of activity significantly greater after the onset of seismic activity. Although the changes do not precede the seismic events (unless the less variable activity is the more anomalous) they at least appear to be correlated. A more complete analysis must await the retreival of additional data.

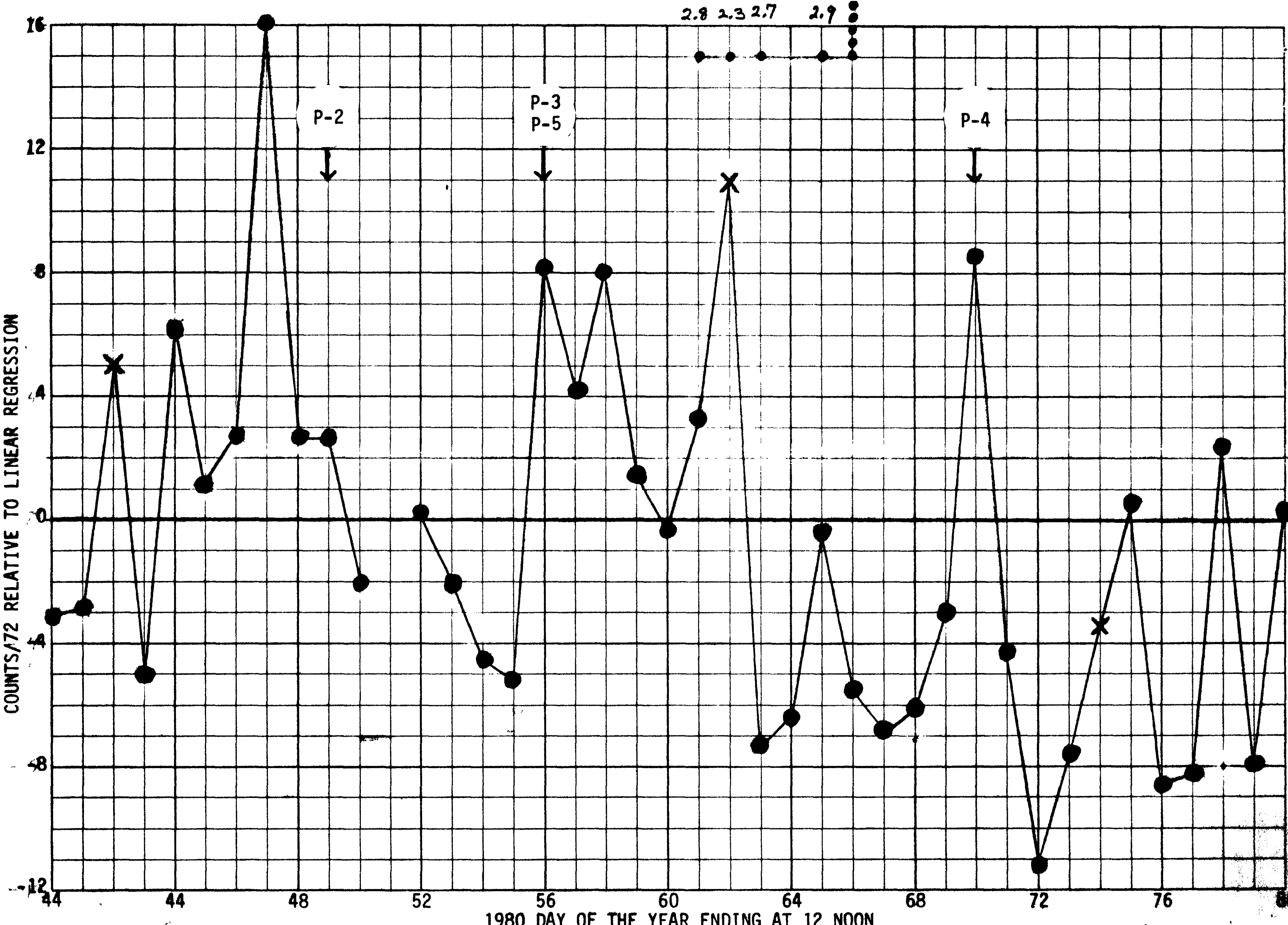

Figure 10. Perognathus longimembris at Stone Canyon. Total counts/72 relative to linear regression (days 10-102) for six animals. Arrows indicate first day of resumption of surface activity. Small dots indicate earthquakes ocurring within 13 km of Stone Canyon. Magnitudes given above dots. X indicates a feeding day.

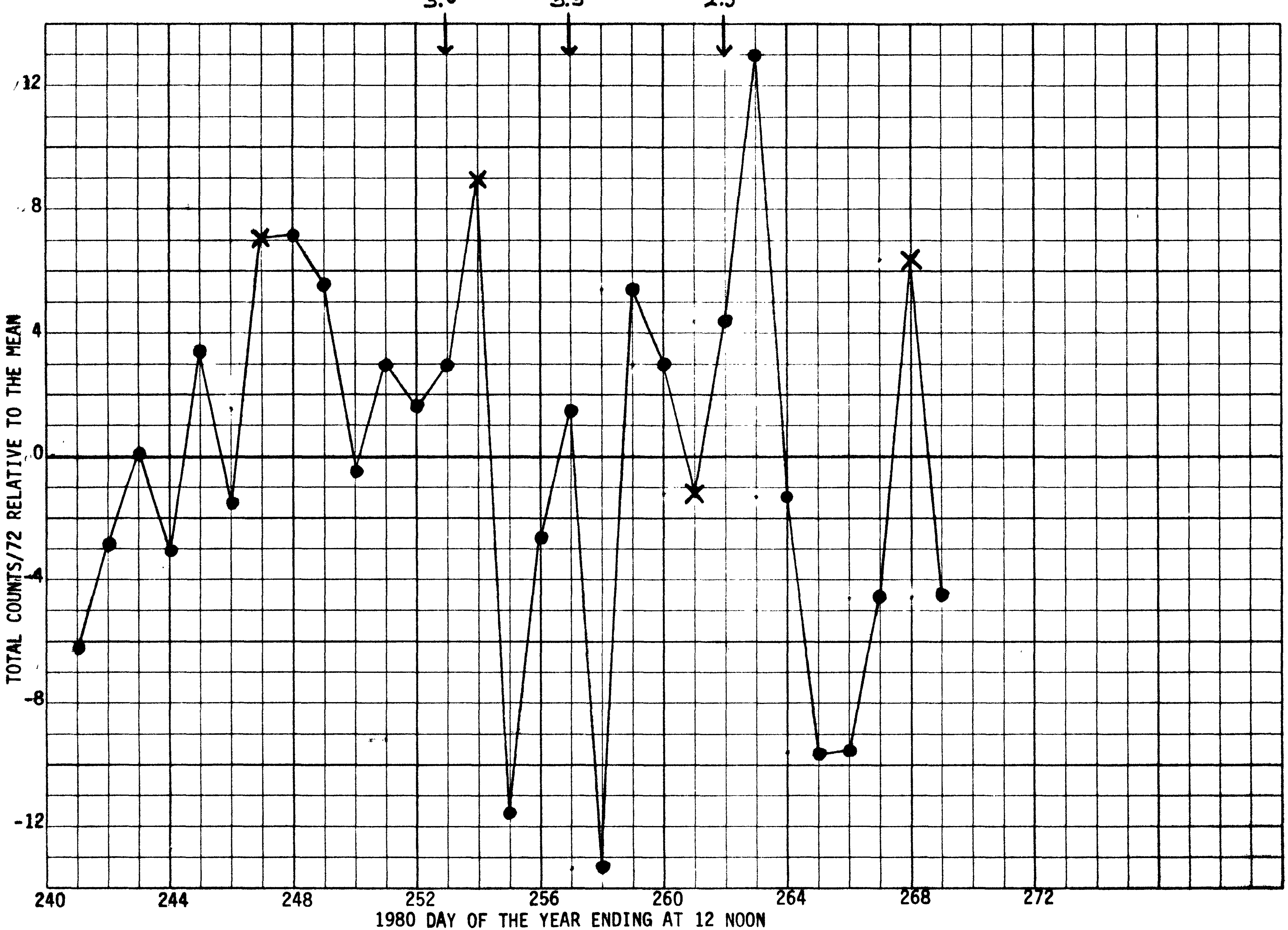

Figure 11. Total counts/72 relative to the mean (days 240-269) for <u>Perognathus longomembris</u> P-4, P-5, P-6. X indicates a feeding day. Arrows indicate earthquakes <u>ocurring within 16km of Stone Canyon.</u>

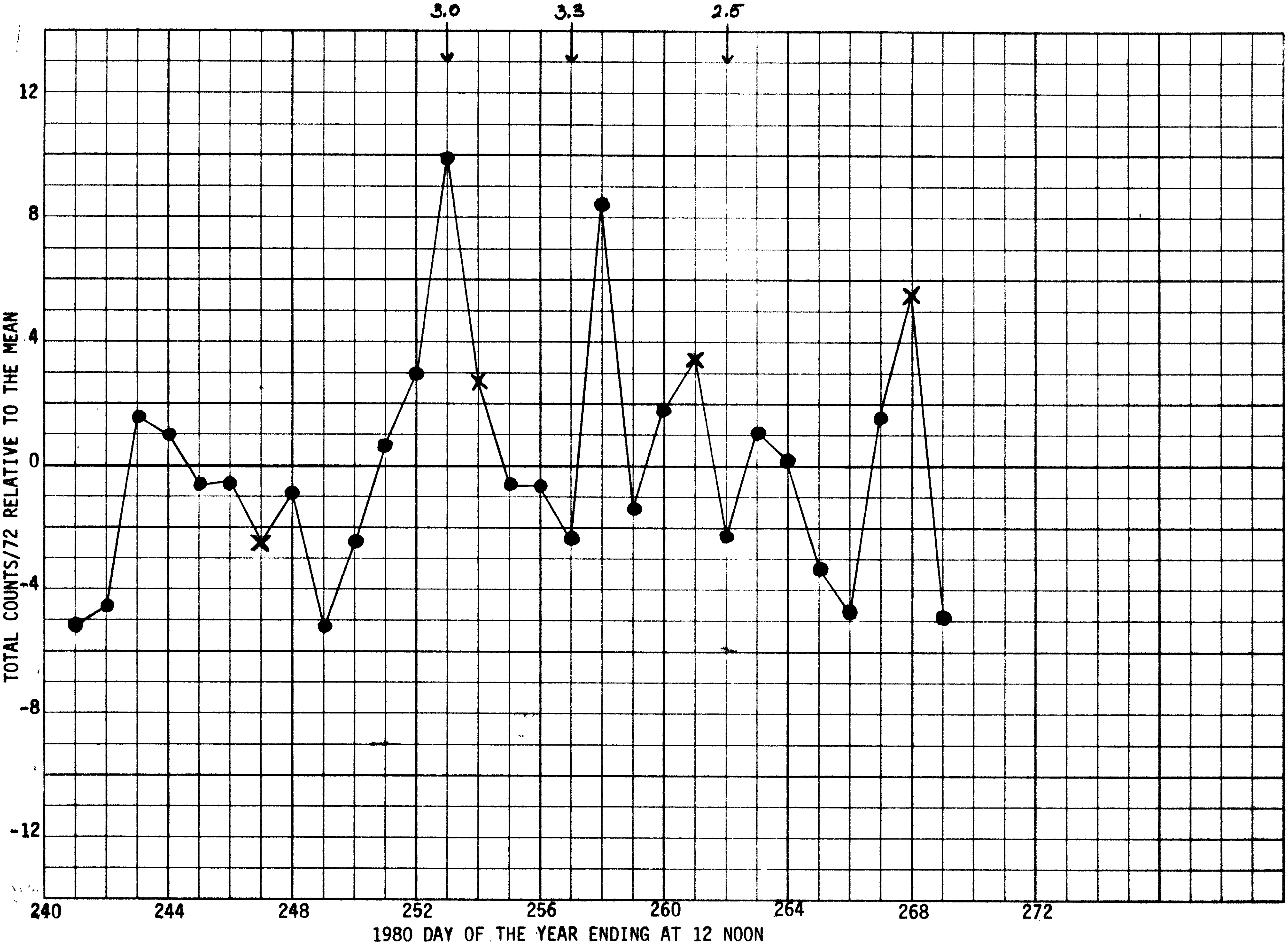

Figure 12. Same as Figure 11 for *Perognathus californicus* PC-1, PC-2, PC-3, PC-4.

Finally, let us briefly examine the data during the winter period of low animal activity (days 347 (1979) to 30 (1980)) where three earthquakes within 12km of the site occurred (days 356 (1979), and 8 and 27 (1980)). Here the activity 'anomalies' for individual animals (Figures 7 and 8) are necessarily activity increases and are obvious. For the magnitude 3.5 event (d≈12km) on day 356, we see that all but one animal (P-1) showed significantly increased activity on one day during the 3 days preceding the event and 4 of the animals displayed increased activity at least one additional day during the 5 days preceding the quake. On the other hand, only P-1 shows a significant (and a very slight at that) increase immediately prior to the magnitude 2.5 earthquake (d≈6.5km) on day 8. Finally, 4 animals showed increase on the day (27) of the magnitude 3.2 (d=4.5km) earthquake.

In fact, if we compare the activity of all animals on days without earthquake activity (46 days) with the activity on the days of earthquakes (3 days) we find that the average activity is greater on days with earthquakes (Table 2).

Table 2. Mean total activity per day (A_{NO}) for groups of mice on N_{NO} days without seismicity near (d≤20km) Stone Canyon compared to mean total activity per day (A_{EQ}) on N_{EQ} days with nearby seismicity. SD = standard deviation.

Animals	Days Examined	N_{NO}	A_{NO} ± SD	N_{EQ}	A_{EQ} ± SD
P-1,P-2,P-3, P-4,P-5,P-6	347-30	46	2.67±1.99	3	3.83±1.77
P-4,P-5,P-6	241-269	26	22.18±6.48	3	25.47±1.06
PC-1,PC-2, PC-3,PC-4	241-269	26	23.35±3.35	3	25.37±5.75

Similar results are found for both species of pocket mice during the period spanning day 241 (1980) to day 269 (1980) (Table 2). However, in only one of the three cases does the difference appear to be statistically significant, and even this significance must be suspect owing to the small number of days (3) with earthquakes.

Another way of viewing the data that produced Table 2 is to compare the proportion (6/9 = 0.67) of days with earthquakes (9) which were above the mean (6) of days without earthquakes with the properties (43/98 = 0.44) of days without earthquakes (98) which were above the mean (43) of days without earthquakes. Again a difference is apparent, but the significance is questionable owing to the small number of days with earthquakes.

E. Summary and Conclusions: Stone Canyon Site

During the reporting period we retrieved 176 days of activity data from six Perognathus longimembris and 29 days of data from three P. longimembris and four P. californicus. During those periods 11 earthquakes of magnitude 2.5 to 3.5 and one swarm comprising 10 events of magnitude 2.3 to 4.0 occurred within 20km of the Stone Canyon study site.

At least 6 of the 12 events were preceded or accompanied by what could be contrived as activity anomalies (5 cases of increased activity, 1 case of decreased activity) by most, but not all, individual animals. Two cases were not preceded or accompanied by anomalies and the remainder were ambiguous owing either to insufficient data or close proximity in time to an earlier earthquake which was correlated with an anomaly. However, the apparent anomalies which were correlated with earthquakes were neither particularly dramatic nor particularly significant statistically.

Thus the Stone Canyon data do not provide strong support for the premise that animals behave anomalously prior to earthquakes. Neither, however, do they support the opposite premise. The earthquakes recorded near Stone Canyon were invariably small and we have no basis for assuming that significant activity anomalies might not be observed in conjunction with moderate or large earthquakes. In fact, the possibly positive, though limited, responses noted in several cases indicate that the data are not entirely ambiguous but lend tentative support to the notion that some animals may behave unusually prior to some earthquakes. We believe this provides ample justification for continuing the study with the hope of improving out statistics and intercepting larger earthquakes.

IV. MORONGO VALLEY STUDY SITE

The Morongo site, as discussed in Section II, consists of an "indoor" and "outdoor" facility. The "outdoor" facility, consisting of artificial burrow systems containing pocket mice and kangaroo rats, has steadily degraded in performance since the heavy winter rains of 1978-79. It was repaired and functioning until September 1979, at which time unseasonal flash flooding completely inundated the installation. Repeated efforts to place the burrow systems back on line have been frustrated by the winter rains of 1979-80. At this point in time we are in the process of overhauling the burrow systems, including replacing the present activity gates with the more water-resistant type developed for the Stone Canyon Site.

The "indoor" facility continues to perform well, and was on line on 25 February 1980 when an earthquake was felt by residents of Morongo Valley. Data collected preceding and following the quake were examined for evidence of unusual animal activity patterns. These data are presented below, as well as correlative data between "outside" animal activity, air temperature, and seismic activity (foreshocks) probably experienced prior to the earthquake swarm in March 1979 near Landers, California.

A. Seismic Activity

Seismic events of magnitude 3 or greater, reported to have occurred in the vicinity of the Morongo site in the first six months of FY 1980, are presented in Table 3. Only the 25 February 1980 event was experienced by residents at the study site. It was also the only event which appeared to have affected animal behavior. Data on the possible occurance of

Table 3

SEISMIC EVENTS IN THE VICINITY OF THE MORONGO STUDY SITE[1]

(Lat 33°45'N to 34°30'N : Long 116°00'W to 117°00'W)

DATE	DAY OF YEAR (1980)	TIME (PST)	MAGNITUDE
10-24-79	297	0532	3.5
11-7-79	311	1350	3.1
12-7-79	341	1554	3.2
2-25-80	56	0250	5.3[2]
3-9-80	69	2254	3.7
3-10-80	70	1304	3.3

1. Source: SCARLET CALTECH-USGS MONTHLY PRELIMINARY EPICENTERS for JANUARY 1980 through MARCH 1980. L.K. Hutton et al.
2. Out of area (Lat 33°30.85'N : Long 116°32.33'W), but only event listed above to be felt by residents at Morongo study site.

foreshocks at Morongo were not available, but will be included in the final analysis.

The possible significance of the foreshock data are indicated by Figure 6, in which the burst of activity shown by one group of pocket mice maintained in artificial burrow systems is plotted against probable foreshock activity occurring prior to the earthquake swarm of March 1979 near Landers, California. Figure 13 also includes ambient air temperature changes during the same period (as previously reported) to underscore the difficulty in establishing cause and effect relationships.

B. Biological Monitoring

1. "Outdoor" Facility

The artificial burrow systems are not operating at present. However, a hive of bees has been instrumented to monitor the time and number of bees leaving the hive. These data are presented in Figure 14 as deviations from the mean number of daily events scored between day 36 and 74. Thus on day 54, just prior to the earthquake, the number of bees leaving the hive was more than 75% greater than average. Does this imply that the bees sensed an impending earthquake? Probably not. Sorties prior to day 54 were surpressed by rain; there is some evidence of a rhythmic pattern to the activity; and the percent deviation is not far beyond the range of one standard deviation of the mean.

2. "Indoor" Facility

During January and February 1980, routine scans of running wheel activity showed great variability, but nothing that we interpreted as particularly unusual. A block of data between days 60 and 64 was lost. Upon learning that an earthquake had been felt by residents of Morongo Valley on 25 February 1980, we undertook to reexamine our data more quantitatively.

The first approach was to examine the data collected during the 10 days preceding 25 February. This analysis showed what appeared to be unusual patterns of activity characterized (as in the case of the 15 March 1979 quakes) by incidents of both increased and decreased activity. A second approach compared the activity levels measured during the 10 days immediately preceding the quake (days 45-54) to activity expressed 10 days earlier (days 35-44). These data are summarized in Table 4 according to species studied and the photoperiodic regimen in which they were held. Individual variability and the caveats associated with using mean values from a group of animals are clearly reflected in the large standard deviations.

These data are repeated on Figures 15,16,17 and 18 in which the percent deviation from mean daily wheel running is plotted against day of the year. The daily mean was derived from days 35-44 and used with an assumption that the same mean would prevail through days 45-54. Thus a change in the mean during days 45-54 might itself signal an unusual level of activity. Observed changes were well within one standard deviation and consequently judged not significant.

Figure 18 shows the way in which selected data may lead to erroneous conclusions. Not only is the envelope of standard deviations large, but the apparent burst of activity just before the earthquake takes on new meaning in conjunction with another "burst" on day 36. Unless one assumes that the animals were disturbed at least 20 days prior to the

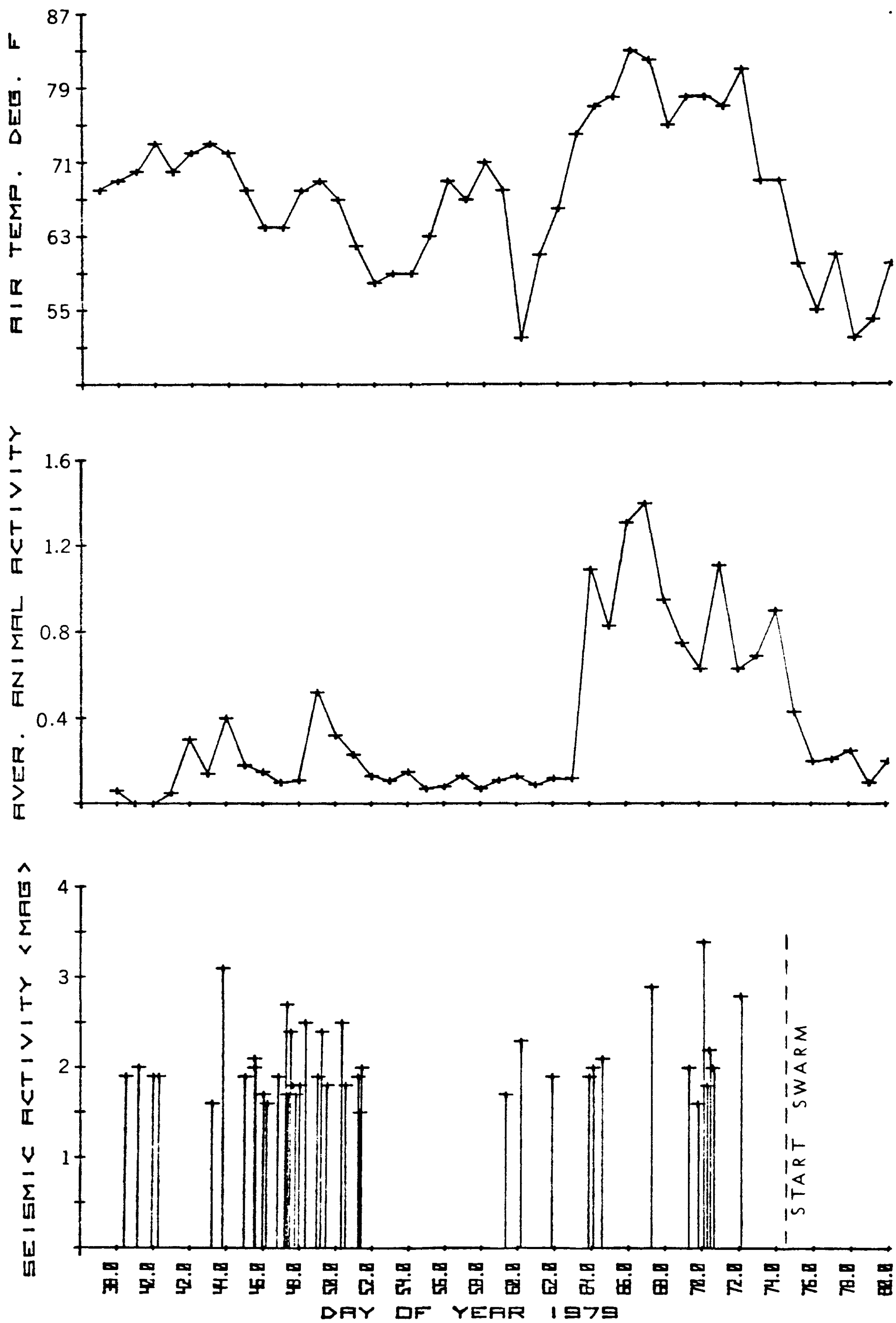

Figure 13

A comparison between the average animal activity measured from five pocket mice in artificial burrow system, air temperature changes, and seismic activity presumed to have occurred at Morongo Valley prior to the 15 March 1979 earthquake swarm, centered about 30 km NNE of Morongo Valley.

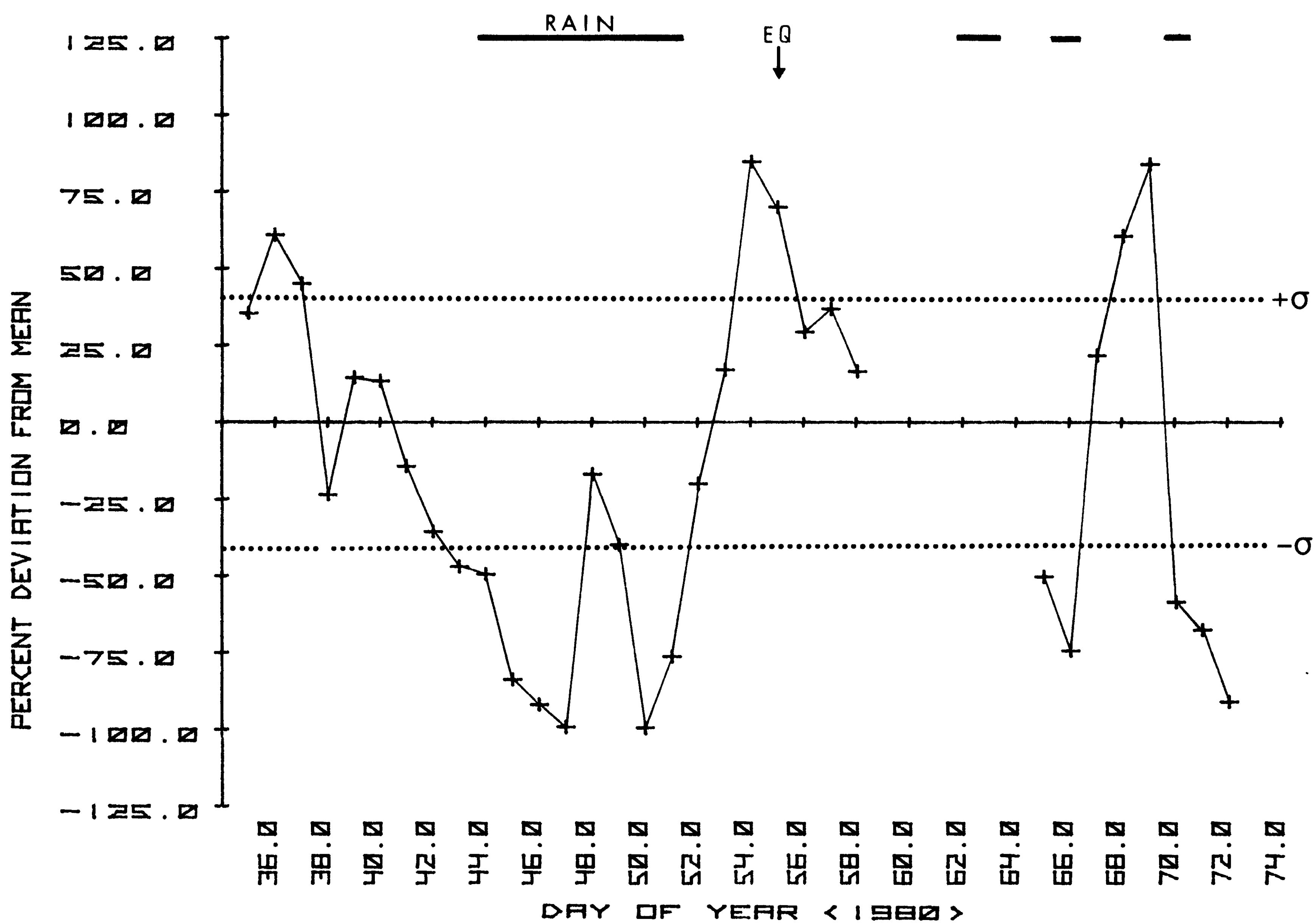

Figure 14. Numbers of bees exiting the hive each day expressed as percent deviation from the mean daily exits derived from the total exits scored between days 36 and 74. The dotted lines denote one standard deviation from the mean. The solid bars denote periods of rain.

Table 4

MEAN WHEEL RUNNING ACTIVITY OF ANIMALS HELD
UNDER "CONSTANT" ENVIRONMENTAL CONDITIONS

ANIMAL NUMBER	Mean Activity (Wheel Turns/Day) $\pm\ \sigma$	
	DAYS 35-44	DAYS 45-54
Perognathus fallax[1]		
Pf-1	332±243	760±257
Pf-2	12410±1297	14353±1846
Pf-8	2277±274	2689±485
Pf-9	4942±4219	5866±5499
Pf-13	517±365	1031±267
Pf-17	22397±3820	24138±2266
Group Mean	$\bar{X}$= 7146±8338	$\bar{X}$= 8140±8922
Dipodomys merriami[2]		
KR-16	60411±9153	60037±5813
KR-19	6499±2658	7929±1997
Group Mean	$\bar{X}$=33455±28424	$\bar{X}$=33983±27064
Dipodomys merriami[3]		
KR-3	48767±3437	45724±2564
KR-7	34756±7926	25882±7453
KR-12	37114±9728	44377±5939
Group Mean	$\bar{X}$=40212±9558	$\bar{X}$=38661±10724
Dipodomys merriami[4]		
KR-5	19267±7572	18671±3354
KR-10	25897±10930	20257±4432
KR-15	4195±2330	1396±2144
KR-20	8075±7829	5865±2249
Group Mean	$\bar{X}$=14358±11538	$\bar{X}$=11547±8748

1 Free running in constant dim light, constant temperature
2 Free running in constant dim light, constant temperature
3 Entrained, LD 12:12 (Light 0600-1800 hrs), constant temperature
4 Entrained, LD 12:12 (Light 1800-0600 hrs), constant temperature

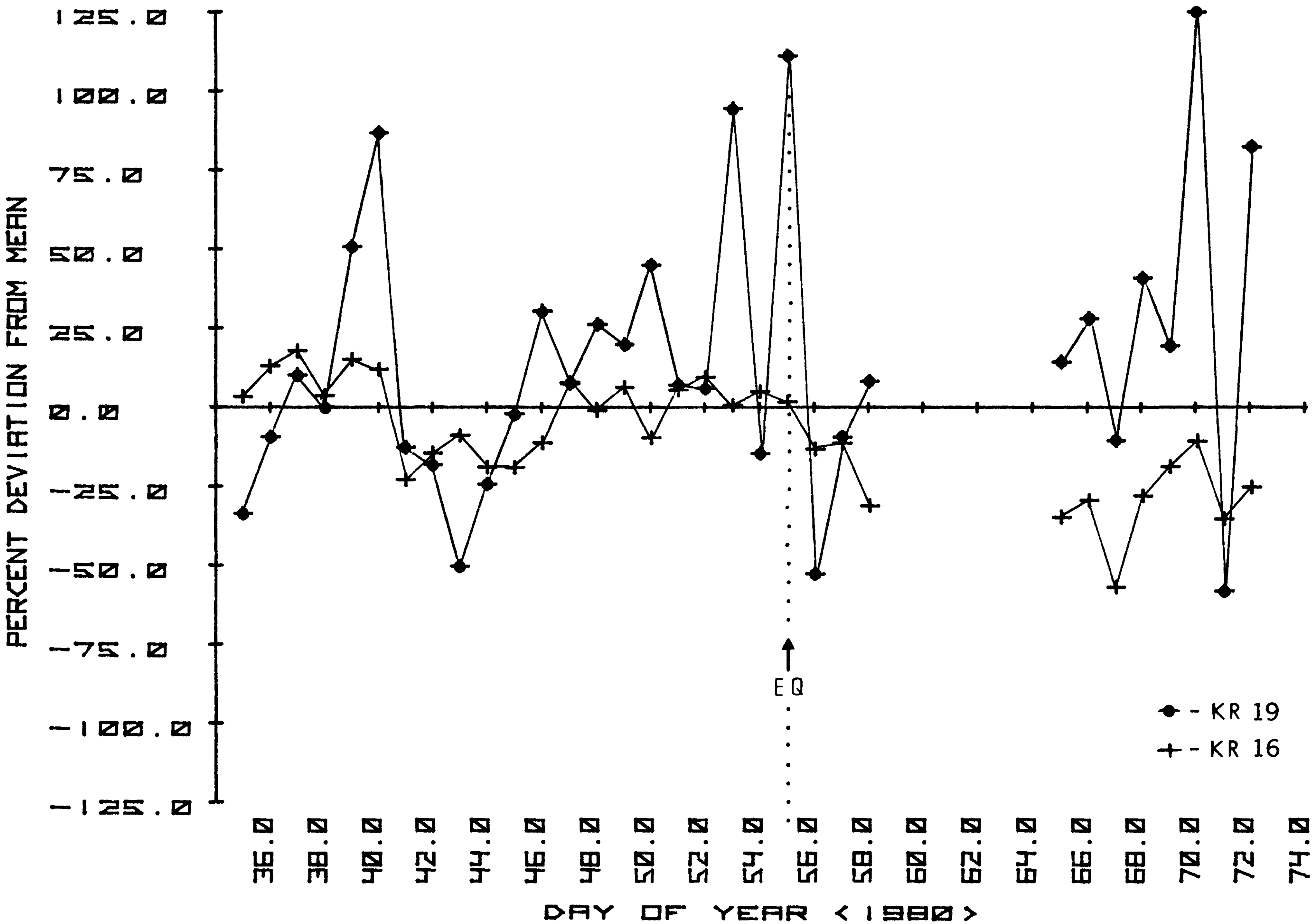

Figure 15. Wheel running activity for two kangaroo rats expressed as percent deviation from the expected daily mean level (see Table 2). Both animals maintained at constant ambient temperature and constant dim light. EQ=Earthquake.

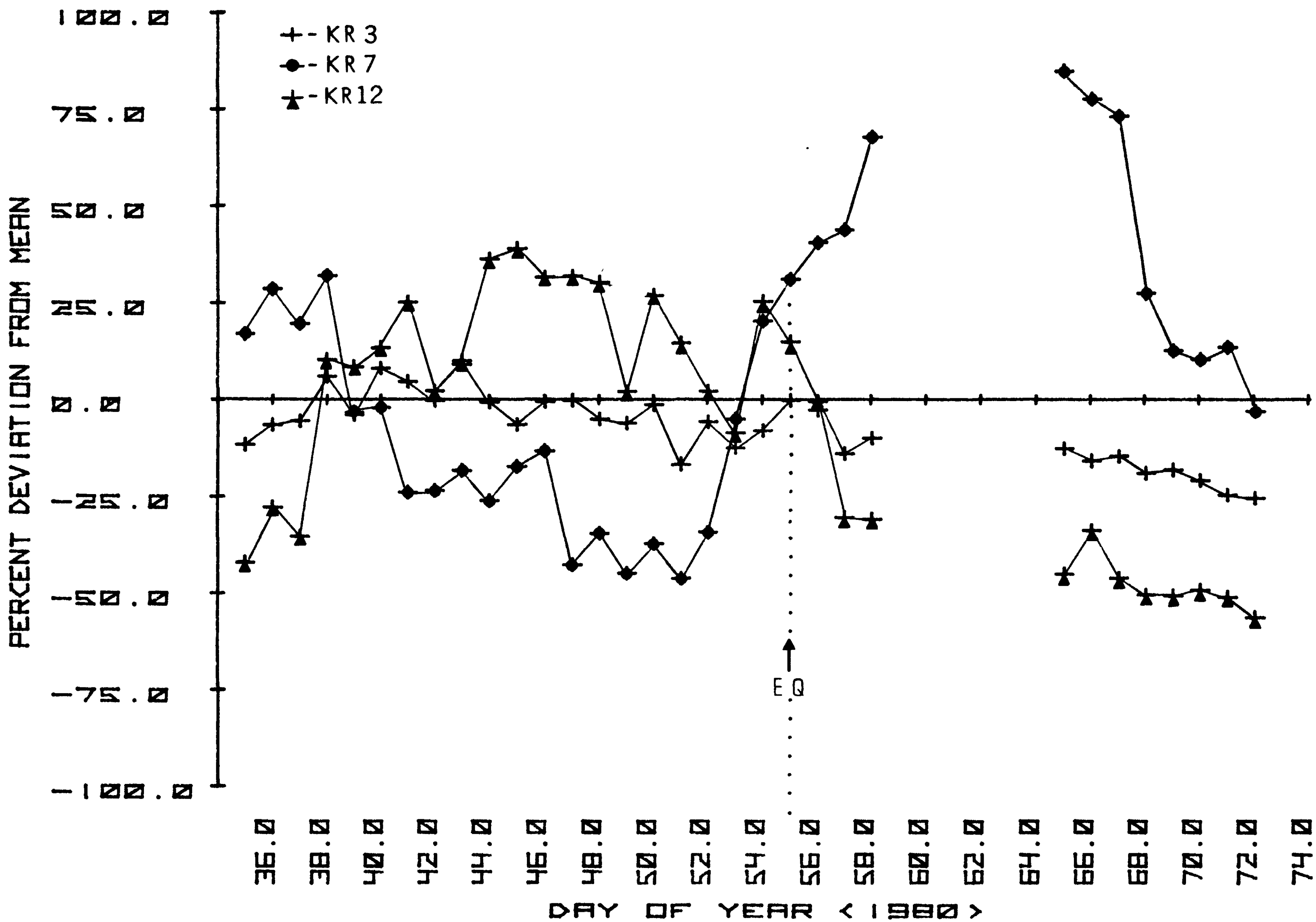

Figure 16. Wheel running activity for three kangaroo rats expressed as percent deviation from the expected daily mean level (see Table 2). All animals maintained at constant ambient temperature and LD 12:12 photoperiod (Light 0600-1800 hrs). EQ=Earthquake.

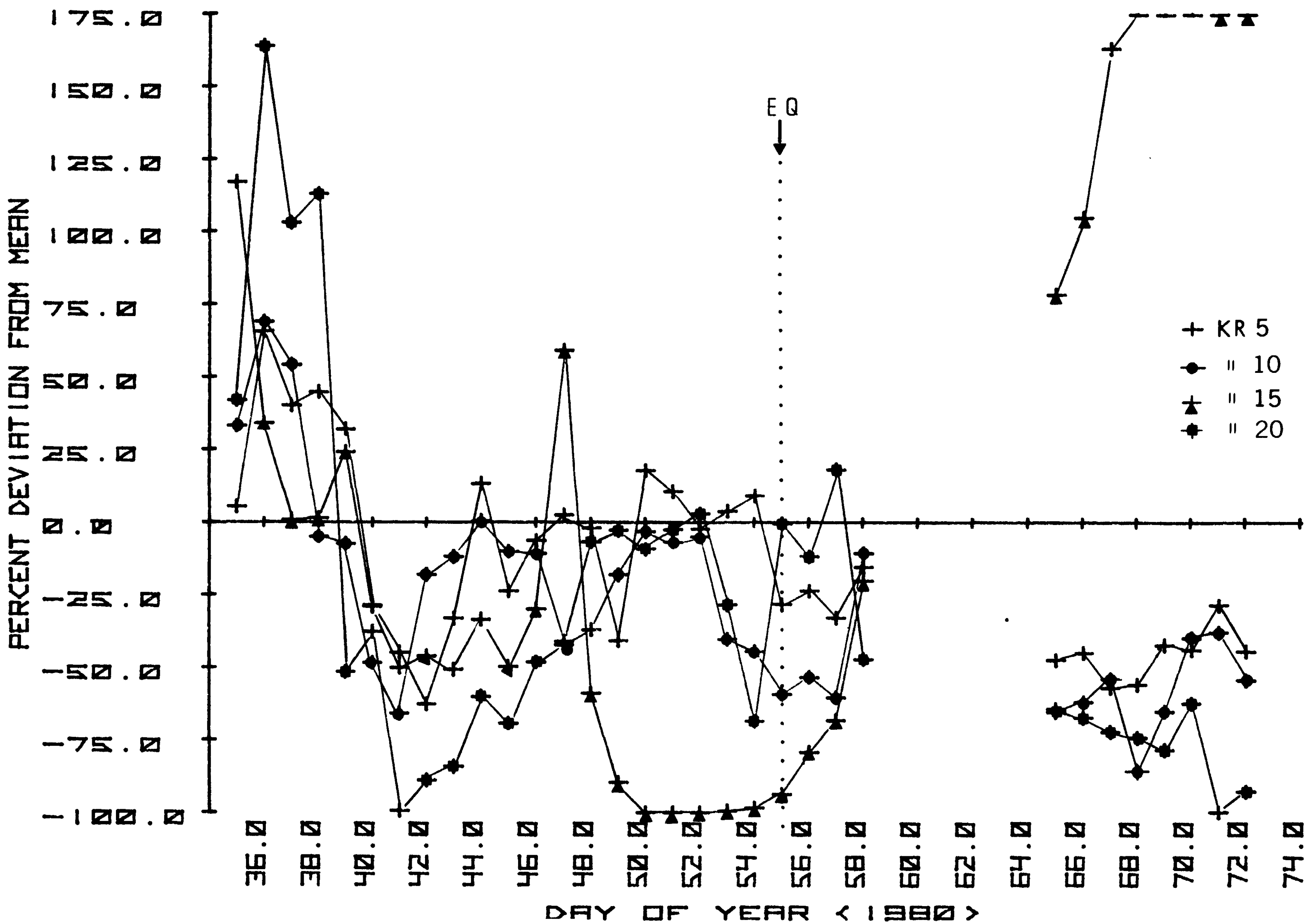

Figure 17. Wheel running activity for four Kangaroo rats expressed as percent deviation from the expected daily mean level (see Table 2). All animals maintained at constant ambient temperature and LD 12:12 photoperiod (Light 1800-0600 hrs). EQ=Earthquake.

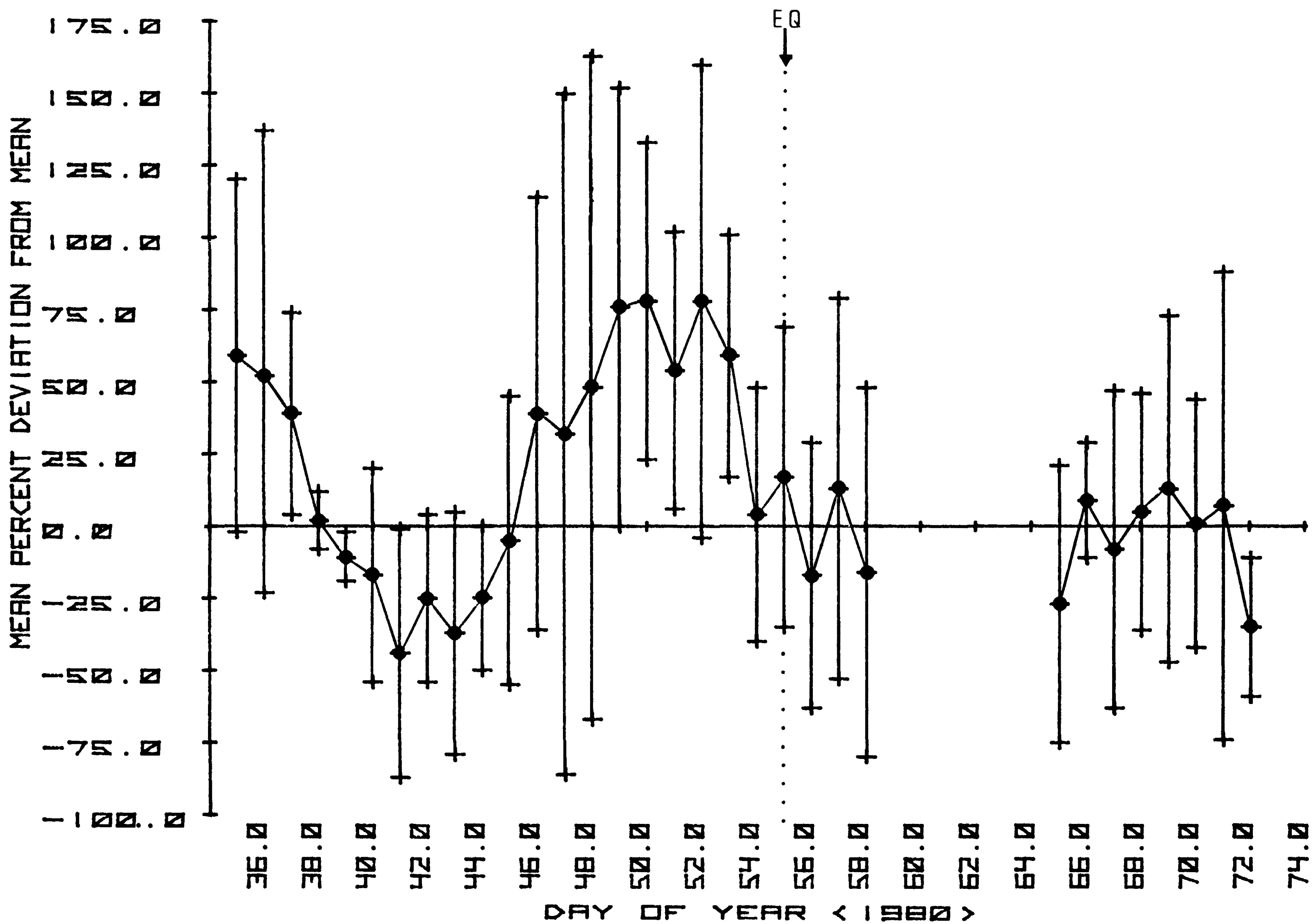

Figure 18. Mean wheel running activity of six pocket mice expressed as mean percent deviation from the expected daily mean level (see Table 2). All animals maintained at constant ambient temperature and in constant dim light. Verticle bars indicate ±1 s.d.

quake, total wheel running activity does not appear to support the premise that our animals sensed an impending earthquake. However, there are other indicators to be examined. For example, was the time of day at which the activity occurred different from expected? This can be answered by calculating the acrophase of activity defined as the time of day in which the arithmetic median of activity falls. Note that this time interval does not necessarily coincide with the time interval in which greatest activity is scored. Data for two groups of Kangaroo rats entrained to photoperiods of LD 12:12 (see Table 4) are presented in Table 5. These data also suggest that the impending earthquakes had no effect on behavior.

Another question is, are animals in an activity period more sensitive to earthquakes than when at rest or asleep? Using a variety of short term (phasic), and somewhat subjective, responses, our analysis showed that none of the animals in a normal rest period showed an unusual response to the quake. Three of seven Kangaroo rats that were active at the time the quake occurred reduced or terminated activity for a short time following the earthquake.

C. Environmental Monitoring

1. "Indoor" Facility

Conditions within the running wheel boxes were maintained at "constant" temperature and constant photoperiods. Ambient temperatures were 75 ± 2^{o} F with occasional excursions due to failure of the air conditioners. The temperature excursions did not appear to influence the activity data.

Relative humidity is not controlled and tended to track measurements taken outside.

2. "Outdoor" Facility

Maximum and minimum ambient air temperature readings taken between days 36 and 74 are presented in Figure 19, along with periods of rainfall and disturbances in the electric field. In general, as good correlations can be drawn between animal activity patterns and these environmental variables as can be drawn between animal activity and seismic events.

D. Summary and Conclusions: Morongo Valley Site

The analyses presented in Section IV were done to demonstrate the way in which we manipulate the data collected. It was not intended to be either exhaustive or highly sophisticated. Rather, it is indicative of the screening processes used to determine which sections of our continuous data warrant furthur attention.

The fact that the data do not support the premise that animals do anticipate seismic events is not surprising, nor does it invalidate our approach. The 25 February 1980 quake was located about 50 km SSW of the Morongo site in a geological setting which, in our judgement, would make seismic precursors at Morongo Valley rather unlikely.

While not providing proof of unusual animal behavior prior to earthquakes, data obtained from our animals prior to the Landers, California earthquake swarm of 15 March 1979 (Skiles, Lindberg, and Hayden 1980) and data obtained from D. merriami prior to the San Fernando, California earthquake of 9 February 1971 (Kenagy and Enright 1980) did show activity anomalies prior to the earthquakes. The existence of independent and ob-

Table 5

Hours of Activity and Acrophase of Entrained Kangaroo Rats in Two Time Periods Prior to 25 February 1980 Earthquake

REGIMEN	Days 35-44	Days 45-54
LD 12:12		
(Light 0600-1800 hrs)		
KR-3 Hract	11.6±1.5	10.0±0.5
Acro	70.2±1.0*	67.9±1.6
KR-7 Hract	7.7±1.5	8.4±1.0
Acro	60.4±3.8	58.7±3.7
KR-12 Hract	9.8±0.6	9.7±0.4
Acro	66.4±4.0	63.7±1.1
LD 12:12		
(Light 1800-0600 hrs)		
KR-5 Hract	11.3±2.0	8.4±1.7
Acro	81.0±11.9	81.8±5.6
KR-10 Hract	11.0±0.7	10.8±0.9
Acro	65.6±4.5	70.7±7.0
KR-15 Hract	7.7±1.0	2.3±2.6
Acro	81.7±5.0	94.9±3.5
KR-20 Hract	6.2±2.5	5.9±1.0
Acro	76.4±10.0	76.2±3.0

*Values denote sampling interval in which the arithmetic median of activity falls.

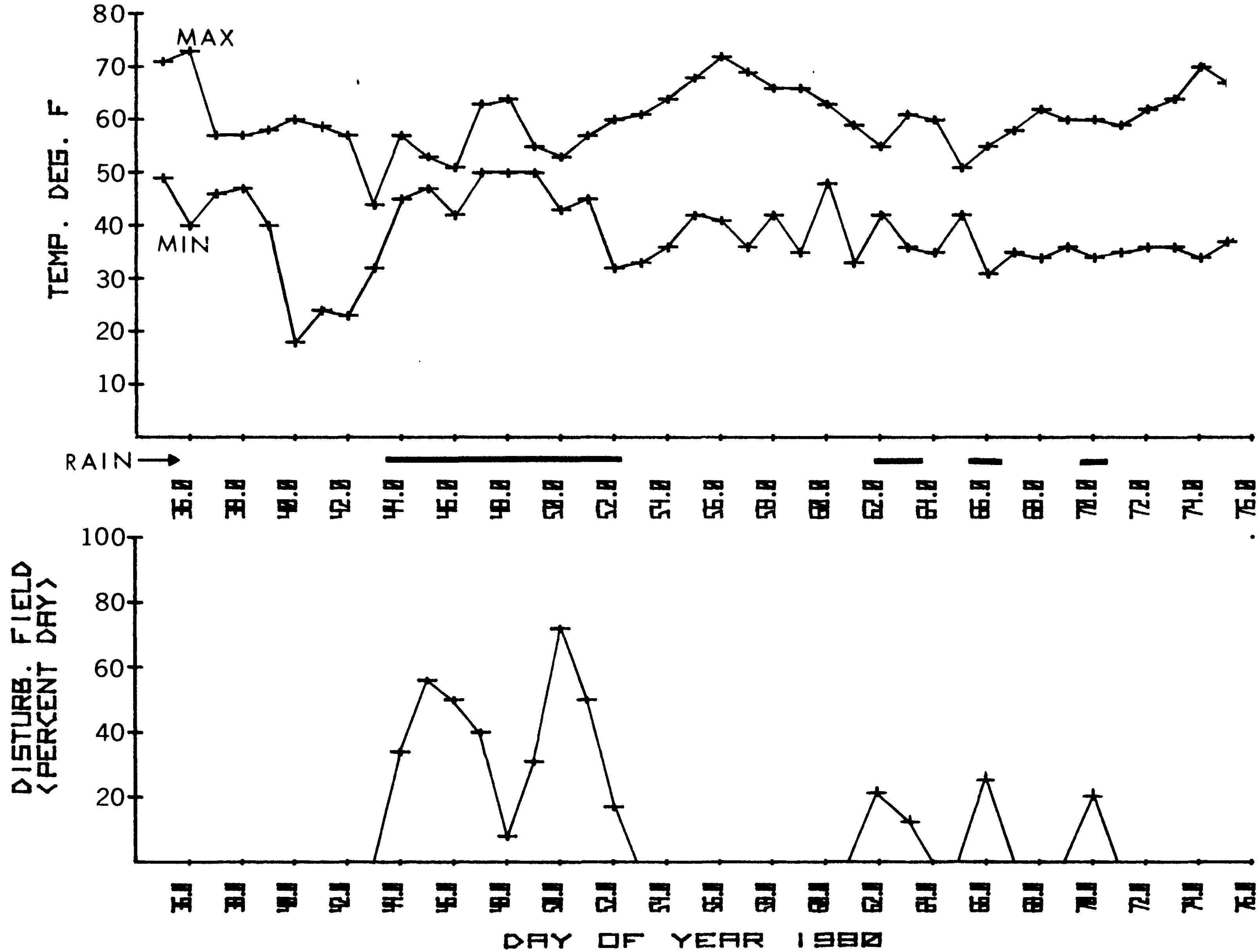

Figure 19. Environmental Variables measured between days 36 and 74 at Morongo Valley. Disturbances in the electric field were measured with a field mill mounted on the roof of the indoor facility.

jective instrumentally recorded data showing behavioral anomalies prior to different earthquakes provides ample justification for continuing our investigation in the hope of determining (or at least of assessing the probability) whether such behavioral anomalies were indeed precipitated by the impending earthquake, or were simply fortuitous on the result of nonseismic environmental factors.

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