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ON BIOINDICATION OF THE SPITAK EARTHQUAKE OF DECEMBER 7, 1988 IN NORTHERN ARMENIA

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INTRODUCTION

Great amounts of evidence are at present available relating to abnormal animal behaviour priot to earthquake [1-4, 6-12]. Most of this evidence was obtained by questioning the residents, which was as a rule done following the earthquake. However, there is as yet no unified, well-developed theory that could explain the ability of animals to feel an imminent catastrophe.

Observations of extensive abnormal behaviour prior to earthquake, several successful cases of earthquake prediction using biological precursors, demand special attention to this problem. The most impressive success has been achieved in China in forecasting the Haicheng earthquake of February 4, 1975 with magnitude 7.3 when a successful prediction was made from a combination of precursors, abnormal animal behaviour playing a decisive role at the final stage of predicting, during the short term stage [12].

The detection of patterns governing this phenomenon, but which are still not known to us, should rely in our opinion on those as yet unique cases in which catastrophic earthquakes were followed by systematic interrogation of local residents and by data collection from various organizations. An example is the Tangshan, magnitude 7.8 earthquake of June 28, 1976 with 2093 cases of unusual animal behaviour detected as a result of an investigation carried out by Chinese scientists.

We know of 50 earthquakes in the USSR area [4,6,7] that have been preceded by unusual animal behaviour, twelve out of these occurring in Armenia and adjacent areas (Fig. 1).

This paper describes biological precursors of the Spitak, Armenia earthquake of December 7, 1988.

INVESTIGATION TECHNIQUE AND DATA COLLECTION

The work on identification of biological precursors to the Spitak earthquake was organized as a direct questioning of eye witnesses and a questionnaire (given in whole in Appendix) among local residents and organizations, the questioners summarizing the main criteria of abnormal animal behaviour, the state of vegetation and the sensations of people prior to the earthquake. A brief questionnair was published in the central newpaper "Komsomolskaya Pravda". To sum up, the array of information to be processed consisted of records of oral answers, questionnaires which had been filled, and written answers. The overwhelming majority of this information had been collected during the first two months after the earthquake.

Most responses came from professional people, i.e. farm and zoo workers, natural reserves, veterinary services, as well as from amateurs who had been observing animals for long periods of time. Although the response, particularly those coming from nonprofessionals, did not always accord with standards of scientific

data acquisition, most of them are trustworthy. This conclusion is based on exact and characteristic details in many reports; on tallying facts obtained from different people; on attention being called to unusual animal behaviour and its being discussed with other people before the earthquake. For example, a citizen of Leninakan, A. Garibyan, being uneasy about an extremely unusual behaviour of his pets, had tried to warn about the danger and telephoned the town authorities.

Uncertain and doubtful cases have not been taken into account here. There is significant evidence concerning reptiles, rodents, aquarium fishes and especially trained dogs. We have managed to collect more than a thousand reports from over 120 sites. It should be noted in this connection that many were concerned with groups or populations of animals rather than with single individuals, hence the number of animals that have shown abnormal behaviour was several times the number of reports.

Description of Collected Data

Numerous facts of distinctive response by a number of animals to the approaching earthquake have not confined to the northern area of the Republic Armenia directly near the epicentre, but came from the distant areas too. There are also many reports from the neighbouring republics. It must be noted that in some cases, including some from the epicentral area, the residents did not notice any changes or refused deviant animal behaviour to the earthquake.

There is another important fact, viz., when several animals of the same group were kept under observation, representatives of the same species did not all respond to the signals that arrived, some of them remaining indifferent, to be attributed to different levels in sensitivity.

The map of isoseismals (Fig. 2), a preliminary version compiled by workers at the Institute of Geophysics and Engineering Seismology, Armen. SSR Acad. Sci. (S.N. Nazaretyan and his associates), shows sites where abnormal animal behavior had been recorded, as well as those sites where no information on biological precursors was available.

From this map one can see that, out of 127 sites where preseismic abnormal animal behaviour had been recorded, 14 lie in the intensity X zone (on the MSK-64 scale), 15 in the intensity IX area, 24 in the area of intensity VIII. The greatest number of sites (37) lie within the intensity VII zone, 32 sites are in the intensity VI zone, and 5 in the intensity V zone.

The sites where positive information is available are sufficiently uniformly distributed over the area around the zone epicentral. This makes it possible to examine some spatial properties of the biological precursors detected.

The distribution of the number of cases with abnormal animal behaviour as a function of epicentral distance is presented in Fig. 3. The epicentral distance was measured from the midpoint between the epicentres of the two main shocks as determined from felt effects. About 200 cases have been identified within 20 km of the epicentre, double that number within 40 km, reaching the maximum, 334 cases. Afterwards, that is, with greater epicentral distance, the number of reports gradually diminished to a few cases. The data collected indicates that stable information on abnormal animal behaviour was available within about 100 km - to the southeast of Erevan, Razdan, Sevan (a town), to the north of the town of Akhalaki, Tbilisy., A few reports came from sites situated at much greater epicentral distances, namely, the town of Kirovabad (180 km) and the town of Orjonikidze (220 km). To sum up, premonitory behaviour of various animals was

detected, not only in the epicentral zone and zones of high intensity, but also in areas where the shaking occured at intensity VI or less. Naturally enough, most reports came from large cities like Leninakan, Erevan, Razdan and so on. A brief description of a small fraction of the total list of reports relating to changes in the behaviour of some animal species prior to the Spitak earthquake can be found in Table 1.

An analysis of the entire information obtained relating to the character of changes in animal behaviour from the physiological point of view enables us to identify two main types of response behaviour before the approaching earthquake [8,10]. The two are widely different as regards both intensity and precursor time and the duration of the changes. This circumstance can be explained by, on the one hand, different manifestations of the intensity of premonitory phenomena at different epicentral distances and, on the other, by differences in the threshold level of individual sensitivity of animals.

The observed character of changes in animal response during abnormal excitation or depressed state is in our opinion due to the appearance of two relevant unconditioned defensive reflexes "what's this" and "what is to be done" in the organism at that time [8].

When the "what's this" reflex arises, which is essentially an investigative one, animal behaviour experiences merely changes in the general emotional responsivity - the appearance of a vague anxiety, agitation, increased motional and vocal activity, panic fear, the use of large amounts of water while not being thirsty and so on. All these manifestations are clearly signs of uncertainty and an absence of purposeful behaviour.

The orientation reflex "what is to be done" reinforced by the instinct of self-preservation typically exhibits specific purposeful actions - going into open spaces from shelter, the tendency to free themselves from a leash or tether, to flee from dangerous zones, the disappearance of fear and agressiveness towards the others, the care taken to preserve the offspring or its masters and so on.

A more detailed analysis of the material relating to abnormal animal behaviour before the earthquake shows that the appearance of any of the above reflexes depends primarily on the intensity of stimulus which varies significantly with epicentral distance. The "what's this" reflex arises when an animal organism experiences a moderate stimulus, while a strong stimulus evokes the "what is to be done" reflex.

It is important to emphasize that all evidence of abnormal animal behaviour before the Spitak earthquake shows no qualitative difference from those recorded before other earthquakes in other seismic regions [1,3,11,12]. This is true, not only for the signs of unusual behaviour themselves shown by several animal species, but also of the fact that just not all animals have responded.

The Spitak earthquake is different from most earthquakes in the USSR area with premonitory biological phenomena only in that the identified manifestations of abnormal animal behaviour were much more numerous. This is another proof of the fact that we deal here with a phenomenon that is quite real, even though not yet studied in sufficient detail, and which requires a deep study and penetration into its causes.

To characterise the precursor time for animal behaviour prior to the earthquake, we have plotted this parameter as a function of epicentral distance for the more frequent species encountered in the reports (Fig. 4). It has turned out that the

closer an animal was to the epicenter of the future earthquake, the earlier was the perception of it. A more detailed analysis of the material collected for different animal species reveals the greatest difference in this index in favour of the so-called more sensitive animals.

There are about 200 reports providing evidence of unusual animal behaviour 2 to 3 days before the earthquake. Manifestation of abnormal behaviour were occuring on a mass scale 24 hours and especially a few hours before the earthquake within a few tens of kilometers of the future epicentre. The same thing happened half an hour to one hour before the earthquake. Just as was the case for other earthquakes, the number of anomalous signs, that of individuals showing them and the degree of response were increasing as the Spitak earthquake drew near. A few minutes before the main shock, its approach could properly speaking be detected by any observer living in northern Armenia, provided he or she ascribed some significance to biological precursors.

Some interest attaches to data on the distrtibution of the number of observations over animal species (Table 2).

Looking at Table 2 one can conclude that the greatest amount of information concerning changes in animal behaviour related to the approaching earthquake as classified by animal groups was obtained for domestic animals (57.1 %), rodents (11.1 %), hydrobiontes (5.3 %), poultry (5.0 %), cage birds (4.2 %), etc. Among animal species predominate dogs (26.3 %), cats (17.4 %), hens (5.6 %), mice (4.5%), aquarium fishes (5.3 %). Domestic animals, certain species of poultry and pets, as well as worms occupy an intermediate position by this index in this list. At the end are wild animals, some insect species and reptiles. However, even these few reports should not be undervalued, if only because observation of these are strongly limited in scope. Also, similar cases in the overall list of biological precursors are considered more reliable in the most seismic regions of Asia and Europe [1, 4, 10-12].

The sequence of species noted above is largely due to differences in the occurrence of the above animals over area in the earthquake zone. Consequently, the quantitative index of abnormal behaviour is in our opinion inadequate in forming judgement on the sensitivity of an animal species to the earthquake under consideration.

SOME ADDITIONAL OBSERVATIONS

Precursory anomalies have been noted for plants too, although in much smaller quantities. Thus, for example, grass and potato tops dried up in the epicentral zone as early as in June, dramatically diminishing potato output, while the output of cabbages in the Gugar region, in contrast to this, sharply increased. Some 12-15 days before the shock one noted the appearance of fresh grass and flowers, changes in the color of various plants during this unusual season, when air temperature in nighttime dropped below -10°C.

Signals of different origin propagating from the source zone of the future earthquake also affected people, particularly pregnant women, younger children, and persons subject to chronic diseases. More than twenty people reported changes in their condition, beginning from 16 and less hours before the main shock, the changes being unaccountable sense of anxiety, weakness, headache, dizziness, sensation of heat, palpitation, buzzing in the ears, asthmatic fits, sensation of burned matter in the mouth, nausea, vomiting and so on.

Researchers at the Chair of Botany, Erevan State University, started investigations in the spring of 1989 within the epicentral zone of the Spitak earthquake just around the ground breakage that formed on the earth surface on December

7, 1988. A study of mycotoxic, destructive, fermentative and other properties of micro-mycelia of different systematic groups on the basis of long-continued work experience in different ecological zones of Armenia might be of great theoretical and practical interest, since most mushrooms are produced by antibiotic, toxins, ferments, growth stimulators etc.

Preliminary data from this study provide evidence of peculiarities in the structure of soil and above-soil micro and macro-mushrooms complexes, expressed as changes in the occurrence ratio of typically frequent and typically rare species. well. For example, cultures of soil micro-micelia have acquired bright colors, copious exudates, the pigment diffuses into the surroundings and makes them coloured.

One notices the violent energy of growth, copious and very early spore formation to be observed already during the second or third day. It is noticeable that persons handling the culture Trichoderma lignorum acquire increased sensibilization expressed as allergic rash, cedematoseness. A high toxicity of isolates of the Aspergillus ficum mushroom from the A. niger group has been recorded. Physiological activity of this mushroom and Trichoderma lignorum is considerably higher than that of the isolates studied in previous experiments.

In the area around the rupture, abnormal biological activity of another biological object was detected too, namely, algae. For example, an area of occurence has been determined for a complex of land-living blue-green algae in a region evidently under the action of extreme factors of chemical and physical nature; in this area species typical of stoppe regions predominated (personal communication of L.A. Akopyan). L.A. Akopyan works at the Chair of Botany mentioned above. The fact of this species flourishing there is quite out of the ordinary and has never been recorded in Armenia. Cases of violent growth of blue-green algae, which are procaryotic and the oldest autotrophic organisms, are described in the literature as a result of electrical phenomena, radiation, high temperatures, chemical contamination and so on. They are explained by the well-known adaptive ability of these algae in extreme environments, the growth proceeding by rapid splitting of chains. It should be noted that blue-green algae typically show mass growth in locations where other organisms are repressed in growth.

DISCUSSION AND CONCLUSION

All the above discussion indicates a mass manifestation of abnormal animal behaviour before the Spitak earthquake.

Comparison of these data obtained on the precursor time of abnormal animal behaviour before the Spitak earthquake with relevant data for previously investigated earthquakes has not revealed any relation of this parameter, either to earthquake location or to the magnitude of the shock. As to the degree and duration of the changes in animal behaviour, they seem to be controlled merely by special features in the preparation stage of the earthquake concerned.

Collected data convincingly show that the existence of biological precursors to large earthquake is real. Their principal manifestations are typical of seismic catastrophes like that of Spitak to wit :

- a stable character of abnormal behaviour for different animals within 100 km;
- the number of anomalous signs, of the individuals that have manifested them, and the degree of response increased as the seismic event approached;
- the precursor time on a mass scale for the event being prepared did not exceeda few tens of hours.

Consequently, one of the causes why the earthquake was so unexpected for people living in northern areas of the Armenia can be considered to be the low level of their seismological education. For this reason seismological self-education and keeping in touch with specialists on the one hand and popularisation of recent scientific advances in the field of biological precursors by specialists among the population of seismic regions on the other, constitute the necessary elements for ensuring safety of the people.

The principal conclusion of this paper is that, in order to integrate biological precursors into an earthquake prediction system, it is necessary to organize extensive competent observations to obtain maximum amount of reliable information. At present the responses shown by animals are largely known. To exclude prediction mistakes, especially at the most critical stage, short term prediction, these responses should be carefully studied and summarized.

Biological objects, from the simplest organisms to man, experienced an intensive action of different factors during the Spitak earthquake. The resulting changes in the biological activity of individual organisms, their communities and biogeocenoses may have lasting and significant consequences for a considerable part of northern Armenia. It is known, for example, that the appearance of stress situations in areas of high seismicity can lead to unpredictable genetic mutations and changes in the biological activity of organisms at all level. There are indications in the literature pointing to relation between a high seismic activity in an area and intensive chromosome formations in the higher animals [13].

Even these data (far from complete) on the action of earthquake preparation processes and seismic shocks proper and accompanying phenomena on biological objects indicate the necessity of a long-continued multidisciplinary biological study of the area hit by the earthquake for all living organisms. A biological monitoring of this kind should combine the recovery of the picture preceding the earthquake, the study of subsequent migrations, repression of old populations and development of new ones, comparison to adjacent and similar zones, identification of organisms and biological processes that can detect these changes.

In a discussion of possible causes giving rise to biological precursors, one may admit that the appearance of fresh grass in an unusual season of the year could be due to increased underground water level and changes in the temperature regime of the environment. The same causes can be invoked to explain premature awakening from their hibernation of repiles and some insect species, and their appearance on the ground. However, these causes could no means produce the abnormal behaviour of dogs, cats, aquarium fishes or cage birds. It also hardly explainsanomalies in the behaviour of fish in Lake Seven before the Spitak earthquake, the only instrumentally detected factor being altered chemical composition of the water (personal communication of the doctor of biological sciences, director of the Seven hydrobiological station, N.O. Oganesyan).

The current attitude to biological precursors as an element of the earthquake prediction system should be rapidly and radically altered. It seems advisable to start, on an international basis, field, laboratory, theoretical and practical studies to develop an efficient concept of a reliable biological service of earthquake prediction.

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TABLE 1

ABNORMAL ANIMAL BEHAVIOUR BEFORE THE SPITAK EARTHQUAKE

No.	Observation site	Epicentral distance (km)	Species and number of animals	Pre-cursor time	Description of animal behaviour	Observer and his profession
1.	2.	3.	4.	5.	6.	7.
1.	Shirakamut Spitak Djrashen Arevatsag	4 6 10 14	Snakes, in great numbers	2-3 days	Awakened prematurely from hibernation, came onto the surface of the earth, crept from dangerous zones away from the epicentre.	Pogosyan A. Muradyan S. Khachatryan E. Arutyunian G. cattle breeders
2.	Dzoraglukh	41	Ants, in great numbers	1.5-2 hours	Despite the low air temperature (-10 to 12°C) they were seen on the snow by some houses.	Mamlvan R.A. researcher
3.	Leninakan Artagyukh Mets Parni Spitak	21 6 4 6	Rain worms, in great numbers	4-5 hours	They came to the surface of the earth during this unusual season. They had been seen on lawns and asphalt pavements.	Goncharenko V. Khachatryan S. researchers Arutyunyan R. housewife
4.	Leninakan	21	A dog	2 days	Began to howl, was greatly agitated, carried a year-old baby to the open place (the house collapsed), just before the earthquake.	Markaryan E.
5.	Leninakan	21	A dog	5 min.	Somwhow managed to get out of a net cage, ran to the master who was on the first floor, caught him by the trousers and pulled him into the street. Had been in great agitation all the preceding night and morning.	Topoyan K. researcher
6.	Anipemza Agin Isaakyan Airavan Karabulag	63 45 42 31 48	Dogs, in great numbers	from a few hours to a whole day	Were agitated, ran to and from in their cages, tried to get away, others hid in enclosures, trembled from fear, did nor respond when called by name, did not obey or carry out commands, were completely out of control.	Oganesyan A.A. Petrosyan S. Tzirakosyan G. Babayan T. Grigoryan R. dog-breeders

Contd..... (Table 1)

1.	2.	3.	4.	5.	6.	7.
7.	Leninakan	21	A dog	15-16 hours	Refused to enter the house and would not let its master do so; when dragged by force, even bit the master.	Garybyan A. pensioner
8.	Ankavan Aigabats Vagramaberd Megrashat G: ullibulag	37 22 26 30 27	Dogs, in great numbers	3-4 hours	Refused to eat, kept away from buildings, gathered in groups and emitted prolonged howlings. Frequently changed posture from lying to standing and back again. Put their legs wide when standing.	Meloyan M. nurse Zadoyan V. housewife
9.	Leninakan	21	A cat	a few hours	Carried her kittens from the house into the open and safe places.	Basentsyan M. geophysicist
10.	Leninakan	21	A cat	14 hours	Rushed to and fro at home as if gone mad, ran past rats that were scampering in the street without manifesting aggressivenes, climbed a tree, getting down only after the shock.	Garibyan A. pensioner
11.	Aikadzor Leninakan Kirovobad Tbilisi Erevan	53 21 180 118 87	Cats, in great numbers	from 2 days to a few hours	Were mewing anxiously, kept to the masters, asked to protect them, refused to eat and walk out. Were jumping onto the windows, door, the master, tried to get away through small openings in window panes, were agitated, manifested vocal activity. Many deserted their houses	Oganesyan L. Mikhailova V. Gud' R. Avetisyan R.
12.	Spitak Leninakan Erevan Kirovokan Stepanovan Razdan	6 21 87 27 27 63	Aquarium fishes, in great numbers	0.5-4 hours	Did not accept food, went down to lie onto the bottom, assumed vertical postures head downwards. Some jumped (even several times) out from the aquarium to the floor through narrow openings between the wall and the roof.	Fursova E. Chakholyan G. Gevondyan A. Grigoryan L. Petrosov Yu. Kalanyan R. fish-keeping amateurs

Contd..... (Table 1)

1.	2.	3.	4.	5.	6.	7.
13.	Lake Seven	77-96	Fishes, in great numbers	1-2 days	In the places where one could usually catch much fish, attempts made before the earth-quake. In other places where no fish were observed previously, there was active splashing.	Organisyan R.O. Khanamyan D.V. fishers
14.	Aigabats	22	Fishes, 15-20 individuals	2-3 days	Afterviolent disorderly movements they died without any apparent cause in a small basin (bellies bursted).	Zadoyan M. cattle-breeder
15.	Leninakan	21	Rats, in great numbers	3-4 hours	They came out of their shelters into open places in many workshops of a meat processing unit. They were not afraid of people. Their movements did not show usual alacrity.	Sargasyan T. superintendent
16.	Artik	31	Rats, in great numbers	1 day	They became scarce in a store of foodstuffs as noticed by sanitary inspectors. They were gone.	Pogosyan A. Store manager
17.	Leninakan	21	Mice, in great numbers	1-3 hours	Came out of their holes into a room, so that they could by no means be made to leave. The children who were frightened by the mice came out into the street and so were saved.	Jinistyan V. Amatunis
18.	Leninakan Kirovakan	21 27	Parrots, canary birds, in great numbers	2.5-3 hours	Showed unusual vocal activity, drank much water without being thirsty, rushed to and fro inside their cages, hurled themselves agains: the rods, tried to get out.	Marakyan E. Aleksanyan A. pensioner
19.	Leninakan Tbilisi	21 118	Wild fowl, in great numbers	3-4 hours	Flew out of the city in the morning, the sky was dark and noisy. Sang louder than usual , all together, fell silent after the shocks.	Anistratova G. doctor Gud' R housewife
20.	Leninakan	21	Lady-birds, a multitude	1-2 days	Awakened from hibernation, appeared every-where : on the floor in the rooms, in the yard and in other places.	Oganisyan V. seismologist

Contd..... (Table 1)

1.	2.	3.	4.	5.	6.	7.
21.	Spitak	6	Hamster, single	16 hours	On December 6, 30 minutes before the fore-shock, it showed unusual anxiety, and dis-appeared altogether before the main shock.	Ustyan G. school boy
22.	Erevan	87	Hamster, single	30-40 minutes	Surprised at the unusual behaviour of the animal, the boy said to his father "There will be an earthquake".	Arutyunyan T. school boy
23.	Spitak	6	Bees, a multitude	1.5-1 hours	Were awakening from hibernation, produced a great noise, flow out of their beehives and died.	Azatyan E. bee keeper
24.	Erevan	87	Bats, in great numbers	20-30 minutes	A mass appearance of during day time caused puzzlement in the people	Malkhasyan R. teacher
25.	Megrashen	25	Cows, in great numbers	1.5-2 hours	Showed unusual anxiety, loudly mooed, refused to eat, tried to get rid of the tether. The cattle-farm workers did not succeed in calming them.	Markaryan A. researcher
26.	Atsik Algabats	18 22	Hens, in great numbers	1.5-2 hours	Some of them showed a strong anxiety : flew up to perch in trees and loudly cackeled. On the contrary others spread their wings and pressed themselves to the ground, did not meve or emit sound.	Makhapetyan A. teacher Zadeyan V. housewife

TABLE 2

DISTRIBUTION OF THE NUMBER OF REPORTS ON ABNORMAL BEHAVIOUR OF ANIMAL SPECIES

No.	Animal species	Number of reports	%
1.	Domestic animals		
	1. Dogs	267	26.3
	2. Cats	174	17.1
	3. Cows	44	4.3
	4. Sheep	24	2.4
	5. Goats	8	0.8
	6. Pigs	13	1.3
	7. Hourses	37	3.7
	8. Donkeys	7	0.7
2.	Cage animals		
	9. Rabbits	21	2.1
	10. Foxes	3	0.3
	11. Hamsters	6	0.6
	12. Guinea-pigs	3	0.3
3.	Poultry		
	13. Hens	35	3.5
	14. Ducks	7	0.7
	15. Geese	5	0.5
4.	Cage birds		
	16. Parrots	29	2.9
	17. Canary birds	14	1.3
5.	Wild animals		
	18. Bears	4	0.4
	19. Wolves	3	0.3
	20. Jackals	2	0.2
	21. Lions	2	0.2
	22. Tigers	2	0.2
	23. Jaguars	1	0.1
	24. Leopards	1	0.1
	25. Pumas	1	0.1
	26. Monkeys	6	0.6
	27. Artiodactyla	7	0.7
6.	Wild fowl		
	28. Sparrows	13	1.3
	29. Crows	7	0.7
	30. Bullfinches	3	0.3
	31. Buntings	3	0.3
	32. Siskins	3	0.3
	33. Goldfinches	3	0.3
	34. Bramblings	3	0.3
	35. Pheasants	2	0.2
7.	36. Bats	3	0.3
8.	Insects		
	37. Bees	16	1.6
	38. Lady-birds	5	0.5
	39. Flies	3	0.3
	40. Cockroaches	2	0.2
	41. Crickets	3	0.3
	42. Moths	2	0.2
	43. Ants	3	0.3
9.	Rodents		
	44. Rats	57	5.6
	45. Mice	46	4.5
	46. Cophers	10	1.0
10.	Reptiles		
	47. Snakes	4	0.4
	48. Worms	28	2.8
11.	Hydrobionts		
	49. Fishes	6	0.6
	50. Aquarium fishes	54	5.3

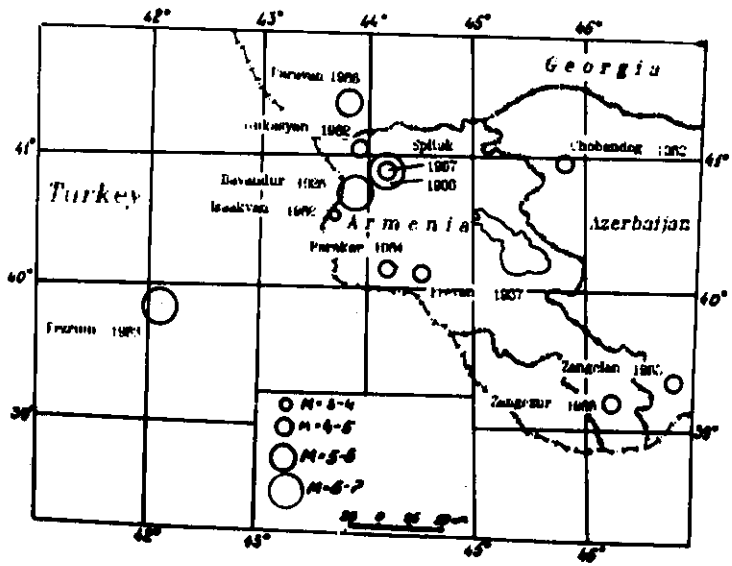

Fig. 1. Map of Earthquake with Premonitory Abnormal Animal Behaviour within the Armenian SSR

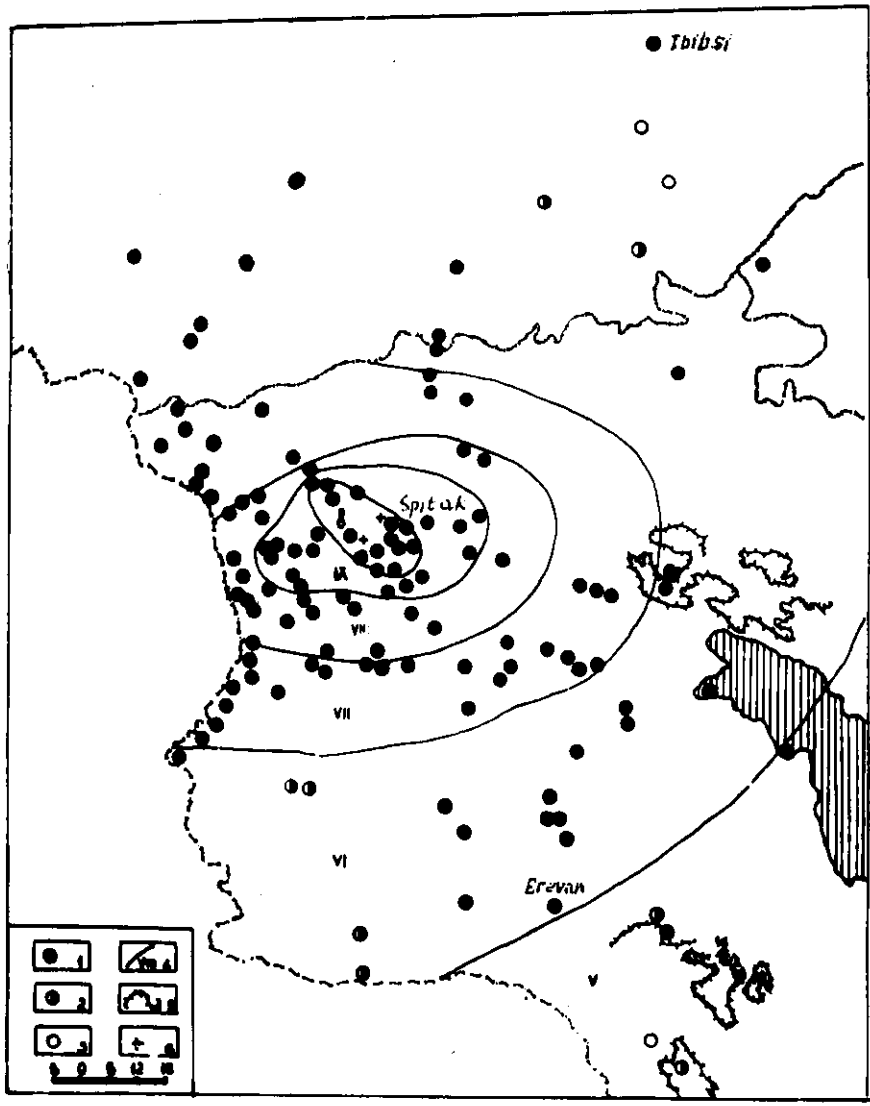

Fig. 2. Map Showing the Distribution of Sites of Biological Observation for the Spitak Earthquake of December 7, 1988. Observation sites :

1 where positive evidence of abnormal animal behaviour before the earthquake was stable in character;

2 where the number of positive reports did not exceed 3;

3 no reports on changes in animal behaviour have come;

4 isoseismic with intensity indicated;

5 boundaries of the Khosrov and Dilizhan nature reserves;

6 epicentres of the first and second shocks as determined from a study of felt effects.

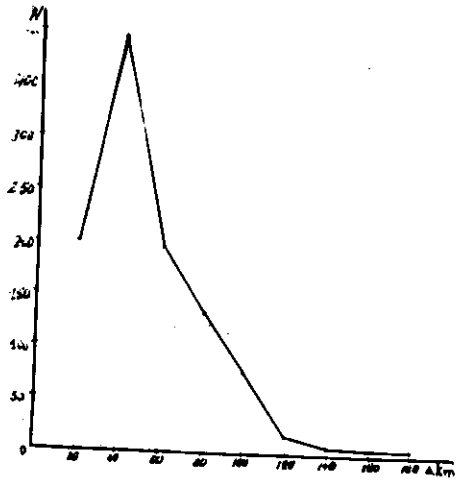

Fig. 3. Distribution of the Number of Reports on Abnormal Animal Behaviour as a Function of Epicentral Distance

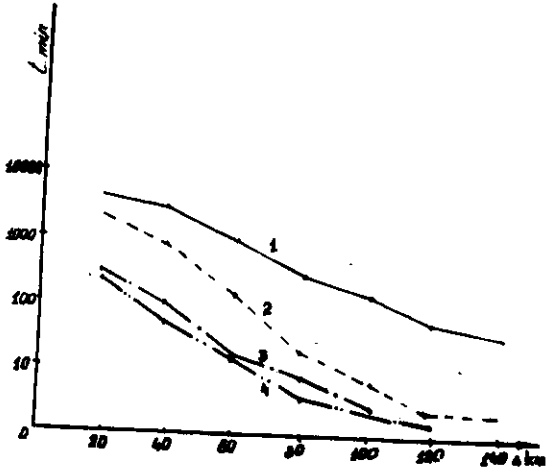

Fig. 4. Precursor Time shown by Animals for the Spitak Earthquake as a Function of Epicentral Distance :

1 - dogs; 2 - rats; 3 - horses; 4 - aquarium fishes.