Earthquake Research in China

Volume 11, Number 1, 1997

Electric Field Effects on Animals: Mechanism of Seismic Anomalous Animal Behaviors (SAABs)

Huang Qinghua[1], Ikeya Motoji[1], and Huang Peihua[2]

[1]Department of Earth and Space Sciences, Graduate School of Science, Osaka University, Osaka 560, Japan
[2]Department of Earth and Space Sciences, University of Science and Technology of China, Hefei 230026, China

Electric field effect on animals has been studied to investigate its relation with seismic anomalous animal behaviors (SAABs) in China. Freshwater eel, crucian carp, catfish, and soft-shelled turtle responded to the threshold electric field of 1-10 V/m, while duck, goose, cat, sheep, pig, dog, and chicken all responded to the ground electric field of about tens of V/m, depending on the species as well as on individuals. Most of the behaviors caused by electric field were similar to those reported as SAABs such as alignment, sudden movement, panic, and convulsion. The intensity of electric field due to a major earthquake would have been over these threshold values. Numerical estimation based on an electromagnetic model of a fault has been made to induce SAABs as electric shocks to pulsed electric fields in electro-physiology. The seismic electric signals (SES) intensity might be estimated from the observation of SAABs.

Key words: Seismic anomalous behaviors of animals (SAABs), Seismic electric signals (SES), Electromagnetism, Piezoelectric effect, Free charge

INTRODUCTION

The earliest report on abnormal animal behaviors that are correlated with earthquakes appeared 373 B.C. in Greece (Wang Shaoyu and Ma Chunqin, 1993). Many seismic anomalous animal behaviors (SAABs) have been collected and published (Wadatsumi, 1995; Earthquake Research Group of Biophysics Institute of Academia Sinica, 1977; Seismological Bureau of Anhui Province, 1978). Some early studies of Hatai (1931) and Tributsch (1978) suggested that SAABs might have some

Received December 1996.

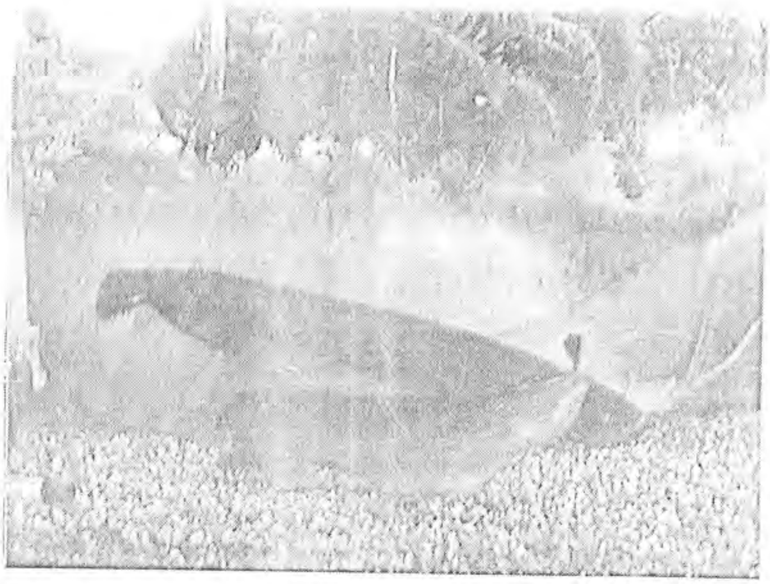

Fig. 1
Photographs of a catfish under electric field.

relation to seismic electric signals (SES) and aerosol effects; Jiang indicated that SAABs are a short-term precursor and are induced by acoustic emission (Jiang Jinchang, 1980). Studies by Ikeya et al. showed that animals respond to electric fields and that SAABs are field avoidance and electro-physiological behaviors (Ikeya et al., 1996a,b); even a single pulse of 0.1 ms given to fish can cause a similar response as a DC electric field.

Study of electric field effects on both aquatic and terrestrial animals in China has been done and the obtained values of minimum electric field are reported in this paper. Now it is possible to estimate the SES intensity from the reported SAABs and clarify the electromagnetic nature of a fault.

1. EXPERIMENTS

1.1. Experimental Methods

A freshwater eel, crucian carp, catfish, and soft-shelled turtle were placed in a small aquarium, basin, or pool, together with two electrodes placed in parallel; a cat, sheep, pig, chicken, duck, and dog were placed on a wet towel on the ground, with two electrodes under both ends of the towel; and chicken and duck were placed in a wooden box with a wet bottom. We applied DC voltage to the electrodes, which were switched on and off in most experiments, or applied a pulsed field of 0.01 ms with an intensity of 0-177 V directly to the two legs of the duck and chicken, respectively. We recorded the animal behaviors in our experiments by a video recorder; photos used in this paper were taken directly from the screen.

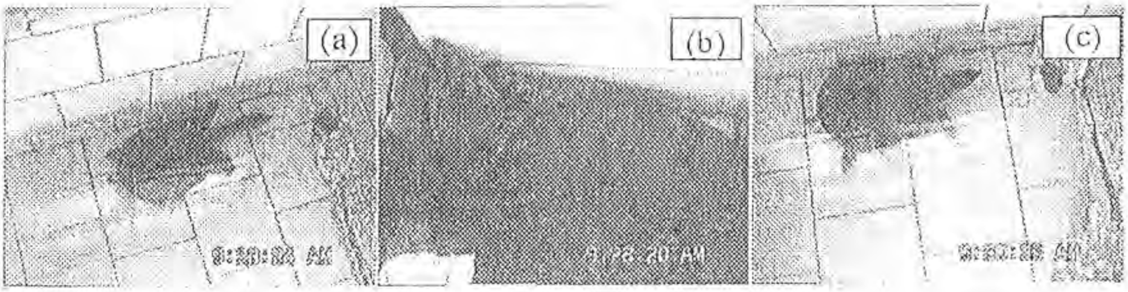

Fig. 2
Electric field effects on a soft-shelled turtle.
(a) without field; (b) opened and closed eyes, stayed in the corner; (c) shocked, stretching and drawing back head.

1.2. Experimental Results

(a) Freshwater eel: A freshwater eel responded to a field as low as 2 V/m. When voltage was enhanced, it was shocked and moved to different degrees, depending on the field intensity.

(b) Crucian carp: A crucian carp of about 15 cm in length was kept in the same aquarium with a freshwater eel. It did not respond to a field of less than 6 V/m, while eels responded violently; crucian carp was shocked at a field of 10 V/m nearly the same as minnows and other fish (Ikeyae et al., 1996a).

(c) Catfish: Two catfish were placed in a small basin perpendicular to the electrodes or parallel to the electric field as shown in Fig. 1(a). They aligned perpendicular to the field at 7.5 V/m [Fig. 1(b)]. In order to check the alignment phenomenon, we let them move perpendicular to the field direction as shown in Fig.1(c) and did the experiment again. They were shocked and moved violently under the electric field and finally stabilized perpendicular to the field [Fig. 1(d)].

(d) Soft-shelled turtle: A wild soft-shelled turtle captured by a farmer was placed in a small pool. Figure 2 describes the turtle's behaviors in the electric field.

(e) Cat: A cat was placed on a wet towel. Its responses to an electric field are shown in Fig. 3.

(f) Dog: Electric field effects on a puppy and an adult dog were studied. An adult dog was fed on the wet towel [Fig. 4(a)]; when we accidentally applied a field of 90 V/m, it gave up eating and fled [Fig. 4(b),(c)]. A puppy with the front and back legs of about 20 cm in length responded to an electric field by barking at the wet towel as shown in Fig. 4(d).

(g) Sheep: A sheep looked normal [Fig. 5(a)] until one of its legs convulsed [Fig. 5(b)] and then it avoided the electrode area [Fig. 5(c)].

(h) Pig: The pig was not friendly and did not co-operate; it took time to let the pig stand on the wet towel. It touched one electrode and was shocked with a field of 72 V/m and then fled.

(i) Goose: A goose panicked at 72 V/m; one of its legs was convulsed under a field of 90 V/m.

(j) Duck: Table 1(b) shows the ducks' responses to the DC electric field. When a pulse electric field of 177V with a width of 0.01ms was applied to both legs of a duck, it screamed and was convulsed.

(k) Chicken: Chickens' behaviors to the DC voltage are shown in Table 1(b). The pulse field was applied directly to both legs of one chicken; when the pulsed field was enhanced to 141 V with a width of 0.01 ms, the leg muscle was convulsed.

(l) Budgerigiar (*Melopsittacus undulafus* L.): Budgerigiar screamed and showed avoidance behaviors when electric field was applied. The detailed analysis of frequency of voice will be reported separately.

Table 1

(a) Electric field effects on aquatic animals.

Animal	Electric field (V/m)[a]	Responses
Freshwater eel	2	Excited: E, Moving: M
	4	M, Shocked: S
	6	S, Moving quickly: MQ
	8	S, Violent movement: VL
	10	VL, Apparently shocked: AS
Crucian carp[b]	8	Looked feeling: LF
	10	S
Catfish	5	LF, Sudden movement: SM
	7.5	M, Aligned:A
	10	S, M, A
Soft-shelled turtle	9	Open & close eyes: O&C eyes
	12	O&C eyes, MQ, Staying in the corner
	15	S, Stretching and drawing back head

[a]Electric field was estimated simply by dividing the voltage by the distance of electrodes.
[b]Electric field was applied together with freshwater eels in the same aquarium.

(b) Electric field effects on terrestrial animals (as well as duck and goose).

Animal	Electric field (V/m)	Leg-to-leg voltage (V)*	Responses
Cat	45	9	Looked feeling: LF, Wagging tail?
	72	14	Washing face: WF
	90	18	Excited: E, Convulsed leg: CL
Sheep	54	22	LF, Nervous: N
	90	36	CL, Avoid field: AF
Pig	<72	<36	N, AF
Dog			
an adult	<90	<36	Giving up eating, Fled
a puppy	72	14	LF?
	90	18	E, Barking, Trying to bite
	180	36	AF
Goose	72	3.6	LF, N
	90	4.5	CL, Fled
Duck			
two adults	54	2.2	Crying: C, grooming: C
	90	3.6	C, G
	180	7.2	shocked: S, cramped
two young	90	2.7	G, CL
Chicken			
young	72	2.1	LF
	90	2.7	N, G, AF
adults	36	1.4	G?
	72	2.9	N, AF?
	180	7.2	AF

*Note: The leg-to-leg voltage was calculated as the maximum parallel to the field direction

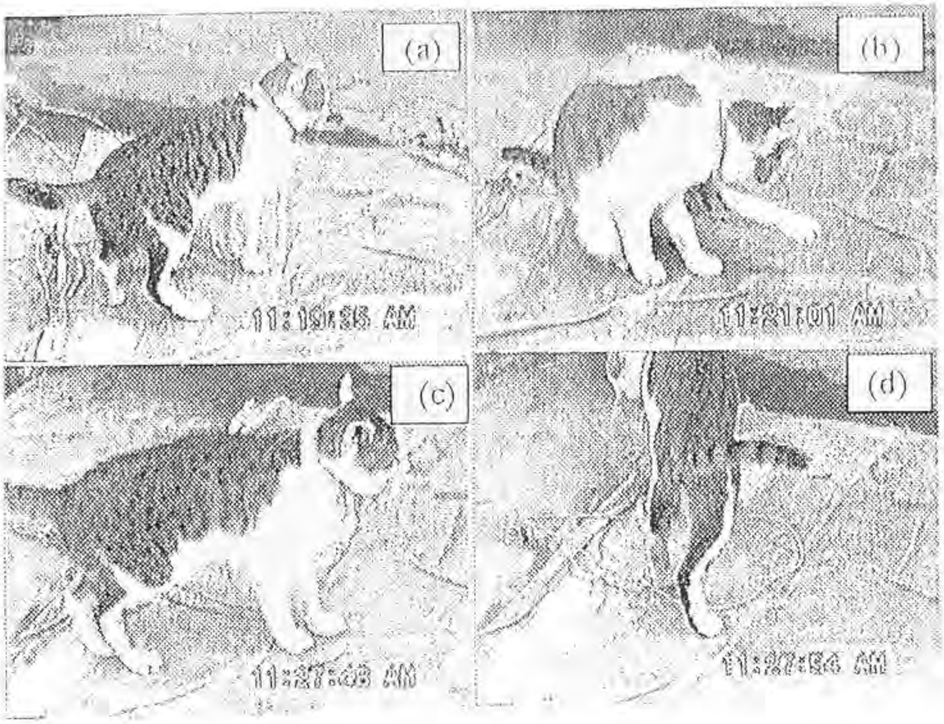

Fig. 3
Behaviors of cats when applying electric field.
(a) wagged tail at 45 V/m; (b)washing face; (c) convulsed legs;
(d) avoid field.

1.3. Electric Field Effects on Animals

The behaviors of animals to the electric field are somewhat similar to those reported as SAABs (Wadatsumi, 1995; Earthquake Research Group of Biophysics Institute of Academia Sinica, 1977; Seismological Bureau of Anhui Province, 1978). Catfish aligned perpendicular to the field direction, similarly to the previous research on minnow, guppy, and loach (Ikeya et al., 1996a). Eel and catfish are more sensitive than minnows. The characteristic field intensity of crucian carp and soft-shelled turtle are almost the same as those of minnow and guppy. Cat, dog, sheep, pig, goose, duck, and chicken have almost the same sensitivity to the field as rats and sparrows (Ikeya et al., 1996b). All these experiments indicated that animals must have felt an electric field at least of 1-100 V/m before earthquakes if SAABs are due to electric field effects. Our preliminary experiment showed no alignment of fish using vibration or sonic waves. It may be appropriate to consider that SES is the main cause of SAABs.

2. ELECTROMAGNETIC (EM) HYPOTHESIS

2.1. Piezoelectric Effect

When stress is applied to a non-symmetrical crystal such as quartz, electric polarization occurs. The phenomenon is called the piezoelectric effect. If the crystal axes of minerals in a rock are randomly oriented, the piezoelectric effect may not be observed. However, once the crystal axes have some preferred orientation, the piezoelectric effect occurs in response to the applied stress.

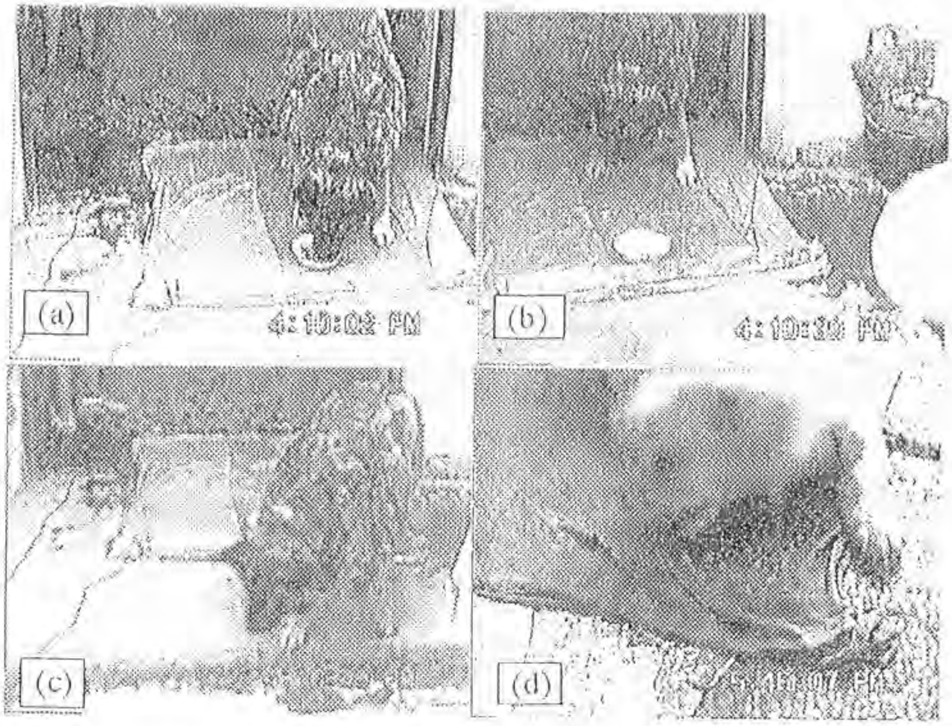

Fig. 4

Behaviors of dogs when applying electric field.
(a) an adult dog eating food; (b) gave up eating at 90 V/m; (c) fleeing to avoid field; (d) a puppy excited and tried to bite the wet towel at 90 V/m.

The density of piezoelectric charges is in proportion to the stress; the coefficient is called the piezoelectric coefficient. We can express such a relationship in a non-tensor form as follows:

$$q_p = \alpha\sigma \tag{1}$$

where q_p is the density of the piezoelectric charges, σ is stress, and α is piezoelectric coefficient.

2.2. EM Model

During the seismogenic process, stress can be accumulated and tends to form some local stress concentration zone near the future hypocenter. Some fracture may occur in such a zone prior to an earthquake and release part of the stress. If quartz with an orientation anisotropy exists in the rocks, the piezoelectric effect would be accumulated and released when the rocks fracture. The charges that have compensated the piezoelectric effect become free due to the disappearance of the piezoelectric effect induced by the release of stress. The charge exists temporarily and decays with a time constant $\varepsilon\rho$, where ε is the dielectric constant and ρ is resistivity. Hence, electric pulses are formed when a segment of a fault is fractured in a time constant τ, where $\tau = \alpha/\beta$, α is the half-length of the fault, and β is the velocity of S-wave.

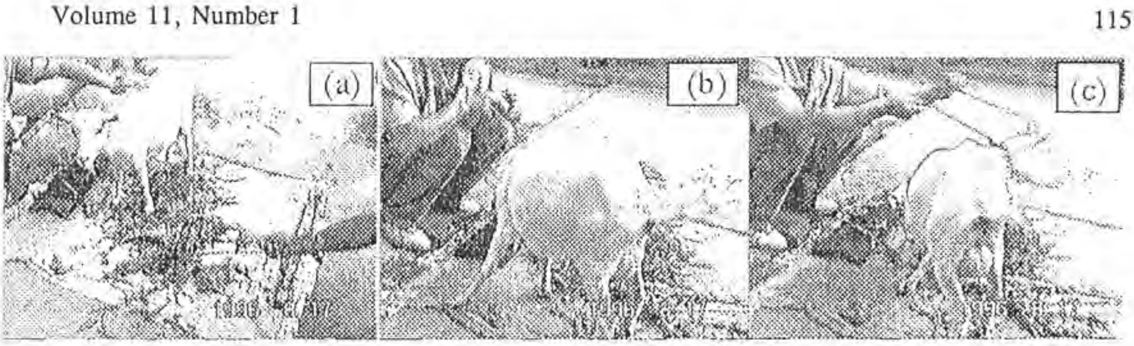

Fig. 5
Experiment on a sheep to investigate the relation between its behaviors and electric field.
(a) no response; (b) convulsed legs; (c) fleeing to avoid field.

The EM model is based on the appearance of the free charge by the disappearance of the piezoelectric effect due to the change of seismic stress (Ikeya and Takaki, 1996). The residual free charge $q(t)$ is

$$q(t) = q_b(t) - q_p(t) \tag{2}$$

where $q_b(t)$ and $q_p(t)$ are the density of bound and piezoelectric charges, respectively. The temporal variation of the charge density is discussed as follows, considering the compensation time $\varepsilon\rho$,

$$dq(t)/dt = -\alpha d\sigma(t)/dt - q(t)/\varepsilon\rho \tag{3}$$

where $\sigma(t)$ is the time-dependent stress in $Pa(N/m^2)$.

We assumed a strike fault model and used the elastic theory to discuss the electric field correlated with an earthquake (Ikeya and Takaki, 1996). For the initial condition of $q(0) = 0$, considering Eq. (3), a mathematical model of strike fault gives

$$q(t) = \alpha\Delta\sigma\,[\varepsilon\rho / (\tau - \varepsilon\rho)](e^{-t/\tau} - e^{-t/\varepsilon\rho}) \tag{4}$$

For foreshocks, the initial stress σ_0 for the local segment of a fault would probably be equal to that of the fracture stress of quartz grains, i.e., $\sigma_0 = 10^8$ N/m^2. Assuming that the local stress releases completely due to the fracture of quartz grains, the local stress drop $\Delta\sigma$ may be equal to about 10^8 N/m^2, which would be 1 order of magnitude larger than the overall stress drop of a fault movement.

The electric field intensity is written from $F(t) = q(t)/\epsilon$ as

$$F(t) = \alpha\Delta\sigma[\rho / (\tau - \varepsilon\rho)](e^{-t/\tau} - e^{-t/\varepsilon\rho}) \tag{5}$$

The field is a kind of pulse field having a risetime τ and a decay time $\epsilon\rho$ or vice versa. We estimated the peak value of such a pulsed electric field due to Haicheng EQ (February 4, 1975). We assume the local fracture as a micro-fault, supposing its length as about $2\alpha = 10$m and $\beta = 3$km/s ($\tau = \alpha/\beta = 1.7$ms) and the piezoelectric coefficient of quartz grains as $\alpha = 10^{-12}$ C/N. If the local stress drop $\Delta\sigma = 10^8$ N/m^2 is used, the peak field may be on the order of 10^4 V/m. If we regard the quartz grain as one virtual fault ($2\alpha = 0.7$mm), the field may approach 10^6 V/m with a pulse width of 10^{-7}s (assuming field intensity saturates at $\alpha\Delta\sigma/\epsilon$ in case of $\tau < \epsilon\rho$). This is 4-6 orders of magnitude larger than the field that affected sensitive animals in our experiments, i.e., 1 V/m.

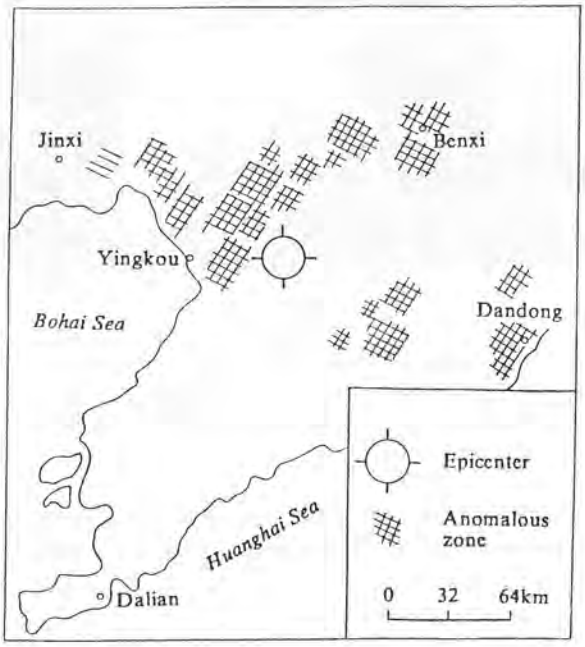

Fig. 6
Spatial distribution of SAABs before Haicheng earthquake ([13]).

3. DISCUSSION

Finkelstein and Powell have estimated that a many thousands V/m field could be generated by pressure waves of earthquakes (σ = 25-250 bar, 1 bar = 10^5 Pa) (Finkelstein and Powell, 1970). However, free charges compensate the piezoelectric effect and the hypothesis of piezoelectricity had been abandoned. We propose that the free charges that bounded the piezoelectric polarization appear by the disappearance of the polarization due to stress release. It is not the piezoelectric effect but the free charges that cause SAABs (Ikeya et al., 1996a,b) and earthquake lightning (Ikeya and Takaki, 1996).

The thresholds of electric field of animals were different for individuals, even for the same species. Aquatic animals seemed more sensitive to electric signals than the other animals. This is consistent with the general results by Buskirk et al. (1981). However, the thresholds of electric fields of terrestrial animals were of the order of 10^{5-7} V/m prior research, much larger than our results. This might be attributed to their experimental methods. The experiments on aquatic animals were done in water with a conductivity of 50 $\Omega\cdot$m. In contrast, terrestrial animals are not affected by the electric field but by the induced current in their bodies. In our experiments, we used a wet towel to apply the electric field from one leg to another. Therefore, our threshold field intensity is more plausible in the real case, considering the observations of SAABs as well as the possibility of forming one conductive zone in a fault region due to the seismogenetic process.

Anomalous behaviors caused by an electric field, such as alignment, sudden startled movement, panic, and convulsion, were similar to those in some reports on SAABs before major earthquakes (Wadatsumi, 1995; Earthquake Research Group of Biophysics Institute of Academia Sinica, 1977; Seismological Bureau of Anhui Province, 1978). The SAABs might be reproduced in our experiments of electric field effects. Behaviors of animals at some electric field intensities are summarized in Table 1 for rough estimation of the seismic electric field from animal behaviors based on the hypothesis.

We analyzed the possible electric field due to Haicheng EQ based on the EM model of a fault. The results showed that it was possible to generate a high electric field of 10^{4-6} V/m prior to the main shock in some local zone. The theoretical seismic electric field was much larger than the threshold values we observed in our experiments, which meant animals can detect such electric signals and show anomalous behaviors prior to an earthquake.

It is interesting to note that the characteristics of anomalous behaviors of animals correlated with Haicheng and Tangshan earthquakes were very different (Zhang Guomin and Fu Zhengxiang, 1989).

(a) Haicheng earthquake: Many SAABs were reported 1-2 months before the main shock along the zone of Dandong-Xiuyan-Panjin (Fig. 6), corresponding to the seismogenetic structure in the NW direction. The SAABs appeared first at the southeast and northwest parts of this zone and then approached the epicenter gradually. This might suggest that the accumulated stress was released first from the site away from the epicenter. Water might flow into the fracture zone and the zone become conductive. Further fracture allows the current flow close to the epicenter and final fracture occurs at the epicenter. Many foreshocks were observed before the main shock (Mei Shirong et al., 1989). This is consistent with the observation of SAABs. The electric field might be over 10^{4-6} V/m for local fracture. For the main shock due to fault movement ($2\alpha = 5.5$ km, $\tau = 1$ s, and $\Delta\sigma = 10^7$ N/m^2), the theoretical electric field was several V/m. It is possible to induce the SAABs considering the geological effects (Ikeya et al., 1996b). Many SAABs were observed because of the presence of many foreshocks (local fracture of rocks).

(b) Tangshan earthquake: A few SAABs occurred just 1-2 days before the main shock. Some more anomalous behaviors were observed after the main shock. The distribution was limited in a quite narrow zone of the epicenter, which had the greatest earthquake intensity presumably because of the geoelectric condition of the epicenter. The maximum electric field of the main shock was on the order of 10^{-1} V/m ($2\alpha = 8$ km, $\tau = 1$ s, and $\Delta\sigma = 10^6$ N/m^2). Only a few SAABs occurred because Tangshan earthquake had almost no foreshocks (Mei Shirong et al., 1989).

Thus we can explain the characteristics of the temporal and spatial distribution of SAABs for the Tangshan and Haicheng earthquakes.

All of our results on field intensity were simply obtained by dividing the voltage by the distance and assuming a uniform field. This is an apparent overestimation, considering the edge effects. Animals may be more sensitive than the field intensity shown in Table 1. We have discussed the macro-anomalous animal behaviors in our experiments by applying a single or a few electric pulses, i.e., on and off of the field. It is known that electric pulses produce Ca^{2+}, Na^+, and K^+ ions in the synapse of the nervous system and cause the evolution of neurotransmitter chemicals, which excite animals. If we use some repeated pulses to accumulate the effect, the thresholds for electric fields of animals may be far lower than our results. Some sensitive aquatic animals have electroreceptors highly sensitive to detect about a 10^{-5} V/m equivalent to the geoelectric field measured by geophysicists (Buskirk et al., 1981). Local fractures along the fault might produce electric pulses successively to accumulate the neurotransmitters, such as serotonin or endorphin.

In this work, we mainly investigated the electric field effects on animals in China and explained the SAABs under the hypothesis that SAABs are caused by electrophysiological effects due to seismic electric fields. The spatial distribution of SAABs around fault zones should be documented by using the approximate electric field intensity so that the electromagnetic nature of the fault is clarified. Further studies on the dynamic characteristics of the electric field correlated with earthquakes are under way and will be reported elsewhere.

ACKNOWLEDGMENTS

The authors thank Prof. Wang Wei, Mr.Wang Yao, and Ms. Shi Yufang of the Seismological Bureau of Anhui Province of China, as well as many local farmers for arrangement and help in the experiments.

REFERENCES

[1] Wang Shaoyu and Ma Chunqin. *The Invisible Effects of Earthquake Disaster*. Beijing: Science and Technology Press of China, 1993 (in Chinese).

[2] K. Wadatsumi. *Witnesses 1519 of Earthquake Precursors*. Tokyo: Tokyo Publisher, 1995 (in Japanese).

[3] Earthquake Research Group of Biophysics Institute of Academia Sinica. *Animals and Earthquakes*. Beijing: Seismological Press, 1977 (in Chinese).

[4] Seismological Bureau of Anhui Province. *Macro-phenomena and Earthquakes*. Beijing: Seismological Press, 1978 (in Chinese).

[5] S. Hatai and N. Abe. "The responses of the catfish, Parasilurus asotus, to earthquakes." *Proc. Imp. Acad. (Tokyo)*, 1931, pp. 375-378.

[6] H. Tributsch. "Do aerosol anomalies precede earthquake?" *Nature*, 1978, 276:606-608.

[7] Jiang Jinchang. "Animal unusual behavior was a short-term earthquake precursor." *Acta Seismologica Sinica*, 1980, 2(3):304-313 (in Chinese).

[8] M. Ikeya, S. Takaki, and D. Takashimizu. "Electric shocks resulting in seismic anomalous animal behaviors (SAABs)." *Journal of Physical Society of Japan*, 1996a, 65(3):710-712.

[9] M. Ikeya, H. Furuta, N. Kajiwara, and H. Anzai. "Ground electric field effects on rats and sparrows: Seismic anomalous animal behaviors (SAABs)." *Japan Journal of Applied Physics*, 1996b, 35(8):4587-4594.

[10] M. Ikeya and S. Takaki. "Electromagnetic fault for earthquake lightning." *Japan Journal of Applied Physics*, 1996, 35:L355-357.

[11] D. Finkelstein and J. Powell. "Earthquake lightning." *Nature*, 1970, 228:759-760.

[12] R. Buskirk, C. Frohlich, and G. Latham. "Unusual animal behavior before earthquakes: A review of possible sensory mechanisms." *Reviews of Geophysics and Space Physics*, 1981, 19: 240-270.

[13] Zhang Guomin and Fu Zhengxiang. "Some characteristics of anomalies of mid-term and short-term prior to earthquakes." In: *Research on Earthquake Prediction*, Beijing: Seismological Press, 1989, pp 299-314 (in Chinese).

[14] Mei Shirong, Zhang Guomin, and Zhang Zhaocheng. "On relationship between strong earthquake prediction and anomalous variation before and after Tangshan earthquake." In: *Research on Earthquake Prediction*. Beijing: Seismological Press, 1989, pp 1-38 (in Chinese).

ABOUT THE AUTHORS

Huang Qinghua, born in December 1967, is a Ph.D. student in the Department of Earth and Space Sciences, Graduate School of Science, Osaka University, Japan. Research interests include geoelectro-magnetism, seismogenic mechanism, rock physics, disaster prevention, and engineering seismology.

Ikeya Motoji, born in May 1940, is a professor of Osaka University in the Department of Earth and Space Sciences, chairs the Laboratory of Quantum Geophysics, and has been involved in developing electron spin resonance (ESR) dating.