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Alignment silkworms as seismic animal anomalous behavior (SAAB) and electromagnetic model of a fault: a theory and laboratory experiment*

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Abstract

Alignment of silkworms and fish, observed as seismic anomalous animal behavior (SAAB) prior to the Kobe earthquake, were duplicated in a laboratory by applying a pulsed electric field assuming SAAB as electrophysiological responses to the stimuli of seismic electric signals (SES). The animals became aligned perpendicularly to the field direction since their skeletal muscle had a higher resistivity perpendicular to the field direction than parallel to it. An electromagnetic model of a fault is proposed in which dipolar charges, $\pm q$ are generated due to the change of seismic stress, $\sigma(t)$. From a mathematical model, $\mathrm{d}q/\mathrm{d}t = -\alpha(\mathrm{d}\sigma/\mathrm{d}t) - q/\varepsilon\rho$, where α is the charge generation constant like a piezoelectric coefficient, ε, the dielectric constant and ρ, the resistivity of bedrock granite. A fault having a length $2a$ and a displacement or rock rupture time τ, during which the stress is changed, gives pulsed dipolar charge surface densities, $+q(t, x)$ and $-q(t, x+2a)$, or an apparent electric dipole moment of $\boldsymbol{P}(t) = 2aQ(t) = 2aAq(t) = \alpha M_0\left[\varepsilon\rho/(\tau - \varepsilon\rho)\right]\left(e^{-t/\tau} - e^{-t/\varepsilon\rho}\right)$ using the earthquake moment M_0. The fault displacement, D, its initial velocity, D' and the stress drop, $\Delta\sigma$ give $\tau = D/D' = (\Delta\sigma/\sigma_0)(\alpha/\beta)$. The field intensity, F, and seismic current density at a fault zone, J were calculated as $F = q/\varepsilon$ and $J = F/\rho'$ using ρ' of water as to give J=0.1~1 A/m^2 sufficient to cause SAAB experimentally. The near-field ultra low frequency (ULF) waves generated by $\boldsymbol{P}(t)$ give SES reciprocally proportional to the distance R.

Key words: animal anomalous piezoelectric stress fault fish silkworm

Introduction

Seismic anomalous animal behavior (SAAB) prior to a major earthquake is used to predict earthquake in China, alongside with other physical methods such as seismic electric signals (SES), Radon emanation and so on. Animals are reported to have shown SAAB: Dogs barking and running in panic, chickens flying to the roof, ducks avoiding to going into a river, pigs trying to climb the wall, horses, donkeys and cows standing on two legs and falling down in panic (Rikitake, 1978; Tributsch, 1978; Biophysical Institute of Academic Sinica, 1979; Seismological Bureau of Anhui Province, 1978).

Mammals, birds, reptiles, fish, insects and worms showed SAAB prior to the Kobe earth-

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quake that destroyed Kobe on January 17, 1995 (Wadatsumi, 1995). Some animals became nervous, excited and panicked before the earthquake. SAAB has been observed for thousands of years all over the world. However, some people, especially some Western scientists, regard SAAB as retrospectively asserted stories created after the earthquake and do not believe it just as they do not trust Chinese medicine. Asian people generally believe in SAAB but consider it beyond our present level of science. Some scientists reject the report as superstition whereas public hope to predict earthquakes by observing various animals, especially violent behavior of catfish which have been interpreted as SAAB in Japan for many years.

Animals cannot predict an earthquake beforehand since most of them do not experience a major earthquake during their relatively short lifetime. The alternative explanation is that they must have detected some signal and panicked. "What did they detect?" has been a puzzle for centuries. Possible explanations are that animals can detect acoustic waves, a seismic electric signal (SES), an aerosol (Tributsch, 1978), an odor, *etc*. (Bushirk *et al*., 1981). Phenomenological observation in China and in Japan is not sufficient to persuade scientists who have not witnessed any seismic anomalies.

Instead, some theory must be developed based on a hypothesis and experiments must be done to prove it. Unless we discuss SAAB quantitatively based on a scientific model, rather than qualitatively based on misleading speculations, they may be regarded as oriental mythology or superstition. So far, no clear mechanism has yet been established for SAAB.

Based on part of our studies on dating fault movements with electron spin resonance (ESR) (Ikeya, 1993), we developed an electromagnetic model of fault (Ikeya and Takaki, 1996) to explain aurora, known as earthquake lightning (EQL), observed just before earthquakes (Durr, 1973; Terada, 1931).

The alignment of carp in a pond and tropical fish in an aquariums prior to the Kobe earthquake were reported, in addition to the observation of aligned silkworms, panicking fish and swarming or dead earthworms. Many aquatic animals have electrosensory systems which are used to acquire information for orientation and to communicate with others (Bastian, 1994). We applied an electric field to fish, birds, and rats in order to investigate the hypothesis that SAAB is a response to electric shocks. The electric field intensity was calculated based on our electromagnetic model of a fault. Japanese minnows, guppies and loaches aligned perpendicularly to the applied field and earthworms congregated presumably to minimize electric shocks (Ikeya *et al*., 1996a). Rats and birds groomed and panicked as the field intensity increased (Ikeya *et al*., 1996b). Hence, SAAB is attributed to electropathological responses of animals.

In this paper, the electric field effects on silkworms, shells and loaches have been studied to demonstrate that the reported alignments are due to detection of the seismic current prior to earthquakes. The theory of an electromagnetic wave generation model of a fault has further been developed to explain SES.

1 Experiment

Fish and reptiles were kept in an aquarium with water and electrodes. Ten silkworms were put on wet artificial food with copper electrodes with a separation d of 15 cm. Earthworms and lugworms purchased from an angling shop were placed in a box filled with wet soil and electrodes with a separation of 10 cm. The voltage was switched on and off manually every 3 s. Responses to the applied DC and AC voltage, V between 0 and 25 V to the electrode were recorded using a commercial video recorder. The critical current density, J that affects animal behaviors was determined by the field intensity, F, where $F=V/d$. The actual voltage applied to the animal was calculated from the potential difference considering the length of the body, l as $V_{body}=Fl$ and the current, I to the animal was estimated using body resistance R_{body} as $I=V_{body}/R_{body}$.

2 Seismic electric field estimation from SAAB

2.1 Fish: Alignment and panicked

Some Japanese minnows kept in a pond near Kobe jumped up to the land in panic and died (committed a suicide?) prior to the Kobe earthquake. Fish were witnessed to be floating and orienting in north and south direction in ponds. Wild Japanese minnows, tropical fish, guppies and fresh water loaches in a styrofoam aquarium with electrodes aligned perpendicularly to the applied electric field of 10 V/m in a laboratory experiment (Ikeya *et al.*, 1996a). Pulsed electric field with the same field intensity and the pulse width of more than 0.1 ms also aligned minnows. Sensitive minnows were paralyzed at $J=1$ A/m^2, but recovered when the applied electric field was removed. Guppies and loaches responded similarly with quick and slow movement, respectively nearly at the same current density in the preliminary work.

Figure 1 shows the typical response of loaches before and after applying the electric field of 70 V/m. Loaches swimming in different direction responded and aligned perpendicularly to the field direction (Figure 1b). When the field intensity is increased to 100 V/m, loaches were panicked and paralyzed. They recovered when the voltage was released. The field intensity ranging from 10 V/m to 100 V/m or more may be presented if SAAB at the Kobe earthquake resulted from electric field effects.

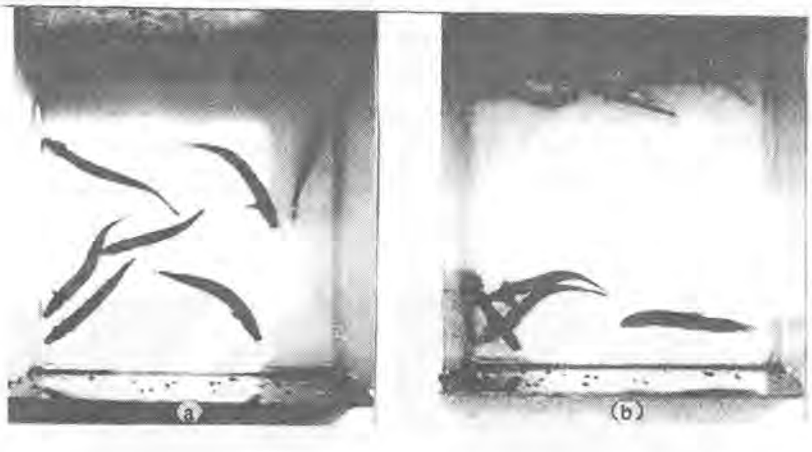

Figure 1 A typical response of loaches before (a) and after (b) the application of electric field of 70 V/m

2.2 Silkworms and earthworms: Panic and alignment

Silkworms were placed as shown in Figure 2a. The DC voltage of 35 V was applied to the electrodes as to give field intensity 230 V/m to the food floor, which aligned silkworms perpendicularly to the field direction as in Figure 2b. Slow movements of silkworms made it difficult to obtain a clear result as reported for minnows (Ikeya *et al.*, 1996a).

Although the peak of the pulsed voltage 10 V (field intensity of 65 V/m) having the pulse-width of 5 ms and the repetition rate of 100 pulses/s was applied to the electrode, silkworms moved only slowly under the pulsed electric field. No clear alignment of silkworms was observed due to their slow movement.

Earthworms came out of the earth and swarmed or were observed to be dead before the Kobe earthquake. Congregation of earthworms was witnessed. Electric field intensity that caused such a phenomena in a laboratory is above 100 V/m (Ikeya *et al.*, 1996a). However, the peak field intensity of a pulsed field more than 0.1 ms gave the similar results. It seems to be the peak intensity.

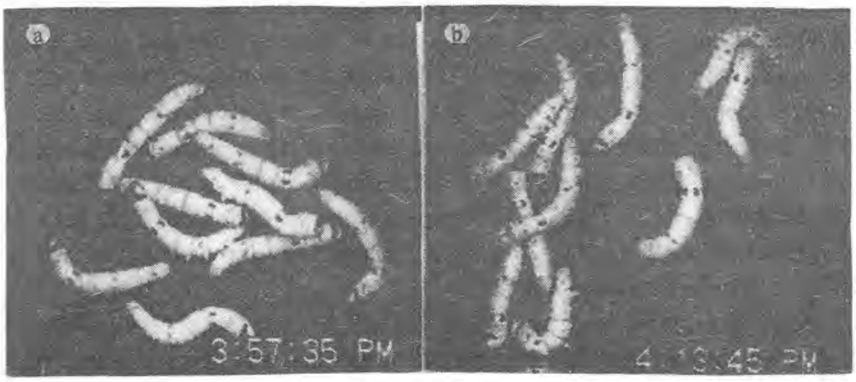

Figure 2 (a) Silkworms were placed, no DC voltage was applied
(b) The DC voltage of 35 V was applied to the electrodes

2.3 Mollusc: Close shell by a single pulse

Mollusc (Venerodia tapes japonica, and Corbicula japonica) showed responses to a single pulse of 0.5 ms. The response of Corbicula japonica before and after electric pulse are shown in Figure 3a and 3b. The open shell quickly closed when fields as low as 50 V/m are applied, even for a single pulse with the width of 5 ms. It is noteworthy that even pulsed current with a width less than 1 ms can also give the same effect. The current to individuals can be estimated roughly 10^{-6} A, which corresponds to the frog muscle cramp in Galvani's experiment of early electrophysiology.

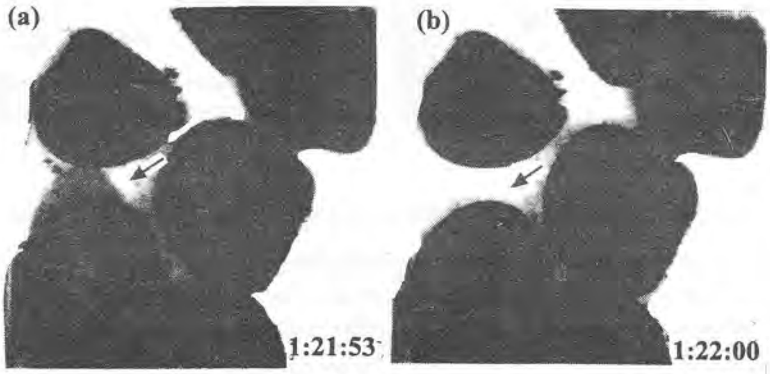

Figure 3 (a) Mollusc (Corbiular japonica) open its shell
(b) The open shell quickly closed when 50 V/m are applied

2.4 Seismic electric field intensity before the Kobe earthquake

Reports of the alignment of several fish and worms before the Kobe earthquake may be considered as SAAB. If SAAB is due to seismic electric field, its intensity may be estimated from the behaviors in a laboratory. It can be said that fish and worms must have experienced the current density of J=0.1~1 A/m^2 or field intensity of F=5~50 V/m before the Kobe earthquake according to the reports on SAAB. This intensity is million times higher than the seismic electric signal known as VAN method, 10~100 mV/km and therefore it is not accepted by seismologists. The model in next section gives an intense electric current density at the epicenter zone and a low intensity SES proportional to $1/R$ as empirically obtained in VAN method, where R is the distance from the epicenter.

3 An electromagnetic model of a fault

3.1 A model based on piezoelectricity

Stress-induced electric polarization called "piezoelectricity" is used in electronic lighters and automatic gas firing system constructed by synthetic piezoelectric ceramics. A single crystal of quartz which lacks inversion symmetry has a piezoelectric coefficient of $\alpha_{\text{quart}} = 2\times10^{-12}$ C/N. The piezoelectric effect in granite with a preferred orientation axis of quartz grains was considered to explain seismo-electric effects but the idea was abandoned as the free charges in a conductive earth cancel the piezoelectric polarization generated by the seismic stress (Finkelstein and Powell, 1970). The orientational anisotropy of olivine and pyroxene is discussed based on the directional velocity change of seismic waves. Hence, there may exist some orientational anisotropy for quartz in the area. The piezoelectric coefficient of granitic rocks was determined experimentally to be of the order of 10^{-14} C/N in this laboratory.

Stress-induced piezoelectric polarization having a surface density q_p as shown in Figure 4a is cancelled in a short time, $\varepsilon\rho$ by true charges called "bound charges" with densities, q_b in the conductive earth as shown in Figure 4b, where the dielectric constant, ε and resistivity, ρ of the earth correspond to C and R, the capacitance and impedance of rocks shown in Figure 4d (Ikeya and Takaki, 1996). Neither free charge nor electric field is present at the fault zone since the seismic

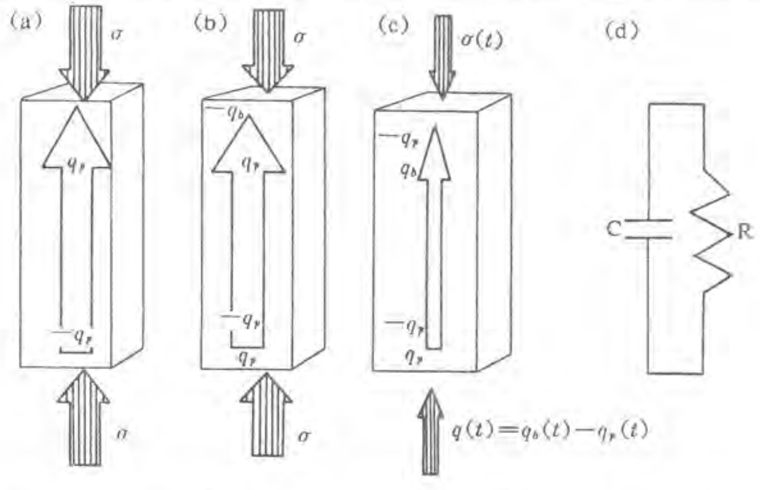

Figure 4 (a) q_p: surface density (b) q_b: "bound charges" density
(c) $q(t) = q_b(t) - q_p(t)$ (d) ε and ρ corresponding to C and R

stress has accumulated gradually for hundreds of years so as to be $q_p - q_b = 0$. However, the charge densities of $+q(t)$ and $-q(t)$, where $q(t) = q_b(t) - q_p(t)$, appear transiently at a fault zone when seismic stress is changed by faulting or by local fracture of rocks as schematically indicated in Figure 4c.

Suppose $q_p(t) = \alpha\sigma(t)$ for simplicity, where α is a piezoelectric coefficient. Both charge densities, q_p and q_b change as

$$\mathrm{d}q_p/\mathrm{d}t = \alpha\,\mathrm{d}\sigma/\mathrm{d}t \tag{1}$$

$$\mathrm{d}q_b/\mathrm{d}t = -(q_b - q_p)/\varepsilon\rho \tag{2}$$

Hence, $q(t) = q_b(t) - q_p(t)$ is, by subtracting equation (1) from equation (2),

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

The released piezo-compensation charges decay with the same time constant, $CR = \varepsilon\rho = 70$ μs for $\varepsilon^* = \varepsilon/\varepsilon_0 = 8$ and $\rho = 10^6$ Ω·m for granite that are generated by the seismic stress changes.

3.2 Alternative mechanisms of charge generation

Any mechanism which generates dipolar charges of $\pm q$ by the stress charge as given in equation (3) is applicable to the following argument. An alternative mechanism of charge separation is "solid plasma" either due to the released bound charges of piezoelectricity or due to electrons and holes during mechanical annealing of radiation-induced defects (Ikeya *et al.*, 1982). Separated charges, $+q$ and $-q$, are enormously large, for example 10^{10} electrons for a quartz grain of 1 mm × 1mm × 1 mm. An ensemble of such dipoles has a large interaction energy as to orient into one direction just as "ferroelectric transitions" within their decay time of $\varepsilon\rho$. No orientational anisotropy of minerals is needed in this mechanism.

The charges might be generated by other mechanisms such as exsoelectron emission by frictional heating (Brady and Rowell, 1986). In fact, indention fracture of rocks gave electric charge bursts with a decay time of 10 μs for heated rocks (Emoto and Hashimoto, 1990). Frictional electricity resulting from the fracture of granitic rock with different minerals may also be a mechanism of charge generation.

3.3 A mathematical model of a fault

The seismic stress drop $\Delta\sigma$ after the fault displacement can be given in a mathematical model of a fault which has a fault length $2a$ and a final displacement D, as $\Delta\sigma = \mu(D/2a)$, where μ is the rigidity of rocks (Kanamori and Anderson, 1975). The seismic stress parallel to the fault plane is given as $\sigma_0 = \mu(D'/2\beta)$, where D' is the initial velocity of the displacement and β, the velocity of the secondary seismic waves. The time-dependent displacement, $D(t)$ is expressed using the fault displacement time $\tau = D/D'$ as

$$D(t) = D(1 - \mathrm{e}^{-t/\tau}) \tag{4}$$

$$\tau = D/D' = (\Delta\sigma/\sigma_0)(\alpha/\beta) \tag{5}$$

Since the remaining strain is $[D - D(t)]/2a$, the time dependent stress is expressed as

$$\sigma(t) = \mu[D - D(t)]/2a = \Delta\sigma\exp(-t/\tau) \tag{6}$$

3.4 A seismic pulse electric field and electromagnetic waves

The condition, $q(0)=0$ gives $q(t)$ from equations (3) and (6) as

$$q(t)=\alpha\sigma_0[\varepsilon\rho\tau/(\tau-\varepsilon\rho)](\beta/\alpha)(\mathrm{e}^{-t/\tau}-\mathrm{e}^{-t/\varepsilon\rho}) \tag{7a}$$

or

$$q(t)=\alpha\Delta\sigma[\varepsilon\rho/(\tau-\varepsilon\rho)](\mathrm{e}^{-t/\tau}-\mathrm{e}^{-t/\varepsilon\rho}) \tag{7b}$$

This represents a pulsed charge density with a rise time of $\varepsilon\rho$ (or τ for $\varepsilon\rho>\tau$) and the decay time τ (or $\varepsilon\rho$). Charges are sustained in the fault zone so long as they are generated by the stress changes. Hence, the duration time is the longer one of τ or $\varepsilon\rho$.

The electric field at a fault zone is obtained using the relationship above and $F(t)=q(t)/\varepsilon$ so that

$$F(t)=\alpha\rho\sigma_0(\beta/\alpha)(\mathrm{e}^{-t/\tau}-\mathrm{e}^{-t/\varepsilon\rho})/(1-\varepsilon\rho/\tau) \tag{8}$$

The time-dependent field intensity has a sharp rise time of $\varepsilon\rho$ depending on the geology of the area and a slow decay time of τ which depends on the mode of fault movement or local fractures.

The total polarization $\boldsymbol{P}(t)$ of the charge $\pm q(t)$ separated $2a$ is $\boldsymbol{P}=2aQ=2aAq=(M_0/\Delta\sigma)q$ using the earthquake moment $\boldsymbol{M}_0=\mu DA=2aA\,\Delta\sigma$ as

$$\boldsymbol{P}(t)=\alpha\boldsymbol{M}_0[\varepsilon\rho/(\tau-\varepsilon\rho)](\mathrm{e}^{-t/\tau}-\mathrm{e}^{-t/\varepsilon\rho}) \tag{9}$$

where the earthquake moment $\boldsymbol{M}_0$ is given by the moment magnitude, M_{W} as $M_0=10^{1.5M_{\mathrm{W}}+9.1}$ The total charge Q at a fault zone is expressed as

$$Q(t)=\alpha[\boldsymbol{M}_0/2a][\varepsilon\rho/(\tau-\varepsilon\rho)](\mathrm{e}^{-t/\tau}-\mathrm{e}^{-t/\varepsilon\rho}) \tag{10}$$

The time-dependent electric dipole moment generates the electromagnetic (EM) waves having a Poynting vector of

$$\begin{aligned}N(x,t)&=(1/4\pi R)^2(\mu_0/c)[\mathrm{d}^2P/\mathrm{d}t^2]^2\sin^2\theta\\&=(1/4\pi R)^2(\mu_0/c)\sin^2\theta\{\alpha\boldsymbol{M}_0[\varepsilon\rho/(\tau-\varepsilon\rho)][\mathrm{e}^{-t/\tau}/\tau^2-\mathrm{e}^{-t/\varepsilon\rho}/\varepsilon^2\rho^2]\}^2\end{aligned} \tag{11}$$

where θ is the angle between the direction of the dipole and the distance R. Therefore the electric field intensity $[\mu cN(x,t)]^{1/2}$ is reciprocally proportional to the distance R from the fault zone somewhat in concordance with the empirical relation in the Greek VAN method (Varatos and Alexopoulos, 1984).

The propagation of electromagnetic waves depends on the wavevector, k, being a complex, i.e., $k=k'+\mathrm{i}k''$ in a conductive earth. The high frequency component decays due to the small skin depth δ, $\delta=1/k''$, where k'' is expressed by the permeability μ' as

$$k''=\omega(\mu'\varepsilon/2)^{1/2}\{[1+(1/\omega\varepsilon\rho)^2]^{1/2}-1\}^{1/2} \tag{12}$$

Only ultra low frequency (ULF) waves can propagate and be reflected by the conductive sea water and come out of the land.

4 Discussion

4.1 SAAB which suggest electric field effects

The potential difference between the head and the tail is about 0.2 V for the length of the minnow, 20 mm for the field of 10 V/m. Assuming the cross section of 1 mm^2 for the eye and electosensory organs, the estimated body current, neglecting the edge effect, is of the order of 1 μA; the skeletal muscle parallel to the field direction has a resistivity of ρ =2 Ω·m. Excitation contraction coupling leads to contraction of the skeletal muscle as known Galvani's frog muscle current of the order of μA in early electrophysiology.

The current is reduced as the resistivity perpendicular to skeletal muscle, since in this case ρ =14 Ω·m (Misakian *et al.*, 1993). The alignment would enable minnows to reduce the body current density from 5 A/m^2 to 0.7 A/m^2, i.e., by nearly one order of magnitude. Swarming of earthworms will reduce the body current in individual worm.

Estimation of the body current for silkworms is difficult considering the contact impedance of the legs to the ground. However, the field intensity is about 230 V/m and so the voltage is about 4 V for parallel and 0.2 V perpendicular to the field considering the size of silkworms. A similar argument on the resistivity difference of skeletal muscle is possible for the orientation of silkworms.

Animals did not anticipate the earthquake but probably responded to intense electric pulses which caused electrophysiological responses. Dissolution of Ca^{2+} from the membranes or synapses of the nervous system by seismic body current will cause some excitement and panic by producing neurotransmitters and postsynaptic conductance of Na^+ ions leading to the excitatory postsynaptic potential. The time required to fire neurons is more than 1 ms. This agree with the result that electric pulses having the width much less than 0.1 ms does not affect animals appreciably. After sufficient excitation, postsynaptic inhibition may occur, resulting in panic and exhaustion; some rats may have become so docile as to be captured prior to the earthquake.

4.2 Coseismic and preseismic SAAB

4.2.1 On earthquake ($\tau >> \varepsilon\rho$)

We estimate $F_{max} = \rho\alpha\sigma_0(\beta/\alpha)$=1 V/m for $\tau >> \varepsilon\rho$ and τ =1 s from the rise time of seismic waves, β=4 km/s, α=5 km, $\sigma_0=10^8$ N/m^2 and $\alpha=1\times10^{-14}$ C/N, 0.5% of that for quartz, α_{quarz} constituting more than 50% of granite. The bedrock granite has $\rho=10^6$ Ω·m down to the depth of the focal point, 20~30 km. The current may be concentrated at the surfaces of conductive wet sediments, the sea, and rivers with $\rho' = 10^2\,\Omega\cdot m$ giving $J = F/\rho' \approx 10^{-2}\,A/m^2$ which is just enough to shock animals sensitive to electric fields. However, a single pulse with a relatively long time of 1 s will not produce sufficient amount of neurotransmitters in their nervous system as to cause prominent SAAB.

4.2.2 Prior to earthquake ($\tau << \varepsilon\rho$)

Small local fractures along the fault prior to the main shock in rocks give τ of the order of 10^{-4} s since the stress drop rate is much smaller than 1%. The fractures may produce acoustic emissions which can not, however, be detected with the present seismographs at 100~200 Hz. Such fractures result in the stress changes and so the local disappearance of the piezoelectric effect giving electric pulses with a decay time τ. Partial movement of a fault gives $\tau = 2.5\times10^{-4}$ leading to

$$J_{max} = \alpha\sigma_0(\beta/a)(\rho/\rho') = 8\ A/m^2$$

It is worthy of being noted that the peak current density is higher in case of local fractures than at the time of earthquake. The animals response is thus preseismic rather than coseismic.

The locations of SAAB and the resistivity of the area should be compared. Geological and geographical studies of the sites where SAAB are observed should be investigated. The seismic current will be focused on a water channel or on a valley surrounded by granitic rocks or on thin sediments on the granite rocks. Such focusing may be understood using the analogy of a strong wind in a valley surrounded by high mountains. A high tidal water or rapid water flow in a narrow valley or a channel may be another analogy. The seismic current may be focused on well conductive sediments and a water channel from granitic rocks.

SAAB is not paranormal phenomena, but simply electrophysiological responses of animals to pulsed SES current. One can estimate the intensity of SES and its direction from the reports on fish orientation before the Kobe earthquake.

4.3 ULF waves and electric pulse as SES

An electromagnetic model of fault behavior based on dipolar charge generation is used to explain the pulsed field and the current which cause abnormal animal behavior. Pulsed electric field is a wave packet of electromagnetic waves. The high frequency component is dissipated due to a small skin depth in propagation. The SES detection by means of VAN method of the order of 10^{-5} V/m might be due to the detection of ULF electromagnetic waves of 0.1~10 Hz. The electric field intensity is proportional to $[\mu c N(x,t)]^{1/2}$ or to $1/R$ for ULF waves rather than to $1/R^3$ for the static electric field induced by dipolar charges. This is agreement with the early experimental result of SES intensity ΔV proportional to $1/R$ (Varatos and Alexopoulos, 1984). The empirical law of SES, $\lg(\Delta V) = 0.37M + c$ can be derived theoretically as $\lg(\Delta V) = 0.375M_W + c'$, where M, M_W and c are magnitude, moment magnitude and a constant related with the site (Ikeya *et al.*, 1997).

The electromagnetic waves will propagate between the conductive Moho plane and the conductive sea just like the microwave propagation on stripline sandwiching dielectric earth and go out to atmosphere and propagate between the ionosphere and the earth surface. Electromagnetic waves from the earth appear at the edge of a conductive sea causing intense field at the boundary as a near-field (or evanescent wave) since the wavelength is longer than the land (island) dimension. The seismic pulse signals from an fault may be detected using modern digital storage oscilloscope with appropriate triggering level rather than by human or electronic watching of animals (Ikeya *et al.*, 1997).

In addition, simultaneous observation of electromagnetic waves and anomalous behavior of eels, rats, mice, hamsters and parrots were made during the fracture experiments of granite using a 200-ton and a 500-ton compression machines. Details of the works will be published separately, elsewhere.

5 Conclusions

Alignment of silkworms and fish, observed before the Kobe earthquake were duplicated in a laboratory by applying a pulsed electric field. An electromagnetic model of a fault is proposed in which dipolar charges, $\pm q$ are generated due to the change of seismic stress. The field intensity, F, and seismic current density at a fault zone, J were calculated as to give $J = 0.1\sim1$ A/m^2 sufficient to cause animal anomalous behavior experimentally. The ULF waves generated by charges give SES reciprocally proportional to the distance R. An equation of pulsed seismic electric signal

(PSES) derived theoretically is a wave packet of electromagnetic waves and should be measured using a digital storage oscilloscope at fault zones for early warning.

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