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Electric Shocks Resulting in Seismic Animal Anomalous Behaviors (SAABs)

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Electric field effects on fish and worms have been studied assuming that the seismic animal anomalous behaviors (SAABs) witnessed prior to the Hansin Earthquake were caused by seismic electric current. Japanese minnows, guppies and loaches responded to the current and aligned perpendicular to the field direction and earthworms swarmed, which are forms of SAABs, at a current density of $J = 0.1 \sim 1\,\mathrm{A/m^2}$ presumably to reduce the effects of the field, F. A mathematical model of a fault was used to express the seismic stress, $\sigma(t)$ corresponding to a fault displacement, $D(t)$. An electromagnetic model of a fault, where a bound charge density, q which compensate the piezoelectric polarization, appears due to the release of seismic stress is used to derive $\mathrm{d}q/\mathrm{d}t = -\alpha(\mathrm{d}\sigma/\mathrm{d}t) - q/\varepsilon\rho$, $F = q/\varepsilon$ and $J = F/\rho'$. Using the piezoelectric coefficient, α, dielectric constant, ε and the resistivity, ρ of bedrock granite and ρ' of water gives $J = 1\,\mathrm{A/m^2}$ in concordance with the experiments.

KEYWORDS: earthquake, piezoelectric, stress, fault, anomalies, fish, worm, guppy, minnow, loach, earthworm, lugworm

§1. Introduction

Seismic animal anomalous behaviors (SAABs) of mammals, birds, reptiles, fish, insects and worms were observed prior to the Hansin Earthquake that destroyed Kobe on January 17, 1995.[1] Some animals became nervous, excited and panicked before the earthquake. SAABs have long been discussed in popular science.[2,3] Some people regard SAABs as superstition and retrospectively asserted stories after the earthquake. Some believe that they are genuine phenomena belonging to superscience and hope to predict earthquakes by observing various animals, especially catfish which have been associated as SAABs for many years.

Most animals do not experience a major earthquake during their relatively short lifetime. They must have detected some kind of intense signal such as sounds, smells or electromagnetism before the Hansin Earthquake.[3] What did they detect? Why did they panic? No clear mechanism has yet been proposed for SAABs.

Reports of aligned fish and silkworms and dead and panicking fish interested us in addition to those of swarming and dead earthworms.[1] We have been dating fault movements[4] and developing an electromagnetic model of a fault to explain auroral light observed just before earthquakes.[5] The current induced by the disappearance of piezoelectric effects due to the seismic stress release might be detected by sensitive animals as to cause electric shocks in water or in wet soil. In fact, many aquatic animals have electrosensory systems which are used to acquire information for orientation and to communicate with others.[6] Some mammals and birds are more sensitive to electric field than human being as studied on hazard close to electric power transmission lines.[7]

We have applied electric fields to fish and worms in order to investigate the hypothesis that SAABs are responses to electric shocks. Japanese minnows, guppies and loaches have aligned perpendicular to the applied field and earthworms congregated presumably to minimize electric shocks. The current density, J obtained in a laboratory was the same as the seismic one calculated using an electromagnetic model of a fault.

§2. Experimental

Ten Japanese minnows, guppies and loaches purchased from a petshop were put into an aquarium with copper electrodes with a separation d, of 20 cm or 10 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. Animal 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 AC frequency ranged from 0.1 to 10 MHz and sinusoidal, saw-tooth and rectangular waveforms were used. The DC voltage was switched on and off. The current density, J that affects animal behavior was determined for the field intensity, F, where $F = V/d$.

§3. Results and Discussion

The Japanese minnows moved quickly under electric field as small as $10\,\mathrm{V/m}$ ($0.2\,\mathrm{A/m^2}$) and aligned perpendicular to the field direction at $0.5\,\mathrm{A/m^2}$ as shown in Fig. 1. The voltage was switched on and off manually every 3 seconds. Sensitive minnows were paralyzed at $J = 1\,\mathrm{A/m^2}$, but recovered. They responded to a single pulse with the width of $100\,\mu\mathrm{s}$. Guppies and loaches responded similarly with quick and slow movement, respectively at the same current density.

The rectangular waveforms produced a large apparent

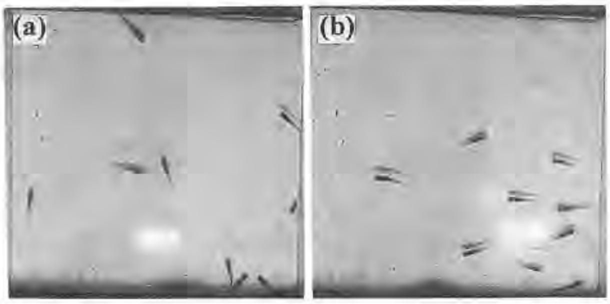

Fig. 1. Japanese minnows (a) before and (b) after application of the electric field. Minnows aligned perpendicular to the electric field, $F = 25\,\mathrm{V/m}$ at the current density of $J = 0.5\,\mathrm{A/m^2}$. Alignment and death of fish were witnessed together with other seismic animal anomalous behaviors (SAABs) before the Hansin Earthquake on January 17, 1995.

response at a particular frequency range. The changes of the electrode separation shifted the response frequency. The responses were very small for sinusoidal waves. The current density, J and the power density $P = FJ$ were high in the case of rectangular waveforms due to the low impedance, $Z = F/J$ in that frequency range. The apparent dependence of the behaviors on frequency and waveform could simply be due to the impedance effect.

Earthworms and lugworms moved out of the soil and swarmed when the current was applied. Some small earthworms responded at a higher frequency than large earthworms in the same environment. The local inductance, L and capacitance C of an earthworm, which are both proportional to its length, will give a low impedance at a resonant frequency $\omega = 1/(LC)^{1/2}$ proportional to the reciprocal length of the animals. This frequency response would also be attributed to the local impedance effect. We dipped our fingers in the same fish tank and felt a very faint stimulus as summarized in Table I. These experiments suggest that fish and worms must have felt a current density of $J = 0.1 \sim 1\,\mathrm{A/m^2}$ or field intensity of $F = 5 \sim 50\,\mathrm{V/m}$ at the earthquake considering reports on SAABs.[1)]

The current density shown in Table I is much larger than the smallest value which sensitive animals can detect in water of $50\,\Omega$-m. Consider the size of the animal, the current is of the order of μA assuming that the animal body has the same resistivity as that of water. If the resistivity is lower than that of water, the current will be concentrated in the fish and thus align them perpendicular to the current flow. This alignment would enable fish to avoid electric field effects. Swarming will reduces current effects in individual worms.

§4. An Electromagnetic Fault Model to Calculate Current

Our proposed model is based on the appearance of the piezo-compensating bound charge densities, $+q$ and $-q$ at the fault zone due to the disappearance of the piezoelectric polarization caused by the release of the seismic stress, σ. Using the piezoelectric coefficient, α, q is given by

$$\mathrm{d}q/\mathrm{d}t = -\alpha(\mathrm{d}\sigma/\mathrm{d}t) - q/\varepsilon\rho, \tag{1}$$

where the dielectric constant, ε and resistivity, ρ of the earth correspond to C and R, the capacitance and resistance of rocks. The bound charges also decay with a time constant, $CR = \varepsilon\rho = 70\ \mu$s for $\varepsilon^* = \varepsilon/\varepsilon_o = 8$ and $\rho = 10^6\,\Omega$-m for granite; Frictional heating at the fault might increase ρ to $10^{10}\,\Omega$-m[8)] giving $\varepsilon\rho = 0.7\,$s.

The piezoelectric effect in granite with a preferred orientation axis of quartz grains is considered by earth scientists to explain seismo-electric effects.[9)] The orientational anisotropy of olivine and pyroxene is discussed based on the directional velocity change of seismic waves. However, the piezoelectric polarization itself is described erroneously as a source of charge and electric field.[10)] In the Earth, which is conductive, the polarization is canceled in a short time, $\varepsilon\rho$ by real charges called "bound

Table I. Effects of electric field, F (V/m) on fish and worms for estimating the critical current density, J (A/m^2) to explain seismic animal anomalous behaviors (SAABs).

Animal	F (V/m)	J (A/m^2)	P (W/m^3)	[a)]Response
Minnow	14	0.27	4	Q
	25	0.5	13	A
	70	1.2	84	P
Guppy	10	0.25	2.5	Q
	14	0.5	7	A
Loach	30	0.3	9	Q
	70	0.7	50	A
	100	1.0	100	P-P
Earthworm	170	3.3	567	P-S
Lugworm	100	4.0	400	P-S
Human	25	0.5	13	SW
(Health bath)[b)]	20	0.1–0.3	3–9	MR

[a)] Q: Quick movements when voltage was swiched on & off
A: Aligned perpendicular to field
P-P: Panic and some paralyzed
P-S: Came out of soil and swarmed
SW: Finger stimulated very weakly
MR: Muscle relaxation

[b)] Calculated from the conditions of an electric bath for health care given by government regulations.

charges". Hence, no electric field is present at a fault zone before stress release occurs.

The mathematical model of a fault[11,12] gives $\sigma(t) = \mu[D - D(t)]/2a$, where μ, D, $D(t)$ and a are the rigidity of rocks, the final and time-dependent displacements and the half-length of a fault, respectively. This gives $D(t) = D(1 - e^{-t/\tau})$ using the time, $\tau = D/D' = (\Delta\sigma/\sigma_o)(a/\beta)$, where D' is the initial displacement velocity, $\Delta\sigma$, the stress drop after displacement, σ_o, the stress parallel to a fault plane and β, the velocity of the secondary seismic waves.

The condition, $q(0) = 0$ gives $q(t)$ from eq. (1) using the relations in the above model and $F(t) = q(t)/\varepsilon$ is obtained as

$$F(t) = \rho\alpha\sigma_o(\beta/a)(e^{-t/\tau} - e^{-t/\varepsilon\rho})/(1 - \varepsilon\rho/\tau), \quad (2)$$

The field has a sharp rise time of $\varepsilon\rho$ and decay time τ. We estimate $F_{max} = \rho\alpha\sigma_o(\beta/a) = 10^2\,V/m$ for $\tau \gg \varepsilon\rho$ and $\tau = 1\,s$ from the risetime of seismic waves, $\beta = 4\,km/s$, $a = 5\,km$, $\sigma_o = 10^8\,N/m^2$ and $\alpha = 10^{-12}\,C/m^2$ for quartz constituting more than 50% of the granite bedrock with $\rho = 10^6\,\Omega$-m down to the depth of the focal point, which is $20 \sim 30\,km$. The current may be concentrated at surface conductive wet sediments, the sea, and rivers with less than $\rho' = 10^2\,\Omega$-m giving $J = F/\rho' =\sim 1\,A/m^2$ which is sufficient to shock animals sensitive to electric field. The areas where SAABs were observed would be limited to granite regions with shallow sediments.[5)]

Small local fractures in rocks prior to the major shock cannot be detected with the seismograph at 100 Hz, but result in the local disappearance of the piezoelectric effect for a short time. A partial movement of a fault with an effective length of $a = 1\,m$ gives $\tau = 2.5 \times 10^{-4}\,s$ leading to $J_{max} = \alpha\sigma_o(\beta/a)(\rho/\rho') = 4000\,A/m^2$. We have used $\alpha = 10^{-12}\,C/N$, half that of a quartz crystal, which might be an overestimation of several orders of magnitude. However, this overestimation is compensated by high current density considering local fractures along the fault prior to the main shock and the enhancement of the current for geographical reasons. The locations of SAABs and the resistivity of the area should be compared.

An electromagnetic fault model based on piezo-compensating bound charges is used to explain the pulsed field and the current which cause abnormal animal behaviors. Any model,[13-15)] if it gives a seismic current density of $J \sim 1\,A/m^2$, is also plausible. If this model is correct, a pulsed seismic electric signal (SES) as expected from eq. (2) rather than the DC signal by VAN method[14)] should be measured in fault zones for early warning although the prediction of the exact time and place of an earthquake will still be difficult due to the catastrophic fracture phenomenon. The warning pulse signals from an electromagnetic fault may be detected using modern electronic techniques rather than by watching animals. This letter asserts that SAABs are not superscientific phenomena, but electrophysiological responses of animals. Further work on the effects of other signals such as acoustic waves may also be needed to confirm this proposal.

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Note added in proof—Mammals, birds and mollusk responded to electric field, some even to a single pulse of 10 V/m having the width of less than 0.1 ms. It corresponds to 1 mV/m in DC-SES measurement. Animals did not predict earthquake but simply responded to electric pulses.