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Seismic Electric Signals and Animal Anomalies

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Abstract Flying bats and flocking birds as well as rats in panic were witnessed in addition to snakes and earthworms coming out of earth prior to the Hansin Earthquake on January 17, 1995. Among seismic animal anomalies (SAAs), the alignment of fishes and animals in panic witnessed as SAAs have been duplicated by applying the electric field intensity, F of less than 100 V/m (the current density, $J=1$ A/m^2) in a laboratory experiment. A model of electromagnetic fault has been proposed to account for critical J by assuming the appearance of bound charges, q by the disappearance of piezoelectric polarization due to the release of the seismic stress, σ at a fault zone. The equation $dq/dt=-\alpha(d\sigma/dt)-q/\varepsilon\rho$, where α, ε and ρ are the piezoelectric coefficient, the dielectric constant and resistivity of earth, leads to $q(t)=\alpha\sigma_0\varepsilon\rho(\beta/a)\ (e^{-t/\tau}-e^{-t/\varepsilon\rho})/(1-\varepsilon\rho/\tau)$. The estimated $F=-q/\varepsilon=100$ V/m and $J=1$ A/m^2 for local fractures of rocks are concordant with those in the experiments. The focusing of J to wet sediments as well as to underground fissures and caves are discussed together with electromagnetic anomalies (EMAs) and earthquake lightnings (EQLs).

1. Introduction

Anomalous behaviors of mammals, birds, reptiles, fish, insects and worms were witnessed prior to the Hansin Earthquake that had destroyed Kobe and killed more than 6,500 people on January 17, 1995 (WADATSUMI, 1995). Seismic animal anomalies (SAAs) has long been interests in popular press and books and treated as if it is superscience beyond our understanding. The SAAs are known from Greek and Roman time (TRIBUTSCH, 1978; BUSKIRK *et al.*, 1981). Some "western" scientists consider observation of such phenomena as "pathological response", as the report is retrospective and exaggerated by people and local presses. Studies on SAAs regarded as superstition are considered as pathological science which no serious scientists should be involved. Some tells as if earthquake prediction is possible from phenomenological observation without scientific reasoning.

Man's friend, dogs barked as if trying to tell the patron coming earthquake. Cats attempted to go out of home. Rats, birds and other animals disappeared or

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were seen in a large number as if they all moved to other place in order to avoid the major earthquake disasters. Snakes and tortoise came out even in winter. A swarm of earth worms came out of soil and died. Bats that usually live in caves were observed flying in winter. They all seem to know the earthquake disaster. These witnesses agree with those reported in a book by the Biophysical Institute, Academica Sinica (1977) and by TRIBUTSCH (1984) and told all over the world for thousands of years.

Most animals had no earthquake in their life-spans, but seemed to know the danger before it. Although the reasons are not clear at the moment, reported SAAs indicate that animals are actually detecting some precursor of major earthquakes. If they do, what do they detect and why were they excited? Are the SAAs still superscience beyond the present level of our sciences?

Among reported witnesses, aligned fish, swarmed earthworms and flying bats (WADATSUMI, 1995) interested us considering our model of an electrostatic fault for earthquake lightnings (EQLs) (DERR, 1973; FINKELSTEIN & POWELL, 1970; LOCKNER *et al.*, 1983; TERADA, 1931), where bound charges that have canceled the stress-induced piezoelectric polarization of quartz bearing rocks appear by disappearance of the polarization by seismic stress release (IKEYA & TAKAKI, 1996).

We have extended the model of bound charge generation to the current flow which causes animal anomalies as electric shocks. To prove the hypothesis, we applied voltage to fish and aligned them perpendicular to the electric field at the current density of a few tenth of 1 A/m^2 corresponding to less than 10 μA for fish (IKEYA *et al.*, 1996 a); the alignment of fish and silkworms were reported as SAAs. Further work using rats and sparrows indicated that current flow of a few μA excite these animals finally to motion in panic (IKEYA *et al.*, 1996 b).

This is the first paper in a series of our scientific works dealing with the superscientific phenomena prior to an earthquake. An outline of our research and the basis are described to explain the bound charge appearance and the induced-current enhancement as to cause the seismic animal anomalies. The calculated current density agrees with the experimental one.

2. A Model of an Electromagnetic Fault for Seismic Current

Piezoelectric polarization by the seismic stress is often mistaken to produce electric field at the fault zone. Bound charges quickly compensate the piezoelectric polarization in the conductive earth with resistivity ρ and the dielectric constant ε in a time constant $\varepsilon\rho$ corresponsing to CR for a capacitance C and the resistance R of the separated charges in earth. Hence, no electric field is detected at the fault zone.

A model of an electromagnetic fault is based on the sudden appearance of

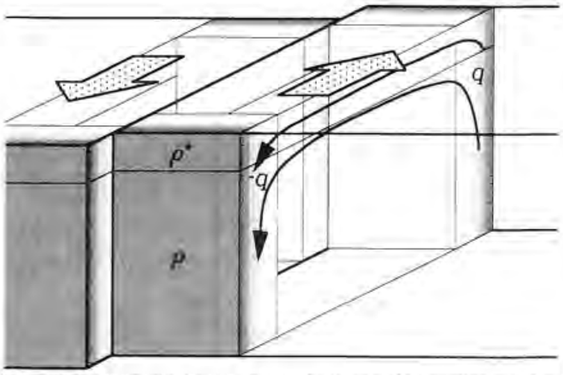

Fig. 1. A schematic model of an electromagnetic fault for illustration of the seismic current in the conductive sediment by the bound charges of piezoelectric polarization after disappearance of the piezoelectric effects by seismic stress release. The conductivity of rocks (granite), $\rho=10^6$ Ωm and $\rho'=10^2$ Ωm were assumed to calculate the current density, J.

the bound charges $+q$ and $-q$ by the disappearance of piezoelectric polarization at the fault zone due to the seismic stress release as schematically shown in Fig. 1. The released bound charge density is described by

$$dq/dt=-\alpha(d\sigma/dt)-q/\varepsilon\rho, \quad (1)$$

where α is the piezoelectric coefficient, $\sigma(t)$ the time dependent stress. A mathematical fault model gives the displacement, $D(t)$ of a fault having the length, $2a$, the final displacement, D, the initial displacement velocity D' (KANAMORI & ANDERSON, 1978; SHOLZ, 1993) and the displacement time, τ as

$$D(t)=D(1-e^{-D't/D})=D(1-e^{-t/\tau}) \quad (2)$$

$$\tau=D/D'=(\Delta\sigma/\sigma_0)/(\beta/a) \quad (3)$$

where $\Delta\sigma/\sigma_0$ is the rate of stress drop, $\beta=3.5\sim4$ km/s is the velocity of the secondary seismic waves using $D=2\Delta\sigma a/\mu$ and $D'=2\sigma_0\beta/\mu$, given in a textbook; $\tau=1.2$ s for $a=6$ km for the Nojima Fault.

The condition of $q=0$ at $t=0$ gives a solution for $q(t)$ using the stress $\sigma(t)=\mu[D-D(t)]/2a$. The charge density, $q(t)$ is

$$q(t)=\alpha\sigma_0\varepsilon\rho(\beta/a)(e^{-t/\tau}-e^{-t/\varepsilon\rho})/(1-\varepsilon\rho/\tau), \quad (4)$$

where σ_0 is the stress parallel to a fault plane, $\sigma_0=10^8$ N/m^2. The field intensity, $F(t)$ is equal to $q(t)/\varepsilon$ and so the current density in a wet sediment or in a channel like a wet cave having the resistivity ρ', $J'(t)$, may be written as

$$J'(t)=-q(t)/\varepsilon\rho'=\alpha\sigma_0(\rho/\rho')(\beta/a)(e^{-t/\tau}-e^{-t/\varepsilon\rho})/(1-\varepsilon\rho/\tau). \quad (5)$$

Eq. 4 and Eq. 5 are the basis for illustrating most phenomena prior to the earthquake including SAAs. Numerical values of α are discussed by VOLAROVICH & SOBOLEV (1965) and other seismic parameters in the literature (KANAMORI & ANDERSON, 1975; SHOLZ, 1993).

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3. Earthquake Lightnings (EQLs)

Earthquake lightnings (EQLs) observed by many including our garduate student were calculated based on the excitation of molecules by electrons accelerated under the electric field F induced by the assumed q considering atmospheric polarization. EQLs at the altitude of z close to the ground was obtained using numerical values of the Nojima Fault. The effective field considering the polarization, $F(z)-(e/\varepsilon_0)n(z)l(z)$ was integrated with the distance from zero to $l(z)$ as to give the acquired electron energy, $E(z)=el(z)[F(z)-(e/\varepsilon_0)n(z)l(z)/2]$. Accelerated electrons excite or ionize atmospheric N_2 and O_2 molecules for $E(z)>10$ eV with the probability of $\exp[-l(z)/\lambda(z)]$, where the mean free path, $\lambda(z)$ depends on the pressure and the temperature.

The spatial distribution of EQLs was calculated from $F(x, y, z)$. The intensity of EQLs with the photon production of $N_{ph}=5\times10^{14}/\mathrm{m^3s}$ close to the fault has an equi-intensity shape photographed at the Matsushiro Earthquake (BUSKIRIK *et al.*, 1981) and also witnessed in the Hansin Earthquake by many (WADATSUMI, 1995). The light intensity entering to 1 cm^2 of human eyes is 10^{10} photons/s per solid angle of 1 degree along the fault line and 10^9 photons/s perpendicular to it. A man standing 50 km away from the fault zone will see roughly 5×10^7 photons/s. These numbers are bright enough to be seen. Two or three successive EQLs at the Hansin Earthquake might come from the movement of two or three faults as estimated from seismic waves. One under sea might be electrically shielded by the conductive sea water.

4. Electromagnetic Anomalies (EMAs)

4.1 *A short time communication disturbances*

The characteristic plasma-electron frequency is expressed as

$$f_e=(e/2\pi)(n/\varepsilon_0\mu)^{1/2}, \tag{6}$$

where n is the number of electrons in the upper atmosphere. The change in n will result in the change in the radiowave reflection at the lower altitude leading to the difficulty in the telecommunication soon after the earthquake.

4.2 *Generation of electromagnetic waves*

(a) *Half-wavelength antenna*

Electromagnetic waves may be produced from the time dependence of $q(t)$ and from the charges produced on both end or the depth of the fault lines. The length $2a$ or the depth $A/2a$ is equivalent to the half wavelength of the electromagnetic waves. For a "half-wavelength antenna", the frequency is as $f=c/4a$ or $f=ca/\varepsilon A$ corresponding to 10 to 20 kHz using the light velocity, c.

(b) *f frequency*

The prompt decay of charges with the decay time $\varepsilon\rho$ and their generation

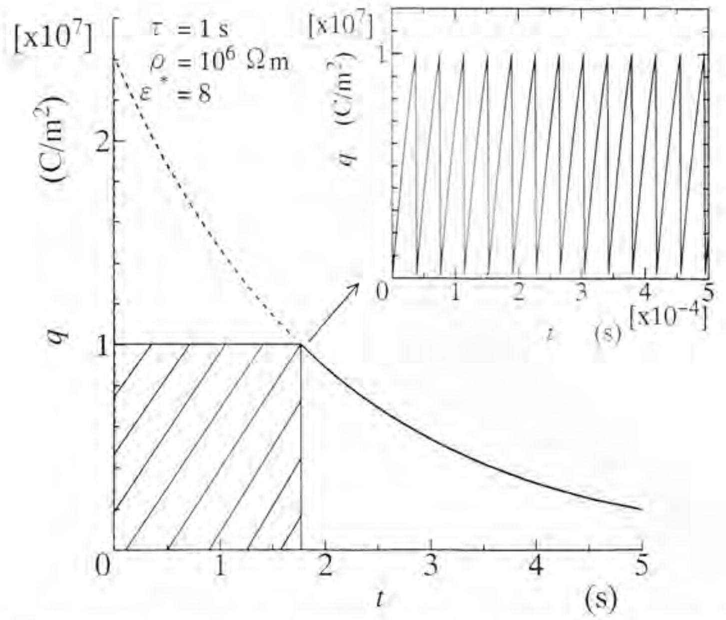

Fig. 2. Change of the bound charge density $q(t)$ by the seismic stress release due to the movement of the fault using Eq. 4 for the specific resistivity ρ and specific dielectric constant $\varepsilon^*=8$. If the dielectric breakdown occurs for a high charge density (a high field intensity of $F=q/\varepsilon$), discharge occurs resulting in the oscillation because of the charge generation by the stress release.

during faulting will produce electromagnetic waves at the frequency of $f=1/\varepsilon\rho$ ranging from 20 kHz to 200 MHz for $\rho=10$ to 10^6 ohm-m. If there were dielectric breakdown due to the induced high voltage, the increased charge density will be rapidly discharged. However, the stress release will again generate the charge so long as the fault moves or the fracture proceeeds. Then, the oscillation is expected as in Fig. 2 calculated by using Eq. 4.

5. Seismic Current and Electric Field Effects on Animals

We estimate $J_{max}=\alpha\sigma_0\beta/a=10^{-4}$ A/m^2 for $\tau\gg\varepsilon\rho$ using $\tau=1$ s from the risetime of seismic waves and tentative piezoelectric coefficient of granite, $\alpha=2\times10^{-14}$ C/N, about 1% of that of quartz which constitutes more than 50% of granite bedrock. The current has a sharp risetime of $\varepsilon\rho$ ranging from 5 ns to 50 μs for $\varepsilon^*=\varepsilon/\varepsilon_0=8$ and $\rho=10^2-10^6$ ohm-m (typically for sandstone and granite). This indicates that J is smaller than 1 A/m^2 at the time of the earthquake.

Local fractures of rocks along fault prior to major shocks[6] will, however, result in the local disappearance of the piezoelectric field in a short time of $\tau=(\Delta\sigma/\sigma_0)(a/\beta)$ for a small a. The local fractures would be as small as a few m for

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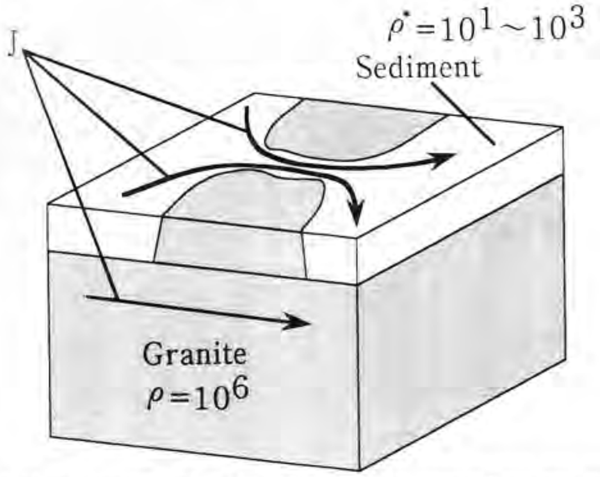

Fig. 3. A model of the current and field enhancement by geographical and geological reason. Seismic animal anomalies were inhomogeneously observed around the epicenter or fault zone because of the inhomogeneous conductivity of earth. The current will be enhanced on thin sediment layers on the bedrock granite, i.e. on mountains with rocks and in water channels. Detailed calculation of the enhancement ratio is shown in Appendix.

rocks or a few mm for quartz grains giving $\tau=10^{-3}\sim10^{-6}$ s. We cannot detect the fracture as seismic waves for $\tau=1\times10^{-3}$ s by the present seismograph at 200 Hz. Hence, $J_{\max}=a\Delta\sigma/\tau=10^{-2}\sim10^{2}$ A/m^2 is obtained. Pulsed current with $J>$ 1 A/m^2 may appear depending on τ and $\varepsilon\rho$ in Eq. 5.

The current will further be focused from the bedrock granite (10^6 ohm-m) to the coductive wet sediments, sea, and rivers ($\rho=1-10^2$ ohm-m), where earth worms, fish, snakes and water birds inhabit as illustrated in Fig. 3 and calculated in Appendix. For example, Japanese minnows showed quick movement responses by applying as small as 2 V/m to the electrodes if the field is switched on and off (IKEYA *et al.*, 1996 a). They have aligned perpendicular to the direction of the applied field, F minimize electric shocks. Sensitive minnows were paralyzed at $J=1$ A/m^2. Loaches also aligned but responded slowly. Earthworms and lug worms moved out of the soil in panic and aggregated and swarmed to avoid the field effects as observed before the Hansin Earthquake. Dead earthworms were observed close to the fault zone. Fish and worms must have felt at least $J=1$ A/m^2 considering reports on SAAs.

Although SAAs recorded in history and reported by Chinese are considered fishy by "western" scientists, these fish experiments clearly indicates that the SAAs may be behaviors of seismic electric shocks. An extraordinary high field intensity and current density might occur in some geographical area as indicated in Appendix: Chinese seismologist observation that SAAs are not uniformly distributed around the fault zone or the earthquake epicenter may be interpreted considering geological and geographical assessment.

It is speculated that more than 10 V has been applied between legs of the animals from the reported SAAs. A report of the swan response that they lied on snow putting their legs up and that of ducks avoiding to enter a river suggest the electric current effect. Alligators running to the forest from rivers and seagulls flying to the inland from sea seem to support this hypothesis.

6. Cave Bats: Seismic Current or Other Signals ?

SAAs systematically catalogued in China for the use in earthquake prediction can be well understood with this model. Dogs, horses, cows and pigs are known to be sensitive to electric current since they possess Pacinian corpuscles in their footpads (BUSKIRK *et al.*, 1981). Animals with a very sensitive paw will feel weak electricity than human beings. Pulsed current of $0.1\sim1$ A/m^2 can be detected with a finger. Chickens flying to the roof and rats climbing to the electric pole and wires as witnessed in China would be to avoid electric current. Experiments indicated that red sparrows fall in anxiety and seek for a place with less current in panic (IKEYA *et al.*, 1996 b).

The field of 1000 V/m corresponds to about 10 V between two legs considering the distance between the legs of $1\sim2$ cm for a bird: this will lead to $I=5\sim10\,\mu$A to the body of the bird for the measured body resistance of $1\sim2$ MΩ. It is of interest to note that the frog muscle cramp at $I=2\,\mu$A as discovered by Galvani. Although the accepted seismic field is 3×10^{-5} V/m, SAAs indicates as large as $F=10$ V/m (minnow alignment), 100 V/m (rats) and 1000 V/m (birds) all leading to $I=\sim10\,\mu$A to the animal body causing electrophysiological effects.

Flying bats observed close to the epicenter might be bats in caves escaping the seismic current. They might have been city bats living in houses and buildings in a middle-sized city. If so, seismic electromagnetic waves as well as sonic waves produced by the pulsed current in Eq. 4 might be another cause since bats are well known to respond to supersonic sounds. Detailed studies of electric field effects on animals including bats in a limestone cave at Akiyoshi will be investigated and described in a separate paper.

7. Summary

Present model of an electromagnetic fault illustrates hitherto unexplained earthquake lightnings and electromagnetic anomalies after the major earthquake shock. The major seismic animal anomalies prior to the earthquake can be explained by electric field effects except for some responses of animals detecting seismic p-waves just before an earthquake.

The flying bats and snakes in winter might be caused by electric current in caves and in surface soils. The discrepancy of the calculated seismic current and the required current to cause anomalies to animals in a laboratory can be solved by considering the current enhancement effect considering the resistivities of granite bedrocks and sediments. The pulsed seismic electric signals (SES) as predicted from the model should be investigated as an early warning signal though prediction of earthquake may still be difficult. Details of the theory and the resultant EQLs will be published in separate papers. EQLs and possible EMAs can be detected earlier than seismic p-waves used for an early earthquake warning system. Hence, they might be used in a new early warning system, if not for earthquake prediction.

Appendix: The current and field enhancement by geological and geographical reason.

Seismic electric field of 3×10^{-5} V/m observed by seismologists for predicting an earthquake is DC voltage at a long distance from the epicenter. Suppose that the distance, R is 500 km and the area of seismic anomalies is 5 km and the F is simply proportional to R^{-2} as a planar dipole field as shown in Fig. 1, $F=0.3$ V/m is obtained. The current induced by this field to sediments is $J=F/\rho'=0.003$ A/m^2. This is still two~three orders of the magnitude smaller than that which causes animal anomalies as witnessed as SAAs.

Figure 4(a) indicates the schematic illustration. The current is focused to the conductive zone with the width l', the depth d' and the resistivity ρ' as

$$J'=J(ld/l'd'-1)/(\rho ld/\rho' l'd'-1) \qquad (6)$$

Hence, for $ld/l'd'\gg1$ and $\rho ld/\rho' l'd'\ll1$, $J'=(\rho/\rho')J=10^4 J$ using $\rho=10^6$ Ωm

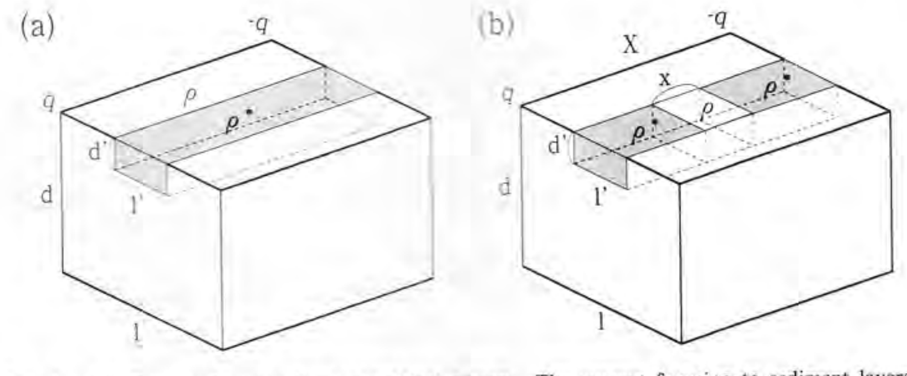

Fig. 4. (a) Current focusing by geographical reason. The current focusing to sediment layers along fault zone from bedrock granite occurs with the enhancement ratio of ρ/ρ' as in Fig. 1 and as shown here with the ratio of J. (b) The field enhancement, $F=J\rho=(\rho^2/\rho')$ at areas with a high resistivity ρ through the path of the current flow is also possible as indicated in Appendix.

of granite and $\rho'=10^2\ \Omega$m of sediments. Thus, the current density is enhanced by the current channel path.

The field intensity is also enhanced by the blocking rocks having the resistivity ρ and the length x in the total length X interrupting the current channel path. Then the field intensity F is changed as

$$F=F_0(\rho/\rho')/(1-x/X+\rho x/\rho' X) \qquad (7)$$

The field intensity is enhanced by the factor ρ/ρ' for $\rho x/\rho' X \ll 1$ and by the factor X/x for $\rho x/\rho' X \gg 1$.

It was discussed that SAAs are not homogeneously distributed around fault zone. The bedrock is granite at the Hansin Earthquake area. The river through the granitic Mt. Rokko form sediments where towns are developed. Appearance of SAAs should be investigated considering geology and geography of the area. Similarly, pulsed seismic electric signal (SES) should be studied considering the equations on F and J and selecting the observation site consulting with field geologists. The current under water may be a good method to measure rather than to measure weak voltage of a long line.

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