Ground Electric Field Effects on Rats and Sparrows: Seismic Anomalous Animal Behaviors (SAABs)

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Electric field effects on behaviors of albino rats, Mongolian gerbils (sand rats), hair-footed Djungarian hamsters, guinea pigs and red sparrows (Avadavat) have been investigated in order to determine whether seismic anomalous animal behaviors (SAABs) witnessed prior to a major earthquake are due to seismic electric signals (SES). Animals placed on a wet conductive floor initially showed grooming, nervous and field avoidance behaviors and finally ran and jumped in panic as the ground field intensity was increased from 1 to 1000 V/m. An electromagnetic model of a fault, in which piezoelectric polarization due to the release of seismic stress, gives sufficient field intensity to produce a critical body current of a few μA. It is considered that animals showed electrophysiological responses to seismic current.

KEYWORDS: earthquake, animal, anomalies, electric field, piezoelectric, current, rat, bird, hamster, electrophysiology

1. Introduction

Rats, birds and other animals evacuated their normal habitats or were, in some cases, seen moving in large numbers as if migrating, in order to avoid the major earthquake that destroyed Kobe on January 17, 1995. 4 A large number of water birds, seagulls, for example, flew inland. Snakes and toadstools emerged from soil in winter. Some fish in ponds and fish tanks either maintained orientation in a particular direction or panicked. Others died after by jumping out of the water. These seismic anomalous animal behaviors (SAABs) prior to an earthquake are often observed and have become a topic of interest in popular science and the press. 5,6 Some scientists, especially western scientists, still doubt such retrospective reports and consider that the SAABs are exaggerated by the press. In contrast, Chinese seismologists routinely employ SAABs for earthquake prediction. 7

Most people believe that animals can instinctively predict earthquakes. However, most animals never experience an earthquake during their lifetimes. Although the mechanisms have not yet been clarified, SAABs seem to indicate that animals are in fact detecting some precursor signal of major earthquakes. 8 A pioneering study involving catfish suggests that seismic electric signals (SES) might elicit SAABs. 9 Many aquatic animals have electroreceptive systems which are used to acquire information for orientation and to communicate with others. 10 The electro-sensing organs of animals may be perturbed by seismic current prior to an earthquake.

Recently we have proposed a model for the appearance of electric charges in order to illustrate seismic-atmospheric phenomena, 11 in particular for the earthquake lightning (EQL) discussed by Teraoka. 12 Bound charges that cancel the stress-induced piezoelectric polarization of quartz-bearing rocks appear as a result of the reduction of the polarization due to seismic stress release. If this model is correct, an electric field might elicit SAAB-like behaviors under laboratory conditions. We have demonstrated that an applied electric current as small as 0.1-1 A/m², a range which was estimated based on an electromagnetic model of a fault, caused fish to align themselves perpendicular to the field direction and forced earthworms to emerge from soil and swarm; 5 these behaviors were observed before the Kobe Earthquake and were reported as SAABs after it. 13

In this work, the effects of an electric field on the behaviors of some mammals and birds have been studied and the critical body current obtained was compared with the theoretical seismic one. SAABs are ascribed to electrophysiological responses to electric shocks caused by seismic electric pulses.

2. Experimental

Rats (Ratus Norvegicus), Mongolian gerbils or sand rats (Meriones unguiculatus), Djungarian hamsters (Rhodops sungarius), guinea pigs (Cavia porcellus) and red sparrows (Red Avadat or Red Munia: Amandava Amandava) were placed on wet tissue paper or a wet towel which had been placed on the floor of their cages or on the perch for sparrows. Electric voltage was applied by placing copper plate electrodes to both ends of the wet floor or the rod. The behaviors of animals upon application of DC voltage to the electrodes were photographed using a commercial video recorder. Photographs of anomalous behaviors were printed from the videotape using commercial computer software.

3. Experimental Results

3.1 Animal behaviors in response to the floor electric current

3.1.1 Albino rats (Rattus Norvegicus)

Rats placed on a wet towel to which DC voltage was applied showed grooming and nervous behaviors at voltage levels as low as the surface electric field of 2 V/m, as shown in Fig. 1(a). Cramping of the legs as shown in Fig. 1(b) was observed at 70 V/m (5 mA/m) for the ground current density. Animals were observed to groom each other (c and d) and stand on their tails to avoid the ground current. Rats learned to avoid field effects by standing on the copper electrode.

3.1.2 Mongolian gerbils (Meriones unguiculatus)

Sand rats were placed on wet tissue on the floor of the cage. Electric current was applied only to the right half
Fig. 1. Photographs of Albino rats during application of electric current to the wet floor. (a) Grooming due to application of electric current to the wet floor so that $E = 25 \text{ V/m}$, (b) Cramping of legs, (c) Grooming each other and (d) Slow and cautious walk due to increased field intensity.

Fig. 2. Photograph of sand rats placed on wet tissue papers. (a) Electric field was applied only to the right half. (b) Sand rats moved to the left to avoid the electric field. (c) Standing and grooming and (d) Running and jumping up due to increased voltage.
of the floor by placing a copper electrode at the center as shown in the photograph in Fig. 2(a). The sand rats learned quickly to move to the left where no field was being applied as shown in Fig. 2(b). When the voltage was applied to the whole floor, they stood up on two legs, ran and jumped up in panic as in Figs. 2(c) and 2(d) and stood on the electrodes to avoid the electric field.

3.1.3 Guinea pigs (Cavia porcellus)

A so-called "marmot" appeared somewhat nervous-looking and began crying when subjected to a field of 100 V/m. It was observed to groom and stand on two legs using its nails and groom as shown in Figs. 3(a)–3(c). Cramped legs routinely occurred when the guinea pig was subjected to a field of 30 V/m. Tumbling was observed at high field.

3.1.4 Djungarian hamsters (Rhodopus sungorus)

The six hamsters moved around constantly, but began to show grooming behavior. Since they were constantly moving, it was difficult to distinguish abnormal behaviors. However, running in panic and tumbling were observed at the increased field, as shown in Figs. 3(d) and 3(e).

3.1.5 Red Avadavat (Amandava Amandava)

Two red sparrows were placed on wet tissue paper as shown in Fig. 4(a). They became puffed up and grew larger as shown in Figs. 4(b) and groomed themselves and sometimes groomed each other similar to the rats. When the voltage increased, they first hopped and flew about as shown in Fig. 4(c), and then perched on the shielded wires as shown in Fig. 4(d).

3.2 Critical body current

Electric field effects have been studied to investigate the effects of high voltage power transmission lines. We also performed an experiment in which animals were placed between parallel copper plate electrodes to which a DC voltage of 3 kV was applied, so as to produce an electric field of 10 kV/m. No abnormal behaviors were observable. These results suggest that the current flow which results from the potential difference between the legs causes the anomalous behaviors.

The specific types of responses seem to depend on the species and individual animals. However, the behaviors begin at low current density for albino rats but relatively high density for hair-footed hamsters. The field intensity and the responses are tabulated in Table I, together with the rough estimate of the body current using the measured leg-to-leg resistivity, $R_{L1}$ of a few MΩ. The current through an animal is a few μA to an animal considering that the direction of the leg-to-leg is parallel to that of the ground electric field. It is not clear why red sparrows puffed and groomed. Rats and tortoises acted as if washing their faces upon application of the field. An old saying in Japan that it will rain when a cat washes its face might be due to the electric field caused by an approaching thunder cloud.

4. Model Calculation of Seismic Current

4.1 Electromagnetic Fault

We have assumed that an orientation anisotropy of microcrystalline quartz grains exists in quartz-bearing

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Table 1. Effects of electric field, $F$ (V/m) on rats and birds to attempt to explain seismic animal anomalous behaviors (SABs). The voltage was applied to electrodes separated by 25 or 30 cm on the floor of the cages, between which wet tissue papers with resistivity of 20 Ω were placed. The voltage, $V_{L1}$ between an animal's two legs with a separation, $L_{L1}$ (cm) and the measured leg-to-leg resistivity $R_{L1}$ are shown with the current $I_{L1}$.

<table>
<thead>
<tr>
<th>Animals</th>
<th>$F$ (V/m)</th>
<th>$V_{L1}$ (V)</th>
<th>$I_{L1}$ (μA)</th>
<th>Response $\downarrow$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rats</td>
<td>$W \approx 300$ g</td>
<td>$L_{L1} = 2.5$ cm</td>
<td>$R_{L1} = 0.4 - 0.5$ MΩ</td>
<td>1000</td>
</tr>
<tr>
<td>(Rattus Norvegicus)</td>
<td>2</td>
<td>~ 0.08</td>
<td>~ 0.15</td>
<td>G, Nervous looking (N)</td>
</tr>
<tr>
<td>Mongolian gerbils</td>
<td>6</td>
<td>~ 0.3</td>
<td>~ 0.5</td>
<td>Biting wires, AF?</td>
</tr>
<tr>
<td>(Meriones unguiculatus)</td>
<td>72</td>
<td>~ 5.0</td>
<td>~ 6.0</td>
<td>G, Jumping (J)</td>
</tr>
<tr>
<td>Guinea pigs</td>
<td>$W = 106$ g</td>
<td>$L_{L1} = 3$ cm</td>
<td>$R_{L1} = 2$ MΩ</td>
<td>1600</td>
</tr>
<tr>
<td>(Cavia porcellus)</td>
<td>100</td>
<td>~ 3</td>
<td>~ 0.15</td>
<td>Nervous looking?</td>
</tr>
<tr>
<td>Djungarian hamster</td>
<td>30</td>
<td>~ 0.6</td>
<td>~ 0.3</td>
<td>Biting wires, AF?</td>
</tr>
<tr>
<td>(Skogeri hamster)</td>
<td>100</td>
<td>~ 2.5</td>
<td>~ 1.3</td>
<td>Running in panic?</td>
</tr>
<tr>
<td>Guinea pigs</td>
<td>$W = 20$ g</td>
<td>$L_{L1} = 2$ cm</td>
<td>$R_{L1} = 2$ MΩ</td>
<td>800</td>
</tr>
<tr>
<td>(Cavia porcellus)</td>
<td>400</td>
<td>~ 8</td>
<td>~ 4</td>
<td>R, P, Screaming (S)</td>
</tr>
<tr>
<td>Red Avadavat</td>
<td>$W = 32$ g</td>
<td>$L_{L1} = 2.5$ cm</td>
<td>$R_{L1} = 2$ MΩ</td>
<td>660</td>
</tr>
<tr>
<td>(Amandava Amandava)</td>
<td>300</td>
<td>~ 19</td>
<td>2–3</td>
<td>Jumping, AF</td>
</tr>
</tbody>
</table>

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a) The $V_{L1}$ and $I_{L1}$ were calculated as the maximum to the animal parallel to the field direction.

b) Behaviors are abbreviated. The behavior that can not be judged clearly as an electric field effect is indicated by ? mark.
Fig. 3. (a) Guinea pigs (Marmot), (b) Grooming due to the current on the wet tissue paper floor, (c) Hamsters avoiding current effects by standing on left electrodes, and (d) Hamsters crying, running, and jumping in panic due to increased current.

Fig. 4. Electric current effects on red sparrows on wet floor. (a) Stationary sparrows with no application of electric field, (b) Sparrows inflating and puffing up due to the current on the floor, (c) Hopping and then flying about to avoid landing on the ground, (d) Staying on the shielded wire to avoid ground current.
rocks which produces weak piezoelectricity as a result of seismic stress. Dislocation twinning in quartz crystal growth under stress, i.e., piezocreep\(^{(15)}\) has been attributed to the orientational anisotropy. Granitic rock under seismic stress may produce an overall orientational anisotropy of piezoelectric quartz crystals. Some studies on granitic rock indicate that its piezoelectric coefficient is two orders of magnitude less than that of quartz.\(^{(11,12)}\)

Piezoelectric charges resulting from the seismic stress are often mistakenly claimed to produce an electric field at the fault zone according to writings in popular science and in some geophysics literature. Bound charges or polarization of the surrounding dielectric matrix materials quickly compensate for the piezoelectric polarization in the conductive and dielectric earth with the resistivity \(\rho\) and the dielectric constant \(\varepsilon\) resulting in a time constant \(\varepsilon\rho\) approximately \(7 \times 10^{-6}\) s for granite (\(\rho = 10^{8}\ \Omega \cdot \text{m}, \varepsilon = 8\)).\(^7\) Hence, neither bound charges nor an electric field is present at the fault zone.

Our electromagnetic model of a fault is based on the appearance of free charges \(+q\) and \(-q\) caused by the reduction of piezoelectric polarization at the fault zone due to the seismic stress release. The charge density is described by

\[
\frac{dq}{dt} = -\alpha(\frac{\Delta \sigma}{\sigma_0})t - q/\varepsilon\rho, \quad (1)
\]

where \(\alpha\) is the piezoelectric coefficient and \(\sigma(t)\), the time dependent stress.\(^7\) Any mechanism, such as frictional electricity or solid plasma (electron and hole) formation, can explain the formation of pulsed charges so long as it produces electric charges at the rate of the stress release as in eq. (1).

### 4.2 Mathematical model of a fault in seismology

A mathematical fault model based on dynamical theory gives the stress \(\sigma(t) = \mu[D - D(t)]/2a\) where \(\mu\) is the rigidity of rocks, \(D\) and \(D(t)\), the final and time-dependent displacement, respectively, of a fault having the length \(2a\).\(^{13,14}\) According to a mathematical model of a fault based on a dynamical theory, \(D(t)\) is expressed by the initial displacement velocity \(D'\) and the displacement time or the rise time of seismic waves, \(t\) as

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

where \(\Delta \sigma/\sigma_0\) is the rate of stress drop, i.e., the stress drop, \(\Delta \sigma\), divided by the stress parallel to a fault plane, \(\sigma_0\) and \(\beta = 3.5 - 4\) km/s is the velocity of the secondary seismic waves. The relations of \(D = 2\Delta \sigma a/\mu\) and \(D' = 2\varepsilon\rho/\mu\) were used to obtain eq. (3).

### 4.3 Current density equation

The initial condition of \(q(0) = 0\) gives a solution for \(q(t)\) as

\[
q(t) = \alpha\Delta \sigma(\frac{\varepsilon}{\varepsilon - \varepsilon_0})\frac{(e^{-t/\tau} - e^{-t/\varepsilon\rho})}{(1 - e^{-t/\varepsilon\rho})}, \quad (4)
\]

which is rewritten symmetric to \(\tau\) and \(\varepsilon\rho\) as

\[
q(t) = \alpha\sigma_0\frac{\varepsilon\rho}{(\varepsilon - \varepsilon_0)}\frac{(e^{-t/\tau} - e^{-t/\varepsilon\rho})}{(1 - e^{-t/\varepsilon\rho})}, \quad (4')
\]

The time dependence is a pulse with the rise time of \(\varepsilon\rho\) and the decay time of \(\tau\) for \(\varepsilon > \varepsilon_0\) or vice versa for \(\tau > \varepsilon\rho\). We can estimate the pulsed electric field intensity, \(F(t) = q(t)/\varepsilon\) as

\[
F(t) = \alpha\sigma_0\frac{\varepsilon\rho}{(\varepsilon - \varepsilon_0)}\frac{(e^{-t/\tau} - e^{-t/\varepsilon\rho})}{(1 - e^{-t/\varepsilon\rho})}, \quad (5)
\]

and the current density to the ground as \(J(t) = F(t)/\rho'\) since

\[
J(t) = \alpha(\rho/\rho')\sigma_0(\varepsilon_0/\varepsilon)(e^{-t/\tau} - e^{-t/\varepsilon\rho})/(1 - e^{-t/\varepsilon\rho}/\tau), \quad (6)
\]

where \(\rho'\) is the resistivity of ground sediment or water channel (1 - 10\(^8\)\(\Omega\cdot\text{m}) leading to \(\rho/\rho' = 10^{3-10^{4}}\). Note that the current is further focused to a channel or to a river in a valley or to the conductive fault zone. The electric field on the small granitic rocks which block the current flow is enhanced as \(F(t) = \rho J(t)\) in some cases.

### 4.3.1 At the time of earthquake: \(\tau \gg \varepsilon\rho\)

One can estimate \(\tau = 1.4\) s for \(\beta = 3.5\) km/s and \(a = 5\) km using eq. (3) for 100% stress decrease. Numerical estimation of the charge density \(q_0 = \alpha\sigma_0(\varepsilon\rho/(\varepsilon - \varepsilon_0))/(\varepsilon_0/\varepsilon)\) in eq. (4) is carried out for the major shock and for foreshocks as shown in Table II using \(\tau = 1.4\) s > \(\tau = 7 \times 10^{-5}\) s, \(\sigma_0 = 10^6\) N/m\(^2\) and \(\alpha = 2 \times 10^{-11}\) C/N, which is about 1% of the piezoelectric coefficient of quartz\(^{(20)}\) which constitutes more than 50% of granite bedrock. The electric field in the earth is \(F_0 = q_0/e\) in V/m. The field has a sharp risetime of \(0.7 \mu\) s for \(\varepsilon = e/e_0 = 8\) and \(\rho = 10^3\ Omega\cdot\text{m}\) for granite and a decay time of \(1\) s for the major shock. The field intensity is marginal on sensitive animals.

We are not considering the conductivity of a brecciated
fault zone with a low resistivity because of the high water content but considering a bedrock granite under seismic stress; there will be an intense piezoelectric polarization and compensating bound charges for \( \rho = 10^8 \Omega \cdot m \) used throughout this work.

The drying of the granite due to frictional heating has been asserted as the cause of the resistivity increase up to \( 10^{19} \Omega \cdot m \), but the dilatancy hypothesis might be more plausible. The resistivity increase to \( 10^9 \Omega \cdot m \) or more is expected due to local fractures of granitic rocks caused by foreshocks resulting in dilatancy which changes the velocity of seismic P-waves prior to the main shock.\(^8\)

The high porosity caused by foreshocks before the main shock prior to the main shock:18) The field intensity enhancement of \( F = J = (\rho' \rho) J = 10^3 J \) using \( \rho = 10^4 \Omega \cdot m \) for granite and \( \rho' = 10^2 \Omega \cdot m \) for sediments.

The field intensity \( F \) is also enhanced to \( F' \) by blocking rocks having resistivity \( \rho \) and length \( x \) in the total path length \( X \) interrupting the current channel as schematically shown in Fig. 5(b) as

\[
F' = \frac{F(\rho' \rho)}{(1 - x/X + px/\rho' X)}.
\]

The field intensity is enhanced by the factor \( \rho' \rho \) for \( px/\rho' X \ll 1 \) and by the factor \( X/px \) for \( X/px \ll 1 \). Thus, the current is focused considerably to a pond or a small channel in the granitic rock which is blocking the major current flow. Hence, SAABs will depend considerably on the geography of an area. The selectivity of SES\(^{15} \) might arise from local geology.

5. Discussion

The current flow from the animal's legs through its body as specified in Table I, was obtained by assuming that the direction from one leg to another is parallel to the field direction considering their leg-to-leg resistivity. The body current is \( I = FL/R \) on the order of \( 1 \mu A \) in agreement with the previous results for minnows\(^9\) and those of early work on catfish.\(^3\) Galvani's electrophysiological muscle current to frog legs was also \( 2 \mu A \).\(^6\) The field intensity of 100–1000 V/m was one or two orders of magnitude higher than 10 V/m causing the alignment of minnows as seen in the previous work.

The threshold stimulus of electrosensitive organs is as low as 5 mV/m in freshwater fish and 0.1 mV/m in marine organisms,\(^8\) which is far less than those observed in this experiment. However, it should be noted that these animals were kept and bred specifically for a laboratory experiment. Albino rats and guinea pigs are not inherently violent. Wild rats may be more sensitive to electric pulses than albinos rats. In fact, wild Japanese minnows...
(black colored) aligned quickly in response to an electric field, while yellow-colored minnows bred specifically for laboratory experiments showed slow responses.

The field intensity is also several orders of magnitude larger than that obtained from SES,\(^{(15)}\) which gives field intensities of only \(\sim 10^{-4}\) V/m. One might wonder whether such a large field intensity of 10–100 V/m appeared before the Kobe Earthquake giving rise to the reported SAABs. Geographically strong wind is observed at local valleys. Similarly the current may be focused as shown in Fig. 5 from the bedrock granite \((10^6 \Omega \cdot m)\) to the conductive wet sediments, sea, and rivers \((p = 1-10^2 \Omega \cdot m)\), which are inhabited by earthworms, fish, snakes and water birds. Observations that SAABs do not uniformly occur around the fault zone or the earthquake epicenter may be explained considering the geography of the area. In fact, the area where SAABs were observed prior to the Kobe earthquake is close to the fault zone of the granite Mt. Rokko indicating that the current flowed along the fault. Seismic stress distributed over a wide area may be released, resulting in seismic current in areas more than 100 km away from the epicenter.\(^{(4)}\)

We have used only rats and birds in this experiment following the work on the electrical current effects on fish and worms\(^{(9)}\) and concluded that SAABs are due to electrophysiological effects as speculated from the results of the catfish experiment.\(^{(5)}\) Many other animals are reported to have shown SAABs such as those used by Chinese seismologists for earthquake prediction. Reports of dogs barking and running in panic, chickens flying to roofs, pigs trying to climb walls, horses and cows standing on two legs and falling down in panic all suggest that the SAABs are caused by the surface current on the wet ground soil. Ducks avoid entering water. Swans lay on the snow and put their legs up, which indicates that the sensors are in their legs and the signal is transmitted through the snow, considering that their feathers function as a good electric insulator. Alligators running to the forest from rivers\(^{(5)}\) and crocodiles crying in the Banana-Alligator Zoo on the Izu Peninsula\(^{(30)}\) before earthquakes (also before volcanic eruptions), as well as seagulls flying inland from the sea,\(^{(3)}\) seem to support this hypothesis. The Banana-Alligator Zoo, where earthquake prediction by animals is often reported, is located in a narrow valley close to the sea, surrounded by igneous rocks. Current focusing is clear from the local geography.

Some fish and earthworms were observed to die or to kill themselves by escaping to land from the water before the Kobe Earthquake. Some animals, such as frogs, tortoises and snakes may have died as a result of the seismic electric current prior to some major earthquake, disturbing the biological balance and causing an increase in the number of other animals. Few frogs were seen in Kobe and its vicinity in the summer of 1995, which caused concern among the population. The old Japanese saying that an earthquake will occur when red dragonflies swarm may be based on an imbalance caused by seismic current in the biosphere prior to an earthquake.

Thus, it is concluded that SAABs can be explained by seismic electric pulses though physical quantities such as acoustic waves, in particular P-waves might have to be considered for some SAABs just before the main shocks. Although detailed study has neither been carried out on the effect of aerosols which might cause SAABs as suggested by Tributsch,\(^{(3)}\) the electromagnetic fault collects charged particles from the electric field in the air. The current of aerosols is a resultant phenomenon and thus is not the main reason for SAABs. Electron and ion emission through fractures or crack formation\(^{(10)}\) might also be phenomena resulting from formation of free charges.

In this model, charges freed due to the stress release from the bound charges compensating piezoelectric polarization are considered to give rise to a long-range electric field. Any mechanism,\(^{(18-25)}\) other than released bound charges of piezoelectricity, if it produces an intense seismic potential and current, is also plausible for explaining SAABs as electrophysiological responses of animals: the post synaptic potential changes due to the stimuli by seismic electric pulse current will result in excitement of the animals causing panic or even jumps from water to land.

6. Summary

Experimentally determined current that affects rats and birds is of the magnitude of a few µA, as found for fish and worms. An electromagnetic model of a fault indicates that the seismic field intensity of 100 V/m, which causes SAABs in mammals and birds on the ground soil, may be produced by local fractures of a fault preceding a major earthquake. Seismic electric current flows immediately at the time of the major shock of an earthquake, and it propagates much faster than seismic P- and S-waves. Pulsed seismic electric signals (SES) as predicted from this model should be investigated as an early warning signal. It is still premature to say whether this current or SAABs can be used to predict earthquakes. Local fractures which produces electric charge pulses do not necessarily lead to a major shock and might end up just as local fractures.

Some animals show anomalous behaviors before thunderstorms presumably also detecting pulsed current due to approaching thunderclouds or to lightning. Flow of a pulse current is equivalent to the passing of a wave packet of electromagnetic waves consisting of a wide range of frequency. In fact, we are observing such electric pulses before earthquake and at the time of thunder lightnings in our preliminary study.

We conclude from the present work only that SAABs are electrophysiological responses caused by the seismic pulse field and that the explanation for the seismic field may be the free charges, i.e., the piezo-compensating bound charges left freed due to the reduction of the piezoelectric polarization or charges produced by other mechanisms.\(^{(21-24)}\)

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