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A Summary of Studies on Luminous Phenomena Accompanied with Earthquakes

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Abstract

From ancient times many people have seen luminous phenomena accompanied with earthquake and recorded. Nevertheless the question of what seismo-luminosity is remains to be unsolved, and some scholars have thought that the phenomena are results of misconception of some other kinds of light.

The author has reported three papers on luminous phenomena accompanied with Hyuganada earthquake (1961) and Matsushiro earthquake swarms (1966–1968) in the previous issues of this memoir.

Present report will be the final one which summarizes his knowledge of seismo-luminosity.

The author has convinced that the luminosity appears in the area of strong acidic rocks under the piezoelectric field caused by an earthquake, as it is pointed out by Drs. Finkelstein and Powell, when emanations in the air are sufficiently increased, trembled out from the earth interior by the earthquake.

Main body of the white or bluish white luminosity is a half of a sphere of several ten meters diameter, whose lower fringe touches the earth surface.

Various shapes and colours of observed luminous phenomena are resulted in from reflection and refraction by clouds or mists surrounding the main body.

As Drs. D. Finkelstein and J. R. Powell's theory of earthquake lightning is not widely known yet in Japan, the author will introduce an outline of their theory in the end of this paper.

1. History of E.Q.L. problems

From ancient ages, many people saw and recorded luminous phenomena accompanied with earthquakes, which were named E.Q.L. by Finkelstein and Powell. E.Q.L. have been put on record since about 1500 years ago in Japan and about 800 years ago in Europe. Ignazio Galli collected such records in Europe, and Prof. K. Musya collected them in Japan, but they collected and arranged them without investigating their origin. Prof. T. Terada of Tokyo Imperial University lectured on his "Water Capillary Potential Theory" (On Luminous Phenomena accompanied with Earthquakes: Bull. of Japan Earthquake Research Institute, Vol. 9, No. 3, 1931) after his studies on E.Q.L. in Japan in 1930, 1931, and he reasoned that E.Q.L. are phenomena in higher atmospheric layers. Dr. T. Yoshimatsu of the Kakioka Magnetic Observatory supported Terada's theory as his own observational results of earth current in Shioyamisaki

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Earthquake in 1938 (Memoirs of the Kakioka Magnetic Observatory, Vol. 1, 1938). Also Prof. T. Shimizu of Tokyo Imperial University presented his "Arc Theory" in 1938. He said "Earthquakes cause many cracks in the ground in many places, cutting off earthcurrent, so arc-discharges happen in several places. These are E.Q.L." Then Mr. Kawase of Japan Meteorological Agency guessed "E.Q.L. is triboluminescence in soildust caused by landslides due to earthquakes" after his researches on Taiwan-Kagi Earthquake in 1941. (Bull. of Taiwan Meteorological Bureau, 1942)

Really many seismo or physical scholars were concerned with E.Q.L. in Japan, but most of their views on E.Q.L. are contradictory and even negative. Some famous seismo-scholars, such as Dr. K. Wadachi and Prof. T. Rikitake, for instance, think the phenomena are the misconception of the sparks of electrical power line. The author supposes that many scholar's opinion on this question also are divided in America and Europe, as in Japan. If a few modifications of the famous phrases of Dr. Singer's lecture on Ball Lightning in 1964 are permitted, the author may say "Does Seismo-Luminosity exist? Yes, it does indeed exist. But the question of what Seismo-Luminosity is arises next". D. Finkelstein and J. R. Powell also said in 1971 "The problem of E.Q.L. is the darkest section in seismology". Lately Dr. Finkelstien and Dr. Powell offered their "Piezoelectricity theory about E.Q.L." in 1972. The author accepted their papers, for which he expresses his hearty approval.

Many scholars in Japan may have no chance to read papers perhaps, so the author begs their permission to introduce the gist of their papers to Japanese scholars at the end of this report (Appendix).

2. E.Q.L. Phenomena

The author got the first chance to see E.Q.L. on March 3, 1933 (Sanriku Earthquake), but he saw it only at a single glance at the early dawn, so he could not get a clear image of it. On Dec. 21, 1946 many E.Q.L. were observed in a wide area of western Japan (Nankaido Earthquake), but the author was still staying in China, so he did not see the phenomena, and he could make researches in them only by Japan Meteorological Agency's Report later.

The author saw E.Q.L. for the first time with scientific considerations on Feb. 27, 1961 (Hyuganada Earthquake), and he published his observed data and some considerations. Since then he got many chances to observe E.Q.L. in 1965, 1966, 1967, in Hokusin Earthquake Swarm, so Matsushiro Earthquake Swarm. At Matsushiro the author and his cooperator, G. Kondo and T. Kuribayashi (amateur photographer) observed many E.Q.L. with magnetometers, electrofield mills, seismographs, and succeeded in taking photographs. But sorry to say, the observations by spectrographs have not been carried out. These results were published in Memoirs of the Kakioka Magnetic Observatory, Vol. 13, No. 1, 1968. After that time, many reports of E.Q.L. on Jan. 5, 6, 1968 (Chiba Earthquake) and Aug. 6, 8, 1968 (Hyuganada Earthquake, second) and the above mentioned Kagi Earthquake on Dec. 17, 1941, were sent to the author. He collected them and all of these reports were printed in Memoirs of the

Kakioka Magnetic Observatory, Vol. 14, No. 1, 1971. Also Dr. L. Salanava sent Mr. D. Engdahl's report about E.Q.L. at St. Rosa, California, Oct. 1, 1969, to the author, so he introduced it to Japanese scholars and published his report about E.Q.L. on Feb. 29, 1972 (Hachijojima Earthquake) in Memoirs of the Kakioka Magnetic Observatory, Vol. 15, No. 1, 1972.

The author synthesizes his views as follows, after some adjustments of these reports.

(1) Configuration of the E.Q.L. ponit

Mostly hill tops or high mountains.

F. Gall (Met. Zeitschr. 23, 35, 1906) and W. Knoche (Met. Zeitschr. 26, 1909; 29, 1912; 31, 1914) expressed the same opinions at an earlier chance.

(2) Geological conditions of the E.Q.L. point

The author thinks that E.Q.L. does not happen necessarily at all places in all kinds of geological conditions.

For example, E.Q.L. on Aug. 6, 1968 and Dec. 21, 1946 happened at the same special place in Kyushu. The common geological conditions of the place where E.Q.L. appear seem to be old volcanoes, and strong acidic rock areas, as the areas of Dacite, Granite, Diorite, specially the area near the faults and outcrops of Quartz-diorite.

Remarkable E.Q.L. happened at Hachijojima in 1972. E.Q.L. happened only at Higashiyama hill (East hill) top of the dacite and quartz-diorite scoria area, but did not happen at Nishiyama (West hill) and Kojima hill tops of the basalt scoria area. The summit distances of there hills are about 3 km each.

At Matsushiro, Mr. Ito and Mr. Nagata reported "CO_2 percentage in free gases and underground waters have good positive correlation and show extraordinarily positive correlation near the outcrops of faults". (News of Geological Research Institute, No. 149, 1967) Also Mr. Y. Hagihara reported "In the area of diorite outcrops at Matsushiro the natural radio-activity in air is extraordinarily high". (Bull. of Earthquake Research Institute, Vol. 44, No. 3, 1966)

The author thinks that soil air under the strong acidic rock contains much radon, so near the outcrop the radon in the air may be increased remarkably by the earthquake.

Dr. J. Hatsuda of Kyoto Imperial University measured the increase of radon in the soil 2 meters deep at Nankaido Earthquake 1946.

In those area mentioned above, abundant free quartz may have been produced by volcanic heat transaction, and the effect of piezoelectricity seems to be strengthened accordingly.

The authar's cooperator, G. Kondo measured the atmospheric electric field with field mills from October to November 1966, at the Matsushiro Seismological Observatory during period of Matsushiro Earthquake swarm—many E.Q.L. happened—and found "The electric field was quite often decreased by the earthquake. The occurrence probability of this variation varied with the activity of the earthquake. The more active earthquakes were, the more frequently the variations occurred. This decrease of the electric field will be explained by the increase of radon contents in the air by the earthquake". (The Memoirs of the Kakioka Magnetic Observatory, Vol. 13, No. 1, 1968)

The Matsushiro Seismological Observatory is situated on sand-soil layer, so the emanation amount observed by Kondo was very small, and so E.Q.L. did not appear at this point. But the amount of emanation on the hill of diorite outcrops may have been enough for the condition indicated by Dr. Finkelstein and Powell so the author thinks. V. F. Bonchkovskii found the same results on an earlier occasion in Siberia. (Geofizicheskii Institute, Trudy, U.S.S.R. No. 25, 1954)

(3) Altitude of E.Q.L. point

Prof. Terada thought the point in the high atmosphere, perhaps in the ionized layer, but the author can not agree with Terada's view as the results of his own observations of E.Q.L. at Matsushiro. The observations were done at 2~3 different directions and the results showed that E.Q.L. were not phenomena in a high atmospheric area, but phenomena in a low and near-earth atmospheric layer.

(4) The Trace of E.Q.L.

Early in the morning the author climbed the summit where E.Q.L. had appeared the previous night at Matsushiro, but he could not find any burned traces on the trees.

(5) Hour for E.Q.L.

E.Q.L. happened more frequently in Winter and at the early dawn, though earthquakes did not show such frequency.

This frequency may perhaps be accidental, but the author thinks that if E.Q.L. are the misconception of common thunder lightning as some scholars insist, then E.Q.L. ought to happen more frequently in the evening in summer.

(6) Relation between E.Q.L. and spherics

E.Q.L. at Matsushiro and E.Q.L. at Tottori (Tottori Earthquake) accompanied spherics frequently, and at Matsushiro they were catched by electro-magnetic seismograph's transport cable and then recorded, and also in some cases common thunders appeared after several hours.

Many scholars say "E.O.L. are the misconceptions of sparks of electric wires—power lines". But E.Q.L. happened even at ancient ages when there were no electric wires.

Mr. R. Yoshiyama, Tottori University, saw lights on electric wires in Tottori as point discharge in 1931. Mr. D. Engdahl reported "people sow lights on electric poles and wires, but the circuits of electric wires had already been cut off by the control engineers at the first shocks" at Santa Rosa, California, 1969. At Hyuganada Earthquake, 1961, many E.Q.L. appeared even after cut off of electric circuits. At Santa Rosa Earthquake the leakage meter at the substation did not show any traces of electric leakage, though people saw lights or fires on wires and poles.

So the author thinks that the lights or fires may have been St. Elmo's fire, namely point discharges on wires and poles. The author interprets "Electric Spark Misconception Theory" in this way. The Magnet at Matsushiro did not show any variations during E.Q.I. period at Matsushiro.

(7) Duration of E.Q.L.

Generally several seconds or several ten seconds. They show longer duration than common thunder lights.

(8) Relation between Weather and E.Q.L.

E.Q.L. appeared frequently at soft wind before the discontinuous lines (cold fronts).

The author supposes that the cold front comes, moderate ascent current exists and the radons which have been trembled out may easily be diffused up to a rather high layer. If there is no ascent current, the radons which have been trembled out from the earth ground may stay on the surface layer only, and the action of the electric field produced by Finkelstein's and Powell's piezoelectricity may lose the help of emanation, and so E.Q.L. may not occur. On the other hand, if the wind is strong, the radons trembled out are blown far away and their density decreases quickly, and so no luminescence will occur.

(9) Relation between Earthquakes and E.Q.L.

E.Q.L. occurs at places near the epicenter, and E.Q.L. does not occur far from its epicenter even in a considerably strong earthquake. Only one exception known to the author is the case of Nankaido Earthquake, 1946: In that earthquake E.Q.L. occurred in the area 500 km distant from the epicenter. Near the epicenter, the period of earth-trembling is short, so the electric field of piezoelectricity may be rather strong. At Matsushiro the magnitude of the earthquakes was small, and their distances from epicenters were very short, so the periods of trembling were 0.1~0.3 seconds even in the principal trembling. Most of E.Q.L. occurred in the intervals of earthquakes and a few of them occurred before or after. The author supposes that tendency depends on the period and amplitude of the earthquake. A strong earthquake (Hyuganada Earthquake, 1961) showed E.Q.L. even in the interval of primary waves.

(10) Intensity of E.Q.L.

Dark or rather strong.

The maximum luminousity measured by the author at Matsushiro was 1~2 lux at the distance 1~2 km from the luminous semisphere.

(11) Shape of E.Q.L.

Many shapes were reported.

The author divides them in two; The main luminous body or part and its refection light.

The main luminous body shows a rather flattened semisphere (its lower fringe on the earth surface) with a diameter of several ten meters and the maximum diameter is about 100 m.

Several times people including the author observed a semisphere rise up from the hill top, then descend down.

The author guessed that various kinds of observed luminous shapes may be the clouds' shapes illuminated by the semisphere or the light beams that came through rift in the surrounding clouds.

(12) Colour of E.Q.L.

Many kinds of colours of E.Q.L. were observed.

The author thinks that the main body of luminosity is bluish white, and in fine or clear weatehr it shines bluish white also, but in cloudy weather clouds around the main body reflect the light and show a reddish or orangish colar through the dispersion of reflected lights in water drops in the clouds. (Fig. I)

The author found that the colour of E.Q.L. is generally white or bluish white, and colourful in cloudy weather, after the arrangement of observation records. When people can not see the main body hindered by obstacles like mountains or low clouds, they may see coloured clouds only.

3. Conclusion

The author has believed all along "The earthquake produces some kind of electric field, and the increase of emanation in the lower air causes a large scale of point discharge which may be E.Q.L." Emanations are likely to be trembled out by the earthquake from the earth surface in the area of strong acidic rocks, especially from the outcrop of the fault, but the origin of the electric field was unknown to the author.

Lately the author learned of Finkelstein's and Powell's Piezoelectricity Theory in the area of Diorite. Sorry to say, the measurement of emanation amount at the time of E.Q.L. in E.Q.L. area was not done by the author, so he could not discuss the problem quantitatively. But Finkelstein and Powell calculated that a large discharge of 100 meter length was possible in the field produced by the short periodical trembling near the epicenter, depending on the amount of emanation, so the author's hypothesis is warrantable at least qualitatively.

The main part (body) of E.Q.L. is thought to be produced in the above process, and the scale and the intensity is being decided by the power of the electric field and its distribution of gradient, and the emanation amount trembled out from the earth and its distribution of density.

The colour of the main body is essentially white or bluish white. Its horizontal

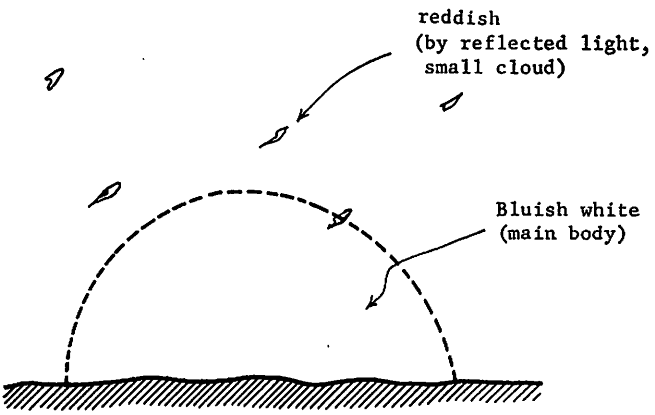

Fig. 1 Assumed Model of Luminosity

locomotion may be caused by the movement of the field due to the propagation of seismo waves.

When people cannot see the main body directly by the configuration of the ground, they may see only a luminescence ascend from the earth surface as a bluish white light of a fan shape, a trumpet shape or a column shape. When fog drops or cloud drops exist around the main body, people may see a colourful—reddish, yellowish, or deeply bluish—semisphere, column or cloud like a sunnset glow through the dispersion

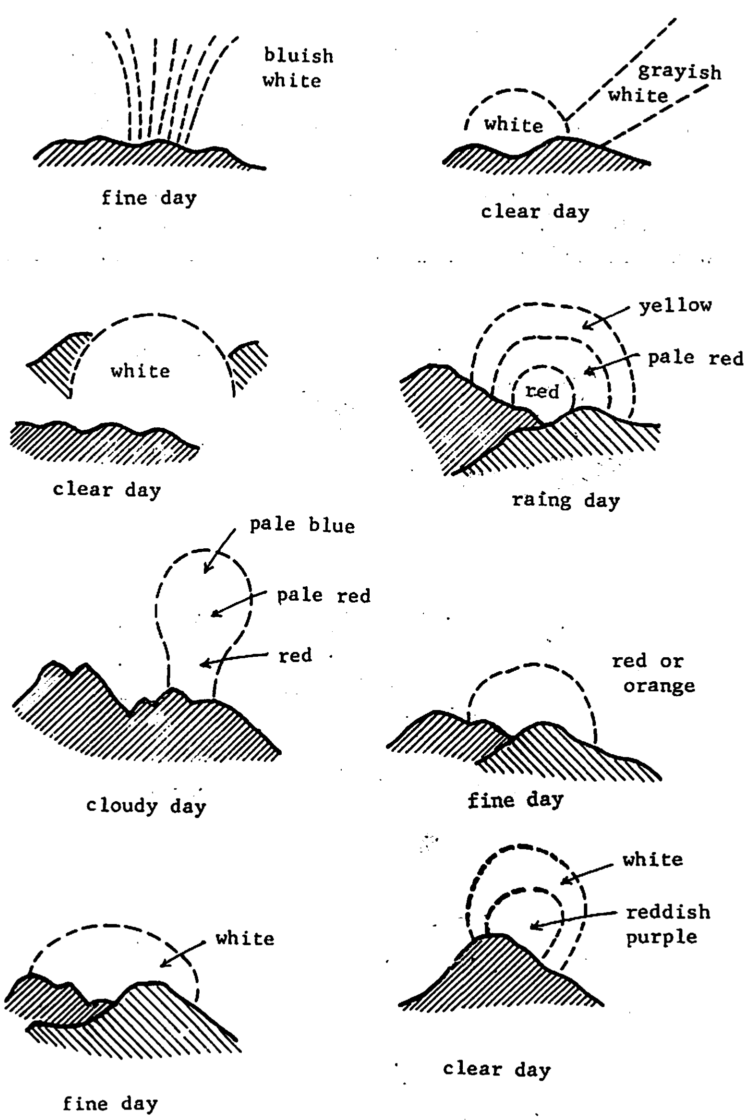

Fig. 2 Sketches at Matsushiro.

of diaphanous light or reflected light in clouds. The author should like to interpret the variety of shapes and colours of E.Q.L. in the above mentioned way.

Several times St. Elmo's fires were observed on electric wires and poles in earthquakes. Those may have been caused by a small point discharge in the field produced by piezoelectricity and in the layer of a small amount of emanation.

The author supposes that these phenomena caused many people to have an incorrect thought "E.Q.L. is the misconception of electric sparks on the electric wires—power lines". Real E.Q.L. is much stronger than St. Elmo's fire.

Several times ordinary thunder happend after earthquakes. The author thinks that the remaining emanation may give rise ot this phenomenon.

There is one more problem left, which is about E.Q.L. on the shallow ocean surface. Is its origin also piezoelectric field of rocks at the bottom of the sea? In this case the substance which increases the conductivity of air may be natrium ion on the sea surface or in wave bubbles.

At last, The author wishes to express his sincere thanks to Dr. J. Hughes at the Naval Research Institute, U.S.A. and Dr. L. E. Salanova at the California Academy of Sciences, who presented many data and helpful advice to him, and to Dr. K.

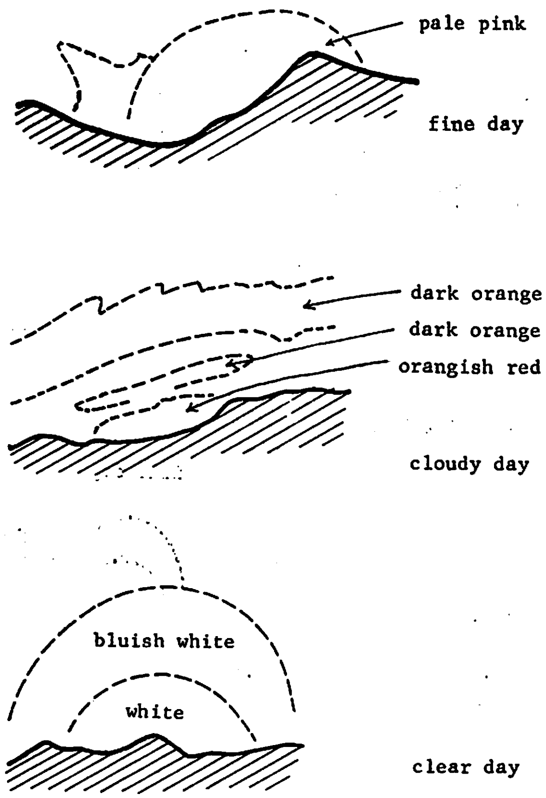

Fig. 3 Sketches of photographies at Matsushiro

Yanagihara at Kakioka Magnetic Observatory, who presented helpful advice and gave the admission of this publication to the author, and to the author's cooperator, G. Kondo and T. Kuribayashi also.

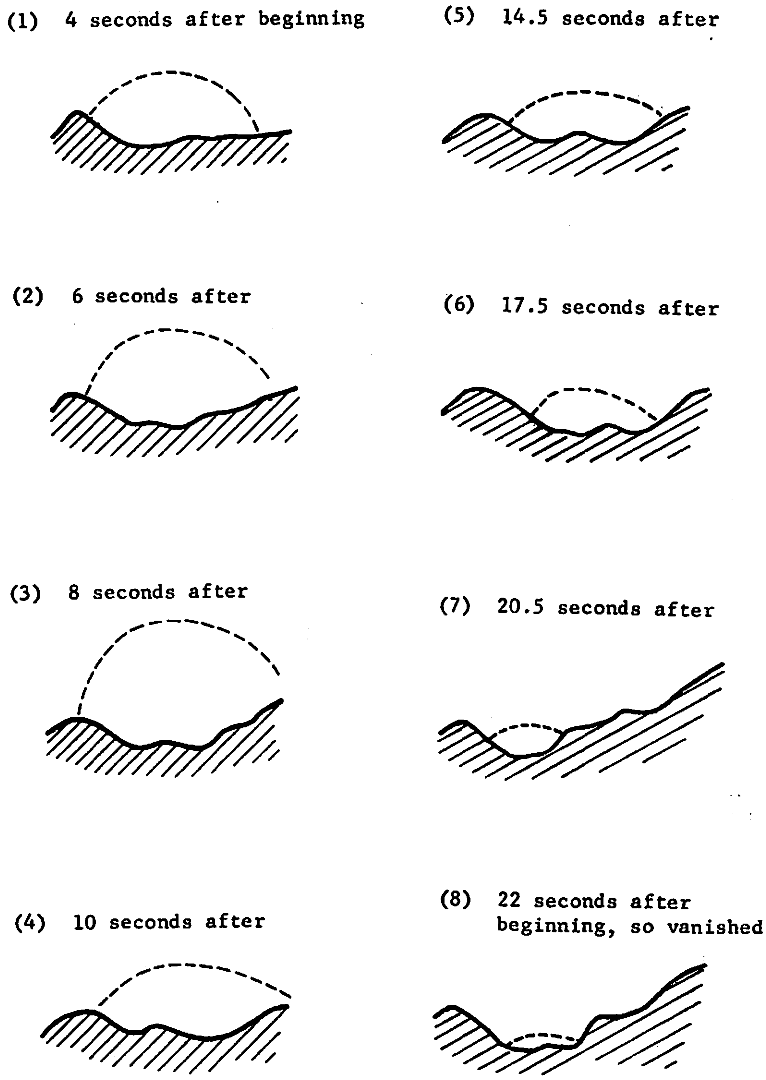

Fig. 4 Sketches of photographies at Matsushiro, showing a course of updown of semisphere (Dec. 4, 1965. 23h 48m J.S.T.)

Appendix

Abstract of Dr. Finkelstein* and Powell's** theory for the accommodation of Japanese enthusiasts.

It seems clear that there are large electric fields in the air during some earthquakes; we asked, how are they made? many mechanisms were considered. All seemed implausible on their face, but the only one that seemed possible at all is the piezoelectric effect.

The conditions that must be met for this effect to be important may be inferred from the piezoelectric equation, the relation

$$V = \alpha d \Delta S L / \varepsilon_0$$

giving the maximum piezoelectric potential difference V. Here α is a dimensionless form factor taking into account the spatial form of the stress and rock distribution, the temporal form of the stress, and the time constants (RC constants) of the media. d is the piezoelectric modulus of the rock body, with the units of coulomb/Newton in the MKS system. ΔS is the scale of the stress change in the rock. L is the scale of length of the process.

The rock-system is a capacitor which is charged by stress and discharged by conduction, both internal and external. If the time scale of stress is larger by a factor α_t than the electrical (RC) time constant of the rock system, the seismoelectric potential is reduced by the time factor α_t. The other factors giving into α include trigonometric factors relating the stress direction to the electric axis of the rock and shape factors, which we will consider ~ 1. Seismic waves have a time scale $\sim .1$ sec ($2Hz$ frequency, or a radian frequency $\omega \approx 4\pi$ sec$^{-1} \sim 10$ sec^{-1}). With a dielectric constant of 4, a rock must have a resistivity $\sim 10^9$ ohm-m to have $\alpha_t \sim 1$. Since such resistivities have been reported for natural rock (Parkhomenko, 1967) we were compelled to consider our hypothesis further.

It is quite implausible on its face that there should be a significant d over an entire tectonic unit. Symmetry of the rock texture with respect either to parity (reflection in a point) or continuous rotations implies $d = 0$. Starting from such a symmetric texture, moreover, no homogeneous stress history can make $d \neq 0$. Therefore, we were surprised to learn that piezoelectric prospecting and laboratory measurements indicate a $d \neq 0$, resulting from quartz crystals in the rock texture, with ranges of 10's of meters (Volarovich and Parkhomenko, 1954 and Parkhomenko, 1968). We write d_Q for the modulus of X-cut single crystal quartz; $d_Q = 2.2 \times 10^{-12}\ C/N$. Typical d's range from $10^{-3} d_Q$ to $10^{-1} d_Q$ for quartz-bearing rock. An inhomogeneous strain or heat treatment can account for this asymmetry, and correlations of quartz orientation with such visible grain has in fact been reported (Milne, 1970).

We considered, therefore, the possibility that this correlation extends over an

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entire tectonic unit. Near an epicenter stress changes from 25 to 250 bars are reasonably expected (Wyss, 1970). An upper limit of 1000 bars is set by the strength of rocks and this is sometimes attained, we suppose, since rocks break freshly in some earthquakes.

The unknown is the distance over which a rock system can exhibit a correlated piezoelectric modulus d. The results of piezoelectric prospecting indicate correlations over $L \gtrsim 10$ m. These can only be the result of the common history of strain and heat treatment shared by the rock. In that case, the correlation should, in suitable cases, extend over $L \sim 1$ km or more. What determines the scale length L of the seismo-electric potential is the least of all the lengths involved: the coherence length of the modulus, the scale length of the seismic stress, etc. The maximum seismoelectric potential would seem to be made by seismic waves in large, smooth piezoelectric rock bodies ($L \sim 1$ km).

The scale of the electric field E is $E = \alpha d \Delta S / \varepsilon_0$. Disturbingly high fields would result from quite reasonable stresses. Can they account for observed luminosities such as photographs by Yasui (1968) show?

We may bracket the visible power required or a luminosity by using the photographic data supplied by Yasui as well as eye witness reports. The luminosity diameter is 100 meters, which is the order of those observed. We have estimated the total power (visible plus nonvisible radiations, and thermal heating) delivered to a lumnious discharge of 100 meters diameter by a piezoelectric rock body for the favorable case of $\alpha \sim 1$ and $d = 0.03\, d_Q$. This total power is calculated as a function of seismic stress change for a range of assumed ion densities. The largest ion density, $N^+ = 1.2 \times 10^{12}$ ions/m^3, corresponds to a discharge conductivity sufficient to cause a 45° phase angle between voltage and current in the discharge, for an effective frequency of 10 radians/sec. This is an approximate upper bound to ion density in the discharge. It is likely that ion density in the discharge will approach this upper bound, since recombination rates are very low.

Of the total imput power, approximately $1 \sim 10\%$ can appear as visible light, with the remainder lost as heat and nonvisible radiation. It is evident that seismic stress changes of 10–100 bars are sufficient to power quite bright luminosities.

Thus, our assumptions would make it possible to understand the occurrence of luminosities in a general way. By taking into account more details of the physical environment, and the non-linear nature of the air discharges, we may likewise understand the occurrence of lightning strokes and other form of discharge. However, because the available energy is small even when potential differences of $\sim 10^8$ V occur, only small currents can flow, and earthquake lightning should rarely be accompanied by thunder.

Our theory of earthquake lightning depends critically on the existence of high resistivity piezoelectric rock in the seismic stress regions. Where this rock is not found above the water table it might be below it. Within ~ 1 km of the surface, high conductivity is to be expected because of water. We must therefore consider what occurs when a resistive strata $\sim 10^9 \Omega$m is overlain by a conductive one $\sim 10^3 \Omega$m. In the idealization of plane parallel geometry, the component of electric field parallel to the stratum will decay quickly with distance into the conductive layer, setting up telluric currents. The component of electric field normal to the stratum will be unattenuated, reappearing as a vertical electric field on the surface of the earth. For this, the resistive stratum must have a horizontal extent much greater than its depth.

If such rock bodies exist, they have great relevance to earthquake forecasting. According to the ideas of the slipstick model earthquakes are preceded by periods of decreasing stress and increasing strain rate, maxima in the stress-strain relation. Single-station strain measurements (seismographic, etc.) cannot give much information about such a situation. However, a large piezoelectric rock body is an *in situ* stress gauge, and moreover one in which incoherent microseismic noise is discriminated against relative to coherent seismic signals. Roughly speaking, periods when the piezoelectric signal has the sign appropriate to decreasing stress while strain gauges indicate increasing strain rate would seem to be periods of earthquake hazard. From the occurrence of E.Q.L. and strong atmospheric field anomalies $\sim$ 1 hr. before many earthquakes, we infer that forecasts $\sim$ 1 hr. are involved. Clearly, the things to do is not look for E.Q.L. or atmospheric fields but to monitor directly the rock bodies generating these voltages. If we are right, it is a giant piezoelectric microphone.

Short-range and long-range earthquake forecasts are both important in their ways. When there is a 50% probability of an earthquake in the next year, we reduce our investment in new construction, increase that in emergency medical facilities. When there is a 50% probability in the next hour, we turn off the gas and take some fresh air. If this paper is relevant to the earthquake problem at all, it is to the hourly earthquake forecast, I believe.

The earth speaks softly
To the mountain
Which trembles
And lights the sky.

Reference

Finkelstein, D. and J. R. Powell; The problem of E.Q.L. is the darkest section in seismology, 1971

Powell, J. R. and D. Finkelstein; Earthquake lightning, 1971

Finkelstein, D. and J. R. Powell; Piezoelectricity theory about E.Q.L., 1972
Publications of Brookhaven National Laboratory
Associated Universities, Inc.

地震に伴って発見する発光現象調査報告

安 井 豊

概 要

「地震に伴って発現する発光現象」は古来より多く知られているが，その成因・機構共にいまだに不分明で，学者の中でも，これは何か他現象の誤認ではないかとする人がかなりある。

筆者は昭和36年の日向灘大地震，昭和41年～43年の松代群発地震に伴った発光現象などについての調査報告を3回にわたって本誌上で発表したが，ここに総報として最終報告をする。

筆者は，強酸性岩地域ではフィンケルスタインとボーエル両氏による圧電気電場内に，地震により地下より揺り出された十分な量のエマナチオンが存在する時に発光現象が生ずるとする。しかしその発光体の本体は直径数十メートルの下半部接地半球上の白色あるいは青白色体であり，付近に雲霧の存在する時は，本体よりの反射光透過光により光が分散されるとして，発光現象の形や色の複雑多岐性が見られるものとした。

フィンケルスタイン，ボーエル氏の岩石圧電気の論文は日本ではまだひろくは紹介されていないようなので，本報告の末尾で同論文の大要を紹介させていただく。