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REVIEW PAPER

EARTHQUAKE LIGHTS: A REVIEW OF OBSERVATIONS AND PRESENT THEORIES

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ABSTRACT

The best documented observations of earthquake lights are from Japanese earthquakes in the early 1930's and mid-1960's. In the latter case, color and black and white photographs were taken of bright, hemispherical, white luminescences based at ground level, about 20 to 200 m in diameter, of duration 10 sec to 2 min, restricted to mountain summits in a quartz-diorite faulted rock. Great difficulties and uncertainties accompany any attempt to explain the phenomenon. Recent calculations include attempts to show that earthquake lights may be associated with auroras through a solar magnetic triggering mechanism. Other more probable explanations include ultrashort-period air oscillations and generation of a large potential difference in quartz-bearing rock by the piezoelectric effect. Considering the existence of well-documented pictures, reproduced here from the work of Yasui, the existence of the phenomenon is considered well-established, although no completely satisfactory explanation has been advanced to date.

INTRODUCTION

The problem of earthquake lights (EQL), or luminous phenomena, as noted by Byerly (1942), has always been the darkest area of seismology. Very few scientists have ever worked on the problem, and few today are willing to tackle it because most of the reports are personal observations of untrained observers, and, until recently, there were no "hard data" which could be subjected to scientific analysis. Observations, however, have been made for many years, as suggested by an old Japanese haiku, quoted by Finkelstein and Powell (1971).

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

Recently, popular interest in EQL has been raised by press reports and the search for methods for earthquake prediction. The data which are now available consist of pictures of luminous phenomena taken at Matsushiro, Japan, from 1965 to 1967. This paper includes descriptions of the phenomenon, and reviews several theories advanced to date as possible explanations.

OBSERVATIONS

The first known investigations which led to significant interpretations and conclusions were done in the early 1930's by two Japanese seismologists, Terada (1931, 1934) and Musya (1931, 1932, 1934), and were described by Davison (1936, 1937). Musya collected some 1,500 reports of EQL from the Idu Peninsula earthquake of November 26, 1930, at 4:30 a.m. "The observations were so abundant and so carefully made that we can no longer feel much doubt as to the reality of the phenomena and of their connection with the shock. In most of them, the sky was lit up as if by sheet lightning, and nearly all the observers agree in estimating the duration of a single flash as decidedly longer than that of lightning. At one place on the east side of Tokyo Bay, the light resembled auroral streamers diverging from a point on the horizon. Beams and columns of light were seen at different places, several observers comparing the beams to those of a searchlight. Others describe the lights as like that of fireballs. Some state that detached clouds were illuminated or that a ruddy glow was seen in the sky. At Hakona-Mati, close to the epicenter and to the northeast, a flash of light was seen, now in one spot, now in another, and, when the earthquake was at its height, a straight row of round masses of light appeared in the southwest. According to most of the observers, the colour of the light was a pale blue or white or like that of lightning, but a large number state that it was of a reddish or orange colour. The light is said to have been so bright in Tokyo that objects in a room could be seen. At another place, about 30 miles from the epicentre, it was brighter than that of moonlight . . . .

"The lights were seen to a distance of 50 miles to the east of the epicentre, nearly 70 miles to the northeast, and more than 40 miles to the west. They were seen both before and for some time after the earthquake, but were most conspicuous during the middle of the shock. The directions in which the lights were seen point, as a rule, to the neighborhood of the epicentre, that is, to the northern part of the Idu Peninsula. The light was, however, seen in other directions, sometimes in the direction of the sea . . . .

"During the year following the Idu earthquake, Mr. Musya studied the luminous phenomena attending four other Japanese earthquakes. The reports that he received were most numerous for the South Hyuga earthquake of November 2, 1931. With this earthquake, the lights were usually described as beams radiating from a point on the horizon, as like lightning or a searchlight turned to the sky, and as of a blue or bluish colour. They were seen before the earthquake by 26 observers, during it by 99, and after it by 22." (Davison, 1937).

Terada and Musya reached no conclusions as to the possible causes of earthquake lights. Terada (1931) made some calculations on potential differences in the Earth, which McDonald (1968) considers to be in error. Nevertheless, he made some perceptive comments about the quality of testimonies of witnesses under stress, which are quite relevant to the problem of collecting subjective data during an earthquake.

"With regards to all these testimonies of witnesses, it must be always kept in mind that people are naturally alive to all kinds of phenomena observed at the time of a severe earthquake and apt to regard them as something connected with the catastrophal occurrence, while they forget to consider that the same phenomena are frequently observed on many other occasions not at all connected with earthquake. On the other hand, we learn from the results of investigations by psychologists in what a ludicrous manner the testimonies of people, otherwise quite normal in mentality, may appear distorted when compared to the bare truth."

Another assessment of the problem of earthquake lights is given by Byerly (1942). In addition to his general description, he documents observations of earthquake lights observed at sea. If these lights have the same cause as those observed on land, severe restrictions are placed on the mechanism of their generation.

"Occasionally during an earthquake shock or immediately before or after, observers report luminous phenomena in the heavens. All types of lights are reported seen, although it is rarely that two observers see exactly the same. There are steady glows, red and blue, and white: there are flashes, balls of fire, and streamers.

"At the time of the earthquake off the coast of northern California in January, 1922, one observer reported a glow at sea which he at first took to be a ship on fire. At the time of earthquake of October, 1926, centering in Monterey Bay, an observer reported a flash at sea which resembled 'a transformer exploding.' During the Humboldt County (California) earthquake of 1932 an observer reported, 'Several of my friends and I saw to the east what appeared to be bolts of lightning travel from the ground toward the sky. The night was clear.' It has been customary to attempt to ascribe earthquake lights to secondary phenomena, since we know of no source of such lights in the original earthquake action. True, movement on a fault would generate considerable heat, and, after the Sonora earthquake of 1897, trees overhanging the fault were scorched. Such would scarcely produce flashes in the sky, particularly over the ocean. In modern times, the prevalence of electric power lines enables one to explain away many such observations as due to probably breaks in such lines; but many may not be so dismissed. Landslides in mountains may generate great heat by friction. In the Owens Valley earthquake of 1872, fires were started in the mountains by such sources. In some cases thunderstorms may happen to accompany earthquakes, and then lightning may be called upon to explain flashes. Lights over the sea have been attributed to luminous marine organisms excited by the earthquake vibrations."

More recently, research into observations of luminous phenomena in Japan has been done by Yasui (1968, 1971, 1972), who collected and studied pictures, taken by various other observers, of earthquake lights observed during the Matsushiro earthquake swarm of 1965 to 1967. He has also studied reports of other sightings in Japan. Of the approximately 35 sightings, any pictures which might have recorded unrelated phenomena—distant lightning, meteors, twilight, zodiacal light, arcing power lines—were eliminated. At least 18 separate sightings remained unexplained. He concludes that luminescence over a mountain area lasting several tens of seconds on a clear and calm winter night is not a known phenomenon. He thinks it to be an atmospheric electrical phenomenon, but the earthquake trigger mechanism is unknown.

There are five general characteristics of the phenomenon as observed by Yasui (1968):

1. The central luminous body is a hemisphere, diameter about 20 to 200 m, contacting the surface. The body is white, but reflections from clouds may be colored.
2. The luminescence generally follows the earthquake with a duration of 10 sec to 2 min.
3. The luminescence is restricted to several areas, none of them the epicenter. Rather, they occur on mountain summits in a quartz-diorite faulted rock.
4. Sferics generally follow the luminescence and are strongest in the 10 to 20 kHz range. The luminescence occurs frequently at the time of a cold frontal passage.
5. There was no indication on the magnetometers at the local observatory.

These observations are not consistent with explanations based on auroras or other ionospheric phenomena, noctilucent clouds, or rapid spark discharges. However, the observations near mountain tops and along faults are consistent with large atmospheric potential gradients and with an unusual increase of radon gas in the vicinity.

Yasui believes that ionization in the lowest atmosphere becomes unusually large at the time of an earthquake and causes the luminous phenomena at the place where the electrical potential gradient is highest. The electric field is not expected to be large, as it is under a thunderstorm, nor is the atmospheric conductivity expected to be high. Therefore, some action of the earthquake must contribute to triggering luminescence, e.g., violent atmospheric oscillation, but the process is still unknown.

An unusual report of EQL near Hollister, California, was given by Nason, personal communication, (1973). In this case, the lights were seen as discrete sources against a hill, also noted by Davison (1937), rather than as the more commonly observed general sky luminosity. Mr. Reese Dooley, a poultry rancher living south of Hollister, observed the EQL in 1961. There were two earthquakes about $2\frac{1}{2}$ min apart. It was dark when he felt the first one, which was strong enough to make him want to go home to check on his family. Just as he reached his car, the second one started. As he looked west toward a hill, he saw a number of small, sequential flashes from different, random places on the hillside. Nason inspected the hillside and found no electric wiring or any other conventional explanation for the lights. Clearly, Mr. Dooley was very close to the source of the lights. This observation suggests that the extensive EQL observed in Japan which lit up most of the sky could be caused by a great number of small, random point discharges over part of the epicentral area.

Lomnitz, personal communication (1972) agrees with the author's hypothesis that a whole range of precursory phenomena including lights, sounds, and animal reactions, are probably caused by electromagnetic effects. For example, Lomnitz reports his personal observation in Mexico City of extremely unusual behavior in a dog, at least 1 min before the August 2, 1968 earthquake near the coast of Oaxaca. He also notes that luminous effects were widely observed in Mexico City at the time of the 1957 earthquake near Acapulco. Thus, any theory of EQL would have to account for the occurrence of electromagnetic effects at distances of 3° to 4° from the epicenter of a shock of magnitude 6.5 or greater.

Most recently Yasui (1972) has commented on observations of EQL during the October 1, 1969 earthquake at Santa Rosa, California (Engdahl, 1969). The lights were seen extensively over the Santa Rosa area and described in terms of lightning or electric sparks, Saint Elmo's Fire, fireballs or meteors. Some people also heard sounds like explosions. Just how many reports are genuine EQL and how many are caused by earthquake effects on man-made objects cannot be determined. From the published description, however, the Santa Rosa observations did not include what was described by Davison (1937) as appearing to be auroral streamers


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diverging from a point on the horizon, a description which does fit observations, for example, in Chiba prefecture, Japan, January 5, 1968, as sketched by Yasui (1971).

Figures 1 to 19 show earthquakes lights as published by Yasui (1968). All are from the Matsushiro, Japan area and are samples of the only known pictures of earthquake lights. They were taken by a Matsashiro dentist, Mr. T. Kuribayashi.

THEORIES

McDonald (1968) investigated many possible mechanisms for producing electric potential gradients in the Earth. One area of his research involved the streaming potentials in water flow through porous rocks and soils, in connection with pressure gradients developed following underground nuclear explosions. The maximum potential difference found was a few hundred millivolts over distances of 1,000 ft from ground zero, far too small to have any effect on corona discharge in the atmosphere. Such potentials are also many orders of magnitude too small to produce any air luminosity.

McDonald also reviewed Terada's (1931) discussion of the streaming potential. He found the calculations to be very obscure and could not see how Terada calculated a potential difference of 3 million volts. This potential, however, was computed to be between the horizontal surface of the Earth and a layer at about 100-km depth. Regardless of the correctness of the calculation, a huge potential difference within the Earth is difficult to relate to electric fields out in the air above the epicentral zone. McDonald concluded that Terada simply misunderstood the equations he was using.

In addition to these arguments, McDonald investigated several examples of earthquakes at sea where luminosity was reported and decided that none of the mechanisms proposed for generating potentials on land could produce luminosity at sea.

In the case of the Hebgen Lake earthquake in Montana in 1956, McDonald considered the possibility that space-charge might be transported through a vertical distance of 1,000 ft by aerodynamic drag by the landslide and might possibly set up temporary electrical imbalances that could lead to luminosity. This mechanism would not account for most of the sightings which do not include landslides but might be one of several mechanisms able to produce luminosity.

McDonald's interpretation of Simpson's (1967) work on solar activity as a triggering mechanism for earthquakes leads to the possible explanation that some earthquake luminosities are auroras. Simpson's hypothesis is that magnetic coupling between the solar plasma and the geomagnetic field may impose torques that alter the rotational velocity of the Earth and hence induce faulting on weak zones that are already under stress. Thus, it is not surprising that auroras would be seen at the same time that earthquakes occur. A number of reports of earthquake lights, both early and recent, are strongly suggestive of auroral luminosities. It would be quite unreasonable to say that the earthquake causes the aurora or any other high altitude luminosity, but McDonald considered the evidence good for the same solar magnetic process to cause both auroras and earthquakes. Lomnitz, however, considers Simpson's data to be not very promising and sees no significant, dominant effect in his attempted sunspot-earthquake correlation.

It is possible that some observations of earthquake lights might be traced to ball lightning. If the earthquake should occur in thunderstorm weather, one might even expect that there would be at least some reports of luminous phenomena which might originate as fireballs descending from clouds. The light might be associated with a hissing sound, might last for several seconds ending with an explosion, and might produce an odor and/or smoke. However, there would also be abundant stroke lightning in the vicinity, so that an investigator would naturally tend

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FIG. 1. Jizo Pass, 0421 (JST), February 7, 1966. Photograph was made with 32-mm lens, 2 sec, at Fl.9, UV filter, Sakura color N, ASA 100. [Figures 1–19 show examples of earthquake lights observed at Matsashiro, Japan, taken by T. Kuribayashi and published by Yasui (1968, 1971).]

FIG. 2. Near Mt. Saijo, 0417 (JST), February 12, 1966; the same camera and film were used as for Figure 1.

FIG. 3. Area around Mt. Kimyo, 0325 (JST), September 26, 1966; photograph was taken with fisheye lens, 36 sec, at F8, UV filter, Sakura color N, ASA 100. Direction was due north. Luminosity lasted 96 sec

FIG. 4. This is the same picture as Figure 3, printed in black and white to reveal foreground detail.

FIG. 5. Mt. Kimyo, 0320 (JST), January 22, 1966 (32-mm lens, 1/8 sec, at F1.9, film Fuji Neopan SSS).

FIG. 6. Matsushiro, 1821 (JST), September 19, 1966.

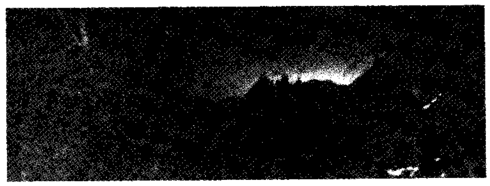

FIG. 7. Matsushiro, 1830 (JST), January 12, 1967.

FIG. 8. This is the first of a series of photographs taken at Matsushiro at 2348 (JST), December 4, 1965, 4 sec after beginning of EQL (32.mm lens, Fl.9, 4-sec exposure).

FIG. 9. 6 sec after beginning of EQL.

FIG. 10. 8 sec after beginning of EQL.

FIG. 11. 10 sec after beginning of EQL.

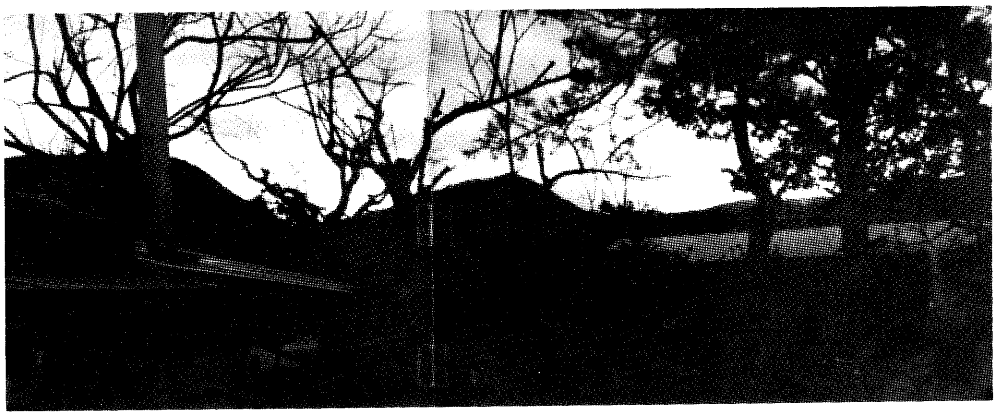

FIG. 12. 11.5 sec after beginning of EQL.

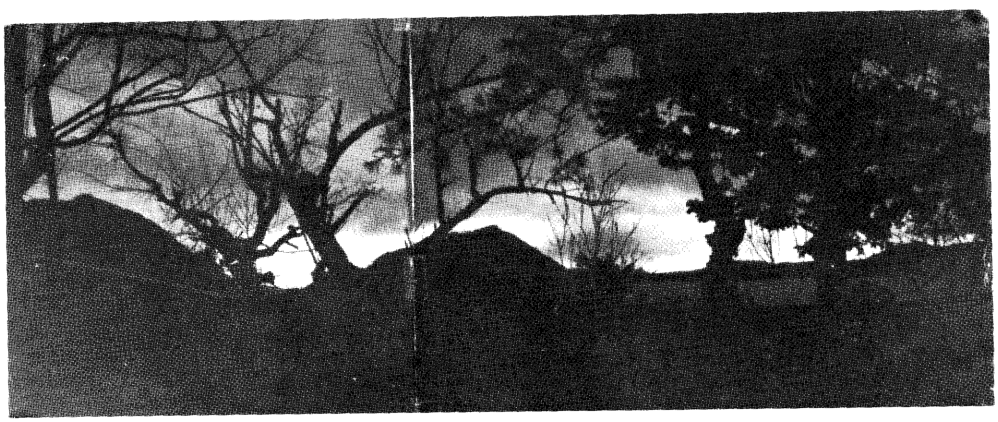

FIG. 13. 13 sec after beginning of EQL.

FIG. 14. 14.5 sec after beginning of EQL.

FIG. 15. 16 sec after beginning of EQL

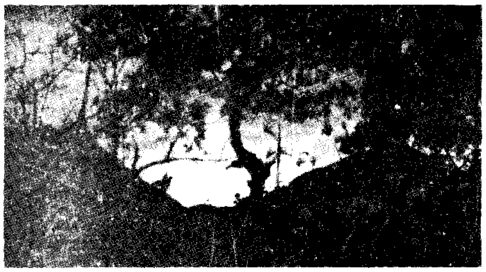

FIG. 16. 17.5 sec after beginning of EQL

FIG. 17. 19 sec after beginning of EQL.

FIG. 18. 20.5 sec after beginning of EQL

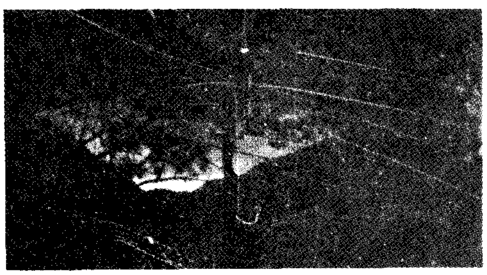

FIG. 19. 22 sec after beginning of EQL; light vanished within 1 sec after this picture was taken

to discount *any* reported lights as being due to atmospheric electricity. If higher electric potentials are generated in the ground during some earthquakes, then it might be possible for earthquake lights to be caused by both stroke and ball lightning, but, at the present time, we have yet to prove even the existence of the electric potential in the ground.

More recently, work on earthquake lights was reported by Finkelstein and Powell (1971) at the Moscow IUGG meeting, in a session devoted to earthquake prediction. Their work concerns the feasibility of generating the required electric field in rocks, both before and during earthquakes, and is a continuation of their previous studies of ball lightning (Powell and Finkelstein, 1970). They showed that these luminous phenomena could be caused by ground-to-ground electric discharges called arch lightning. Some evidence exists to suggest that the stress accumulated in rocks over a period of years may begin to be released very slowly several days before a large quake. This straining could lead to generation of a high-seismo-electric potential, generated by stress on piezoelectric quartz in the rocks, and the resultant discharges might be seen several hours before the actual fault break of the major earthquake. (It should be noted here that Yasui, Byerly, and others have reported luminescences before, during, and after earthquakes.) An earthquake stress drop of 100 bars will generate fields of 10^5 volts/m, voltage of 10^8 volts, and currents of 10 amps. Thus, the potential should be measurable, and would give a few hours or more warning before a major earthquake.

Most seismologists hearing the paper were of the opinion that enough evidence exists to warrant investigations, and that the subject should no longer be ignored. There was some question as to whether rock formations are dry enough to have the required high resistivity, about 10^9 ohm-m. However, if this theory of seismo-electric potential should prove to be correct, at least some occurrence of earthquake lights may be explained in this way.

Yasui (1971) reports that Kondo (1968) observed an unusual decrease of the atmospheric potential gradient at the Matsushiro seismological observatory at the time of some local earthquakes, although none of his observations were made during sightings of EQL. Yasui concludes that EQL are "essentially an atmospheric electric phenomenon, e.g., a large scale point discharge." This occurs in the part of the lower atmosphere contacting the ground surface in the vicinity of the epicenter where the geological conditions are favorable, i.e., high acidic rocks. He believes that the phenomenon may be generated by violent, ultrashort-period oscillations in the air occurring at the time of the earthquake. Unfortunately, the lack of facilities to record EQL results in the phenomenon remaining a mystery.

The study of earthquake lights also leads to investigation of those observations of UFOs during earthquakes which have been given much attention in the popular press, particularly in South America and Japan. A brief mention of this problem is given by Altschuler (1969) in the *Condon Report*. Altschuler gives a short description of luminous phenomena and then simply assumes without proof that they are caused by plasmas, thereby dismissing them as natural phenomena. That EQL are the causes of these observations seems to be the least unlikely hypothesis, but it certainly has not yet been proved. In view of the observational evidence, however, it seems highly unlikely that most of what is reported as luminous phenomena could be UFOs.

Conclusions

The existence of luminous phenomena, or earthquake lights, is well established. The luminosity occurs in the air close to the ground, generally over certain areas in the epicentral region principally during, but also before and after, the earthquakes. Sightings occur both on land and at sea and have been reported from as far as 3° to 4° from the epicenter of an $M = 6.5$ shock. Two theories have been advanced which are worthy of further investigation: (1) violent low-level air oscillation, and (2) piezoelectric effect in quartz-bearing rock. If the latter theory is correct, it may be possible to develop electrical monitoring methods for earthquake prediction. Observations of EQL at sea might be explained by air oscillation but probably not by the piezoelectric effect. On the other hand, observations 3° or 4° distant are probably more easily explained by the piezoelectric effect than by air oscillation. Hence, multiple causes may be operating in different circumstances.

ACKNOWLEDGMENTS

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REFERENCES

Altschuler, M. D. (1969). Atmospheric electricity and plasma interpretations of UFOs, in *Scientific Study of Unidentified Flying Objects*, E. U. Condon, Editor, Bantam Books, New York, 723–755.

Byerly, (1942). *Seismology*, Prentice-Hall, New York, p. 76.

Davison, C. (1936). *Great Earthquakes*, Thomas Murby, London, 259–260.

Davison, C. (1937). Luminous phenomena of earthquakes, *Discovery* **18**, 278–279.

Engdahl, D. (1969). *Newspaper report*, Press Democrat Publishing Co., Santa Rosa, Calif., Nov. 30, 1969.

Finkelstein, D. and J. R. Powell (1971). Lighting production in earthquakes, General Assembly, Intern. Union Geodesy Geophysics, 15th, Moscow.

Kondo, G. (1968). The variation of the atmospheric field at the time of earthquake, *Mem. Kakioka Mag. Obs.* **13**, 11–23.

McDonald, J. E. (1968). Unpublished notes.

Musya, K. (1931). On the luminous phenomenon that attended the Idu earthquake, November 26th, 1930, *Bull. Earthquake Res. Inst., Tokyo Univ.* **9**, 214–215.

Musya, K. (1932). Investigations into the luminous phenomena accompanying earthquakes, *Bull. Earthquake Res. Inst., Tokyo Univ.* **10**, 666–673.

Musya, K. (1934). On the luminous phenomena that accompanied the great sanriku tunami in 1933. (part I). *Bull. Earthquake Res. Inst., Tokyo Univ., Suppl.* **1**, 87–111.

Powell, J. R. and D. Finkelstein (1970). Ball lightning, *Am. Scientist* **58**, 262–280.

Simpson, J. F. (1967). Solar activity as a triggering mechanism for earthquakes, *Earth Planet. Sci. Let.* **3**, 417–425.

Terada, T. (1931). On luminous phenomena accompanying earthquakes, *Bull. Earthquake Res. Inst., Tokyo Univ.* **9**, 225–255.

Terada, T. (1934). Luminous phenomena accompanying destructive sea-waves (tunami), *Bull. Earthquake Res. Inst., Tokyo Univ., Suppl.* **1**, 25–35.

Yasui, Y. (1968). A study on the luminous phenomena accompanied with earthquake (part I), *Mem. Kakioka Mag. Obs.*, **13**, 25–61.

Yasui, Y. (1971). A study on the luminous phenomena accompanied with earthquake (part II), *Mem. Kakioka Mag. Obs.* **14**, 67–68.

Yasui, Y. (1972). Seismo-luminous phenomena at Santa Rosa, *Mem. Kakioka Mag. Obs.* **15**, 81–86.

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Note added in proof:

Lomnitz, personal communication (1973), notes that Sr. Octavio R. Garcia A. of Mexico City reported a strong noise on his car FM radio on all stations after the July 16, 1973 earthquake on the coast of Guerrero State (1812Z, $M_S = 5.7$). The noise reportedly lasted for 5 min. This report gives strong support to the hypothesis that EQL are an electromagnetic phenomenon.