17. *On Luminous Phenomena Accompanying Earthquakes.*

By Torahiko TERADA,

Earthquake Research Institute.

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Introduction.

Among the historical documents regarding severe earthquakes of the past, in Japan as well as in the other parts of the worlds, we find not infrequently some descriptions of remarkable luminous phenomena observed in the sky or on the ground before, during, or after the time of severe shocks. The phenomena were observed sometimes in the immediate vicinity of the epicentre and sometimes in very remote quarters. The descriptions of the form, colour, intensity, duration, motion and fluctuation of the luminosity observed are extremely variegated as the case may be. Still, it is interesting to remark that among these chaos of testimonies we may pick up almost parallel statements of quite independent witnesses. Thus, for example, we may cite a number of testimonies recorded in Galli's collection[1] of such data, which have their respective facsimiles among the Japanese data collected by Mr. Musya[2] and the present author. The agreement between the independent witnesses is not only referred to vague statements of the general features of the luminosity, but also to very detailed descriptions only capable for keen observers.

Notwithstanding these almost superfluously abundant materials of testimonies, the phenomena failed to attract any serious attention from the majority of seismologists, who apparently did not care for these documents at all. Even among those who came eventually to be confronted with some examples of the phenomena, skeptical opinions usually

1) IGNAZIO GALLI, "Raccolta e classificazione di fenomeni luminosi osservati nei terremoti," *Bolletino della Società Italiana*, 14 (1910), 221.

2) K. MUSYA, *Bull. E.R.I.*, 9 (1931), 177, (in Japanese, with English abstract).

prevailed. Psychological or physiological illusions were often quoted, without proof. Distant lightnings, firebrands, camp-fires will be often mentioned, again mostly without proof. In the recent years, the possibility of short-circuiting of electric transmission lines has furnished a new item for these would-be causes of the phenomena in question. For those who does not spare the trouble of examining these documents with open mind, it will be, however, found difficult to discard the phenomena a priori as utterly unreal or independent from the earthquakes. Thus, for example, A. Sieberg[3] spared a special chapter in his book on seismology for this phenomenon and states that there are some examples for which the usual explanation by the trivial causes seems to fail. He concludes by saying rightly enough that this luminous phenomenon is just the darkest chapter in seismology.

Mr. Kinkiti Musya of our Institute was early interested with the luminous phenomena frequently described in the historical documents of our country concerning earthquakes and has made an excellent collection of these materials. The present writer was also of the opinion that the phenomena may be well worth a serious study and at least cannot be discarded as trivial without scrutiny. The Idu Earthquake of Nov. 26 1931 occurred just at this time when our attentions towards this particular phenomenon was ripening, and at once furnished us with so many conspicuous examples that any doubt about the physical reality of phenomena was completely removed and, moreover, their physical connection with the earthquake became a matter beyond any question. It seems, therefore, not without interest to attempt here a brief review of the literatures regarding the matter and also to make some discussions regarding them though the results of Mr. Musya's investigation are already published in the previous number of this Bulletin.

Occidental Literatures regarding the Phenomena.

Besides 148 examples given in Galli's collections and those cited in Sieberg's Erdbebenkunde, there are a number of other data at the hand of the writer for which the reference is made in the footnote.[4]

3) A. SIEBERG, "Erdbebenkunde," Kap. 14, Jena, 1923. See also A. SIEBERG u. R. LAIS, "Das mitteleuropäische Erdbeben von 16 Nov. 1911," *Veröff. Reichsanst. f. Erdb. fors. i. Jena*, Heft 4.

4) S. GÜNTHER, "Geophysik," I, (Stuttgart 1897), 477; CORN. TACITUS's Annali cited regarding the luminous phenomena observed on the occasion of an earthquake in Achäian cities in 373 B.C., which is the earliest example; literatures on allied matters found in citate

Examining these numerous materials it will be seen that the phenomena recorded are of extremely variegated features but may be conveniently classified into a number of types, which are represented on different occassions in different nuances of forms and combinations. I. Galli classified:[5] (I) indefinite instantaneous illumination, (II) well-defined and mobile luminous mass, (III) bright flame and emanation and (IV) phosphorescence of sky and clouds. The class (I) was subdivided into (a) lightning (lampi e bagliori), (b) sprinkles (sprazzi luminosi) and (c) streamer (strisce luminosi sottili). The class (II) contains (d) fire-ball (globo di fuoco) (e) fire-column (colonna di fuoco), (f) beam of fire (trave di fuoco) and (g) luminous funnel (tromba luminosa). The class (III) including those phenomena which appear from the earth and last for a sensible duration of time, is subdivided as (h) flame (fiamme), (i) little flame (fiamelle) (j) spark (scintille numerose) and (k) luminous vapour (vapori luminosi). Lastly, the class (IV) is divided into (l) diffused light in the sky (luce diffusa nell'aria) and (m) luminous cloud (nube luminosa). These classifications seem to cover almost all the examples in the occidental literatures above cited as well as in our collection of the Japanese documents and testimonies. Though such a classification is liable to much ambiguity, as the meaning of the same words used by different witnesses may have more or less different contents, we will sometimes conveniently refer to this classification in the following description of Japanese examples.

Examples in Japan.[6]

Above forty examples of documents concerning the luminous phenomena observed in connection with severe earthquakes dated up to the

at the end of Chap. 4. URBANITZSKY, "Die Elektrizität des Himmels u. d. Erde," (1888), 358. R. HOERNES, "Erdbebenkunde," (1893), 113–116. E. HENNIG, "Erdbebenkunde," (1909), 111–113. J. MILNE, "Seismology," 330. K. FUTTERER, "Das Erdbeben vom 22 Jan. 1896," Karlsruhe 1896, 32. "On Earthquake of Dec. 17, 1896," *Symons's Met. Mag.*, (1897), 183. W. GAW, "Atmospheric Phenomena during the Chili Earthquake," *Symons's Met. Mag.*, (1906), 225. A. SIEBERG u. R. LAIS, *loc. cit.* MYRON L. FULLER, "The New Madrid Earthquake," *Bull. U.S. Geol. Surv.*, 494 (1912), 46. BAILY WILLIS, "Earthquake Condition in Chile," 30. I. GALLI, *loc. cit.* It is said that luminous phenomena were also observed on the occasions of San Fransisco Earthquake of 1906 and the recent Italian Earthquake of 1930, though the reliable documents are not at hand. For an example of Chinese earthquake, we may cite 章振藻, 雲南地震考 (1926), in which it is stated that on the occassion of Yunnan earthquake of March 1925, immediately before each of the severe shocks sulphurous smell was felt and fiery light discovered in the sky which moved from N to S.

5) The numbering of the classes and the alphabetical denominations are not given in Galli's paper, but introduced here for the sake of convenience.

6) Most of these examples are cited from "Dainihon-Disiu-Siryô", some from Musya's collection and the rest from other miscellaneous sources.

beginning of Meidi Era (1868), are found in Musya's collection, of which about twenty refer to the Ansei Earthquakes (1854 and 1855). The earliest record in Sandai-Zituroku (三代實錄) states that on the occasion of the severe earthquake in Mutu, N. Japan, in 869 A. D., "streaming light was seen as if it was daytime" and its intensity seems to have shown some sensible fluctuation (流光如晝隱映). The phraseology suggests that the luminosity was something unusual and different from that of lightning, perhaps belonging to Galli's class I or IV. In Kamakura Earthquake of 1257, bluish flames were seen to emerge from the fissures opened on the ground[7]. This belongs apparently to Galli's class III. In the case of an earthquake in Suruga and Tôtômi 1589, the luminosity observed from a distant quarter is expressedly stated as "not like lightning" and also "whole sky illuminated." Flying luminous bodies are mentioned in connection with two local earthquakes in Yedo in 1630 and 1672; as these occurred in winter, the connection with thunderstorm is improbable. In the case of 1672, a fire-ball resembling paper-lantern is mentioned which was seen flying through the sky towards E. In the case of Tosa Earthquake of 1698, a number of fire-balls like wheel were seen flying in different directions. In the case of Great Genroku Earthquake of 31 Dec., 1703, in Tôkaidô, luminous "bodies" and "air" were frequently seen in the nights preceding the day of the severest shock[8] and, afterwards, a kind of luminosity like the sheet-lightning continued to be seen for about twenty days, even when there was no cloud to be seen. This earthquake occurred also in the season when the thunderstorms are extremely rare. It is needless to say that there existed no electric transmission lines. Galli's "fiamme" is again met with in the case of Sandyô Earthquake of 1828 and Sinano Earthquake of 1847. In the latter case, "lampi e bagliori" are also reported. One of the records states: "Under the dark sky, a fiery cloud appeared in the direction of Mt. Iduna. It was seen to make a whirling motion[9] and then disappeared. Immediately afterward, a roaring sound was heard, followed by severe earthquakes." Again, "the luminosity accompanying the enormous land-slide of Mt. Iwakura was of so strong intensity that it was as bright as daylight to

7) *Cf.* GALLI, N. 128: "……par les fentes que l'on me montrait (fentes causèes par le tremblement de terre et qui n'existaient pas auparavant) on avait vu sortir du feu"; and many others.

8) See foot-note, p. 235.

9) *Cf.* resolving motion mentioned in p. 240.

every corner of houses." At the time of earthquake of 19 Aug. 1830 in Kyôto and its vicinity, it is stated that in the night preceding to the earthquake luminous phenomena were seen in the whole sky and some kinds of luminosity were emitted also from the ground which were so bright as to be compared with daylight. The people were wondering at the unusual phenomena until the severe earthquake was experienced on the next day. In the case of Ansei earthquake of Nov., 1855, different forms of luminous phenomena[10] were reported and, in this case also, the season was near the minimum of thunderstorm frequency.

As for the examples recorded after the Restoration of Meidi, we may cite the following.

1889, July 28, Kumamoto Earthquake: According to "Kumamoto Meidi Sinsai Nikki", a fearful lightning flash (or flashes ?) was seen towards E immediately before the arrival of shocks. Afterwards, lightnings were observed towards W till the next dawn. In the previous (?)

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10) We may cite a few examples from MUSYA's collections: "At the time of the earthquake, a luminosity resembling lightning was seen towards E which disappeared after a short time". "Before the noon, something like a vertical rainbow was seen towards SE". "An witness, who were afishing off Sinagawa, saw flashes like lightnings towards Yedo (Tôkyô) at three or four places." "A party of 19 persons went to sea on the eve of the earthquake. Before the time of the shock a sudden luminosity was seen towards NE, which was so bright that the coloured patterns of their clothes could be well discerned. Soon afterwards, a horrible roaring sound was heard from underneath the sea, which gave them an impression as if a mass of gravels were impinging upon the bottom of the boat. At the same time a mass of flame went flying through the sky accompanied with sounds." "A person in Ikenohata, Sitaya, observed at the time of the shocks a luminosity towards NNW which was quite unlike a lighting. "At Yosiwara, fissures were formed on the ground, from which a beam of white 'air' (luminosity) emerged. It moved aslant toward Asakusa Temple." "A man in Usigome was surprised to see the window illuminated. Towards S he saw a slender beam of ruddy light which was bent like the handle of a kettle. He was wondering at the phenomenon when the sudden shaking of the ground was felt." It seems that the luminosity preceded the first shock; moreover, the curved beam of light mentioned resembles to a similar phenomenon observed by Mr. HATTORI on the occasion of Tanzawa-yama Earthquake of Jan. 15, 1924, cited later. "A traveller on his way through Koisikaw at midnight saw some 'dark air containing bluish luminosity' which moved rapidly from NE to S accompanied with a sound like strong gusts of wind. Soon afterwards, the earthquake shock was felt." There are several witnesses who state to have seen some dark object flying through the sky which is rarely mentioned on the other occasions. It is possible that a physiological effect might here be concerned. "In the night of the earthquake, fire was seen to be emitted from the ground somewhere near Gyôtoku, Simôsa. On approaching the spot where the flame seemed to emerge, nothing could be found, but the similar fire was seen in front again at some distance from thence."

night, a fire-column had been seen to pierce the cloud, while it was raining. In the night of the earthquake which occurred at about 12h, the sky was at first clear with abundunt shooting stars and afterwards it begun to rain. The season was near the maximum of thunderstorm frequency and we are not in possession of the weather chart of that time so that it is difficult to tell whether the light seen was not the usual lightning.

1891, Oct. 28, Nôbi Earthquake: In the preceding night lightnings were seen towards W from the village Miyake. Frequent lightnings were also seen at Tusima-Mati.

1896, June. 15, Sanriku Earthquake with tunamis: Fishermen 30–40 ri off the coast saw something like burning fire and after a short time heard a sound like cannonading towards the land.

1909, Aug. 14, Kônô or Anegawa Earthquake: According to Prof. Koto's report, the western slope of Mt. Ibuki slided down and some luminous phenomena observed.

1917, May 18, Earthquake in Suruga and its vicinity: Fire-column was seen in the mountain north of Siduoka.

1918, Sept. 11, Oomati Earthquake: According to Prof. S. Tsuboi's report, at the time of the second severe shock, a kind of luminosity was seen in the directions of mountains in Hida and Sinano to W. of Ikeda-Mati.

1923, Sept. 1, Kwantô Earthquake: Fishermen of Awa saw several fire-column appearing in (?) the sea in a part of the Sagami Bay near the mouth of the Bay of Tôkyô, on 1 (or 2) Sept. A staff-member of the Central Meteorological Observatory observed a kind of stationary fire-ball in the sky of Tokyo. A woman in Hukagawa saw a flashing light on the sea in the morning, i.e. before the earthquake, of Sept. 1. A student observed unusual luminous phenomena towards the direction of Bôsyû in the night of Sept. 2 (?).

1924, Jan. 15, earthquake in Tanzawa-yama district: A luminosity was seen in Yokosuka at the time of shocks. Such was also seen from C.M.O., Tôkyô, towards W. Fishermen off the coast of Kôdu saw a strong light on the southern slope of Mt. Tanzawa. Mr. K. Hattori, Assistant in Aeron. Res. Inst., who was dwelling at that time in Terazima-mati on the E-side of R. Sumida, was awakened by the first shocks and hurried out of door, when he happened to observe a pillar of fire over the roof of a house towards N. It was slightly bent with its concave side to the right and its upper end merged into a diffuse sheet of light attaining

a considerable altitude. The colour of the light was pale white. The sky was clear. Two persons saw the same phenomenon. It is interesting to notice that this latter example bears a remarkable similarity with that depicted in Fig. 58 of Sieberg's book cited.[11]

1925, May 23, Tazima Earthquake: At the time of one of the severest after-shocks which occurred during the night, Mrs. Yamamoto of Hukutiyama observed a luminous ball, reminding her of a foot-ball, in the sky in the direction opposite to Kinosaki, i.e. the epicentral region. It moved rapidly from NE to S like a shooting star and disappeared somewhere.

1927, March 7, Oku-Tango Earthquake: Mr. S. Sawada of Hirakata-Mati, observed at Huse-Mati a luminosity towards E which he supposed to be due to sparking of an electric transmission line in the neighbourhood. Mr. K. Saito of Kyôto was in an electric car running from Kôbe to Osaka at the time of earthquake. He observed an unusual luminosity of night sky towards Mts. Muko and Rokkô, not quite unlike a distant fire-brand, but of quite unusual colour. Fishermen of Taiza who were fishing off the mouth of R. Asamo observed a luminosity above the sea towards E, which was more reddish in hue than the usual lightning flash, and paler compared with a candle light.

1928, May 21, a local earthquake in the NE part of the Tokyo Bay: Mr. Hattori, Aeron. Res. Inst., observed a diffuse illumination of sky a few second after the first severe shock. The flashes which seemed to be of longer duration than that of a lightning, were repeated two or three times; they also seemed to occur nearly simultaneously with the maxima of earth's disturbances. Dr. S. Yamaguti of our Institute observed a flickering luminosity in the southern sky which continued during the shocks and abated with it. The colour was like that of an electric spark and the luminosity seemed to reach an alittude of about 10°.

1930, Dec. 20, a local earthquake in Hirosima Prefecture: Mr. B. Takeda of Syôbara-Mati states that several persons observed some luminous phenomena towards N at the time of the severest shocks as well as during some of the aftershocks. It is stated by several witnesses that the northern sky was illuminated by a ruddy light as in the case of a fire-brand. Some one is said to have seen a fire-ball. Elecric light was extinguished at the time of earthquake. Mr. K. Nozaka, the Master

11) A similar kind of curved fire-column was seen at the time of Ansei Earthquake (see foot-note p. 229); another, probably of the same class, was seen in the present case of Idu Earthquake (see p. 232).

of Syôbara Common School, reports that a fire-ball was seen from the school towards NNW, which moved upward and vanished, followed by a luminosity in all directions. A member of the Village Office in Syôbara observed a purple flash of radiating light towards WNW. Mr. N. Emura of Kimita School saw white light of indefinite extention towards SE, NW and E respectively. The report from Kimita Village Office states that immediately after the severe shock of 20 Dec., an illumination of the sky towards NE was seen resembling a distant fire and the similar phenomenon was also seen in the night of 21st. in two directions N and S. Lastly, Mr. M. Hara of Kutikita-Mura, Hiba District, observed immediately after the shock a beam of light like an inverted brush or a signal fire rising upward and illuminating the clouds with a hue similar to a fire-brand. The light gradually faded upwards. Besides, a faint general illumination was seen in the lower sky just above the mountains, first in SW direction and then in SE and N.

In most of the above examples, no strong evidence could be brought forth against the criticism which may be applied as regards the suspicions whether they were not due to lightning, electric short-circuiting etc. In this respect the recent Idu Earthquake of Nov. 26, 1931, may be cited as an unique case in which the abundance in number of testimonies far surpassed the total sum of all the above cited and the detailed features of evidences allows no room for suspicion as to the physical reality of the phenomena as an immediate appendage of earthquake shocks.

Examples from Idu Earthquake of 1930.

Immediately after the earthquake of Nov. 26, 1930 in Idu district, Mr. K. Musya sent a circular inquiring after detailed informations regarding any form of luminosity observed in connection with the earthquake, adressed chiefly to the masters of the boys' and girls' middle schools in the neighbouring prefectures. The data accumulated in this way amount to 1168 in number.[12] Mr. K. Musya made a thorough study of these data and already published a summary of his results of investigations in the preceding number of this Bulletin.[13] The present

12) On examining these data from the school boys and girls, it was noticed that their testimonies are neither always original nor independent from each other, being apparently influenced by the effect of mutual conversations and inquiries, so that the coincidence of testimonies is not necessarily the proof of their truth.

13) In the following his paper will be as K.M.

author also examined these data which was kindly placed at his disposal, and confirmed Musya's results in the essential points. Besides, the author was able to obtain about 15 data from the sides of persons more or less trained in scientific observations. Besides, about twenty other reports were also gathered from the side of laymen witnesses among the inhabitants of Tokyo as well as of different localities in Sagami and Idu. Moreover, another set of valuable data was obtained by the courtesy of the Central Fire-Brigade Station of Tôkyô which consists of the testimonies of the firemen who were in charge of night watch on the watching towers of different local fire-brigade stations situated in different quarters of the city. The latter data are especially valuable, as the witnesses were awake before the arrival of the earthquake shocks and they could be expected to be especially alert to any trace of unusual luminous phenomena of night. These additional data taken altogether bring, however, nothing essentially new to the summary given by Musya.

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 with the bare truth. These points taken into due account a sufficiently numerous independent testimonies may still give at least a general outlines of what really happened.

In the following will be given a review of the essential features of the phenomena with some discussions.

(*1*) *The extent of localities where the phenomena were observed:*

The phenomena were seen as far as 80 km. to E, 110 km. to NE and 70 km. to W of the epicentral region. The geographical distribution of the observers shows a peculiarity which seems to be due to different factors such as the density of population and the intensity of shocks felt. Abundance of data in the city and suburb of Tôkyô may naturally be explained by the former factor. The same factor seems to explain the decided superiority in number of data on the western side of R. Sagami compared with the eastern side. Extreme scantiness of the reports from the Tama Terrace, situated between Tôkyô and Sagami River Plain, may

probably be due to both the causes above mentioned. The observers in Bôsô Peninsula are confined within a zone with a breadth of 5–10 km. along the coast of the Bay of Tôkyô, extending to the mouth of R. Yôrô to N and to Tateyama to S. The western-most point of observation was at Yaidu in Siduoka Prefecture and the southern-most at the vicinity of Simoda, Idu. No report was obtained from the mountainous districts to N of the line connecting Mt. Ooyama with Hatano, Yamakita and Gotenba.

(*2*) *The time of observation:*

The greatest majority of witnesses were those who were awakened by the severe shocks, and hurried to open the door and get out. There are a few who became aware of the phenomena by looking out through glass windows immeditately after awakening. A watch-man who was in charge on the top of the watch-tower of Sibaura Branch Fire-Brigade Station, Minami-Hamatyô 18, states that he has observed a flash of light towards S about 10 minutes[14] before the shocks, and afterward four or five spark-like flashes during the earthquake. He also states that the peculiarity of the time relation drew his special notice. Another report due to Mr. T. Makino of Itô is worth of special notice, which states that a number of fishermen who were about to set their boat afloat in the evening previous to the earthquake observed a spherical luminous body to W of Mt. Amagi which moved towards NW with considerable speed. This fire-ball was seen at about 4 o'clock pm. of 25th. while the severe shock occurred at 4 h 3 m in the next morning.[15] Three other examples of unusual light phenomena seen before the midnight of 25th. in different places near the epicentral district are given in Musya's paper, K.M. p. 179.

14) The examples abunduntly cited in GALLI's collection as well as in ours in which the shocks were felt immediately after the luminosity, may be explained by the time required by the earthquake waves to traverse the distance from the origin to the observer. The time here stated seems to be too long. It is, however, not clear whether the luminosity began to appear so early, or some kind of illusion was committed.

15) This testimony of the fisherman reminds us of an article in NANKEI TATIBANA'S "Tôyûki" (橘南谿, 東遊記 A Journey to Eastern Countries) in which a luminous phenomenon is described as a foreboding of a dreadful landslide. The fishermen of Nadati, Etigo, who were afishing off the coast observed a remarkable ruddy glow towards the land which they considered to be due to a great conflagration. On landing and returning to their native village they were surprised to found that nothing unusual has happened in the vicinity. On the next day, however, a landslide of enormous scale took place in the same locality and buried the unfortunate fishermen who could not understand the fearful omen of the previous night. It may be supposed that the landslide had already been commenced preceding the final catastroph, somewhere in remote regions devoid of popula-

In this connection, a very singular fact may be recorded that Mr. Mukuhira in Tango, an amateur in "earthquake prediction" sent in the afternoon of 25th. a telegram adressed to the Director of the Science College of the Imperial Kyôto University giving the warning of an earthquake to be expected in Idu districts at about 4 o'clock next morning, which turned out to be true. The photogram of the telegram was reproduced in *Oosaka Mainiti* of 28th. Nov. According to the newspaper he based his prediction on the observation of a certain rainbow-like phenomenon which was seen in the morning of 25th. Though we are unable to trace any scientific basis in his way of prediction, the coincidence is nevertheless quite remarkable. It must be remarked, however, that vague anticipations of a severe earthquake to occur in Idu was prevalent among the laymen interested, on account of the frequent repetition of swarm earthquake in that region since the spring of the year. What is remarkable is that the exact time of occurrence was "predicted" and moreover that he was so convinced and determined as to send the telegram stating this very time. From the present status of our science we cannot but attribute this coincidence to a rare chance, but it is too rare and interesting to be entirely discarded from the literatures of earthquake phenomena, especially because it is connected with some luminous phenomena in the sky, though his "rainbow" was seen in the daytime and belongs to none of Galli's classification above cited.[16]

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tion. In the present example of Idu Earthquake above cited, it may also be conjectured that somewhere in the mountainous district of the epicentral zone a conspicuous sliding has happened on the eve of the day of the earthquake though there is no positive evidence available. At any rate it is desirable in view of such a possibility to pay due attention to any luminous phenomenon reported to have been observed preceding a severe earthquake and not to cast away such data too hastily as a priori improbable. In this respect, cf. for example, GALLI, No. 72, in which different luminous phenomena are given which were seen in the evening before the severe shocks.

16) According to the newspaper "*Tôkyô Asahi*" of June 8, a telegram from London states that an unusual luminous phenomenon was observed in London in the night two days before the earthquake of 7th. June. A detailed description of the phenomena, if real, is desirable, whatever may be their actual causes. Here, we may add a case of an apparent prediction of the earthquake of Genroku 16 (1703 Dec. 31) by SUKEZAEMON SIBUKAWA, the Astronomer of that age in service of Syôgun. It is stated in a document recorded in "Dainihon-Disin-Siryô" that on the eve of the great earthquake, he gave a positive warning to the officers in the residence of Syôgun to the effect that a severe thunderstorm or earthquake is expected in the course of that night. It is also stated that he was constantly in the habit of watching the night sky, as is natural for an astronomer. It is worthy of notice that he apparently treated thunderstorms and earthquakes under the common category (cf. ARISTOTELES: Meteororum, lib. II, cap. 9). This suggests that his premonition

(*3*) *Varieties of phenomena observed.*

Almost all the varieties of phenomena classified by Galli were represented in the present occasion (cf. K. M. pp. 183–197). Most numerous examples seem to belong to Galli's (Ia) lampi e bagliori, i.e. the sky was illuminated in a manner not unlike the usual sheet-lightning. The greatest majority of the observers remote from the epicentral region describe the phenomena as such. Most witnesses in Tôkyô observed one of the flashes immediately after the first shock which was followed by three or four similar flashes with irregular intervals of few seconds, varying from 1 sec. to 10 sec. according to the estimation by a number of physicists. Almost all agree in saying that the duration of a single flash was decidedly longer than that of a usual lightning. The unusual duration has also attracted the attention of some laymen who positively emphacize this point in their reports. On the other hand, some state that a single flash was steady and showed no fluctuation, while other speak to the contrary. This latter point may depend upon some physiological effect so that it is not easy to decide which was right. Or, the different descriptions may refer to different phenomena. As to the extent of the part of sky illuminated, there are some testimonies which state that it reached 20–30 degrees from the horizon, but it must be kept in mind that probably no one would care to look towards the zenith in such an occasion. The directions in which this kind of phenomena was observed are extremely various and contradicting with each other even among the observers in the same locality. It seems to depend on the direction at which the observer happened to be facing at the time of the occurrence of flash. Thus, it will depend on the direction towards which the window or door opens, and also on the topographical conditions, such as the slope of the land as well as the vicinity of sea. There will also come into play a probable psychological moment of the inhabitants of suburban districts to look involuntarily towards the city centre in the case of occurrences arousing general alarm. It is, therefore, hopeless to decide upon the position of the source of these "lampi" from the data at

was based on some luminous phenomena not unlike lightnings. As already mentioned, it is recorded also in other documents regarding this very earthquake that luminous phenomena were frequently observed in the night (or nights?) preceding the catastroph, notwithstanding that the season was just near the minimum of thunderstorm frequency. All these examples as such are certainly not able to stand the criticism of scientists, but it will not be legitimate to cast away these cases on account of mere prejudical reasoning, especially when there are more than one physical possibility of premonitory phenomena as are discussed in the present paper.

hand. It will not be far from the truth to assume that in Tôkyô and its western suburb almost the entire sky was illuminated at the moment of flash.

On the other hand, the distribution of clouds at that time must be taken into consideration with regard to the above question. Mr. Kita, Student of Physics, reported from Takinogawa Observatory that the sky was generally clear with KC 3 towards SE–SW at 4h 5 m. Another reliable testimony by Dr. Wadati who observed about four flashes at his dwelling in the western suburb, states that the sky towards S was overcast with greyish stratified clouds and the light seemed to be emitted from one of the strata. According to the data kindly furnished by Mr. Saki of C. M. O., the cloudiness at 2h am. was: Numadu 10, Yokohama 4, Iida 0, Kôhu 1, Kumagaya 0; at 6 am., however, a remarkable change had occurred, i.e. it was 10 for Hamamatu, Numadu, Nagatoro, Tigasaki, Yokosuka, Yokohama, Misima, Tôkyô, Mera, Tateyama, Hakoneyama, Kumagaya, Oome, Tokorozawa and Titibu, 9 for Katuura, Tyôsi, Mito, 8 for Tukubasan, and 6 for Maebasi. Mr. Kita went out of door again at 4h 10 m and was surprised to notice the rapid change in cloudiness within so short a time, as the cloudiness now attained about 8 and beside KC in the sourthern sky there was seen a *thin sheet of SC* which was moving towards SW with the speed 5. On more flash was observed at that time which was decidedly longer in duration than ordinary lightning.

Looking at the map constructed by Mr. Musya giving the statistical distribution of the directions of light observed, a tendency may be observed that a large number of the data point either towards the Bay of Tôkyô or to the Sagami-gawa Plain. As the hour was just at the minimum of daily temperature, it may be suspected that there was some component of ascending air current above the bay and the river plain, resulting in somewhat earlier cloud formation in these region compared with the others.

A phenomenon reminding us of auroral streamers diverging from a point on horizon is described accompanied with a sketch, by a witness at Minato-mati in Awa on the eastern side of the Bay of Tôkyô (see K. M. p. 187, No. 73). The radiant point is identified by reference to the profile of hills in the background of the sketch and may be traced to the direction of the epicentral region. Similar sketches are given by others.

Beams (trave) and columns (colonna) were also seen at different places with different forms, directions and modes of motion (cf. K. M., pp. 190–

194). Several observers compare the phenomena to the beam of a search light. Fire-balls (globo di fuoco) are also repeatedly mentioned (K. M. pp. 195, 196–197). It may be noticed that the ball-form and also the funnel-or trampet-form (tromba, K.M. p. 195) of luminosity were mostly seen near the epicentral districts. A witness in Odawara observed a fire-column, one (upper ?) end of which was bent towards Idu Peninsula. This reminds us of what was seen by Mr. Hattori on the occasion of Tanzawa-yama Earthquake (p. 230) of 1924 and also of another similar example of Ansei Earthquake (p. 229 foot-note).

Highly variegated forms of luminosity which may belong to Galli's (IV m) " nube luminosa " (K. M. pp. 195–196, also pp. 188) are abundantly reported, often apparently with fantastic exaggerations. Some positively state that detached clouds were illuminated. Mr. Musya is in possession of an oil painting by an observer in Hibusuma-Mura, which may be cited as an example of this same class. Another remarkable example probably belonging to this class is reported by an observer at Hongô, a few km. to N of Simoda in Idu, who observed three blinding flashes of light towards S, i.e. in the direction opposite to that of the epicentral region. He gives a well depicted pen-drawing sketch, according to which it seems that the luminosity was concentrated to a portion of the sky with considerable altitude, giving the impression of a luminous cloud. It is stated that the luminosity was so strong that different objects at a distance of about 250 m. could be well discerned. Another observer in Otiai, near the former place, saw " a funnel-shaped light (sic) resembling a beam of search-light " also to S.

In the districts not far from the epicentral region, the descriptions of the phenomena assume more or less definite form instead of an indefinite flashing of sky. One of the class of phenomena is represented by the personal observation of Dr. S. Nasu of our Institute who happened to be staying in Itô at the time of earthquake. Immediately after the severe shock he observed a ruddy glow above the profile of mountain ridges towards NW and WSW, which remained for a few minute.[17] Mr. Makino, the observer in charge of the seismograph in that town, observed the same phenomena. He had once happened to observe somewhat similar phenomena on the occasion of a great fire in Numadu (27 km.

17) *Cf.* GALLI No. 121: " Si videro delle fiammelle sortire dal suolo, e queste durarono per qualche minuto dopo cessato il terremoto." " Sopra questo monte poco dopo il terremoto fu vista una luce rossastra per brevissima durata di tempo, che illumina il paese di Pioraco e sembrava uscire dal medesimo monte."

NW). "Comparing the two phenomena the glow due to the fire-brand was characterized by frequent fluctuations of intensity, whereas the glow seen in the present case of the earthquake was kept nearly steady in luminosity showing no sensible flickering." The colour of the light was dark red with orange tint, according to a colour match made by Mr. Watanabe of Itô Common School. It seems rather strange that the flashing light was not stated by these witnesses. Another example of the same kind of glow is given by Prof. Saem. Nakamura in Vol. 3, No. 2 of "Disin" with a coloured sketch by the observer Mr. S. Nisimura in Ubako, Hakone. In the same Plate is shown a similar sketch by Dr. Nasu of his personal observation in Itô above mentioned.

A very vivid description of the most remarkable phenomena observed at Hakone-Mati which was one of the most severely shaken places, is given by one of Musya's collection which is due to Mr. Isiuti, his son and others. His son who hurried out of door and was clinging to a tree to keep his equilibrium observed a flashing luminosity on the slope on the NE side of the Lake ranging from Komagadake (4 km. N) to Kami-yama (5 km. N) now in a spot and then in another, thus successively in different places. The intensity of light was such that trees and clouds illuminated by it could be sharply discerned. The sources of light seemed to be of a round shape sometimes large and sometimes small. According to Mr. Musya there is no electric transmission line passing this side of the lake. On the other hand, numerous land-slides took place on the slopes of mountains facing to the Lake. Again, according to the testimonies of the others the following details are given.

"Luminosities were seen on the mountains in different directions. The brightest one was at a spot near the wireless tower (1·5 km. SW). They were seen towards Kurakake (1·5 km. S) as well as on the mountains in SW. The colour of the light was limpid blue."

"The garden and the pond of the neighbouring Hakone Hotel were clearly seen on account of the illumination so that the observer was not aware of the fact that the electric light was extinguished."

"The illumination was so strong that the *broken electric transmission line* lying on the ground was clearly seen and the witness took care not to touch it on his way. The brightness was similar to that at the time of full moon. Everything in the neghbourhood could be well discerned."

"While a staff-member of the wireless station was hurrying to Mr. Isiuti's house, he could make his way without the aid of a lantern," which is apparently needed in a dark night. "He became aware of the

darkness only when hails began to fall, about 40 minutes after the earthquake. Up to that time, he could attend to his affairs without the aid of a candle."[18]

"The light appeared to be emitted from below, during the earthquake. It was after a considerable time that it was seen in higher quarter."

"When the earthquake was at its height, *a straight row of round masses of light*[19] was seen towards the Manpukuzi Temple (SW). Each of these luminous bodies was seen to be in revolving motion. The brightness was considerable. Their heights seemed to be equal to the top of poles of transmission lines."

"Formerly, it had once happened that a crow caused the sparking of a transmission line. A loud noise was heard at that time. In the pressent occasion, however, no unusual sound was heard."

There are some reports regarding the observations made off the coast of Idu, which are interesting in many respects. According to Mr. R. Nisizima of Aziro, a number of fishermen afishing off the coast near the island Hasima at the time of the earthquake, observed a fearful display of luminous phenomena all along the mountainous districts of the epicentral zone. According to the manuscript of a fisherman, as reported from Kawana Common School, the phenomena were observed from the beginning on a boat off the island Hasima. The light first appeared above Mt. Hakone and it was seen to be propagated southwards, towards Mt. Amagi.[20] Then it was reversed in its direction of propagation and went back towards Mt. Hakone. The light which was white in colour was seen only near the ground. When he was wondering at the unusual

18) *Cf.* GALLI, No. 54: "Poco prima delle furiosissime scosse ... quelli, que avevano gli scuri o sportelli delle fenestre aperti, veddero nella loro camera tal chiarore, che per non breve spazio di tempo poterono distinguere tutti gli oggetti anchorchè piccoli, che si presentavano alla loro vista, in modo che qualcheduno credette che fosse già cominciato il giorno." "... un grandissimo chiarore, col quale vedeva distintamente tutto il paese, e che tale si mantenne nel tempo ch'egli impiegò a percorrere lo spazio di 20 passi, dopo del quale senti egli tremare la terra."

19) *Cf.* GALLI, No. 59: "osservato di sera venir fuora certe fiammette della grandezza e similitudine di quelle di una picciola candela, situate una presso d'altra quasi in eguale distanza e direzione, formando una linea retta.

20) *Cf.* GALLI, No. 141: "... si vedere di notte delle striscie di fuoco attraversare il M. Nerone in senso orizzontale, fenomeno che si ripetè poche ore prima della scossa successiva ..." Also No. 127, last paragraph. Again, No. 146: an observation, made on sea, of "una luce come un faro luminoso, che lentamente procedeva da Sud-Est verso Nord-West, lasciando dietro una gran fascia di luce donde cadeva una pioggia di scintille." The latter description reminds us of the description of land-slide in Siroyama, Oohito (p. 241).

sight, sudden shaking of the boat was felt, which he attributed to an earthquake. While talking with the others about the unusual nature of the shock felt, they saw fiery displays at three spots of the land, which he considered to be due to some volcanic eruptions accompanied by the earthquake. On landing, he found that there was no eruption, but a fire-brand was caused by the earthquake." As a matter of fact, fire broke out in the town of Itô after the earthquake by which a number of houses were destroyed. Another conflagration seems to have taken place in Kôdu which was however due to other cause than the earthquake, and had been almost extinguished at the time of the earthquake shocks. Again, a fisherman of Siduura on the western coast of Idu is said to have observed on sea a large fire-ball starting from Mt. Wasidu and moving towards S.

There are a few reports regarding the light observed in apparent connection with land-slides, inspite of the fact that the latter were quite numerous in the epicentral region. According to the newspaper, "*Misima Asahi Sinbun*," a minor land-slide at Siroyama in front of Oohito Station was accompanied by a display of light similar to that of a pyro-technic show initating a waterfall; it is stated that light was produced by the mass of small stones falling down along the rocky slopes of the mountain. In Mr. K. Hasimoto's letter to Mr. Musya, the testimony of a newspaper-saler is given who saw a luminosity at the moment when a land-slide took place at a distance of about one km. and he attributes the light to the heat produced as the effect of sliding. Another example is given by the testimony obtained by Mr. Musya from a chauffeur at Yugasima, who states that a large fire-column appeared at the time of great land-slide at Kadiyama. The same fact was also stated by another witness in Nakaômi.

The row of round luminous bodies observed by the family of Mr. Isiuti above mentioned (p. 240) may also be connected with land-slides which took place in numerous spots on the slopes facing the Lake.

On the other hand, according to the statement of a witness in Kadiyama recorded by Mr. Musya, no one in the immediate neighbourhood of that place seems to have observed the luminous phenomena at the time of the great land-slide, while those at distant places saw such phenomena towards the direction of Kadiyama.

It is rather remarkable that among the thousand data accumulated there are few reliable testimony of those witnesses who happened to observe remarkable electric sparks actually caused by breaking or short-

circuiting of electric transmissoin lines, though there are superfluous number of reports stating that the light was much *alike* the flash produced by such a sparking. It is said that a man at Misaki actually saw a broken electric line sparking at the ground. Another reporter from Matuda near Kôdu writes to the effect that the luminosity observed was due to the short-circuiting, but it is not clear whether he actually observed such thing. A similar report from Mera Observatory is equally not quite convincing. On the other hand, there are some reports stating that the light was seen towards the direction at which there is passing no transmission line. As a matter of fact, in the circular send out asking for informations there was no special item inquiring after such accidences, so that it might be supposed that the report regarding this point was naturally eliminated.

There are, on the other hand, a few reports stating the conditions of the electric lighting at the time of earthquake. In a village named Seya (瀬谷), Kamakura-Gôri, a transformer was seen to be sparking and immediately afterwards, the electric light went out. In Hudisawa and Kugenuma, the electric light dimmed awhile at the time of shock and recovered after a short time. Prof. N. Mononobe who was awaken and reading in his residence in Azabu, Tôkyô, noticed a momentary dimming of light. The light soon recovered and then the preliminary tremor of the earthquake was felt.

The author made an inquiry at the Department of Communication with the purpose of ascertaining whether any powerful trasmission line was seriously affected by the earthquake. No positive evidence could however been obtained up to this day. Perhaps it is not practicable to confirm this point after the lapse of several months.

(*4*) *Colour and intensity of light observed.*

The colour of the light observed is reported by a great majority of of observers, in the case of flashing "lampi", as pale blue, white, or as similar to that of electric sparking or lightning. There are also a large number of witnesses who state positively that the light was decidedly of reddish or orange colour compared wiih the usual lightnings or sparks. In the case of that kind of glow which was observed over the mountain ridges the ruddy colour predominates. Sieberg and Lais emphacized the reddish tint of the light observed on the occasion of the earthquake as one of its characteristics. The present examples seem to confirm their opinion.

It is well known that a faint light is perceived mainly by the peripheral region of retina which is devoid of colour sense. The colour of lightnings or sparks usually described as blue, pale blue, greenish grey, etc. seems to be really connected with this colourless luminosity.

In this connection it may be added that an electric spark may sometimes show an apparent propagation of luminosity along its track due to an optical illusion,[21] while the actual discharge phenomena is completed within a very short interval of time, 10^{-6} sec. say, and no such propagation can be detected by means of ordinary rotating mirror or the like. Some of the descriptions regarding the apparent propagation of luminosity *along* the track or beam of light, may be due to this kind of illusion.

As to the intensity of luminosity observed at distant quarters, it is stated by a number of reliable witnesses in Tôkyô that different objectss in the room illuminated through glass windows could be discerned (cf. foot-note 18). At that time, the eyes of the most observers were completely accustomed to darkness, so that the light might have been quite weak, though it is difficult to give any reliable quantitative estimation. Assuming, for example, that the illumination of a wall in Tokyo was of the same degree as that due to a single candle placed at a distance of 10 m. and that the source of the luminosity was in Idu at 100 km. distance the candle power of the source will amount to $10.^8$ According to the estimation of an expert in naval engineering, the total candle power of a certain squadron in full display of festival illumination amounts to about 3.10^7 CP. If a light source of these orders of magnitude were placed in an elevated mountain region with comparatively clear atmosphere, it may probably produce a considerable illumination of sky even at 100 km. distance, especially when there was a suitable distribution of clouds to catch and reflect the light. The question is how a source of light of such an enormous candle power could be produced by earthquake.

(*5*) *Probable and possible causes of luminosity accompanying earthquake.*

From the superfluous number of testimonies, among which we may cite those given by most reliable scientists, it will be beyond any doubt that the luminous phenomena reported are neither entirely due to the illusion of untrained minds struck by the earthquake shocks, nor due to

21) T. Terada, *Nature*, **125** (1930), 528; *Bull. Inst. Phys. Chem. Res.*, **9** (1930), 287.

some purely physiological effects, though much distortion or exaggeration might have slipped into the descriptions of the phenomena especially in the case of laymen witnesses. We may, therefore, safely take the phenomena as physically real and inquire after their probable causes.

There are left many points still obscure as to the true nature of the phenonema observed, as is quite natural if we consider that they happened utterly unexpected at the moment of general alarm and passed away rapidly before a few of the witnesses could recover the coolness of mind. Hence, it will not be legitimate to draw any decisive conclusion for the present, but it will be plausible and desirable to enumerate and discuss as many causes as are conceivable, either probable or possible, and thus prepare for the next occasion on which we may hope to obtain more accurate data from those witnesses who are well prepared for observations of the rare phenomena and well aware of the variety of causes as are here enumerated.

(a) Fire-brand. As already mentioned, a conflagration took place in Kôdu before the earthquake which was already extinguished at the monent of the first shock. Fire-brand in Itô broke out after the earthquake and might have been seen from some observers at distant quarters and confounded with the other luminous phenomena. It is, however, difficult to attribute to this cause all kinds of luminosity observed in wide extent, especially those flashes resembling lightning. The ruddy glow seen from Itô above the mountain ridges and the similar phenomena observed at the other localities near the epicentral region coincide in their directions with no fire-brand reported. Besides, the characteristic difference of the nature of the glow compared with that of a fire is emphacized by more than one reliable witnesses. Thence, it may be safely concluded that fire-brand could not have been the main cause of the phenomena observed by the majority of witnesses.

(b) Lightnings. There is no room for the doubt whether some of the luminosity observed were not due to lightning flashes of a remote origin. Consulting the weather maps of that time it is found that the weather in the night was such as is characteristic to any calm and clear winter night, the central part of Honsyû being under the reign of an anticyclonic area. Moreover, according to the reports from local meteorological observatories, no thunderstorm could be traced within the range possible of such a suspicion. It was only in the night of 26th. that thunders are reported from Hatidyôzima and Miyadu, i. e. above 200 km. from the epicentral district, but nowhere else. Thus, the ambiguity due

to the simultaneous occurrence of lightning is fortunately got rid of in the present case.

(c) Electric sparking. The question regarding the possibility that the short-circuiting of a powerful transmission line might have been responsible for the flash-light observed in wide extent, cannot be too hastily discarded, though indeed positive testimonies to this effect are yet wanting. There are evidences showing that the electric light got dimmer for a short time or extinguished at the time of earthquake in some locatilies at least. Some state that a transmission line was broken and the others that sparks actually were observed on the line or transformer. Moreover, it seems to be of quite common occurrence that sparkings of transmission lines are observed during an earthquake. It must, therefore, be admitted that at least a part of the luminosity observed was actually due to such causes. At the time of the earthquake no electric tramway was running, so that the usual sparking at the pole of an electric car is quite out of question. The question arises as regards the possible intensity of the light emitted by sparking of a transmission main. In the case of the full display of illumination of a squadron the estimation of the total candle power amounts to 3.10^7 CP. when the electric power consumed is 3000 kw. in round number. In the case of a spark caused by short-circuiting, the efficiency as a light source must be low compared with the above case. Estimating the latter efficiency at 1/10 of that of the former and assuming that a transmission main of 30 000 kw. was made to spark, the result will be same as that of the squadron illumination above quoted and may be sufficient for the sensible illumination of sky to a considerable extent. There is, however, no evidence for assuming that any such powerful main was actually short-circuited and brought about a general extinction of light for a very wide area depending on such a main. Moreover, the above provisory estimation may be probably too high.

On the other hand, there is a class of luminosity observed especially in the epicentral region and described as resembling that of a firebrand and having a considerable duration of time compared with an electric spark, which cannot by all means be explained by an electric sparking. Again, the testimony above given of Mr. Isituti, as reported by Mr. Musya, shows that the light source of another class was seen also at the side of the Lake where no transmission line is running. These phenomena are utterly impossible to be explained by the short-circuiting as above considered. Again, Mr. Kita's observation of a flash at 4 h 10 m

seems to be difficult to be attributed to this cause. Prof. T. Itô of the Mineralogical Institute, College of Science, Tôkyô, observed the flash-light at the western suburb of Tôkyô, which was seen to emerge from the distant horizon in the direction of the epicentral region. He observed a sensible after-glow of the sky in in the same direction which he compares to the after-glow of an aurora observed by him in Norway. Such an remarkable after-glow is again utterly difficult to be explained by electric sparking. His observation gives at the same time an evidence to the effect that the after-glow was not quite independent from the flash-light. Hence, it must be admitted that the spark theory cannot cover the entire ground of the phenomena observed.

Lastly, it appears to the author very remarkable that there are so many records of luminous phenomena which are described as resembling to lightnings, but not quite similar to these, either with regards to their duration, or to their colour, and moreover, that the descriptions of these phenomena by the modern witnesses agree in many essential points with those given by the documents, either Japanese or European, dating back to the time when no electric transmission line existed at all.

(c) Land-slides and triboluminecences produced by them. It is known that considerable luminosity is observed on the occasion of land-slides. O. Vogler's and C. L. Griesbach's papers are cited in Sieberg's book in this very respect. The luminosity emitted from chalk-pits, which is mentioned in Milne's "Seismology," may probably belong to the same category. In Prof. B. Kotô's report on Kônô Earthquake, it is stated that some luminous phenomena were seen in connection with the land-slide on the slope of Mt. Ibuki. In the present occasion, some examples have already been given which positively state that some kinds of such phenomena were actually seen accompaying land-slides. It seems, therefore, that the most probable cause of some kinds of the luminosity observed in the present occasion may be attributed to this effect of land-slides. According to the map prepared by the Land Survey Department showing the geographical distribution of land-slides caused by the present earthquake they are quite numerous along the meizoseismal zones, i.e. over seventy, even if we only take the most conspicuous ones into account. The question of after-glow could also be solved by this effect, if we consider that a land-slide may be followed by subsequent series of minor slidings and it may take a sensible time before settling down to the stable state of equilibrium, especially when the earthquake is still continuing to disturb

the equilibrium. It is not necessary to inquire after the after-glow effect of triboluminescence itself, which seems to be not yet fully investigated. The question is, however, whether this effect may quantitatively suffice to explain the enormous intensity of luminosity observed. In this respect, the author devised a provisory experiment which was carried out in the Institute of Physical and Chemical Research by the able hands of Dr. M. Hirata and Mr. T. Utigasaki, to whom the best thanks of the author are due. Different kinds of rocks at hand were subjected to grinding by means of a usual tool-grinder in form of a disc which is revolved with an electric motor. The light emitted from the line of contact between the rock specimen and the cylindrical surface of the grinder disc (5 mm. in thickness) was compared with that of 100 lighted "senkô" (incense sticks used by Buddists), by means of a simple Bunsen photometer, as a candle or Hefner lamp was not convenient for the direct comparison. The "100 senkô" light was afterwards compared with a candle by the same photometer. Though the measurement was very rough, it was deemed sufficient for determining the order of magnitude of the luminosity, as such only is here in question. The results of the experiments show firstly that the luminosity is almost independent on the

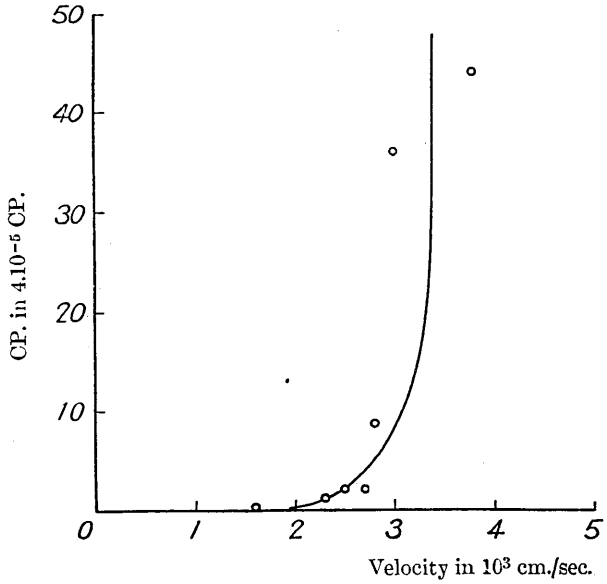

Fig. 1.

pressure between the specimen and the grinder, at least within the range practicable without stopping the motor by the braking action. Secondly, the intensity of light emitted increase with the peripheral velocity of the grinder, first slowly and later rapidly, as shown by Fig. 1, in which the abscissa gives the peripheral velocity in 10^3 cm./sec. and the ordinates in a provisional unit of "100 senkô" which is roughly equivalent to 4.10^{-5} CP. The order of magnitude is not much different for different kinds of rocks tested. Assume now for the sake of estimation that in the area disturbed by a land-slide, every unit area contains l cm. of the luminous line-element similar to that of the line of contact between the rock specimen and the grinder. It will not matter much that in the case of the experiment the two pieces in contact were of different substances. Take the emission per 5 mm. as $p \times 4.10^{-5}$ CP. Then the emission per 1 cm.^{2} of the area will be $pl \times 8.10^{-5}$ CP. Assuming one of the land-slide to be of an area equal to that of a semicircle with the radius of 100 m., the total area of a single slide will be $1{\cdot}57.10^8$ cm.^{2} Thence, the total light for the single slide area will be about $pl \times 12{\cdot}8.10^3$ CP. If one hunderd similar land-slides may be assumed to cooperate at the same time, the total will make $pl \times 1{\cdot}28.10^5$ CP. Hence if we put $p=10$ and $l=10$, the result may become $1{\cdot}28.10^7$ CP. which is of the same order of magnitude as the total CP. of the luminous display of a squadron above cited. It seems, however, that the above is a very exaggerated estimation. Firstly, the entire area affected by land-slide cannot become luminous, since the large relative velocities between consecutive masses of rock can only be sensible at the very slip-plane,[22] so that the effective area must be estimated at most at 1/10 of the above value. Secondly, the assumption $l=10$ means that every cm.^{2} contains 10 cm. of luminous lines, which appears almost incredible, since the finer the grains produced, the more the relative velocity of grains is decreased. Again, $p=10$ is also an over-estimation which according to Fig. corresponds to a velocity of 3×10^3 cm./sec. If the height of fall of a rock mass be h m. which is assumed to fall freely, the velocity aquired is $\sqrt{2hg}$. If $h=50$ m., we obtain a velocity of 31·3 m./sec. which is of the order of magnitude required. In actual case, however, the sliding mass is subjected to a considerable braking action on account of the friction, so that the effective acceleration will be multiplied by a reducing factor equivalent to the

22) Different kinds of beam or column of light can be explained if we assume that the light is emitted from the interior of the crevasse formed at the instant of its opening and sliding. A fire-ball might be due to an illuminated spot of cloud.

difference between the static and kinetic coefficients of friction. Even if $v=20$ m./sec., p is only of the order of unity. Thirdly, it is also an over-estimation to assume that 100 land-slides took place simulaneously to contribute to a single flash of illumination of the sky at a given direction, a fortiori because the solid angle of illumination is always limited by the topographical configurations.

Thus, putting $l=1$, $p=1$ and the effective area$=1/10$ of the value above assumed, the total candle power is reduced to the order of 10^4. This is still no small figure, but it seems doubtful whether the source of these order of magnitude may explain the observed intensity at a distance of 100 km. The illumination of a source of 10^4 CP. at 100 km. will be equivalent to that of a single candle at 1 km., even if there were no absorbing medium. Hence, the light observed within a house in Tôkyô is difficult to be attributed to this cause. On the other hand, there are some evidences already mentioned showing that at least some of the flash-light observed in Tôkyô are originated from somewhere in epicentral region and not connected with electric sparks.

In the above, the estimation of p was based on the laboratory experiment and given as the function of the relative velocity of sliding. A possibility must be kept in reserve that in the actual case of land-slides in a great scale, another kind of mechanism for producing luminosity may come into play and contribute to increase the value of p to a considerable amount. If some of the old documents, stating emission of light from fissures on ground, may be true, we must take account of such effect which does not depend on the velocity of sliding. Even in that case, it is difficult to assume that the order of magnitude of the luminosity can be quite different. A thorough investigation is, however, desirable on this very respect.

Lastly, it may be remarked that there are some phemomena observed which are not easy to be explained by the luminosity due to land-slides even in qualitative sense, such as the strong luminosity observed towards the southern sky from the vicinity of Simoda, Idu, as no remarkable land-slide is reported from that region and also it is improbable judged from the intensity of shocks in that district. It is, indeed, not yet certain whether a sparking of electric line has not occurred somewhere near Simoda. If we may rely upon the fine sketch made by the witness, the altitude of the concentrated luminosity is seems to have been far too greater than that of any transmission line possible.

(d) A possible cause of luminosity due to the motion of water in the earth's crust.

In the early stage of the author's present investigations, the data from the immediate vicinity of the epicentral region could not yet be obtained; especially, no report was at hand regarding the luminosity observed in connection with land-slides. While seeking then after all conceivable causes of luminosity which may come into play on such an occasion, the author hit upon a possibilty which seems to have been utterly neglected to be taken in account in all previous discussions concerning the phenomena. A preliminary discussion was therefore made on this point and the result was communicated to the Proceedings of Imperial Academy, Vol. VI, 1930, No. 10, p. 401–404.[23] It was shown that the motion of water through subterranean layers containing a network of capillary channels may, under favourable conditions, produce an enormous potential difference in the upper atmosphere and excite a luminous electric discharge in a higher region. The dscussion will be reproduced in the following with little modification.

According to the investigations of Wiedemann, Quincke, Helmholtz and the recent students of "surface chemistry," a potential difference called "Strömungspotential" is established between the two ends of a capillary tube, through which a liquid is made to flow under a pressure gradient. The P.D. is given by

$$E = \frac{\varphi D p \sigma}{4\pi\eta},$$

where φ is the kinetic potential (mostly 0·01–0·05 volts), p the total hydrostatic pressure difference, D, σ and η respectively the dielectric constant, specific resistance, and coefficient of viscosity of the liquid.

For application to the case of earthquake, we will consider here two kinds of "models," for which the juvenile and meteorological waters are the respective working liquids.

(1) The disturbance of a severe earthquake will affect the earth crust to a depth comparable with the linear dimension of the megaseismic

23) When later consulting GALLI's paper, loc. cit. the author came across the following passages among the article No. 128, regarding to Andalusian Earthquake of 25 Dec., 1884, quoted as "dai rapporti ufficiali di Formes, Murchas, Nigüelas e Periana": "...ne abbiamo una spiegazione semplicissima quando si ammetta la teoria geodinamica, fondata principalmente sul vapore d'acqua. Questo, infatti, salendo con sufficiente pressione per le fessure, può dare origine ad una manifestazione elettrica, come si ottiene artificialmente nei gabinetti di fisica colla machina Armstrong."

area. We will assume, for example, that the water is displaced vertically upwards through numerous capillary channels existing, or freshly set free in the crust due to the deformation, under a pressure which is of the order of that prevailing in the depth of 100 km. or may be much larger at least for a short time in the case of a catastroph. In that case, P.D. calculated from the above formula will be established between the upper and the lower layers and maintained as long as the flow is continued.

For a rough estimation, we will take $\varphi=0{\cdot}05$ volts, $D=81$, $\sigma=1000$ ohms/cm^3., $\eta=10^{-3}$ c.g.s.[24] For p we take $p=ap_0$, where a is an unknown numerical factor and p_0 the hydrostatic pressure due to 100 km. column of rock with the density of 3, i.e. $p_0=3.10^{10}$ c.g.s.[25] In this case we obtain $E\fallingdotseq 3{\cdot}3\ a.\ 10^6$ volts. Thus, even if $a=1$, we have a value of 3000 KV.

The value of the potential in the atmosphere depends on the geometrical form of the equipotential surface on the ground. If it be assumed as spherical, with a radius R, the potential at a height H will be $E_H = ER/(R+H)$ and the field $F_H = -ER/(R+H)^2$. The sparking potential of atmosphere is the least at about 60 km. height, where the pressure is of the order of 0·1 mm. Hg. Putting $R = H = 5$ km., the field at the height H is $F_H = -5E.10^{-8}$. If we take the value of E above obtained, then $F_H = -0{\cdot}165$ volts/cm. In the case of the Moore vacuum light, the driving field is about 2 volts/cm. which will require $a = 12$, a value a little too large to be expected. This is, however, not necessary in the present case. The sparking is facilitated by many circumstances such as the heterogeneity[26] in conductivity and the presence of ionisation and

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24) We take this value, since the water may be of a temperature higher than 100°C. For σ we have no available data for subterranean water. Besides, the conductivity of rock in the depth is unknown and if it be large the result of calculation will be sensibly modified. On the other hand, the subterranean water may be in gaseous form in which case no experimental data are available. The fact that an enormous P.D. is produced along the pillar of volcanic dust on the occasion of eruption will show that the kinetic potential between the rock materials and the superheated steam must be of a large value, as in this case also the P.D. is produced by the relative flow of the gas along the heated rock material.

25) The strength of rock materials against one-sided crushing load is usually of the order of 1000 kg./cm^2. = 10^9 c.g.s. The hydrostatic pressure in the depth corresponding to such an order of stress difference may be of a higher degree than this strength. This will also support the above assumption for p.

26) In this repect, the readers are referred to a paper: T. Terada, U. Nakaya and K. Yumoto "Some experiments on spark discharge in heterogeneous media—a hint on the mechanism of lightning discharge," *Sci. Pap. Inst. Phys. Chem. Res.*, 4 (1926), 129–160. It is demonstrated that an abnormally long spark may be drawn under suitable conditions.

space charge. For example, we may expect a considerable increase of the field near the lower boundary of the Heaviside layer. At any rate, the value of P.D. between the layer above the epicentral region and the surrounding atmosphere is far greater than the ordinary cathode fall of any vacuuam discharge, even if we take $a<1$.[27]

The duration of the above phenomena may be short and could not affect the usual recording instrument of the atmospheric potential. Again, the horizontal potential gradient is small, so that the telegraphic lines might not necessarily be sensibly affected.[28]

(2) The meteorological water contained in the water-bearing layer near the ground surface may be forced to a horizontal displacement under the pressure gradient caused by earthquake. In this case the process may be of a more gradual one than in (1). Here we may take $a = 1$ and $\eta = 0{\cdot}01$ ($t = 15°$). Then, $E = 3 \times 10^5$ volts. The head and end of the canal may be compared with a dipole, in roughly estimating the effect at the a great distance. If the length of the dipole be l, we may take $E/l = F_m$ for the field in the middle point of it and compare F_m with the field F_d at a distance ρl. For $l = 20$ km. $F_m = 1{\cdot}5 \times 10^{-1}$. K. Shiratori[29] observed a change in earth's potential gradient of about 4.10^{-7} volts/cm. at Sendai, on the occasion of the Kwantô Earthquake of 1923. Thus $F_d/F_m = 2{\cdot}7 \times 10^{-6}$. As the distance of Sendai from the epicentre is about 800 km., $\rho = 40$. On the other hand, the field due to a dipole varies as $\rho^{-3}F_m$, disregarding the factor due to the azimuth. The above ρ will therefore give $F_d/F_m = 4{\cdot}7 \times 10^{-6}$, which is of the same order of magnitude as derived above from the observed F_d. Hence, it is possible that the effect observed by Shiratori cannot be merely due to the change in contact potential or resistance of electrodes, but might well have been produced by the real electrical effect of the earthquake.

The case of quadruplets as well as of octuplets may also happen, especially the former in the case of Shida's "pull-push" model.

At the present moment, the above may be taken as a suggestion regarding to a physical possibility, which must at any rate be taken in

27) In the above model, the case was considered as statical. It may also be possible that a disruptive discharge may take place somewhere in an underground layer and induce an additional field in the atmosphere. Moreover, a large P.D. may already exist in the upper atmosphere before the seismic disturbance, and the latter may then act as a kind of trigger. For the present we may better leave these possibilities as open questions.

28) The magnetic effect may also be small due to the radial nature of the current sheet.

29) K. SHIRATORI, *Jap. Journ. Astr. Geoph.*, 2 (1924), 173.

account, if we attempt to make a thorough investigation of the problem at hand, though the author is far from venturing to explain all the phenomena observed in the present case by this special possible cause[30].

In this connection, it will be of some interest to remark that on the occasion of the Idu Earthquake an unusual fluctuation of current were recorded by the recording system for the submarine cable of Guam Line, though it cannot be ascertained whether it was not due to a merely mechanical cause. Again, on the occasion of an earthquake in the neighbourhood of Tôkyô on 30th January of this year, a remarkable oscillation was revealed in the recording system[31] of earth-current between Tôkyô and Hôya, while the similar system between Tôkyô and Yokohama showed no trace of such fluctuation of the current. The former circuit is perpendicular to the direction of the epicentre, while the latter is nearly parallel to it. Similar cases may be found frequently in the earlier literatures[32] of earthquake phenomena, though regarded mostly as trivial and neglected by modern students of seismology. It seems, however, not quite superfluous to resume the investigations in this line with improvements of the method which will be possible in these days to be applied for ensuring the reliability of the results far greater than was attainable in the past.

Another fact already mentioned that the cloudiness of sky showed a remarkable abrupt change at the time of earthquake, cannot be overlooked as purely accidental without a further inquiry. It is well known[33] that the formation of cirrus cloud is frequently connected with an auroral display which is a mode of electric discharge in upper air, though the real physical connection between these two phenomena is still obscure.

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30) There remains to be mentioned another electro-capillary effect which is complementary to that of "Strömungspotential," i.e. of "electro-endosmose," by which a hydrostatic pressure gradient may be generated by an electric current. The fact that severe earthquakes seems to take place frequently associated with thunderstorm may be worth attention when viewed under the stand point of the present note.

31) The self-recording apparatuses of the earth-currents have recently been installed by the authorities of the Department of Communication. The records here mentioned were kindly shown to the author by Mr. S. INADA of that Department for which the author feels greatly obliged. The earthquake occurred at 10h 10 m. 41 sec., 30th. Jan., 1931; the epicentre is located at the Kokai-gawa basin; the maximim amplitude in Tôkyô was about 0.4 m.m.

32) Some of them are mentioned in URBANITZKY's book, *loc. cit.*, 917.

33) ARRHENNIUS, "Lehrbuch der komischen Physik," (1903), 907; E. MATHIAS, "Traité d'electricité atmosphérique et tellurique," (1924), 346; Handbuch der Experimental-Physik, Bd. 25, Teil 1, 472. Also GALLI, *loc. cit.*, 439.

It seems therefore interesting to pay attention on this special point in future occasions of severe earthquakes accompanied with, or without, luminous phenomena, and to make a thorough investigation regarding the clouds as well as the general weather conditions before and after the earthquakes.[34]

In concluding, we may repeat that certain classes of the luminous phenomena observed on the occasion of severe earthquakes are physically real and directly connected with the earthquake. The question as to the true cause of the phenomena is not yet settled. The ultimate solution of the problem must be reserved for a future when a more sufficient reliable material of observations would have been accumlated. It is, therefore, desirable that on any future occasion of severe earthquake the seismologists as well as the other scientists capable of reliable observations with open mind would be keenly alive to the appearance of such phenomena and keep detailed records of what were observed.

The author's cordial thanks are due to Mr. Musya who kindly placed his entire collection of data at the author's disposal and not less to many of the scientific members of different Institutes, among which our Earthquake Research Institute, Aeronautical Research Institute and Central Meteorological Observatory must be especially mentioned, for the most reliable data of their personal observations. For the valuable informations regarding the literatures of the subject, he is greatly obliged to Prof. T. Okada, Director of the Central Meteorological Observatory.

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17. 地震に伴ふ發光現象に就て

地震研究所 寺 田 寅 彦

地震の際に空中又は地上に著しい發光を伴ふことがあるといふことは、日本のみならず西洋諸國の地震に關する記事中に多數に發見され、しかも其記事の內容が古今東西を通じて共通な諸點を具備して居るのは興味のあることである。それにも拘らず此現象は從來學者の側からは餘り注意されず、稀に注意されても多くは初から疑の眼をもつて見られ、充分に檢討されなかつた場合が多いやうに見える。昭和五年十一月の伊豆地震に際しても此種の現象が到處で觀測され、此れ

34) A similar change of weather happened in the case of Kumamoto Earthquake of 1889 above cited. Other parallel cases are not wanting, e.g. B. Willis, Chile earthquake, loc. cit., though a thorough statical investigation must be carried out in order to make this point clear.

に關する多數の報告を纏めた武者金吉氏の報文は既に本誌前號に掲載された。著者も武者氏蒐集材料と、竝に、少數ではあるが若干の信頼すべき科學者の觀察した材料とを併せ調べた結果、武者氏の結果を確かめることが出來た。

本篇では先づ古來西洋諸國に於ける此現象の文獻を略記し、次には本邦に於ける古來の記錄中から若干の例を採錄し、特に明治以後のものは詳しく列記した。

次に今回の伊豆地震に關する諸資料に就て著者の所見を述べた。(1) 光の見へた場所の分布 (2) 光の現はれた時刻 (3) 光り方の種類 (4) 光の色と (5) 强度等に就て多少の考察を試みた。

又此現象の原因に就て考察した結果は次の通である。(1) 火事と (2) 雷雨に伴ふ電光とは此際問題にならない。(3) 送電線の接觸又切斷によるスパークは、現象の一部を說明するとしても、此れでは說明されない著しい現象がある。さうして其等は (4) 山崩れ地辷りによる triboluminescence として說明すれば多くの場合に質的には容易に說明されさうである。併し著者が行つた簡單な實驗を基礎として試みた量的の計算 (勿論或假定の下に) の結果では、此れだけで凡ての現象を說明するのは困難であるやうに見える。それで電線のショートと山崩と兩方で凡てを說明すれば一應は尤らしいやうである。併し充分强力な放電に關する確證が得られないのみならず、又電線の存在しなかつた時代に於ける東西兩洋の記錄の共通圈內に多數に現はれる閃光的現象が、今日の場合にショートで說明されるものと殆同一であり、しかもそれが雷雨の疑のない時にでも度々あつたと考へられるところに困難がある。

以上の原因の外に從來全く考慮されなかつたと思はるゝ一つの可能な原因がある。それは毛管電氣現象に關するもので、地殼內に於ける水の運動の爲に地殼中、從て空中に著しき電位差を起こし、場合によつては高層の空中放電を生することが可能であるといふのである。此に關する若干の考察をした結果を述べてある。現在では確に此の爲と考へるべき實證はないが、多少の手掛と見られる二三の現象を附記して將來の參考とした。

武者氏竝に著者の調査によつて、「地震に伴ふ發光現象」の少くも大部分が單なる幻覺ではないこと、又此れが、凡ての場合に火事や、電光や、電線の故障等だけで說明することは出來ないので、兎も角、直接に地震によつて惹起される一つの發光現象が存在することが明になつたと思はれる。

此樣な發光が主なる地震の前から現はれることもありはしないかと疑はせるに足るやうな若干の例もあるので、此點から見ても、此現象は、地震學上必ずしも輕視することの出來ない一つの問題を提供するものであらう。

此研究に關して貴重な材料を供給された武者氏其他多數の舊知又未知の諸君の好意ある援助に對して茲に深謝の意を表する。