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Earthquake light: 1995 Kobe earthquake in Japan

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Abstract

There were eyewitness reports of earthquake light, co-seismic luminous phenomena in the 1995 Kobe earthquake (Hyogo-ken Nanbu earthquake) in Japan. The Kobe earthquake occurred at 5:46 a.m. (LT) on January 17, 1995 around the Hanshin area in Japan. The M7.2 earthquake strongly attacked Kobe City. On that early morning, two young persons on Mt. Rokko (northeast side of Kobe) saw a luminous object moving a few seconds before the main shock. Independently, fishermen working around Osaka Bay (opposite side of Mt. Rokko) also noticed a moving luminous object. The direction of movement and the orbit of the luminous object might coincide with the direction of the rupture.

Keywords: Earthquake; Fault; Luminous phenomena; Lightning

1. Introduction

There are many reports of luminous phenomena or spherical lightning (ball lightning) associated with earthquakes (see Derr, 1973, 1986). In Japan, Musha (1931, 1932) and Terada (1931) developed pioneering researches on the luminous phenomena associated

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with earthquakes. Especially, Musha collected about 2000 eyewitness reports for 65 earthquakes. On the other hand, Terada approached the theoretical consideration of the luminous phenomena and concluded that it was difficult to explain them by using tribo-luminescence theory, although the laboratory experiment was successful. Moreover, there was an earthquake swarm at Matsushiro area located in the middle of Japan from 1965 to 1967. Numerous luminous phenomena were observed during the earthquake occurrences. Fortunately, photographs were taken and depicted in papers reported by Yasui (1968, 1971, 1972).

A few papers of eyewitness reports of the earthquake light in the 1995 Kobe earthquake have been published. Enomoto and Zheng (1998) investigated that a gas emitted from the fault line caused local luminous phenomena at the edge of the Awaji Island where the rupture of the earthquake started. Tsukuda (1997) also investigated many eyewitness reports around the fault area, most of which were the local luminous phenomena. Ikeya and Takaki (1996) numerically showed that the neutralization of the screening charge around the piezo-electrical rock yielded the luminous phenomena at the stress release of the earthquake. Although there were some eyewitness reports of the local luminous phenomena, there was no eyewitness report that showed that the relatively extensive earthquake light was coincidentally obtained by some independent groups, and consistently agreed with each other. Therefore, we also investigated earthquake light, and carefully paid attention to the following two processes: firstly, the existence of a few or many eyewitness reports that seem to be consistently the same, although they belong to independent places and persons; and, secondly, the discrimination of artificial effects such as discharge of broken electric power lines. This paper focuses on the detailed description of the eyewitness reports of co-seismic luminous phenomena associated with the 1995 Kobe earthquake in Japan.

2. Eyewitness reports and discussion

The Kobe earthquake occurred at 5:46:52 a.m. (LT) on January 17, 1995 around the Hanshin area. The M7.2 earthquake strongly attacked Kobe City. The rupture process of the Kobe earthquake has been analyzed by Kikuchi and Kanamori (1996) by using an inversion process of data collected from seismic stations in Japan and other countries. According to their analysis, the Kobe earthquake consisted of the following three sub-events: a first event occurred during first 0–6 s (line 1, Fig. 1), a second event occurred during 3–8 s (line 2, Fig. 1), and the last one occurred during 6–11 s (line 3, Fig. 1). Furthermore, the collapsed region moved from the edge of Awaji Island to Mt. Rokko (altitude: 931 m). The velocity of this rupture might be approximately 2.5–3 km/s, and depth was less than 10 km. The total length of the fault dislocation was 40 km.

We investigated eyewitness reports of co-seismic luminous phenomena in the Kobe earthquake and two of them were especially remarkable (see Fig. 1). A brief description of these reports is the following: (1) There is a hotel with a nice view on Mt. Rokko. Two young persons who worked at this hotel were looking at the night view of Kobe City and the bay. Then, they noticed a luminous object moving from the edge of Awaji Island to the

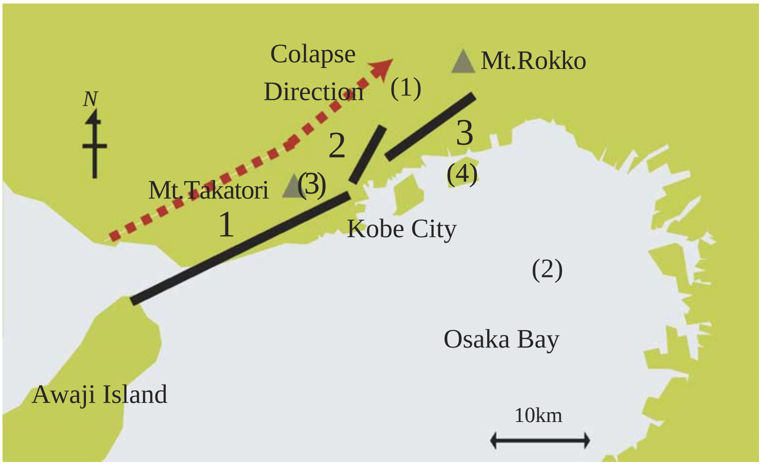

Fig. 1. Dislocated fault shown by solid lines (1)–(3), reported by Kikuchi and Kanamori (1996). Dotted line with an arrow shows the direction of the collapse region of the earthquake. The location of the eyewitness, indicated (1)–(4), corresponds to the reports in this paper.

Mt. Rokko direction for a few seconds. Note that they had their back facing the top of Mt. Rokko. A few seconds later, they strongly felt the ground shaking. From their position, they saw the luminous object quickly moving from right to left. (2) In Osaka Bay, many fishermen had been working before the main shock. They also saw an orange luminous object moving from the edge of Awaji Island toward Mt. Rokko. Since the luminous object was of an observable size from their locations (approximately 40 km distance) and close to the sea surface in their reports, the diameter and the height would be estimated to be around 100 m. They additionally claimed that the luminous object finally hit Mt. Rokko, causing lightning to strike from the sky toward the ground. Almost immediately after that, they also felt the sea surface moving up and down. From their position, the luminous phenomenon moved quickly from the left to the right.

The data of the cloud-to-ground lightning were compared with the fishermen's report. The Chugoku Electric Power Co., Inc. continuously detects the cloud-to-ground lightning events around Kobe area. Around the time of the main shock, lightning data were also recorded. However, their locations were far away from Kobe area as shown in Fig. 2, and they were out of synchronization. Consequently, no typical cloud-to-ground lightning was observed near Mt. Rokko by their detector. Since the lightning detector is triggered above a certain intensity, it is concluded that the electric current of this lightning should be small. On the other hand, some of the electromagnetic observations of which the frequency band ranged widely from DC to HF were concurrently operated during the earthquakes (Nagao et al., 2002). Only DC and ULF electromagnetic variations were observed at the time of the earthquake. There was also an observation station in VLF-LF band which was located in Kyoto (60 km away). Although the cloud-to-ground lightning can excite VLF and LF electromagnetic waves, the pulse of the electromagnetic emission that could support the eyewitness report could not be observed. Therefore, it is also concluded that the electric current of this lightning flash should be small.

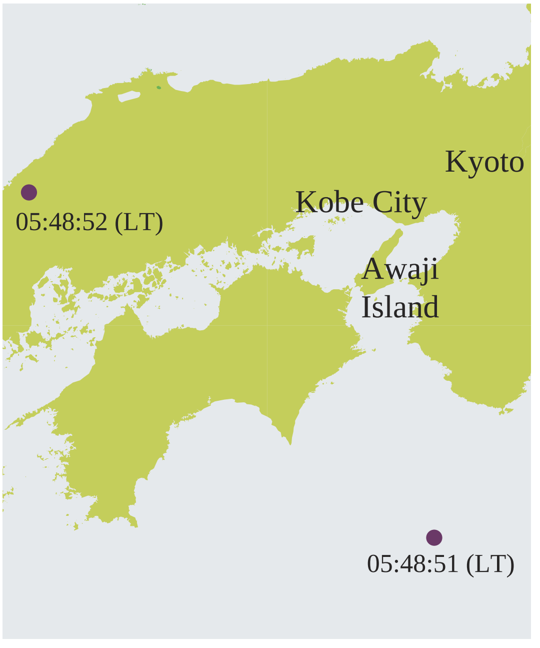

Fig. 2. Lightning data recorded by the Chugoku Electric Power Co., Inc. Only two cloud-to-ground lightning could be detected around the main shock time.

Tsukuda (1997) also has investigated the luminous phenomena associated with the Kobe earthquake. In his paper, luminous phenomena of lightning shape and zone have been reported around the time of the main shock. Tsukuda's observation and our reports agree on the following topics: (3) A man saw a zonal luminous object at an altitude of 150–200 m, which was of the same height as his eyes when he climbed Mt. Takatori (altitude: 320 m) in the west side of Kobe City. The direction of the luminous phenomenon from his position was the east side. (4) A person who stayed at the artificial land called Port Island, located in the south of Kobe City, saw a blue-white luminous object moving toward the top of Mt. Rokko from the west to the east (from left to right) for a few seconds while hearing the Earth's sounds. The altitude of the luminous phenomenon seemed to be a little higher than that of Mt. Rokko. After that, he felt the arrival of the strong P-wave of the earthquake.

Tsukuda's reports mostly support our eyewitness reports. However, there were differences concerning the height and the color. The fact that the persons in the report (1) looked at the light from the Mt. Rokko indicates that the luminous object should be located much lower than their own height. Therefore, it might be difficult for them to estimate the accurate height of the luminous object from their upper position. Since the persons in report (2) looked far away from the light source, their height estimation also is not expected to have a good resolution. The person in report (3) was located near the orbit of the luminous object and looked at the luminous object in the horizontal direction from his position (on the mountain), although it might be difficult to look at the whole orbit. Therefore, the height reported by him is expected to be relatively accurate. On the other

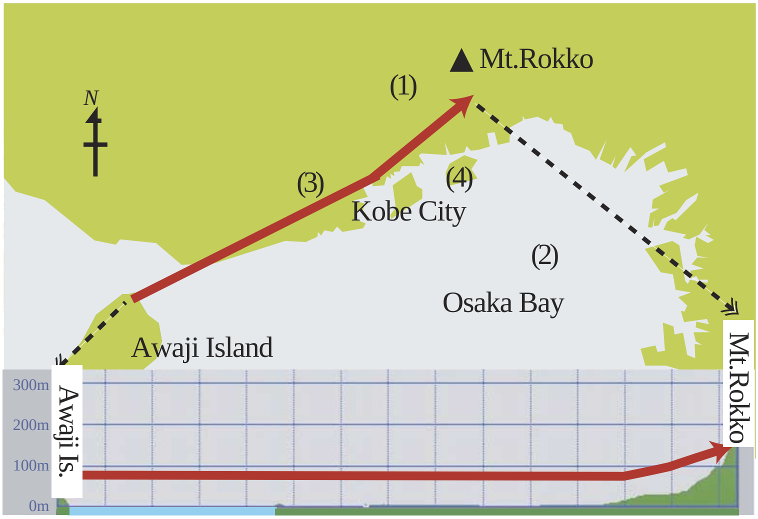

Fig. 3. Direction and trace of movement of the luminous object according to eyewitness reports. The cross-section in the trace line is also shown.

hand, the farther locations of the persons in reports (1) and (2) seem to give us a more accurate color information.

From reports (1)–(4), the direction of the rupture area was equivalent to that of the movement of the luminous phenomenon and the orbit of the movement was expected to be coincident with the fault line (see Fig. 3). Also, all of them recognized the seismic wave arrival a few seconds after they saw the luminous phenomenon. Unfortunately, from their reports, it could not be discriminated whether the luminous phenomenon was pre-seismic, just co-seismic, or coincident with the arrival time of the P-wave at the sea or at the ground surface.

Although it is extremely difficult to propose the mechanism of earthquake light, we would like to alternatively suggest two scenarios for the future study. The orbit of the luminous phenomenon was close to the surface of the sea and land. In the sea area, it was suggested that there should be a possibility that the luminous phenomena were caused by sonoluminescence (Johnston, 1991), which is a luminous phenomenon of multi-bubbles caused by the ultrasonic sound waves (see Yasui, 1999). The line spectrum of the multi-bubble sonoluminescence including the sodium line (589 nm) (Matula et al., 1995) explained the orange color. The radiation from the vicinity to the sea surface might cause the luminous object image over the sea surface. Additionally, on land, exo-electrons caused by a fault fracture excited air molecules and caused visible photons because the broken surface along the fault entirely appeared. A laboratory experiment reported by Enomoto and Hashimoto (1990) showed that a huge amount of exo-electrons could be observed when they broke rocks. Alternatively, we also suggest another scenario. A theory of the emission mechanism of higher frequency (MHz–GHz order; in a higher conductivity area like Kobe, GHz range) electromagnetic waves associated with earthquakes has been proposed (Kamogawa and Ohtsuki, 1999). The model showed that when exo-electrons were excited and emitted during the fracture around the fault, the bulk plasmon of plasma waves in the solid conductive Earth's crust or liquid conductive sea should be produced. The plasmon model concluded that the plasmon should propagate to the Earth's surface, and transform into electromagnetic waves by the surface roughness of the ground or sea due to the conservation of the momentum. Once the electromagnetic waves are emitted over the surface, the atmospheric inhomogeneity that is equivalent to the dielectric constant inhomogeneity can cause electromagnetic wave localization (theoretically: Tanaka and Tanaka, 1997; experimentally: Kamogawa et al., 1999). The strong intensity of the localized electromagnetic waves generates the luminous object that is low electron density plasma (Ohtsuki and Ofuruton, 1991; Ofuruton et al., 2001).

Although two scenarios were proposed, it is still difficult to discuss and reveal the mechanism of earthquake light. For future developments of the study, the accumulation of eyewitness reports discussing consistency should be needed. Therefore, the present eyewitness reports would contribute to future studies in revealing the mechanism of earthquake light.

3. Conclusion

Eyewitness reports of co-seismic luminous phenomena were observed in the Kobe earthquake. All eyewitness reports of the luminous phenomena were consistently observed at different sites by independent persons. Therefore, it was concluded that the direction of the orbit of the luminous object in the Kobe earthquake coincided with the direction of the rupture of the main shock fault. Although the mechanism is still unclear, they will support the understanding of the mechanism of earthquake light.

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