Urgent Issues and New Suggestions for Geo-disaster Prevention in Japan

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Abstract

Following the devastating damage caused by the heavy rains in western Japan in 2018, the Japan Geotechnical Society compiled and published recommendations for future disasters. This report introduces an outline of the recommendation on slope disasters. In particular, the recommendation emphasises the need for measures to evacuate residents from dangerous places before a disaster occurs. For this purpose, it is noted that it is important to identify potentially dangerous places and their characteristics in the long term based on past disaster information and to inform the residents of the identified areas. As a pioneering effort to achieve this recommendation, this paper describes the results of research conducted in Yamaguchi, Hiroshima, Tokyo, and Kumamoto in Japan, to clarify the frequency of the occurrence of debris flows and its utilisation measures. The main result is that debris flows occur once every few hundred years in weathered granite areas, whereas volcanic ash areas experience even more frequent debris flows than granite areas.

Keywords

Debris flow • Occurrence frequency • Risk assessment • Disaster history

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Introduction

In order to maintain a safe living environment in Japan, where heavy rain disasters often occur, it is very important to identify the places where past collapses and debris flows have occurred and the extent of the resulting damage. Slope failures and debris flows occur under the same topographic and geological conditions, hence in the long run they tend to occur repeatedly at the same or adjacent locations. However, it is difficult to understand this over the span of one person's short life. Our predecessors preserved disaster records in the forms of monuments, documentary records, oral traditions such as legends, and local festivals in order to transmit these records to later generations. Unfortunately, modern people have not correctly recognised this information or used it to prevent the next disaster. Therefore, it is important to pass on these results to future generations and to utilise highly reliable data based on many years of history when developing measures to prevent sediment-related disasters.

Under such social conditions, heavy rains in western Japan in early July 2018 caused devastating damage in various places. In the Japanese Geotechnical Society (JGS), the full extent of the damage was investigated at the direction of the president of the JGS, and a special committee was organised to make recommendations based on analysis of the results. The results were published as 'The Issues of Geotechnical Engineering for Heavy Rain Geo-Disasters Based on the Heavy Rain event of July 2018—Recommendations from Geotechnical Engineering' (JGS 2019).

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This report was then submitted to the Minister of Land, Infrastructure, Transport, and Tourism by the JGS. The first author was the leader of the committee's group on managing slope disaster preparedness. This group of 28 members compiled fourteen recommendations based on the results of several reviews. The titles of the recommendations are given in Table 1.

Of all these recommendations, recommendation 2.13 noted below relates to the effective use of disaster histories and is mainly based on the authors' research results (Sakaguchi et al. 2018; Matsugi et al. 2018).

The recommendation 2.13: Creation and use of hazard maps including information on previous geo-disasters is necessary to develop a hazard map that includes ground history information that cumulatively records past landslides and floods. It is necessary for residents to properly understand and share the importance and urgency of information (sediment disaster alert information, etc.) and to incorporate sociological ideas for the appropriate evacuation of residents.

In this study, we investigated the damage caused by debris flows that occurred as a result of torrential rainfalls in various places during the past 10 years and assessed the long-term risk of sediment-related disasters using a research approach consisting of radiocarbon (^{14}C) dating and literature surveys. Field surveys were also performed for debris flow disasters that occurred in Hofu and Yamaguchi Cities in Yamaguchi Prefecture, Aso City in Kumamoto Prefecture, Oshima Town in Tokyo, Asaminami and Asakita Wards in Hiroshima City and Nagiso Town in Nagano Prefecture. New and old debris flow deposits were identified and stratigraphically classified. To estimate the ages of these debris flow deposits, radiocarbon dating was performed on the organic material in the sediments of the debris flow. The dating results obtained from this study were collated with the disaster events described in historical documents remaining in each area. In addition, we created prototypes of the debris flow chronology in both Hofu and Hiroshima Cities, plotting debris flow generation ages and disaster events (Sakaguchi et al. 2018; Matsugi et al. 2018).

In this paper, the occurrence frequency of sediment-related disasters in Hofu City, Aso City, Oshima Town, and Hiroshima City are reported. Based on the survey results for these four areas, the relationship between topographical and geological conditions and the frequency of sediment-related disasters is discussed. Furthermore, based on the recommendations of JGS (2019), the authors suggest ways to use disaster histories for future disaster prevention.

Table 1 Recommendations from JGS for slope disaster preparedness

No.	Title of recommendation
2.1	Technology in geotechnical engineering to protect human lives and property
2.2	Improvement of accuracy of risk assessment, effective countermeasures, and maintenance and upgrade of existing countermeasures
2.3	Development of geo-disaster prevention system based on management of monitoring and real-time information
2.4	Establishment and disclosure of geotechnical and groundwater information database
2.5	Road/Railway: Efficient disaster preventive inspection by integrated management of design, construction, and disaster information
2.6	Road/Rail: R&D for preventive maintenance and appropriate regulation and deregulation of pre-traffic of road and operation control of train
2.7	Road/Railway: Introduction of concept of performance to resist disasters and realisation of advanced design and countermeasures
2.8	Erosion and mountain controls: Development of a wide-area and efficient geotechnical investigation method for weathered subsoil
2.9	Erosion and mountain controls: Improvement of performance of erosion control facilities throughout mountain streams and promotion of education for disaster prevention
2.10	Erosion and mountain controls: Promotion of comprehensive forest management from landscape and ecosystem to disaster countermeasures
2.11	Residential land: Disclosure of information on residential land safety and promotion of risk communication
2.12	Residential land: Establishment of a system for inheriting geo-information at transaction of real estate
2.13	Creation and use of hazard maps including information on previous geo-disasters
2.14	Strengthen public involvement of land and ground

Debris Flow Disaster in Hofu City, Yamaguchi Prefecture

Overview of Damage

On July 21, 2009, slope failures and large-scale debris flows occurred in various places, mainly in Hofu City, Yamaguchi Prefecture, resulting in 17 deaths in the prefecture. In the city, heavy rainfall on August 2, 1993 caused several slope collapses. It is presumed that sediment-related disasters have been occurred repeatedly in the city in the past. The mountains in this region are mainly composed of Late Cretaceous granite (Hiroshima granites). The granite has been significantly weathered and transformed into sandy and gravelly soil (Masado). There are also exposed core stones from the hillside to the summit. In addition, sheeting joints are densely distributed in the exposed rocks on the collapsed slope. This paper describes the results of on-site surveys of six affected areas: Katsusaka, Matsugatani, Gyokusen Tameike and Mitani River on the right bank of the Saba River flowing south of Hofu City as well as Manao and Ishihara on the left bank of the Saba River. In the field survey, the authors performed stratigraphy of debris flow deposits and collected samples for ^{14}C dating at 41 locations where organic material (carbonized plant material) were found in the sedimentary strata.

Estimation of Debris Flow Frequency Through Dating and Literature Surveys

The samples collected at each site were dated using an acceleration mass spectrometer (Compact AMS, NEC, 1.5SDH). The ^{14}C ages and calendar ages were calculated by correcting for the isotope fractionation effect (carbon isotope ratio $\delta^{13}C$) in the measured results. OxCal 14.1 (calibration curve data: IntCal09) was used for calendar year calibration. Figure 1 is based on the authors' data (a part of the data refers to Sakaguchi et al. 2018); its horizontal axis indicates each district and the vertical axis indicates the historical date (CE). The results of Sugihara et al. (2010) are also plotted in Fig. 1. The measurement results including the error was around 1340 for all districts. The data obtained showed that more than one-third of the data was from the 1300s. This suggests that a large-scale debris flow disaster occurred in each area at this time. In Katsusaka, debris flows have occurred frequently since tenth century. The longest debris flow interval with sedimentary layers coverage was about 300 years and the shortest was about 70 years. Excluding the debris flow in 2009, it is presumed that at least six debris flows have occurred in the Manao area and three or more have occurred in the Katsusaka, Matsugatani, and Ishihara areas simultaneously or individually. On the other hand, the dating data was examined for consistency with disaster records from around 500 CE, which are compiled in 'Yamaguchi-ken Saii-shi' (Shimonoseki Local Meteorological Observatory 1953). Figure 1 shows the dates of the events in which earthquakes and heavy rains are mentioned. The record mentioned heavy rains in 1350. Therefore, this historical data seems to support the occurrence of a debris flow in the 1300s, as mentioned above. In addition, it was confirmed that the dating results and reports in old documents generally corresponded. According to the same report, the intervals between heavy rainfalls were very short, 60 years between 1653 and 1713. The report also noted that earthquakes had occurred frequently since 1677. In particular, the Hoei earthquake, one of the largest earthquakes in Japan, was recorded in 1707, and the Aio area near Hofu City was reported to be severely damaged. The interval between debris flows immediately after the Hoei earthquake was particularly short; this is probably because weathered rocks loosened, and rock masses collapsed due to the effect of the earthquake, and the subsequent heavy rains made it prone for debris flow appearances.

In addition, the debris flow sediments could be divided into gravel-dominated strata and sand-dominated strata based on the geological observations in the field survey. Debris flows mainly composed of gravel (debris flow Nos. 2, 4 to 6, and 8 in Fig. 1) occurred in several mountain streams between 1300 and 1400. It was also found that debris flows mainly composed of sand (debris flow Nos. 1, 3, and 7) occurred before and after the debris flows mainly composed of gravel. This suggests that the debris flow deposits in the region of Hofu are mainly composed of sand, but there is a period when gravel is produced, and that gravel also would be source material for a debris flow.

Although the sediment mainly composed of gravel generally remained in the midstream of the mountain stream, the distribution area was large and the layer was thick, indicating that gravel was produced on a large scale. Debris flows in mountain streams located in areas where granite is distributed are expected to occur with a frequency of once every few hundred years. However, the recurrence interval in the thirteenth and fifteenth centuries was approximately 100 years, while in the eighteenth century, there was a period when the frequency increased to slightly less than 100 years.

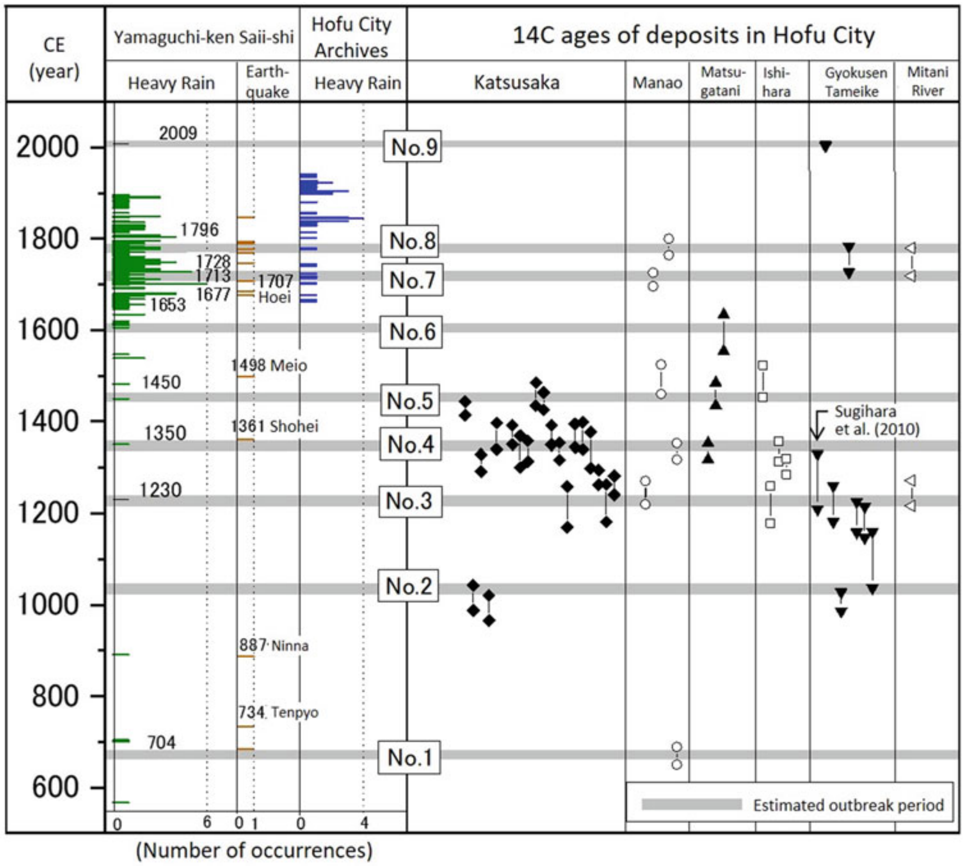

Fig. 1 Chronological table of debris flow occurrence in Hofu City (a part of the data: Sakaguchi et al. 2018)

Topographic and Geological Conditions and Debris Flow Frequency in Other Areas

Asa-Minami and Asa-Kita Wards, Hiroshima City

Heavy rainfalls from August 19–20, 2014, caused a large number of debris flows, mainly in Yagi and Midorii, Asa-minami Ward and Kabe, Asa-Kita Ward, Hiroshima City. A field survey was conducted on the mountain stream where the debris flows occurred. A majority of the mountains in Hiroshima City, as well as those in Hofu City, consist of Late Cretaceous granites (Hiroshima granites). The main lithology of these Hiroshima granites is weathered coarse-grained granite. The Jurassic accretionary complex is distributed along the Ota River from Kabe to Kake. Gentle slopes and alluvial fans are distributed between the mountains and lowlands. Based on the dating of past debris flow deposits shown in Fig. 2, it was estimated that more than five debris flows occurred in the Yagi and more than three occurred in Kabe-Higashi since the beginning of the CE before the disaster in 2014 (Matsugi et al. 2018). Umaki was a place where debris flows occurred due to heavy rain in 2018. The frequency of debris flows in one mountain stream is expected to be approximately once every several hundred years as in Hofu City. Past disaster records around Hiroshima City are described in 'Geihan Tsu-shi' (Rai et al. 1825) and 'Hishiroma Ken-shi' (Hiroshima Prefectural Government 1925). The number of dating materials are limited, and not all events are available. However, event No. 5 shown in Fig. 2 corresponds to a description of the occurrence of a debris flow in 1532 in 'Intoku Taiheiki' (1911). Event No. 6 was also found to correspond to a description of the 1850 landslide in 'Gion Cho-shi' (Gion Town history Compilation Committee 1970). These ages are almost consistent with the dates of the events in each document.

Oshima Town, Tokyo

Heavy rains caused by Typhoon No. 26 on October 16, 2013 caused many shallow slope collapses and mudflows at the western foot of Mt. Mihara, Oshima Town (Izu-Oshima). Mt. Mihara is a Quaternary volcano, and medium to large eruptions have occurred 24 times in the last 1500 years. Tephra was deposited during each eruption. During the period when the eruptive activity paused, loess was accumulated. The current surface is covered by unconsolidated volcanic ash layers such as scoria. As it shown in Fig. 3,

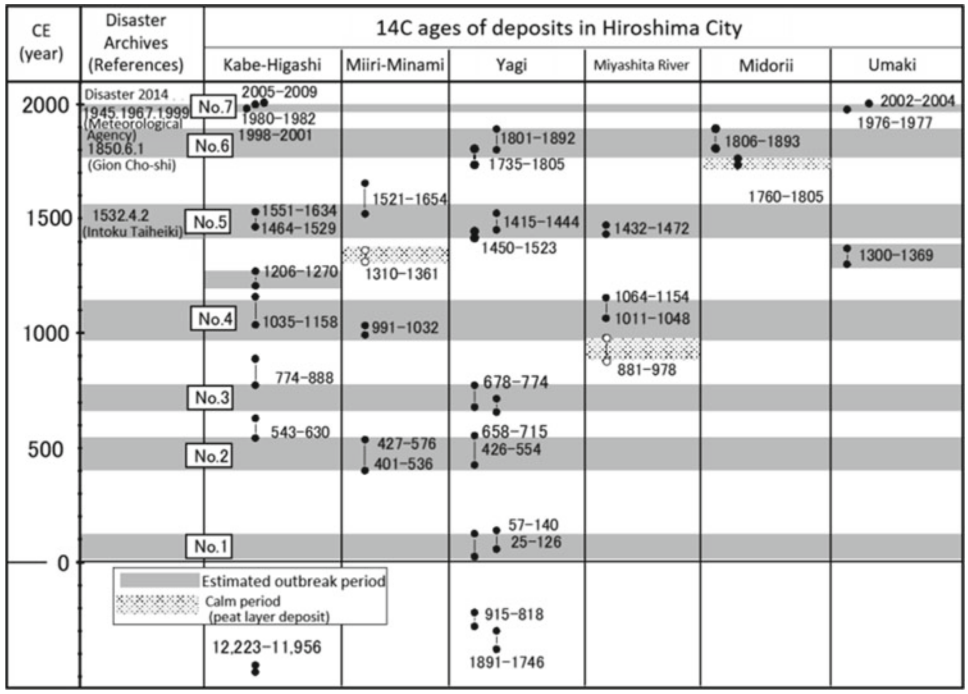

Fig. 2 Chronological table of debris flow occurrence in Hiroshima City (most of the data: Matsugi et al. 2018)

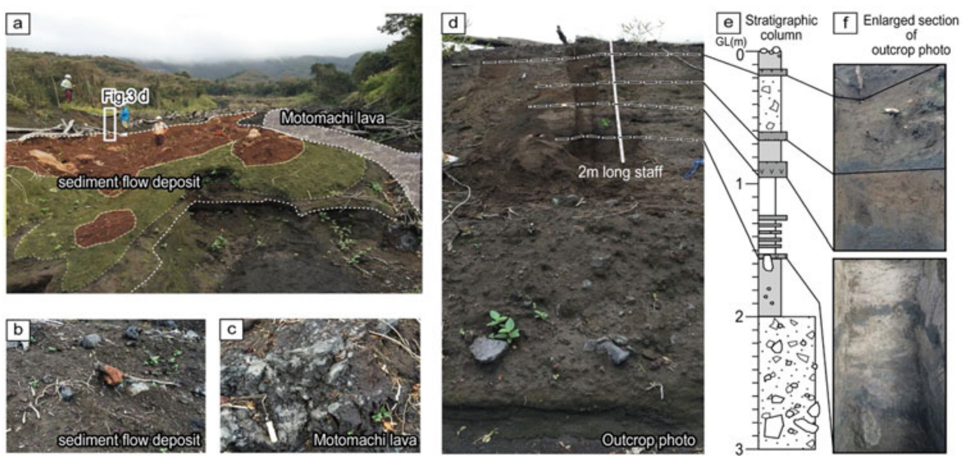

Fig. 3 Condition of sedimentation and geological profile in the downstream area of the survey site (Okanazawa) in Izu-Oshima (JSCE 2015)

mudflow sediments were identified as heterogeneous sediments in which scoria of different colours, lava gravel, and muddy gravel were mixed. In the valley of Okanazawa, where a part of the sediment was stripped off during Typhoon No. 26, it was confirmed that the fourteenth century Motomachi lava flow and tephra from the subsequent eruption activity were stacked.

At that point, it is probable that at least two sediment flows occurred between the time of the Motomachi lava flow to the end of 2013. The intervals were approximately 100 to 150 years. Koyama and Suzuki (2014) stated that the last seven sediment-related disasters (including eruptions) occurred around Motomachi town. According to historical sources, the remarkable sediment-related disaster on Izu-Oshima was caused by heavy rains due to a typhoon such as the Kanogawa Typhoon in 1958. Previous studies have shown that disasters occur approximately every 30–80 years around the Motomachi area, and there is significant evidence that more frequent sediment flows occur in volcanic areas.

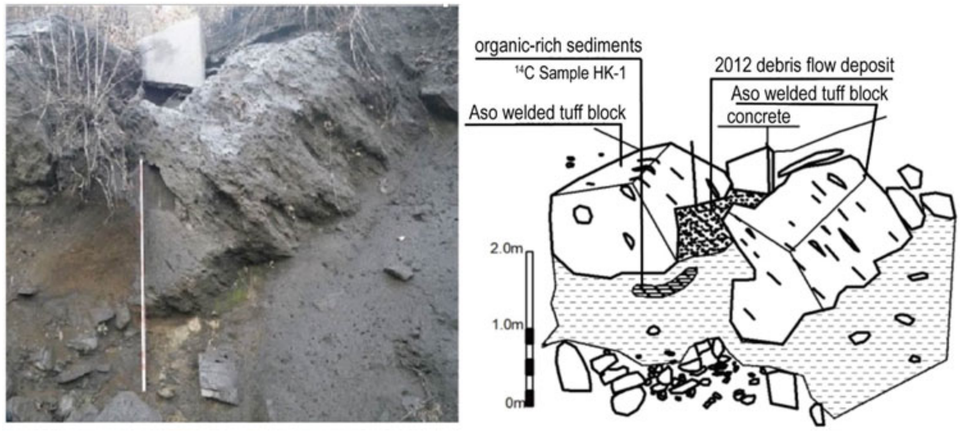

Fig. 4 Left: Debris flow deposits, Right: Overview of the site (JSCE 2015)

Aso City, Kumamoto Prefecture

The heavy rainfall on July 12, 2012 caused a tongue-like flaky slope failure everywhere on the outer rim of Mt. Aso. Mt. Aso is a Quaternary volcano, and the geology of the survey area is covered with tephra fall above the Aso welded tuff; a black volcanic ash layer with humus (Kuroboku) is present near the surface. Three carbon samples collected from debris flow sediments at Ichinomiya-machi Sakanashi and Hakoishi Pass (Fig. 4) had more recent ages since 1970. This suggests that the frequency of debris flows caused by rainfall is relatively high as compared with those caused by granite.

Conclusions

The results obtained from this study are summarised as follows.

(1) In Hofu City and two districts of Hiroshima City where weathered granite is widely distributed, the frequency of debris flows in one mountain stream is estimated to be about once every several hundred years. The reason why the occurrence interval is longer in granite areas seems to be due to the debris production and deposition process in the mountain streams. It is generally understood that the time required for granite up to 1 cm in depth to be transformed to Masado by weathering is on the order of thousands of years. Considering the production volume of Masado, the debris flow interval should be on the order of 1000 years. However, debris flows occurred at shorter intervals of 100–200 years, and the degree of weathering of the granite gravel contained in the debris flow deposits was low. The presence of sheeting jointed rock found on slopes may promote the progress of debris flows.

(2) It is estimated that shallow landslides, mudflows, and debris flows occur approximately once every several decades in one district of Oshima Town and two districts of Aso City, which are Quaternary volcanic areas. The reason for the high frequency of occurrence in Quaternary volcanic regions is thought to be the structure of the volcanic ash layer, which has high permeability on the ground surface, is loosely deposited along the slope and is vulnerable to precipitation.

(3) Finally, the authors would like to state an effective use for the findings of this study. In the studied areas, the risk of sediment-related disasters is very high, and debris flows have frequently occurred in the past. Nevertheless, the victims said, ‘*I have never heard of such a disaster here before’,* and ‘*I believed here was a safe place'*. The lessons learned from past disasters have not been passed on and used for disaster prevention. For Japan, which keeps extensive historical records, this is regrettably wasteful. In the future, information on when, where, what, and how much has previously happened should be included in hazard maps by finding traces of disasters on the ground and comparing them with disaster facts in historical records stored in the area. If hazard maps are confirmed by the facts, it will raise the awareness of residents.

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References

Gion Town history Compilation Committee (1970) Gion Cho-shi (in Japanese)

Hiroshima Prefectural Government (1925) Hirosima Ken-shi. Appendix Geibi Chronicles. Imperial Local Administration Association, 86 pp (in Japanese)

Japan Society of Civil Engineers, Geotechnical Committee (2015) 2014 Priority Research Project (Research Grant). Research report on comprehensive disaster prevention and mitigation measures considering occurrence mechanism of sediment disaster in vulnerable volcanic nations Japan and legal systems, 200 pp (in Japanese)

Japanese Geotechnical Society (2019) The issues of geotechnical engineering for heavy rain geo-disasters based on heavy rainfall in July 2018—Recommendations from geotechnical engineering. https://www.jiban.or.jp/file/saigai/houkoku/H30_TeigenSaishu.pdf (in Japanese)

Kagawa M (1911) Intoku Taiheiki. In: Inuyama S (ed) Collection in one volume, vol 1–18, 232 pp (in Japanese)

Koyama M, Suzuki Y (2014) Volcanic mudflow disaster in October 2013 from the eruption history of Izu Oshima. Geography 59–5:34–41 (in Japanese)

Matsugi H, Suzuki M, Kagohara K, Sakaguchi K, Ogasahara H, Kataoka S (2018) Sediment conditions and frequency of debris flows in and around Asaminami-ku and Asakita-ku, Hiroshima City. Japan Geotech J 13(4):403–421 (in Japanese)

Rai K, Kato S, Rai S, Kurokawa K, Tsumura S, Yoshida K, Masaoka G (eds) (1825) Geihan Tsu-shi (in Japanese)

Sakaguchi K, Suzuki M, Kagohara K, Matsugi H, Kanaori Y, Sakurai M, Kataoka S (2018) Occurrence frequency and sedimentation properties of debris flows in Ishihara district, Hofu City, Yamaguchi Prefecture. Japan Geotech J 13(3):237–247 (in Japanese)

Shimonoseki Local Meteorological Observatory (1953) Yamaguchi-ken Saii-shi: Prefectural record of convulsion of nature (in Japanese)

Sugihara S, Kaibori M, Kubota T, Kashiwabara Y, Furukawa K (2010) Consideration of regularity of sediment deposition in Hofu City in Yamaguchi Prefecture by using radiocarbon dating. J Jpn Soc Erosion Control Eng 63(3):27–33 (in Japanese)