論文の内容の要旨

Flood history of central Japan during the past 7000 years based on detrital flux to Lake Suigetsu

（水月湖への砕屑物フラックスに基づく

中部日本における過去 7000 年間の洪水史）

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Recently, extraordinary meteorological hazards such as floods and droughts occurring with low frequency gather attentions of many researchers. Especially, in coastal regions, rivers provide rich water resources in one aspect, but they could cause floods that may exert a fatal impact on human society. Therefore, it is important to observe these meteorological hazards and resolve their mechanisms in order to prepare for future occurrences of flood events. Frequency and magnitude of floods are important information to make decision to prevent these hazards. However, it is difficult to observe flood events directly because their occurrences are unpredictable and too dangerous to observe closely. To understand the frequency and magnitude of flood events, collecting the record of flood events in the past is a useful and important approach. However, observational records can only go back to the last few centuries, which is too short to evaluate the frequency and magnitude of flood events. As a potential recorder of flood events going back before observational records, event deposits in sediments are promising. When a flood occurred, significant amount of detrital material was delivered into the sedimentary basin within a geologically instantaneous period and preserved as an “event deposit” within the background sediment. Although sedimentary records have high potential for extending the time range of the flood record, it is difficult to extract quantitative information such as the magnitude of flood events. To improve the quantitative understanding of the flood event preserved in the sedimentary record, a comparison of characters of flood deposits and meteorological data is important. For this purpose, a correlation between sedimentary record and observational and/or historical record is critical.

In this study, I focused on the sediments of Lake Suigetsu, central Japan, that record flood history of the area during the entire Holocene. Sediment of Lake Suigetsu

preserve annual lamination (varves) since 1664 and many detrital layers called “event layers”, which were deposited instantaneously based on macroscopic observations. Therefore, sediments of Lake Suigetsu have high potential to correlate with meteorological record and to extend the flood record back to the entire Holocene. I try to reconstruct a long term and quantitative record of flood events covering the late Holocene using the sediment cores from Lake Suigetsu to establish the method to reconstruct long term floods, and correlate the record with other records on climatic hazard to understand the spatio-temporal variability of flood events in East Asia region.

Based on the observation of sediments and modern sedimentary processes, I estimate the cause and mechanism of sedimentation of event layers in the sediment of Lake Suigetsu. Lake Suigetsu is one of Mikata Five Lakes in Wakasa Bay, Fukui Prefecture, Japan. The drainage area of Lake Suigetsu is relatively small and most of its lake water is supplied from the drainage area of Lake Mikata, which is located immediately upstream of Lake Suigetsu and connected to Lake Suigetsu only by a shallow channel. When flood occurs, large amount of muddy water of Lake Mikata which was supplied from the drainage area of Hasu River, major feeder river of Lake Mikata, flow into Lake Suigetsu. Also landslides occasionally occur in the drainage of Lake Suigetsu. Because Lake Mikata acts as a sediment trap for coarse detrital material from its drainage area, only fine grained detrital material can flow into Lake Suigetsu. I classified the sediment of Lake Suigetsu into two types, background sediments and event layers, and described the occurrence and characteristics of each type of the sediment. The background sediment of Lake Suigetsu are composed of diatom frustules, organic material, detrital material and chemically precipitated minerals such as Fe-Mn oxide, siderite and pyrite. The event layers are distinguished from the background sediment by their colors and a sharp contact with the underlying sediment. Event layers are dominantly composed of fine grained detrital material with less than ~10 μm in diameter.

I unraveled the origin of event layers in the sediment of Lake Suigetsu accumulated during the last century and revealed the relationship between the scale of flood event and thickness of the event layer based on the correlation with observational meteorological data at Tsuruga, 20km Northeast of Lake Suigetsu. To correlate sedimentary record with the available observational record, I established an age model of the near-surface sediment of Lake Suigetsu based on varve counting, measurement of radioactive nuclides (^{137}Cs and ^{210}Pb), and fine-tuning by matching of flood events versus event layers with Bayesian error estimation. As a result, high resolution age model of the last century was established within the error of 2 years. Based on the correlation of the near-surface sediment with the observational precipitation record, it

is revealed that gray event layers deposited in the last century can be correlated with flood events in this region mainly by strong rainfall due to Typhoon hits. It is also revealed that thickness of gray event layer increases with the amount of rainfall that caused the flood. Because the flux of detrital materials does not have clear relationship with annual precipitation, it is interpreted that the flux of detrital material is mainly controlled by the flood events and frequency of moderately strong rainfall events (30 -100 mm/day).

Because Lake Mikata acts as a sediment trap of coarse grained detrital materials, only fine-grained detrital materials transported as the muddy water from the drainage area would have flowed into Lake Suigetsu and caused the deposition of event layers. However, there are several other sources of detrital materials into Lake Suigetsu such as detritals from surrounding slopes and eolian dusts. Therefore, contribution of fine-grained detrital materials in the bulk sediment and/or bulk detrital materials has to be evaluated with more precise proxy for flood event. To evaluate the origin of detrital material in the sediment of Lake Suigetsu and estimate their contribution, I applied Q-mode factor analysis to the normalized compositional data of major elements that are included only in detrital material (DetXRF data), such as Al_2O_3, TiO_2, MgO, CaO, Na_2O and K_2O in the samples which are not affected by brackish water from Lake Kugushi. A comparison of the chemical composition of estimated end members (EMs) with analyzed chemical composition of surface detrital materials sampled from the drainage of Lake Suigetsu and Lake Mikata is also conducted. It is revealed that the major components of detrital materials in Lake Suigetsu are fine grained detrital materials from the drainage area of Lake Mikata (D-EM1), coarse/fine detrital materials from surrounding slope of Lake Suigetsu, and eolian dust from the Asian continent.

I estimated the contents of bulk detrital materials (fine particles from Hasu River, coarse particles from surrounding slope and eolian dust), diatom frustules, organic material and Fe-Mn oxides in the bulk sediment core samples based on multiple regression analysis (MRA) of chemical composition data of the upper part of SG12 core corresponding to the last 7000 years measured in X-ray Fluorescence (XRF). I also estimated flux of each component to the sediment, and discussed about the change of sedimentary environments of Lake Suigetsu during the last 7000 years. Based on these results, I validated the reliability of flux of fine-grained detrital materials from Lake Mikata as a proxy to heavy rainfall. As the base erosion level is higher in the last 1000 years than before, application of flood and rainfall proxies using detrital flux would provide the minimum estimate for magnitude and frequency of flood and rainfall events before 1000 yr B.P. High-stand of D-EM1 flux during the last 1000 years could be

explained by tectonic change of geomorphology caused by earthquake or human landuse.

Two proxies are established to estimate the minimum magnitude and frequency of flood events and moderately strong rainfall events in the past 7000 years using the sediment of Lake Suigetsu.

1) Occurrence and thickness of gray event layers represent frequency and magnitude of each flood event. Since the Holocene sediment suffers from weak bioturbation, I focused event layers thicker than 1mm (corresponding to heavy rainfall more than 400 mm estimated by the relationship between event layer thickness and rainfall amount in the flood) and used as a proxy for relatively large flood events.

2) Flux of fine grained detrital materials from the drainage area of Lake Mikata to Lake Suigetsu represents frequency of moderately strong rainfalls (30-100 mm/day) in one year causing flood events in this region. Because flux of fine grained detrital materials in "background sediment" in the Holocene are potentially includes thin event layers erased by bioturbation, this proxy could include relatively small flood events.

Combining these proxies, a semi-quantitative flood record of central Japan during the last 7000 years is reconstructed. The correlation of the record with other paleoclimate records such as discharge from Yangtze River (rainfall induced by East Asian Summer Monsoon: Kubota et al., 2015) and sea surface temperature(SST) record in northwestern Pacific (Isono et al., 2009), it is revealed that in a warm interval, precipitation variability in central Japan and Yangtze drainage agree with each other. In contrast, in a cold period, these two precipitation records do not synchronize. These results suggest that spatial pattern of rainfall and flood events vary along with the change in broader climate pattern, such as SST. It is also revealed that the number of flood events in central Japan increased during the period when SST increase rapidly, indicating that flood events in this region could be influenced by the change of climate pattern, rather than stable states such as warm or cold conditions.

In this study, I established the method to reconstruct semi-quantitative heavy rainfall and flood events distinguishing them with earthquakes based on correlation of sediment versus observation and reconstruction of flux of detrital materials. This method can be applied to the sedimentary sequences with enough precise and high resolution age model especially covering the last century and with weak bioturbation or annual lamination. We could apply this method to other sedimentary sequences to obtain spatio-temporal variation of occurrence and magnitude of hazards such as floods or earthquakes.