

Stratigraphic changes and sedimentary facies of lacustrine sediment gravity flow deposits in the Middle Pleistocene Miyajima Formation, Tochigi Prefecture, northeast Japan

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Sediment gravity-flow deposits, induced by flood and slope failure events, are widely observed in varied environments from deep sea to lake environments. In marine environments, many sedimentological studies have been carried out; however, it is hard to distinguish event origins from the deposits. In recent years, modern lacustrine sediment gravity-flow deposits have been studied using sedimentary cores. Studies of lacustrine sediment gravity-flow deposits can provide a high-resolution event stratigraphy and the basis for identification event types because of their confined sedimentary environments. In this study, we analyzed sedimentary facies of lacustrine sediment gravity flow deposits in outcrops and studied their stratigraphic changes.

The Middle Pleistocene Miyajima Formation, consisting of lacustrine deposits, is located in Nasushiobara City, Tochigi Prefecture, northeast Japan. The main portion of the formation includes varved sediments intercalating many sediment gravity flow deposits. A varve in the formation is composed of light lamina dominated by *Stephanodiscus niagarae* and dark lamina dominated by inflow particles. The studied outcrop is located in Nakashiobara, Nasushiobara City and is exposed continuously along the Hahaki River. We obtained a continuous photograph series and columnar samples of the outcrop. Sedimentary facies of sediment gravity-flow deposits, their recurrence intervals, stratigraphic variations of facies types and their thicknesses were analyzed using the photographs and samples.

The 1,177 varves with 634 sediment gravity-flow deposits were obtained from the analyzed section. The average of thickness of a varve is ca. 1.2 mm and the average thickness of sediment gravity-flow deposits is ca. 9.3 mm. The sediment gravity-flow deposits can be classified into 310 beds of grading types, 315 beds of structureless types, and 9 beds of inverse grading types. The sediment gravity flow deposits have a silty matrix except for several layers in the uppermost part. Each type is subdivided by conditions of basal erosion, including rip-up clasts and sand-sized particles.

Because most parts of the varved sediments in the formation comprise of lacustrine planktonic diatoms, the sediment gravity flow deposits consisting mainly of clastics are suggested to have been formed by a flood inflow. Flood-induced slope failure deposits, including rip-up clasts and blocks of slump-folded beds and diatomaceous beds, are also included. Sediment gravity-flow deposits with an erosional base are suggested to have been deposited by a hyperpycnal flow along the bottom of the lake, whereas sediment gravity-flow deposits without an erosional base are thought to have been deposited by hypopycnal or homopycnal flows that spread along a lake surface or a thermocline of the lake. Graded bedding is a typical characteristic of a base cut hyperpycnite or is suggested to have been deposited by a suspended cloud, whereas an inverse grading is considered a relict of acceleration-phase deposits uneroded by following phases. Structureless beds are suggested to be deposited from floc of suspended particles.

Sedimentary facies of varved sediments and sediment gravity-flow deposits differ between the lower 720-year and upper 450-year intervals. In the upper part, "double laminae" and sediment gravity-flow deposits without an erosional base are dominant, whereas "single lamina", including sediment gravity-flow deposits with the erosional base, are dominant in the lower part. Different lake water conditions are suggested between the parts. Double laminae were formed by two diatom blooms induced

by lake water circulations after lake water stratifications in summer and during a “cool” winter. Because low-density sediment gravity flows are relatively difficult to submerge into stratified lake waters as a hyperpycnal flow, it is suggested that sediment gravity flow deposits without an erosional base are dominant in the upper part.

Keywords: sediment gravity flow deposit, hyperpycnal flow, varve, lacustrine sediment, Miyajima Formation, Shiobara Group