

Dating rock failure by speleothem and cave use of Japanese monkeys: a case study of Saru-ana Cave in the karst region along Kurobe Gorge in eastern Toyama Prefecture of central Japan

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Saru-ana Cave, a main cave system in the karst region, approximately 120 m and 40 m in plan length and relative height respectively, consists of combined galleries of horizontal passages and vertical shaft. It opens onto the south-facing steep cliff, which has probably originated as rupture surface of an ancient rock failure. In this study, we have investigated the cave and its surrounding landform comprehensively, and conclude that ancient rock failures occurred at least twice during the last 14,500 years, and opened the entrance of the cave intermittently.

The karst region for research is heavily snowy area where snowfall cover ranges in depth from 2 to 3 meters in winter. The Japanese monkeys (*Macaca fuscata*) of this area use Saru-ana Cave for protecting themselves against severe winter coldness during the mid-snow season. Five ¹⁴C ages measured from skeletal remains of Japanese monkeys recovered from the cave inside are 500-2,740 cal BP, suggesting that the cave entrance has been opened to the cliff surface since 2,800 cal BP.

Speleothems, which are secondary deposits in caves, form generally under the cave environment: completely dark space with nearly 100 % moisture. Around the entrance of Saru-ana Cave, there are abundant speleothems, which cover the ceiling and walls, and they had already been dried to stop growing due to aridification, sunlight from the entrance and active air circulation between inside and outside of the cave. The existences of speleothems around the entrance suggest that the area around the present cave entrance was primarily enclosed by the limestone mass, hence speleothems could grow under the cave environment.

A specimen of a stalactite collected around the entrance consists of the two layers: the inner typical stalactite has concentric, transparent layers, and the outer tufa-like layer is similar in porous and white-colored to tufa deposits, which usually precipitates outside the cave. 14,400 BP of ²³⁰Th age were measured from outermost surfaces of the stalactite layer and 9,500 BP from outermost surfaces of the tufa-like layer, respectively. In general the growth cessation of speleothems is caused by decreasing or suspension of supersaturated H₂O-CO₂-CaCO₃ solutions supply through the fissures of the limestone bedrock or aridification within the cave due to active air circulation. The presence of tufa-like layer suggests that the environment around the present entrance during the 14,400-9,500 BP period was not suitable for speleothems to grow. The ancient rock failure about 14,400 years ago removed the surficial rock masses of steep slope to let the enclosed cave passage to be opened physically to the outside. ²³⁰Th age for the outermost tufa-like layer indicates that more ancient rock failure probably occurred after about 9,500 years ago and activated the air circulation between the inside and outside of the cave. Here we formulate the rock failure-induced cave-opening hypothesis based on ²³⁰Th ages for a stalactite, ¹⁴C ages of the skeletal remains of Japanese monkeys and behavior as cave use by Japanese monkeys, to be more precise, at least two ancient rock failures occurred about 14,400 years ago and during 9,500-2800 years ago. For dating the slope movements within the karst region, various pieces of information obtained from caves; e.g. speleothems, behavior as cave use by some kinds of mammals, and others, may be useful tools.

Keywords: rock failure, stalactite, cave, cave use, Japanese monkey, speleothem