Rimstone pool: topographic analysis and theoretical insight into the formation mechanism

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Rimstone is a type of stalactite that looks like a ridge of rice field. In general, stalactites are secondary products of surface water and groundwater that have eroded the limestone inside the cave; more precisely, it refers to sediments generated when water containing a large amount of lime travels along the floor and ceiling of the cave. A levee-shaped puddle surrounded by rimstones is called a rimstone pool. The appearance of various-sized rimstone pools formed along a gentle slope reminds us of terraced fields made by cutting down the slopes of the mountain. Famous examples of rimstone pools include "Hyakumai-zara" in Akiyoshido cave in Japan, "Pamukkale" in Turkey, and "Huanglong" in China. In addition to rimstones, icicles and stalagmites are included in the category of stalactites; the stalactite in the narrow sense means only icicle, but here we use the stalactite in the broad sense.

How is such a step-shaped rimstone pool formed spontaneously? One of the theories proposed earlier focuses on the velocity of water flowing along the pool ridges. This theory assumes that the amount of lime that precipitates on the pool surface (bottom of the floor and side of the ridge) per unit time is proportional to the local flow velocity of the water flowing down the slope. Since the water flowing on the surface of the ridge has a higher flow velocity than the floor, a large amount of lime deposits on the surface of the initial slight bulge and grows into a large ridge. The assumption that the deposition velocity is proportional to the flow velocity seems to be valid in the turbulent flow, where chemical reaction leading to precipitation may be promoted; nevertheless, its validity remains questionable in the laminar flow that is observed in the actual lime cave. In the present work, we examine the validity of the above assumption by applying a linear stability analysis to the theoretical model. In our theoretical consideration, we vary the relationship between the deposition rate of lime and the flow rate of water in a systematic manner, and discuss the instability of the initial almost-flattened floor under calcium-rich water flow.

As a further investigation, we have conducted a field survey of a rimstone pool "Hyakumai-zara" in Akiyoshido (Mine City, Yamaguchi Prefecture, Japan), and have analyzed the geometric patterns created by ridges with various sizes and perimeter lengths. A previous numerical simulation suggests that, when the size of a pool is set to be a random variable, its probability distribution curve follows a power law with a negative exponent. This numerical result implies that the self-organized pattern realized in the rimstone pool is endowed with the self-similarity, which may provide a clue to understanding the formation mechanism of rimstone. Still, this conclusion was obtained from numerical simulations, and there has been no example that verified this conclusion with real rimstones. Against the background, we conducted a field survey the rimstone pool "Hyakumai-zara" , one of the rarest rim stone pools in the world, using a laser range finder and a high-resolution camera. First, a laser range finder was installed on the sightseeing road, and the linear distance and elevation angle to each rimstone pool wall were measured for approximately 200 different pools. Next, using the measurement data, the height of the walls separating the adjacent pools and the horizontal distances between the walls were calculated. This result allowed us to evaluate the spatial distribution of the gradient over the entire rimstone. Further, using a commercially available digital camera, each part of the rimstone was photographed under the condition of about 16

million pixels, and then these images were combined into one large photograph using image analysis software. As a consequence, we successfully extracted the statistical properties characterizing the geometric pattern of the entire rimstone.

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