Ancient Machu Picchu Drainage Engineering

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Abstract: The drainage infrastructure constructed by the Inca at ancient Machu Picchu represents a significant public works achievement. The difficult site constraints associated with the nearly 2,000 mm per year of rainfall, steep slopes, landslides, and inaccessibility posed drainage challenges that were met successfully by the Inca. The technical analysis of the Inca drainage works demonstrates that the drainage criteria used were reasonable and the implementation exceptional, and that the Inca were good engineers even though they labored without the benefit of a written language or the use of a wheel. Proof of the Inca success with drainage rests with the fact that Machu Picchu lay in the rainforest for 400 years without failure. There is no better example of successful ancient civil engineering than Machu Picchu. It was built by Native Americans before the arrival of the Spanish Conquistadors, was essentially abandoned in 1540 A.D., and endured for 4 1/2 centuries under a thick rainforest until the 20th century. Scientists, engineers, and laymen alike continue to marvel at the wonders of Machu Picchu.

INTRODUCTION

When Professor Hiram Bingham returned to Yale University after his discovery of Machu Picchu, Peru, in 1911, he stated that "the Inca were good engineers" (Bingham 1913). Recent engineering research at Machu Picchu has demonstrated that Bingham was correct. This paper describes the carefully planned and constructed drainage infrastructure at Machu Picchu, without which it would not have endured to the present (Fig. 1).

Machu Picchu served a permanent population of about 300 with a peak of 1,000 when the Inca emperor was in residence. When Bingham stumbled upon the ruins of the beautiful Andean Inca community, it had endured nearly intact for over four centuries without suffering from foundation failures or landslide damage (Bingham 1930) (Fig. 2). The potential ravages of time, steep mountain slopes, and excessive rainfall were overcome by the exceptional ability of the Inca engineers to construct good building foundations and install effective drainage systems. These two Inca achievements delivered Machu Picchu to the 20th century scientists in a condition nearly as it had existed when it was abandoned in the 16th century. It was occupied between 1450 and 1540 A.D., with some people remaining until 1572 A.D. (Rowe 1990).

Machu Picchu, the royal estate of the Inca ruler Pachacuti (Rowe 1990), is the most well known of all Inca archeological sites. While numerous visitors view the site in awe each year, little was known about its paleohydrology or surface and subsurface drainage, or how the various infrastructure components of this Andean community functioned. It was for this reason that the Peruvian government issued an archeological permit to the writers in 1994 to carry out research on the agriculture, water supply, hydraulics, and drainage of this ancient Andean community (Wright 1996); this paper deals with its surface and subsurface drainage.

When viewing the complex but orderly layout of the ruins, scientists and laymen alike express wonder and ask questions about the drainage and potential irrigation of the numerous agricultural terraces. Because the annual average precipitation likely was about 1,940 mm per year at the time of occupation, there was no need to irrigate agricultural land at Machu Picchu, and field investigations by the writers indicated that no irrigation delivery or distribution system existed [Wright et al. 1997(c)]. Fig. 3 presents the ice core data from the Quelccaya ice cap, representing long-term precipitation patterns (Thompson et al. 1992; Thompson and Moseley-Thompson 1989). The Machu Picchu period is shown for comparison.

SETTING AND GEOLOGY

The Inca royal estate of Machu Picchu is situated on a high mountain ridge between two prominent peaks at an elevation of 2,438 m (Fig. 4). The ridge plunges precipitously on both sides some 450 m to the Urubamba River. It would appear to be an unlikely location for ancient peoples to have been able to construct a complex of beautiful buildings that would endure for so long a time.

Machu Picchu is about 1,400 km south of the equator on the eastern slope of the Peruvian Andes (Fig. 5). The site lies near the headwaters of the Amazon River, at long. 72°32′ W and lat. 13°9′ S. Machu Picchu is laid out like a patchwork quilt on a mountain ridge between two prominent mountain peaks—Machu Picchu and Huayna Picchu. The dramatic site is a manifestation of tectonic forces and valley downcutting by the Urubamba River, which meanders along three sides of the ridgetop retreat. Further away, but visually dominating, is the ice-capped peak of Mount Veronica to the east (5,850 m).

This Inca site lies within the Cordillera Oriental (Eastern Cordillera) between the High Plateau and Subandine zones of the Peruvian Andes (Marocco 1977) on a 40 km^2 portion of the complex Vilcabamba Batholith (Caillaux n.d.). This 250-million-year-old intrusion is white to gray-colored granite, characterized by its abundance of quartz, feldspar, and mica (predominantly biotite). This mineralogical composition made the granite of Machu Picchu a durable construction material. Nonetheless, it was the inherent, rectangular joint pattern that the Inca workmen recognized and masterfully used as building stones to construct Machu Picchu [Wright 1997(b)].

The most significant geologic characteristics of the Machu Picchu site are the numerous faults and abundant rock fractures. Two principal faults are named for the two prominent local peaks: Huayna Picchu Fault and Machu Picchu Fault, as shown in Fig. 4. These high-angle reverse faults formed a wedge-shaped structural block relative to their namesakes. This block, or graben, is the structure on which the ancient

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