Workers dragged Forbidden City stones along roads of artificial ice

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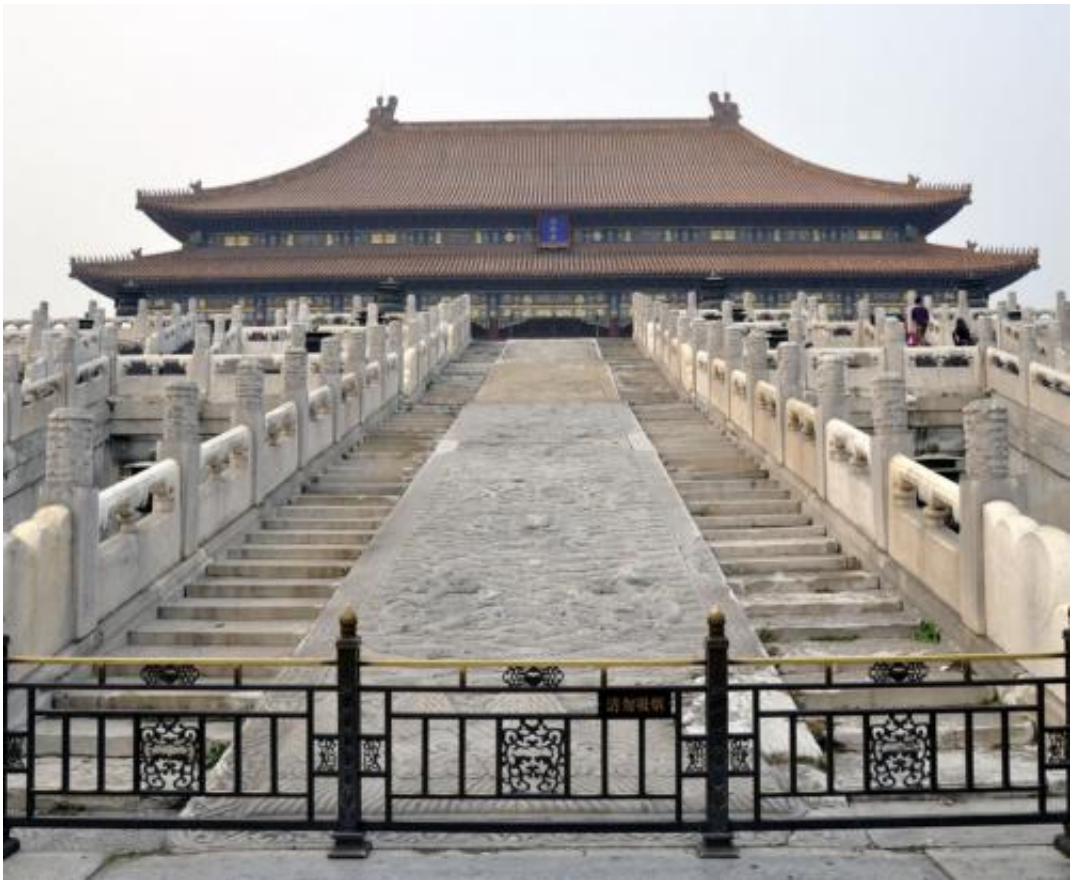

Workers likely slid massive stones, such as this 300-ton marble carving in front of the Hall of Supreme Harmony in the Forbidden City, Beijing, China, along artificial ice paths. Credit: Chui Hu

(Phys.org) —Fifteenth and sixteenth century Chinese workers

transported enormous stones to the Forbidden City by carrying them in sledges along roads of artificial ice, according to Jiang Li of the University of Science and Technology in Beijing and his colleagues. The researchers translated a document showing that in 1557, workers used this method to transport a 123-ton stone more than 70 kilometers. Li and his team say that dragging large stones over ice, rather than over dry ground, reduced the amount of friction created and the number of workers needed for the job. The study appears in the *Proceedings of the National Academy of Sciences*.

Construction of China's Forbidden City, in present-day Beijing, began in 1417. The home of China's emperors for almost 500 years, The Forbidden City incorporates stones weighing more than 100 tons extracted from the Dashiwo quarry, 70 kilometers away. The heaviest of these is the Large Stone Carving, which weighs more than 300 tons.

Previous researchers assumed that the Chinese used wheeled vehicles to move the stones. The Chinese were using wheeled vehicles for transport by around 1500 BC, and there are no images of workers dragging stones over dry ground. However, none of the wheeled vehicles built before 1596 could carry more than 95 tons. Although some books mention that workers used an artificial ice path to transport the Large Stone Carving, there are no detailed historical records of this event.

Li and his colleagues translated a Chinese text written in 1618 that describes how workers brought a 123-ton stone to the Forbidden City in 1557, during a mid-winter renovation project. The workers placed the stone on a sledge, which they then dragged along an artificial ice path, created by pouring well water onto the ground and then allowing the water to freeze. They dug wells every half kilometer. By pouring water over ice that had already frozen, they created a liquid surface that decreased the friction between the sledge and the ice. The workers had time to move the sledge across the liquid film before it froze.

The team calculated that it would have taken 1,537 men to drag the load over dry ground. Dragging a sledge over ice would have required 338 men. Lubricating the ice would have reduced the workforce to 46 men. An ice road also eliminated the need to lay out wooden planks to create a smooth surface.

Architects of the reconstruction debated whether to use sledges or mule-driven wagons. They chose sledges because they were safer and more reliable than wagons, although sledges required more time, money and manpower.

The research suggests that, at the time, Chinese engineers knew more about friction than Western engineers did.

More information: Ice lubrication for moving heavy stones to the Forbidden City in 15th- and 16th-century China, *PNAS*, www.pnas.org/content/early/2013/10/30/1309319110

Abstract
Lubrication plays a crucial role in reducing friction for transporting heavy objects, from moving a 60-ton statue in ancient Egypt to relocating a 15,000-ton building in modern society. Although in China spoked wheels appeared ca. 1500 B.C., in the 15th and 16th centuries sliding sledges were still used in transporting huge stones to the Forbidden City in Beijing. We show that an ice lubrication technique of water-lubricated wood-on-ice sliding was used instead of the common ancient approaches, such as wood-on-wood sliding or the use of log rollers. The technique took full advantage of the natural properties of ice, such as sufficient hardness, flatness, and low friction with a water film. This ice-assisted movement is more efficient for such heavy-load and low-speed transportation necessary for the stones of the Forbidden City. The transportation of the huge stones provides an early example of ice lubrication and complements current studies of the high-speed

regime relevant to competitive ice sports.