Scientific study of layered corrosion products spalled from iron objects in Pujindu Site, Yongji, Shanxi Province, China

Yusheng Lei[1], Ningrui Jia[1], Jingdan Wang[1], Puheng Nan[2], **Shasha Long**[1], Zhimin Li[1], Qinglin Ma[3]

[1] *Institute of Cultural Heritage, Shandong University, Shandong 266237, China*

[2] *Shanxi Provincial Institute of Archaeology, Shanxi 030001, China*

[3] *Beijing University of Chemical Technology, Beijing 100029, China*

Presenter Shasha Long: sashaL31@163.com

Abstract The Pujindu Site in Yongji, Shanxi Province,China, is a notable ancient ferry location on the Yellow River. During the Tang Dynasty(724 AD), iron objects, such as cattle and human figures, were cast as ground anchors for the Pujindu Bridge. These iron objects, excavated in the 20th century, represent a significant collection. Rescue protection was performed in 2004. Nowadays, these iron objects are experiencing new forms of corrosion, including extensive layered spalling, which poses a threat to the matrix. In this study, representative cross-sectional samples of layered spalling were collected and analyzed using microscopic morphology, X-ray diffraction, and Raman spectroscopy.The results show that the corrosion phenomena primarily consist of black-brown corrosion layers (BBL) parallel to the outer surface, along with red-brown corrosion layers (RBL) and cracks. The BBL primarily cover the cracks and the outer surface. The corrosion products include goethite (α-FeOOH), lepidocrocite (γ-FeOOH), akaganeite (β-FeOOH), magnetite (Fe_3O_4), and hematite (Fe_2O_3). The lepidocrocite content is higher in the RBL compared to the BBL. Cracks within the corrosion layer (CL) are filled with needle-like crystals and exhibit high chlorine (Cl) content. High humidity and rainfall facilitate the entry of water and oxygen into the objects through these cracks, leading to the formation of corrosive galvanic cells on the iron surface. Iron initially oxidizes to form lepidocrocite, which gradually transforms into goethite and akaganeite under environmental influences. Additionally, iron may participate in oxidation reactions to produce magnetite, which can further oxidize to form maghemite and hematite. Fluctuations in atmospheric temperature and humidity cause the surfaces of artifacts to undergo repeated drying and wetting cycles. This process leads to the development of corrosion cracks and the continuous formation of new iron oxides within these cracks. The varying internal stresses among different corrosion products contribute to the creation of additional cracks. Over time, the prolonged environmental effects result in ongoing deterioration of the objects until they are completely damaged.

Understanding these processes is crucial for developing effective protection strategies for iron artifacts.

Keywords Iron objects; layered spalling; corrosion products; Pujindu Site

This work is supported by Shanxi Province Key R & D Program(202202130501019)