

X-ray Spectroscopies for Mesoamerican Green Stone Characterization: Challenges and Complementary Techniques

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Usually, archaeological materials require non-invasive methods and *in situ* analysis for their characterization. This is particularly the case for pre-Hispanic artifacts made from green stone materials, like jade. Often the archaeological questions about this kind of pieces are focused on provenance of the raw materials, but other questions regarding the cultural choices for manufacturing and ritual preferences for offerings can be answered by a material characterization. In the case of green stone artifacts, a wide variety of minerals can be used, not only jade. These materials are also heterogeneous, thus their mineral characterization is a challenging problem.

In this work, we present several cases studies on Mesoamerican collections from the Maya area of Palenque and Bonampak, Mexico, as well as jadeite samples to show the advantages and limitations of the spectroscopic techniques for the identification of green stone minerals. For the *in situ* non-invasive analysis of the pieces, X-ray diffraction (XRD) and X-ray fluorescence (XRF) were applied by a modified diffractometer system, called ADIS (75W Cu X-ray tube, Curve Position Sensitive (CPS) detector with a 180 mm radius and a Amptek SDD X-ray detector for XRF). Also, complementary XRF punctual analyses were carried out by our home-made spectrometer SANDRA using a 75W Mo X-ray tube from Oxford Instruments and a SDD X-ray detector from Amptek (1 mm diameter spot). On the other hand, Infrared spectroscopy (FTIR) was carried out by an Bruker Alpha spectrometer in reflection mode (analysis area of 5 mm²). Raman spectroscopy was applied using two i-Raman-Plus spectrometers (BWTek), with two different excitation wavelengths, 532 and 785 nm (105 μm spot).

From our results, we observed that the X-ray techniques are more sensitive than the molecular spectroscopies since more mineral phases were detected. Moreover, the combination of XRD-XRF and punctual XRF is the most suitable method for the identification of the mineral composition but it is time consuming by comparison to Infrared spectroscopy (FTIR) in reflection mode. Raman is a complementary method for the punctual characterization but fluorescence may become a difficulty. For archaeometric measurements, FTIR followed by Raman and XRF seems to be the most suitable combination of techniques for the green stone characterization. However, XRD-XRF can be applied for the most difficult cases when the molecular techniques fail but it can be used only for few artifacts since these measurements require at least 20 min per region on an artifact.

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