Scientific Methods of Turquoise Identification

**X-Ray Diffraction**
- Unique turquoise spectrum
- Used for identification in jewelry industry
- Requires sample

**Fourier Transform-Infrared Spectroscopy**
- Unique turquoise spectrum
- Used for identification in jewelry industry
- Can show organic additions
- Requires sample

**Ultrasound Examination**
- No sampling
- No fluorescence under short wave UV light
- Variable fluorescence under long wave UV light
- Can't identify turquoise, only some substitutes

**X-Ray Fluorescence Spectroscopy**
- No sampling
- Identifies presence of aluminum and phosphorus
- Large spot size (~1 cm)
- Requires use of helium chamber to see phosphorus and aluminum
- Aluminum peak is often too small to observe, even using helium chamber
- Gilding interferes with phosphorus identification

**Fiber Optic Reflectance Spectroscopy**
- No sampling
- Small spot size (~1 mm)
- Can help identify “enhanced” turquoise
- Identifies Fe³⁺ substitution in turquoise at 422 and 430 nm
- Peak visibility varies with Fe³⁺ content and turquoise degradation

**Turquoise**
- Turquoise is a hydrated copper aluminum phosphate: Cu₄[Al₆O₁₈](OH)₄·5 H₂O
- Iron can substitute for the aluminum in the turquoise structure
- Copper and iron give turquoise its characteristic blue-green color
- Turquoise was available in China from mines and trade along the silk route
- Many materials have been used to imitate turquoise, including:
  - Dyed bone and odontolite (copper colored fossilized bone)
  - Other blue-green minerals such as chrysocolla, lazulite, and wardite
  - Glass
  - Enamel
  - Stained minerals
  - Plastics
- Fragmented, degraded or inferior turquoise dyed and/or impregnated with resin

**Results**
- Fiber Optic Reflectance Spectroscopy
  - The doublet at 422 and 430 nm varies with Fe³⁺ concentration and the state of degradation of the turquoise
  - The doublet may appear as a single broad peak or may not be visible at all
  - The non-uniformity of turquoise can lead to different spectra in the same sample of turquoise
- Peaks in the blue region (600+ nm) indicate the presence of organic dyes, either to enhance the blue color of poor quality turquoise or in a dyed substitute inlay material

- Fourier Transform-Infrared Spectroscopy
  - FT-IR was used in our study to independently confirm the presence (or absence) of turquoise
  - IR was also helpful in giving more information about replacement inlay pieces containing plastics and dyes

- X-Ray Fluorescence Spectroscopy
  - The presence of a phosphorus and an aluminum peak indicate the presence of turquoise
  - Gold peaks overlap the phosphorus peak: turquoise on gilded belt hooks could not be identified
  - The aluminum peak is very small, and may not be visible
  - The presence of a phosphorus and a large calcium peak can indicate the presence of bone
  - The peaks of other elements can give additional information about the belt hook

**Conclusions**
- Our investigation found that a combination of XRF, FORS and careful examination can usually identify turquoise inlay
- Although helpful, IR didn't provide any turquoise identifications that the combination of FORS, XRF and careful examination didn't previously identify
- If sampling is possible, IR or XRD can be used to confirm ambiguous identifications or give more information about replacement inlay
- Although FORS has been most commonly used in pigment analysis on paintings, this study shows that FORS can have a useful application in the study of objects

**References**