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X-ray investigations on ancient gold coins

synchrotron radiation contribution to history and numismatics

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XRF beamline
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X-ray investigations on ancient gold coins: synchrotron radiation contribution to history and numismatics

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International Conference on
Accelerators for Research and Sustainable Development
#Accelerators2022
23–27 May 2022
IAEA, Vienna, Austria

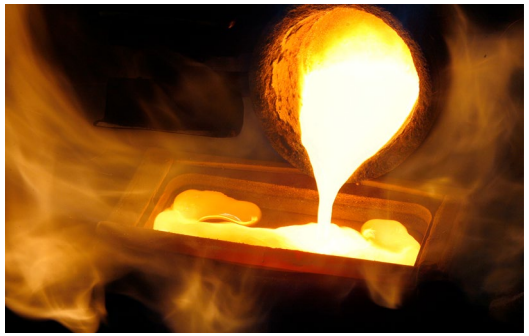
Roman Empire

IV century AD

- Emperor: Constantine
- Constantinople: new capital
- Western/Eastern Roman Empire
- Reorganization of political and religious powers
- Introduction of the Constantinian **solidus**

Economic dynamics

Constantinian solidus (310 AD):



- Stability of its alloy (98-99% Au)
  → reference for the Empire
- Deflation processes: fineness decreased over the years
  → **assess fineness over time**
- Lack of gold: new coins made from tax collection
  → **identify trace elements and contaminants**
- Different Au sources (mining sites)
  → **identify trace elements and contaminants**

Investigation techniques

Preliminary analysis @ UniTS
Inductively coupled plasma-mass spectrometry (ICP-MS)

Elemental composition and distribution @ XRF beamline
X-Ray Fluorescence (XRF) and
X-ray Absorption Near Edge Structure (XANES)

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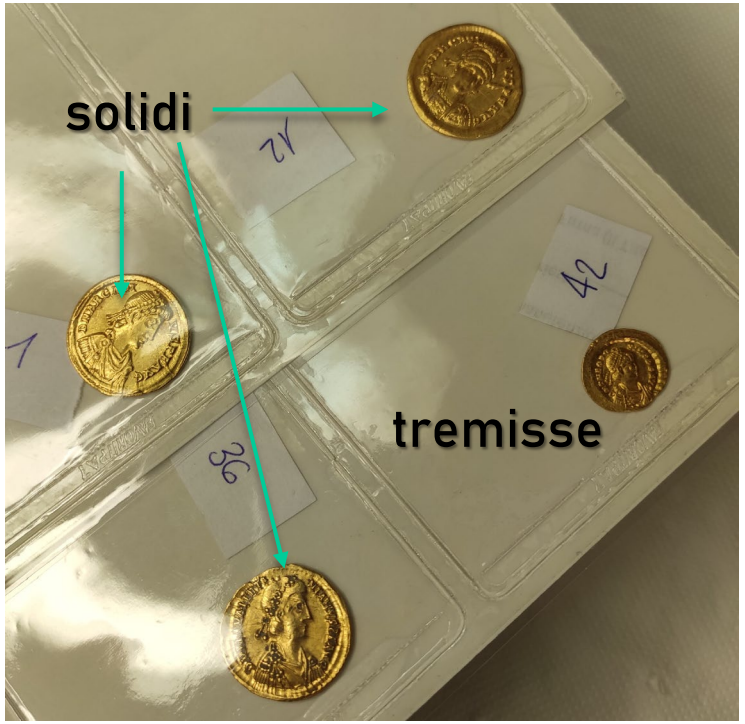

X-ray Fluorescence

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XRF beamline

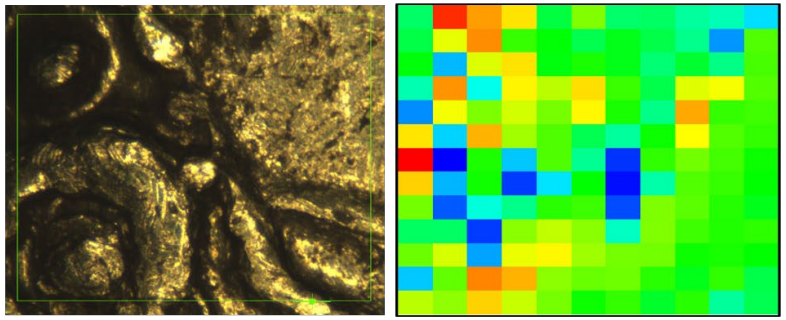
Energy range: 2 – 14 keV
Monochromator: high flux | high energy resolution
Exit slits: beam size down to 50 x 50 mm^2
(max 200 x 800 μm^2 V x H)

XRF and XANES

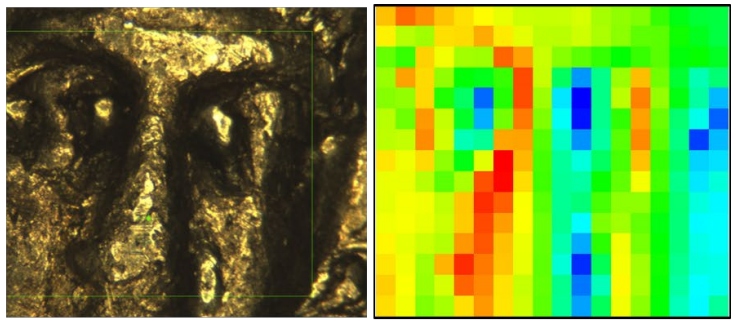
- **Surface distribution** of the elements
- **Chemical composition** of the alloy
- **Identification** of the contaminants

XRF mapping

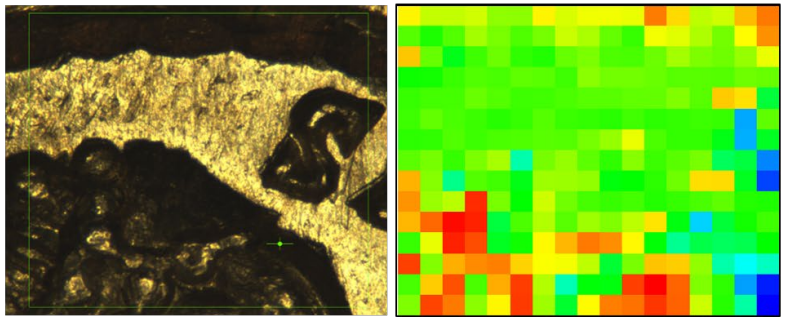
Coin A



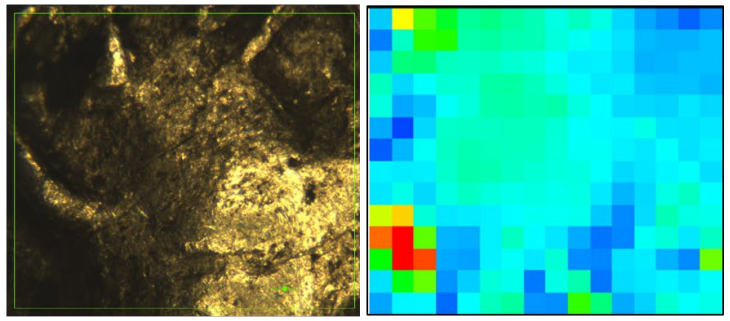
Coin B



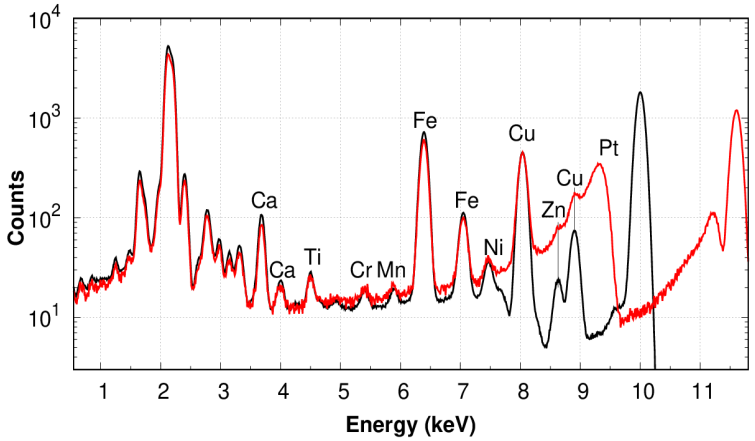
Coin C



Coin D



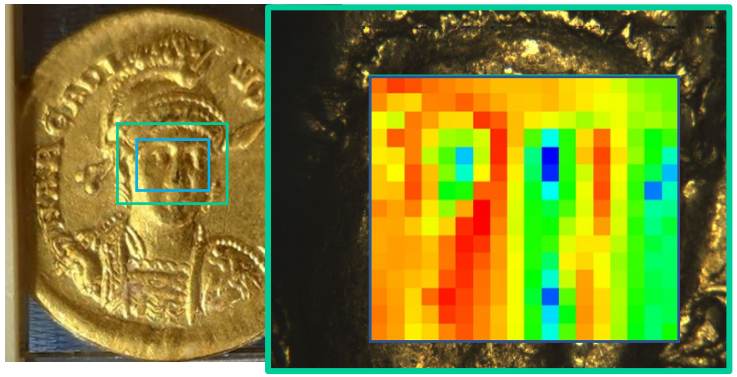
- 45/45° geometry
- 100 x 100 μm^2 resolution
- hv = **10 keV** and **11.6 keV**

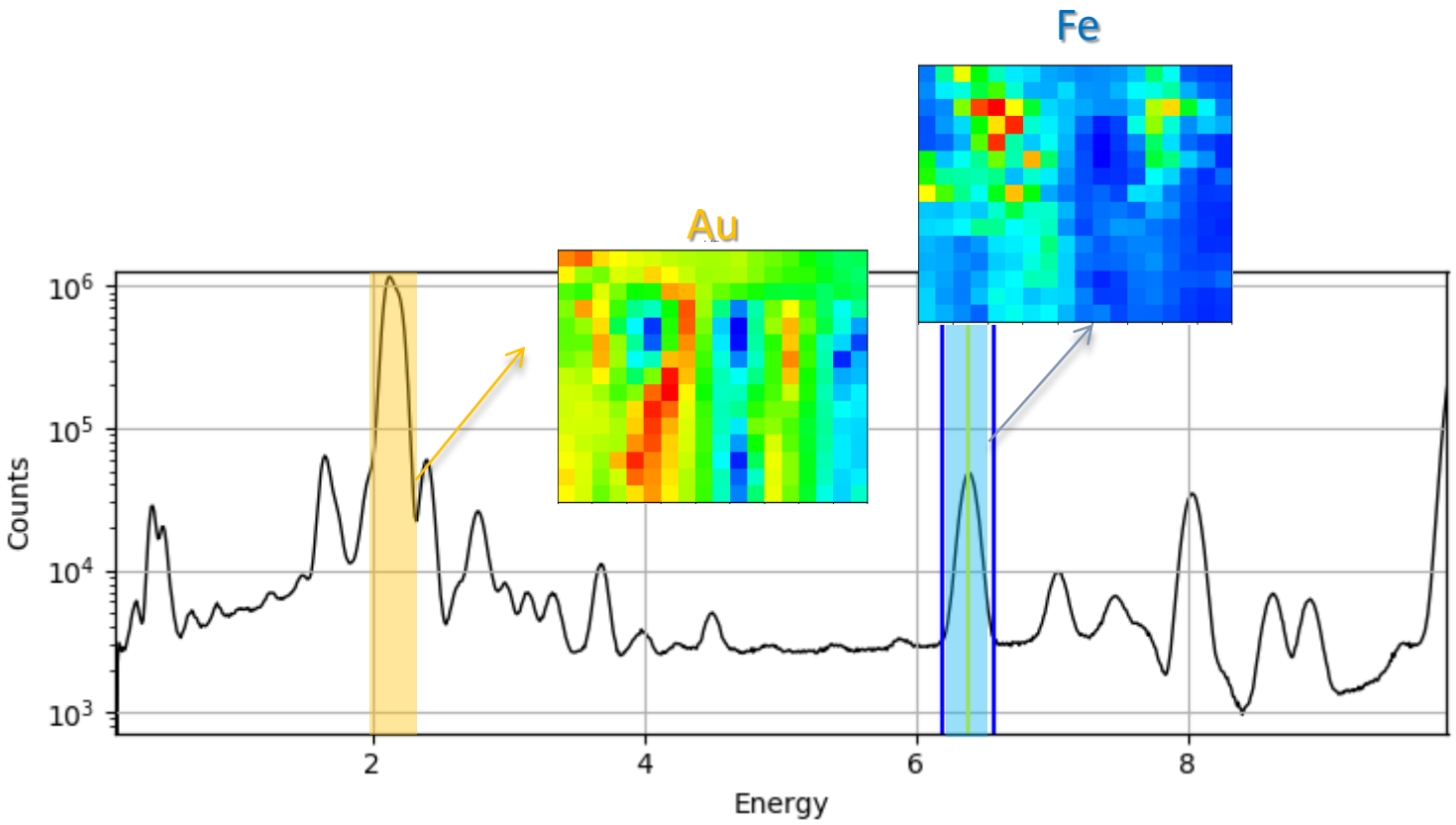


Elemental distribution

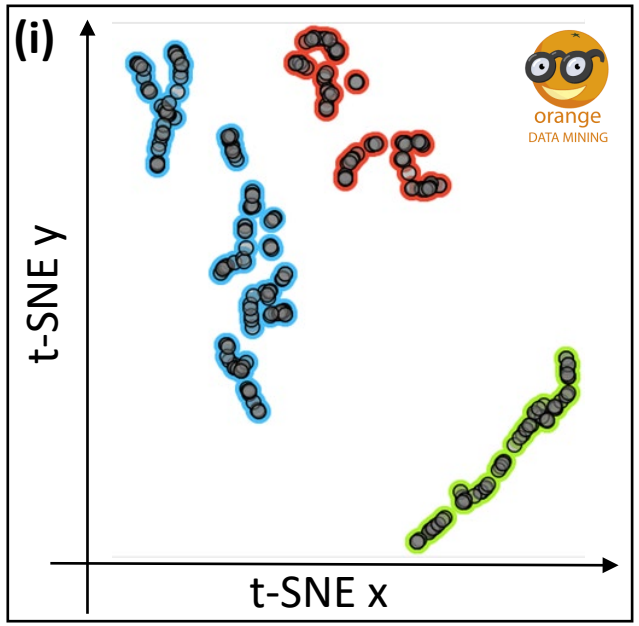
hv = 10 keV

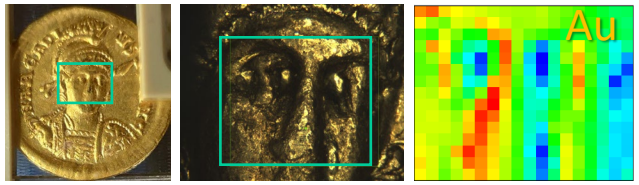
100 x 100 μm^2 resolution





t-SNE analysis – 10 keV

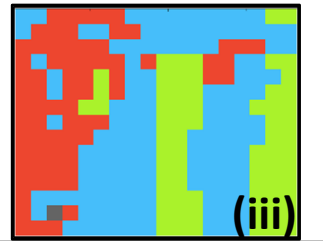


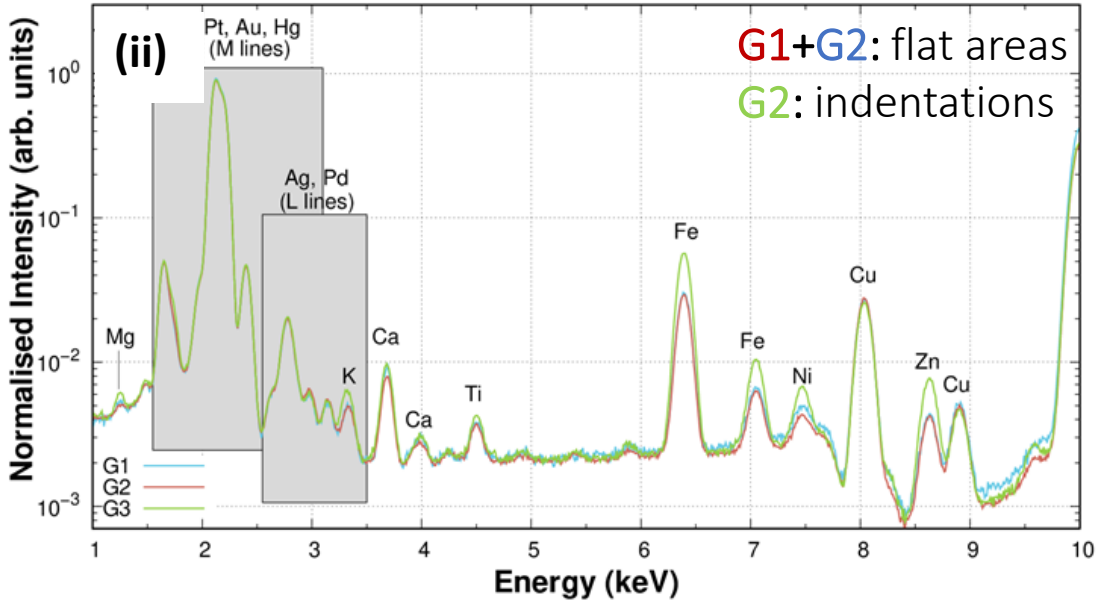


(i) Evaluate spectral similarity of pixels.

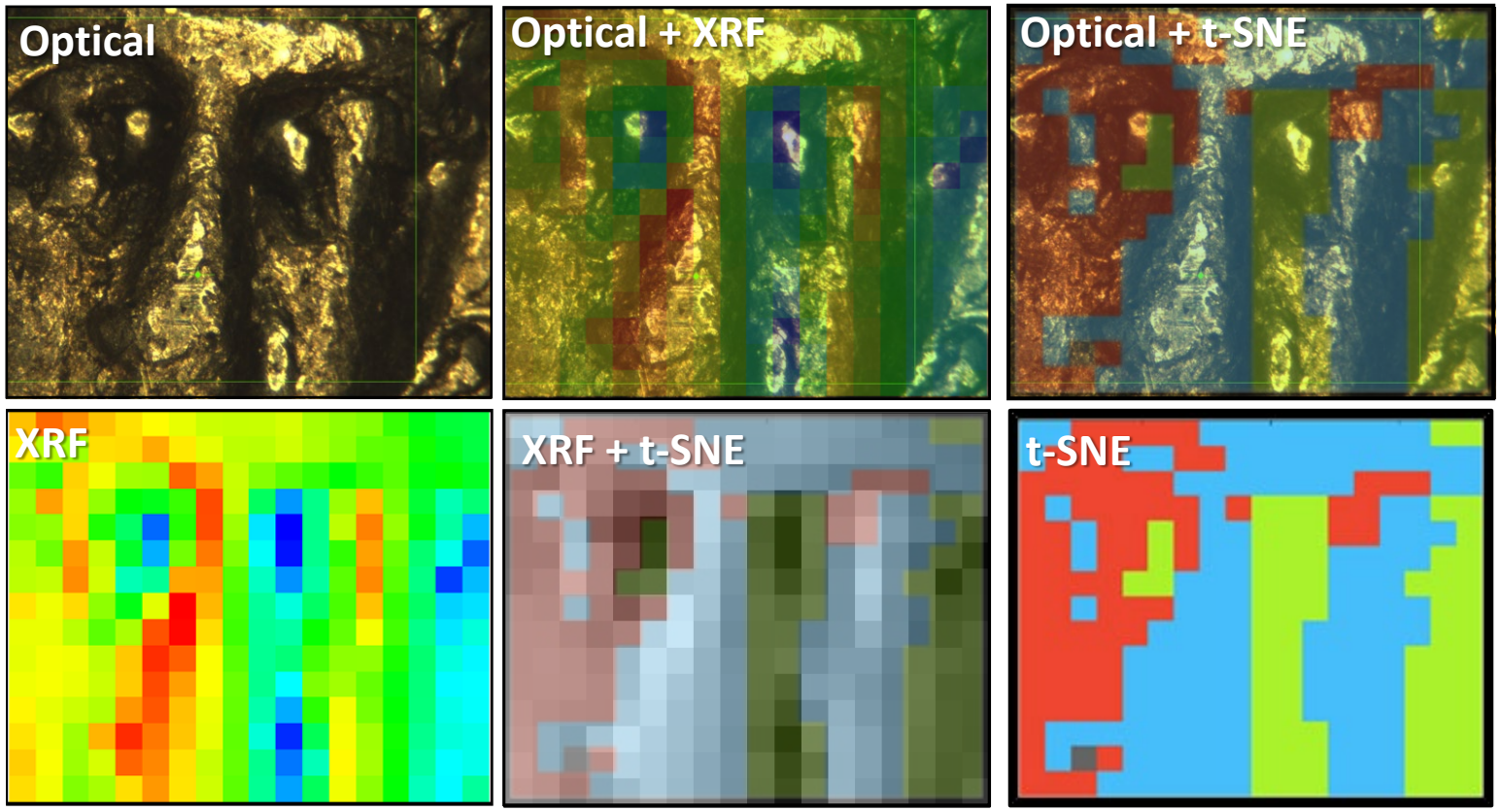
(ii) Evaluate composition from the spectra of the 3 groups.

(iii) <u>Discriminate between alloy and debris</u> contributions through pixels position.



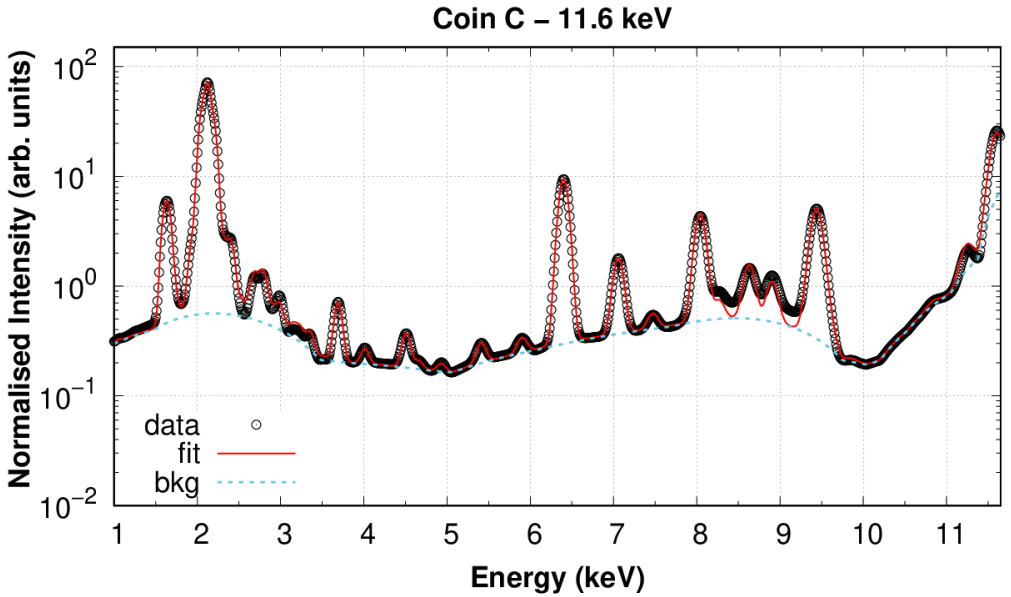


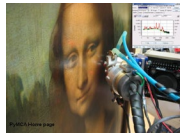
Elemental distribution



G1 + G2 flat areas
G3 indentations

Gold alloy composition

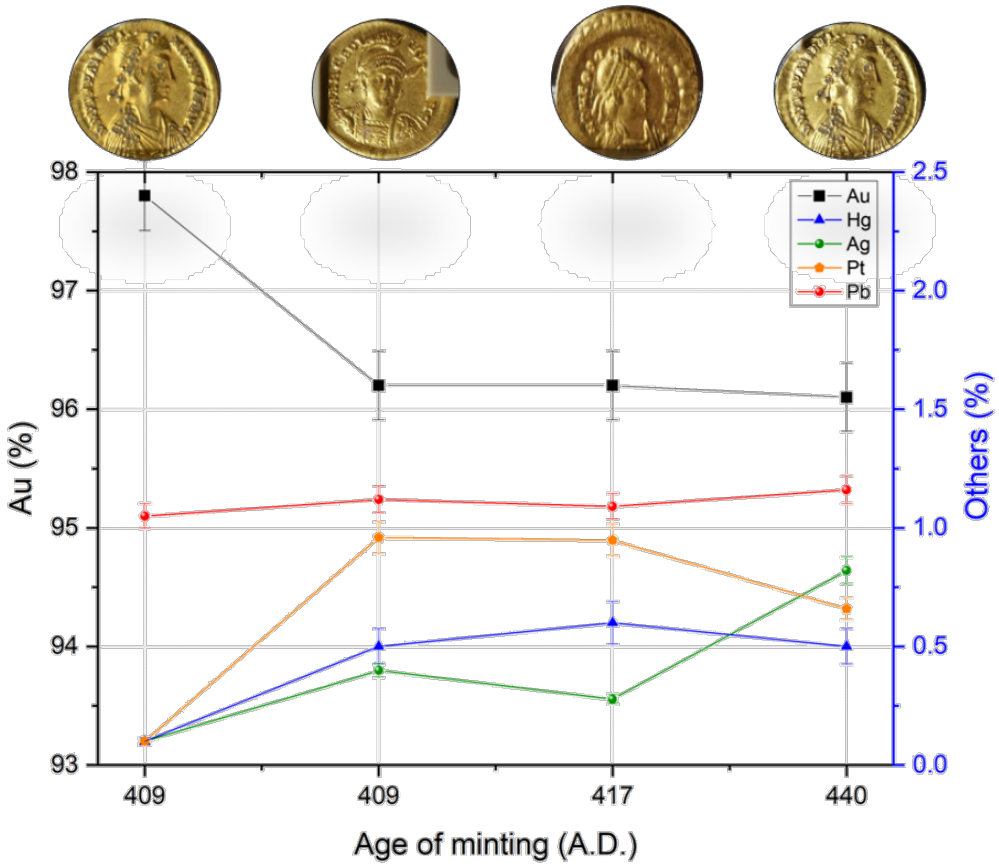




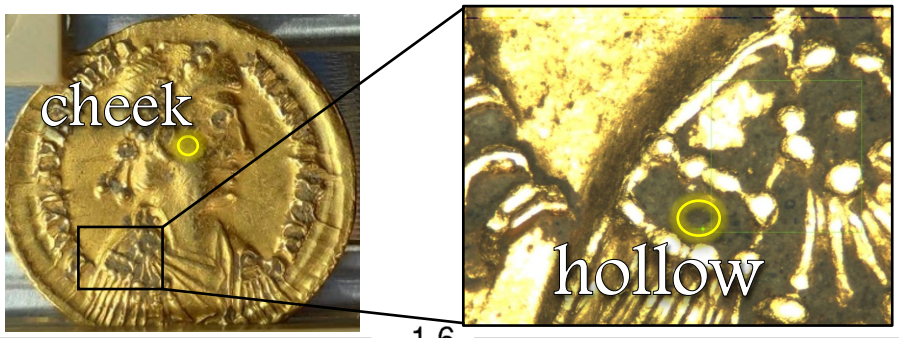
PyMCA

Fit of XRF spectra at 11.6 keV

- Au purity: 96 to 98 %
- Traces of Pb, Ag, Hg, Pt
- Pt concentration suggests different origin of Au source for one of the coins (Pt rare in primary deposits)



Debris analysis



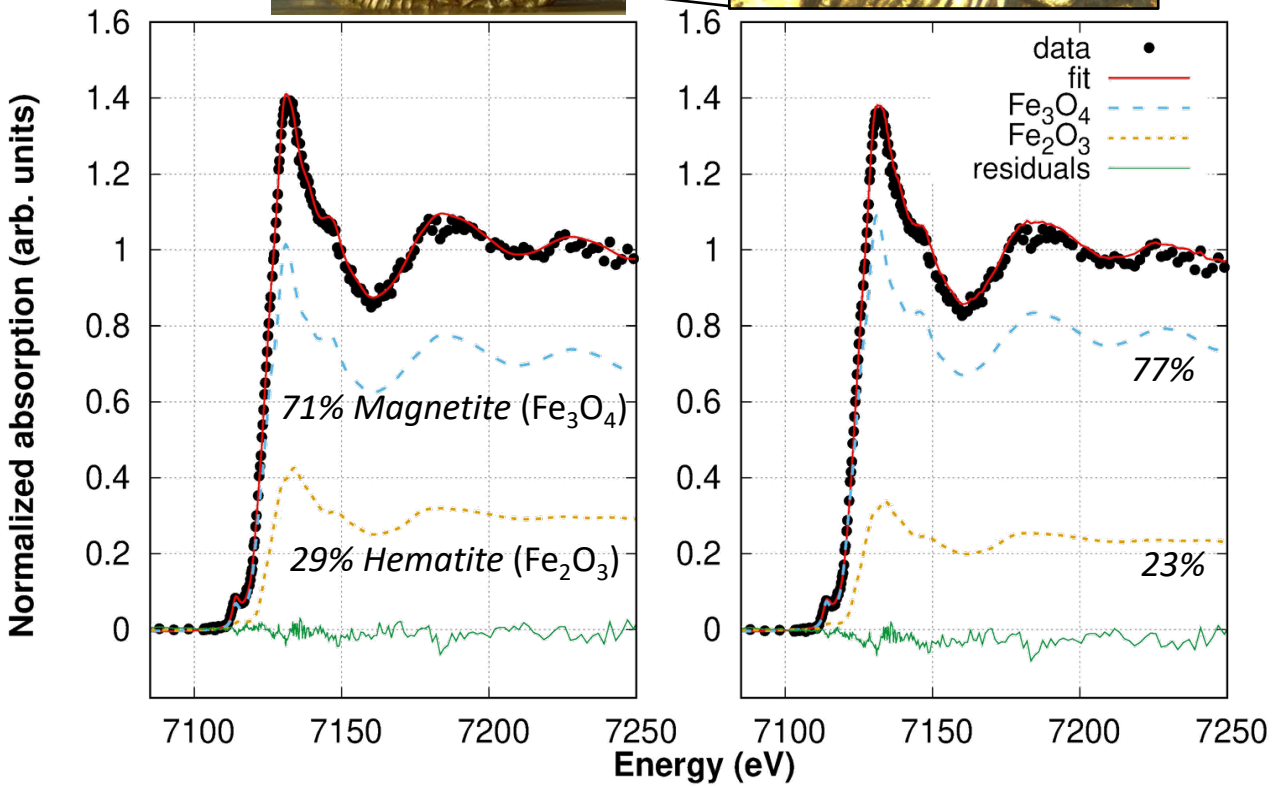
XANES @ Fe K-edge: SOIL IDENTIFICATION

Even (cheek) and hollow areas were studied to analyse the dirt accumulated over time.

Hematite, goethite, and magnetite prevail in tropical and subtropical soils. Hematite favoured by:

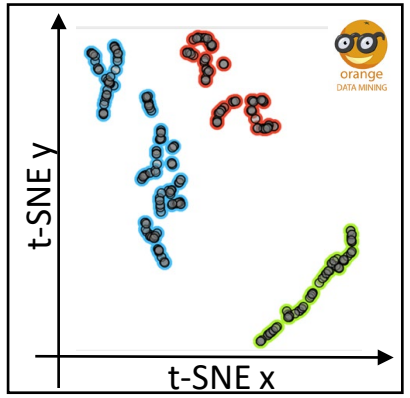
- low organic matter contents
- basic pH of the soil
- **higher temperature or lower water activity**

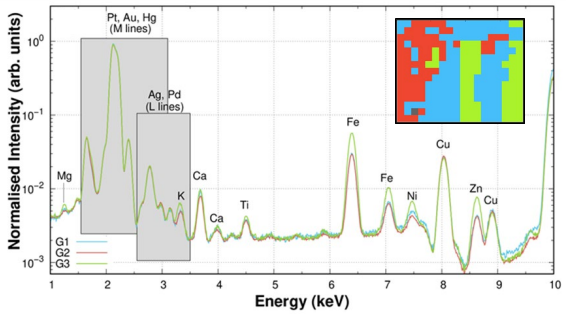
Typical conditions of tropical environments or **well drained soils in temperate regions** (e.g. draining by calcareous gravel)



Conclusions

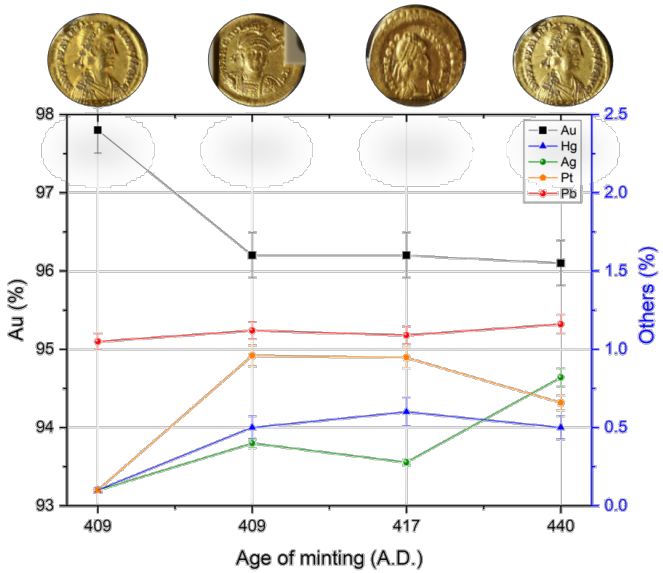
1.





t-SNE: discrimination of gold alloy vs debris

2.

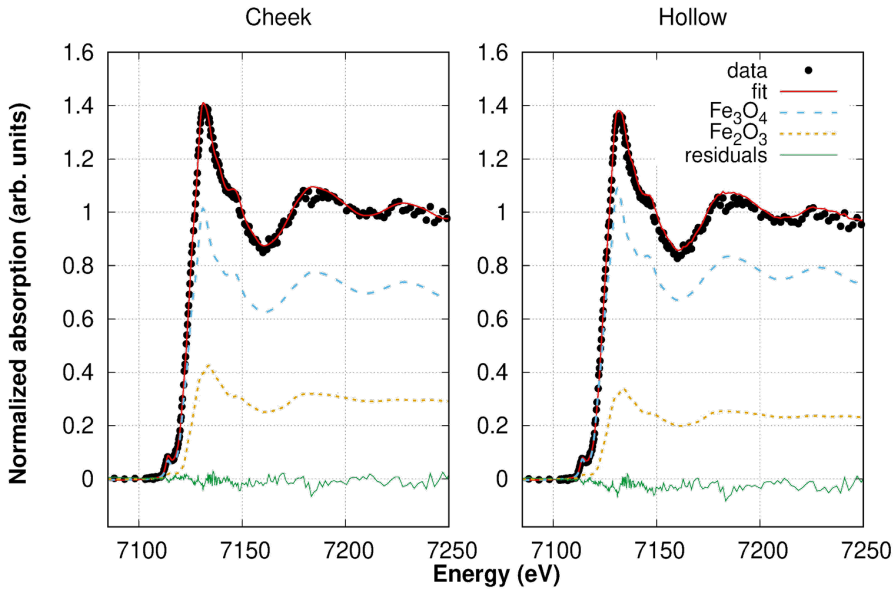


XRF

Au purity assessment

Pt content**:** different Au sources (*primary and secondary deposits)*

3.



XANES

Debris analysis: soil from Mediterranean coasts

Thank you!

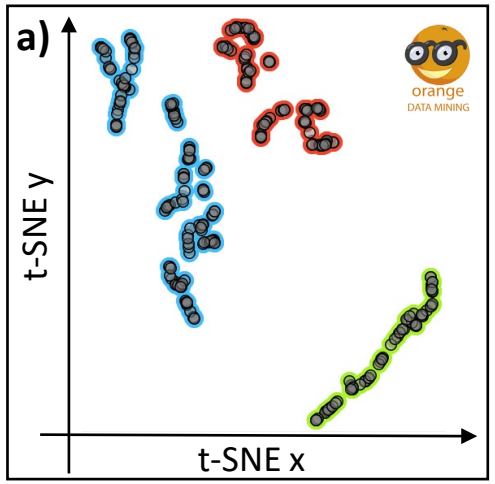
Au provenance

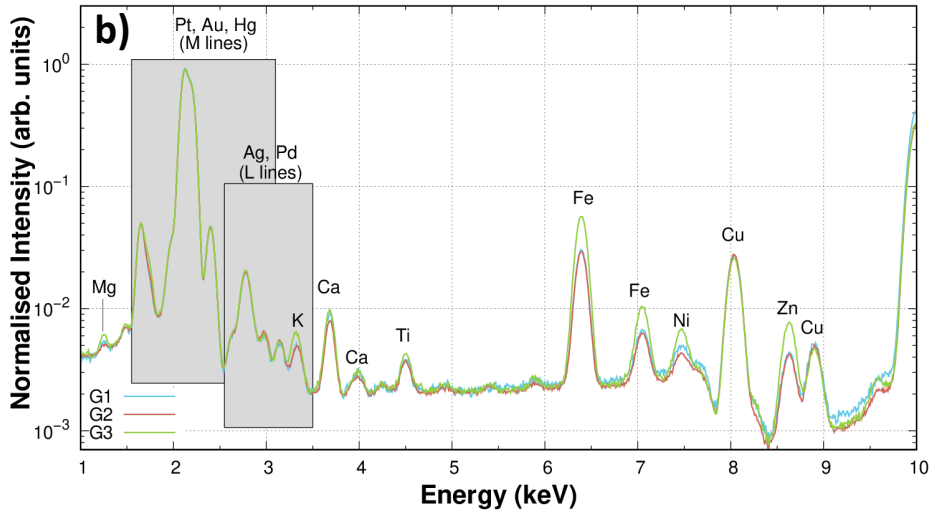
Figure 2.1: Roman Mines in the First Century CE

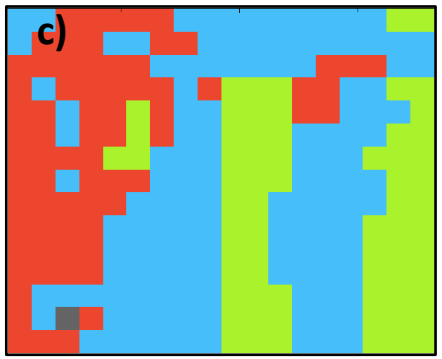
Different rock formations

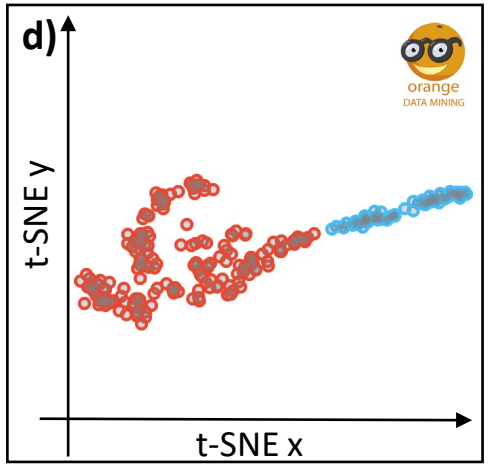
Different impurities in the Au (Pt, Pd)

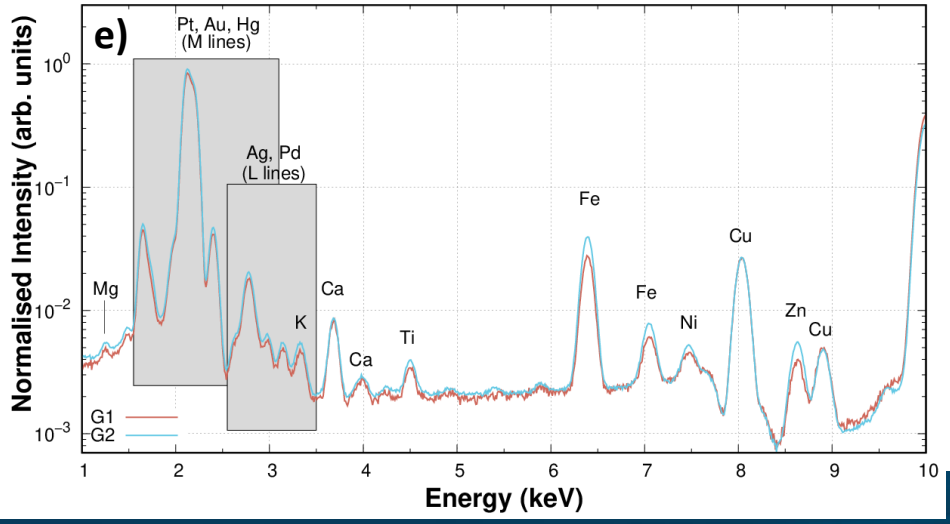
t-SNE analysis

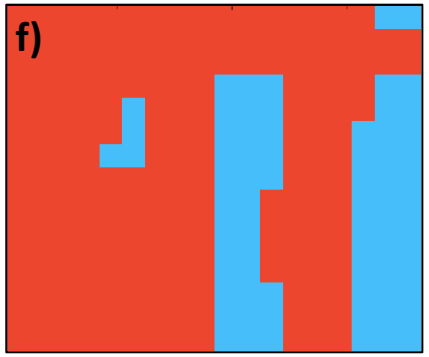




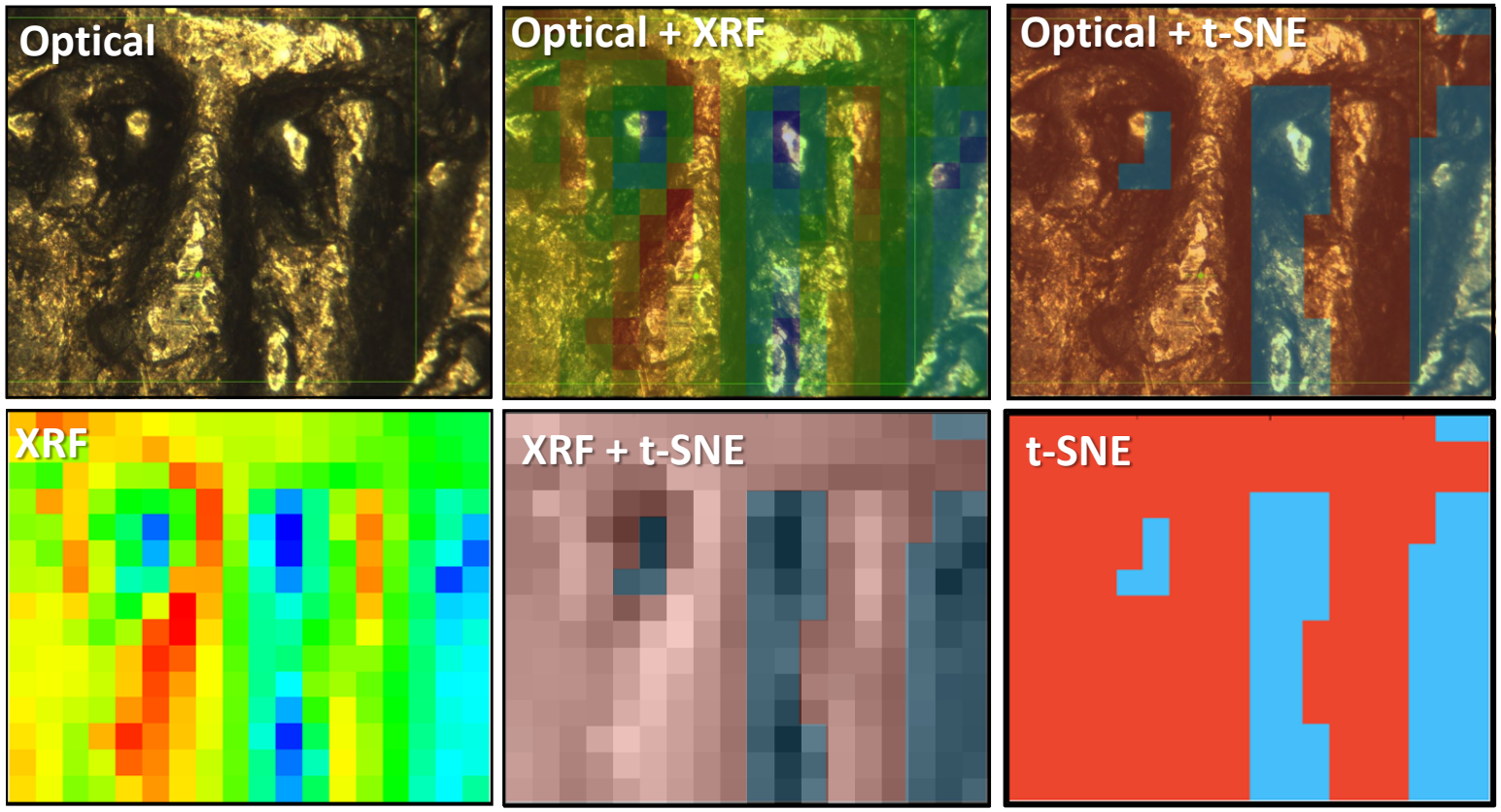








Elemental distribution



G1 flat areas
G2 indentations