



# Classification of mortars from the St. George Cathedral of the Yuryev Monastery (Veliky Novgorod, Russia) based on neutron activation analysis data at the IREN facility (JINR, Russia) and the WWR-K reactor (INP, Kazakhstan)

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- Introduction and objectives
- Neutron Activation Analysis (NAA)
- Statistical methods for classification
- Conclusions



# St. George Cathedral of the Yuryev Monastery

1. The cultural heritage site of global (UNESCO) and federal significance;
2. It was built in the first half of the XII century;
3. One of the few significant cultural sites that survived after the Mongol invasion;
4. It was seriously reconstructed in the 1830s.





# Typical samples of mortars





# Sample features

Number	Source	Approximate dating
1	South-western crypt, foundation plaster	19th century
2	South-western crypt, mortar with crushed bricks from the floor	12th century
3	South-western crypt, mortar with crushed bricks from the wall	12th century
4	South-western crypt, mortar with crushed bricks from the crevice	12th century
5	Plaster and mortar for laying relics on the eastern side of the throne of the northern apse	19th century
6	Addition of Photios on the northern ribbon foundation	19th century
7	North wall of the central apse, mortar with crushed bricks	12th century
8	Pigment for coloring. North arch from below	undefined
9	Chapel above the tower	12th century
10	Excavation XI. Mortar from rubble masonry	undefined
11	Excavation XI. Mortar from Photios' construction	19th century



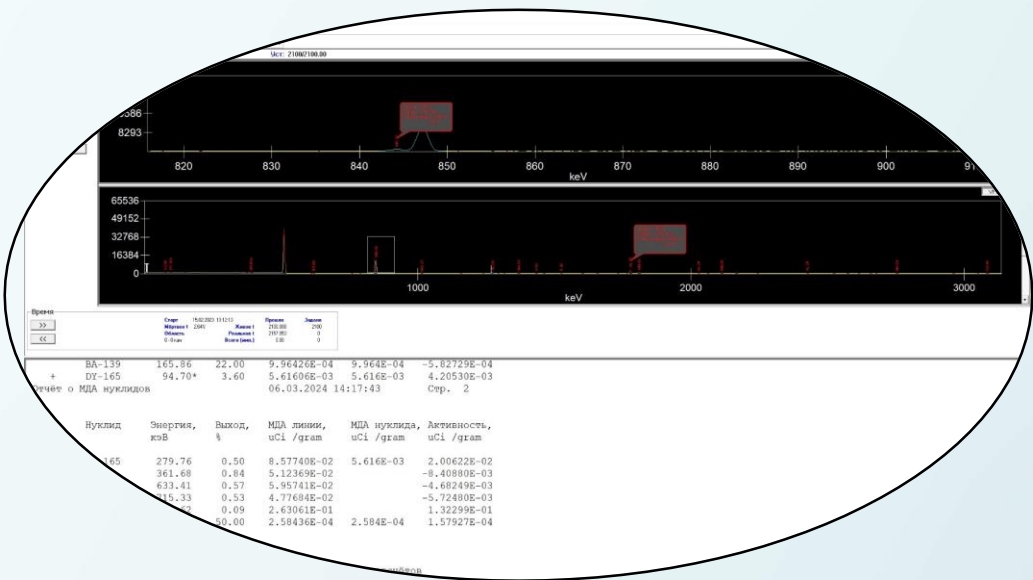
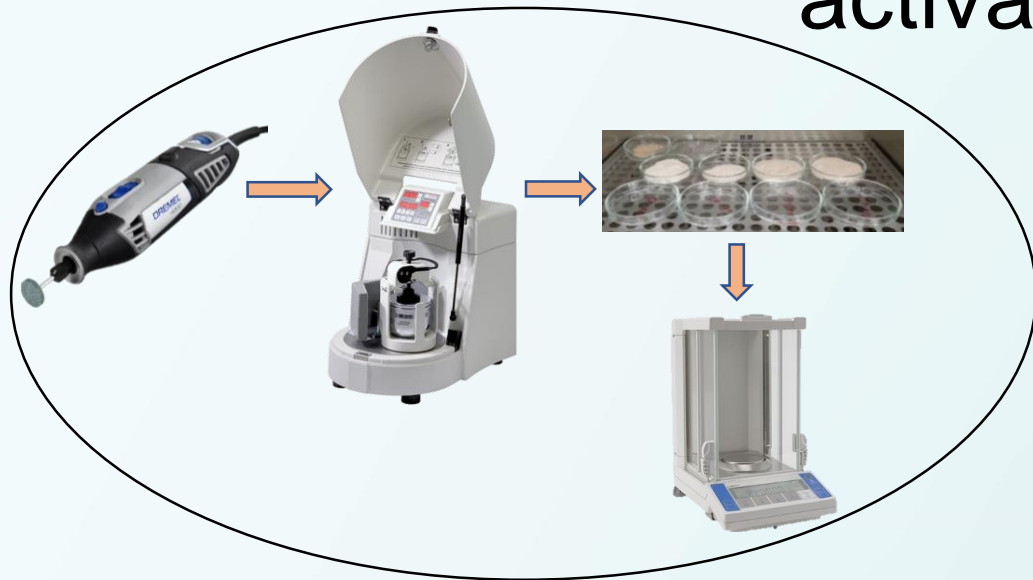
Classification of mortars with unknown date based on the elemental composition



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# Sequence of neutron activation analysis







# Radiation exposure parameters

IREN facility for short-lived  
isotopes:

Neutron flux:

- thermal:  $1.6 \cdot 10^8$  n / cm<sup>2</sup>s;
- resonance:  $2.6 \cdot 10^7$  n / cm<sup>2</sup>s.

Weight of samples:

- 3 grams

Irradiation time:

- 40 minutes

Number of irradiated samples:

- 5

WWR-K reactor “Dry” channel for  
short-lived isotopes:

Neutron flux:

- thermal:  $4.4 \cdot 10^{12}$  n / cm<sup>2</sup>s;
- resonance:  $3.8 \cdot 10^{10}$  n / cm<sup>2</sup>s.

Weight of samples:

- 0.1 grams

Irradiation time:

- 1 minute

Number of irradiated samples:

- 11

WWR-K reactor “Wet” channel for  
long-lived isotopes:

Neutron flux:

- thermal:  $6.6 \cdot 10^{13}$  n / cm<sup>2</sup>s;
- resonance:  $3.0 \cdot 10^{12}$  n / cm<sup>2</sup>s.

Weight of samples:

- 0.1 grams

Irradiation time:

- 90 minutes

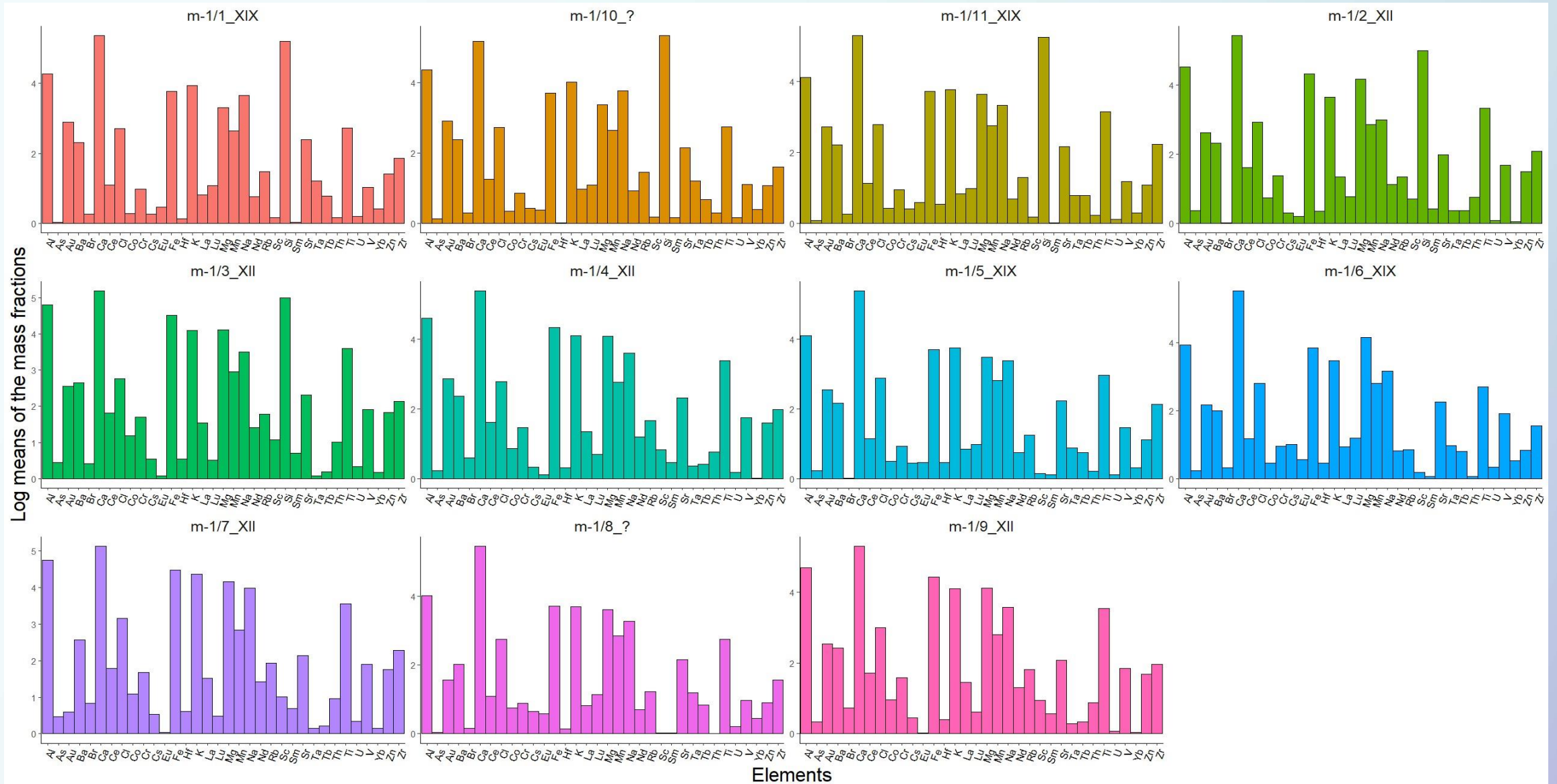
Number of irradiated samples:

- 11





# Mass fractions of elements in samples





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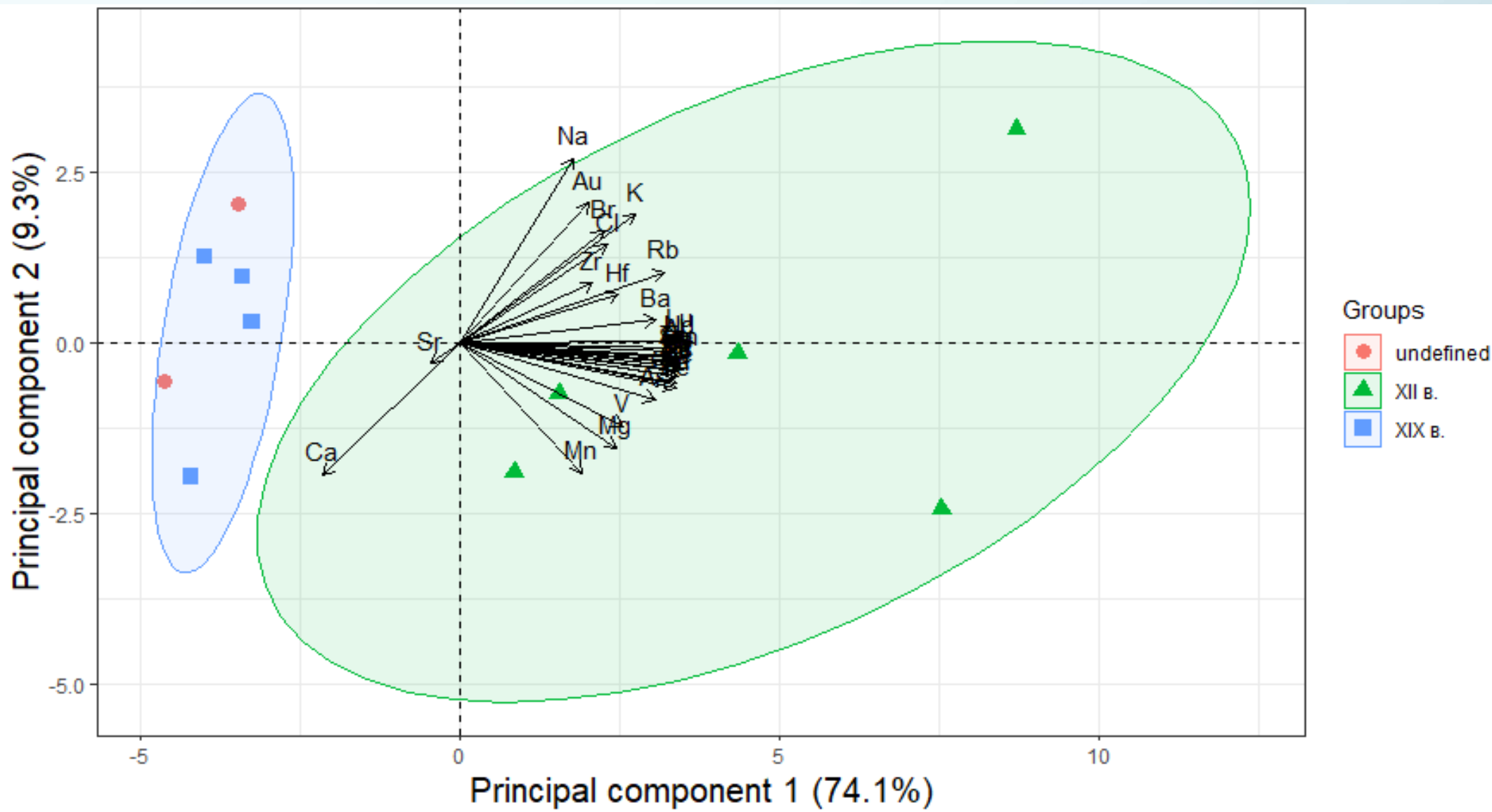


# Methods for sample classification

- Principal component analysis;
- Hierarchical cluster analysis;
- Linear discriminant analysis.

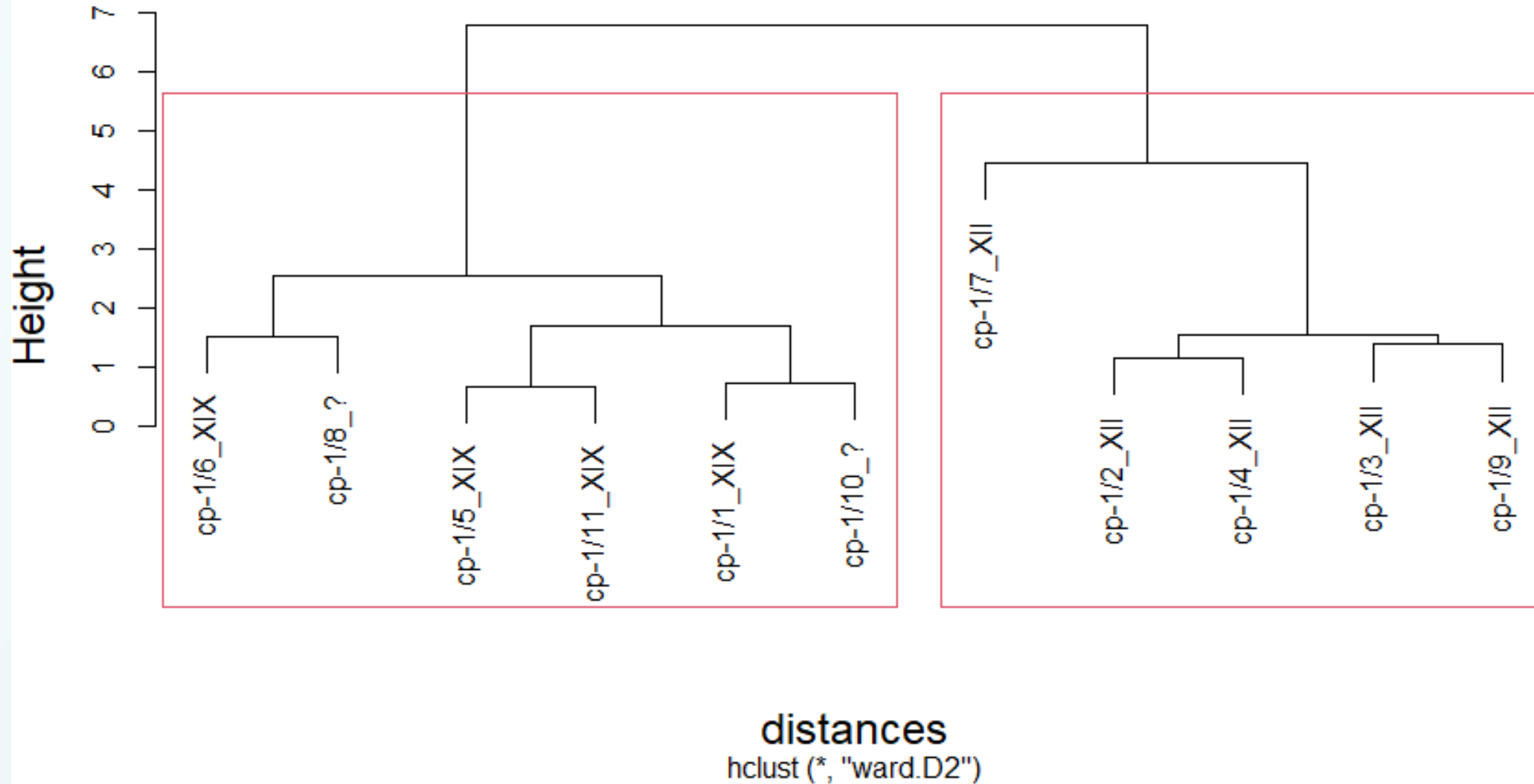


# Principal Components Analysis of all elements



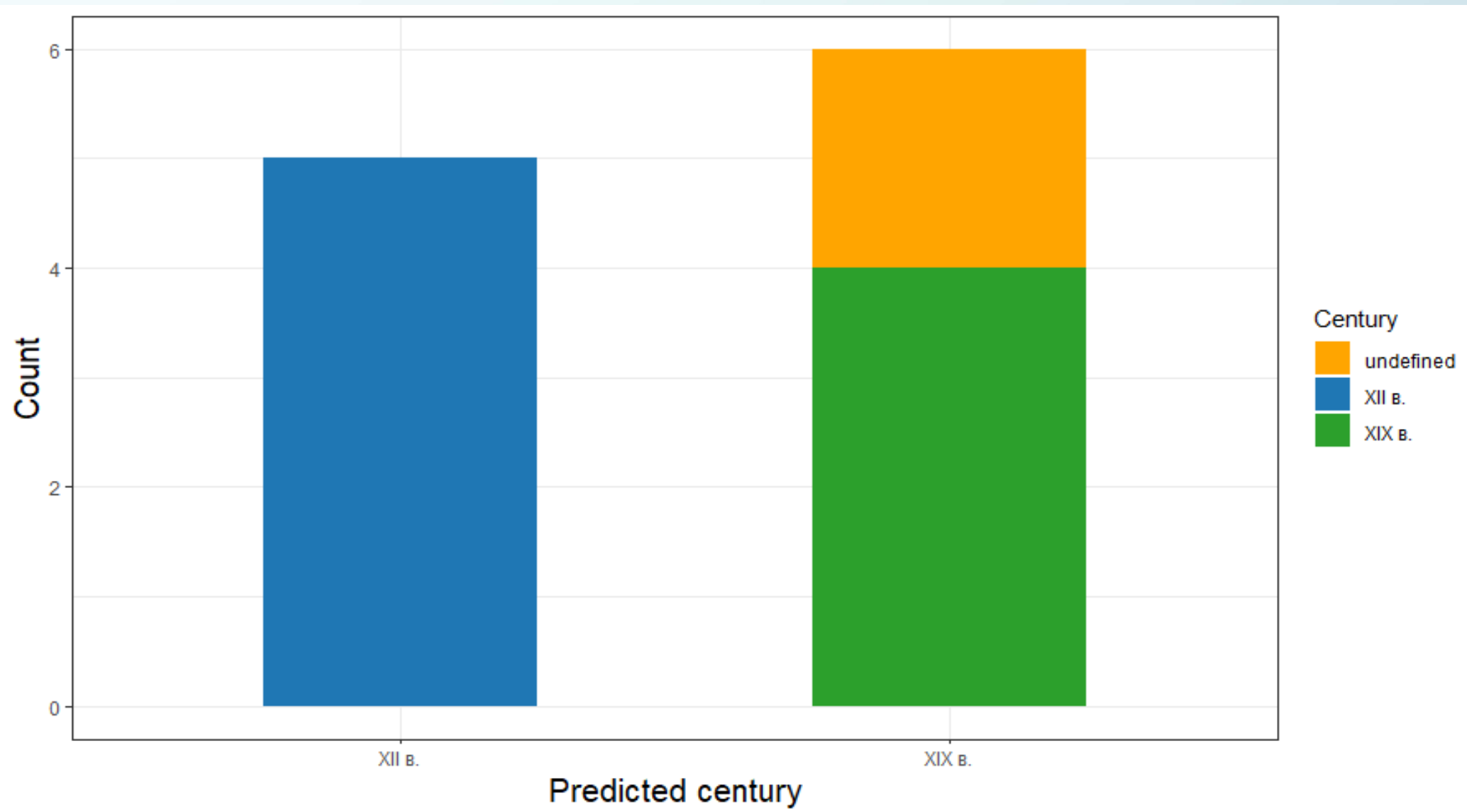


# Cluster Dendrogram of all elements





# Linear Discriminant Analysis of basic oxides







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# Conclusion

- A total of 11 samples of mortars were irradiated;
- Mass fractions of 35 elements were obtained;
- Classification was carried out using three statistical methods;
- A hypothesis are put forward about the date of certain samples.



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**Thank you for your attention!**