

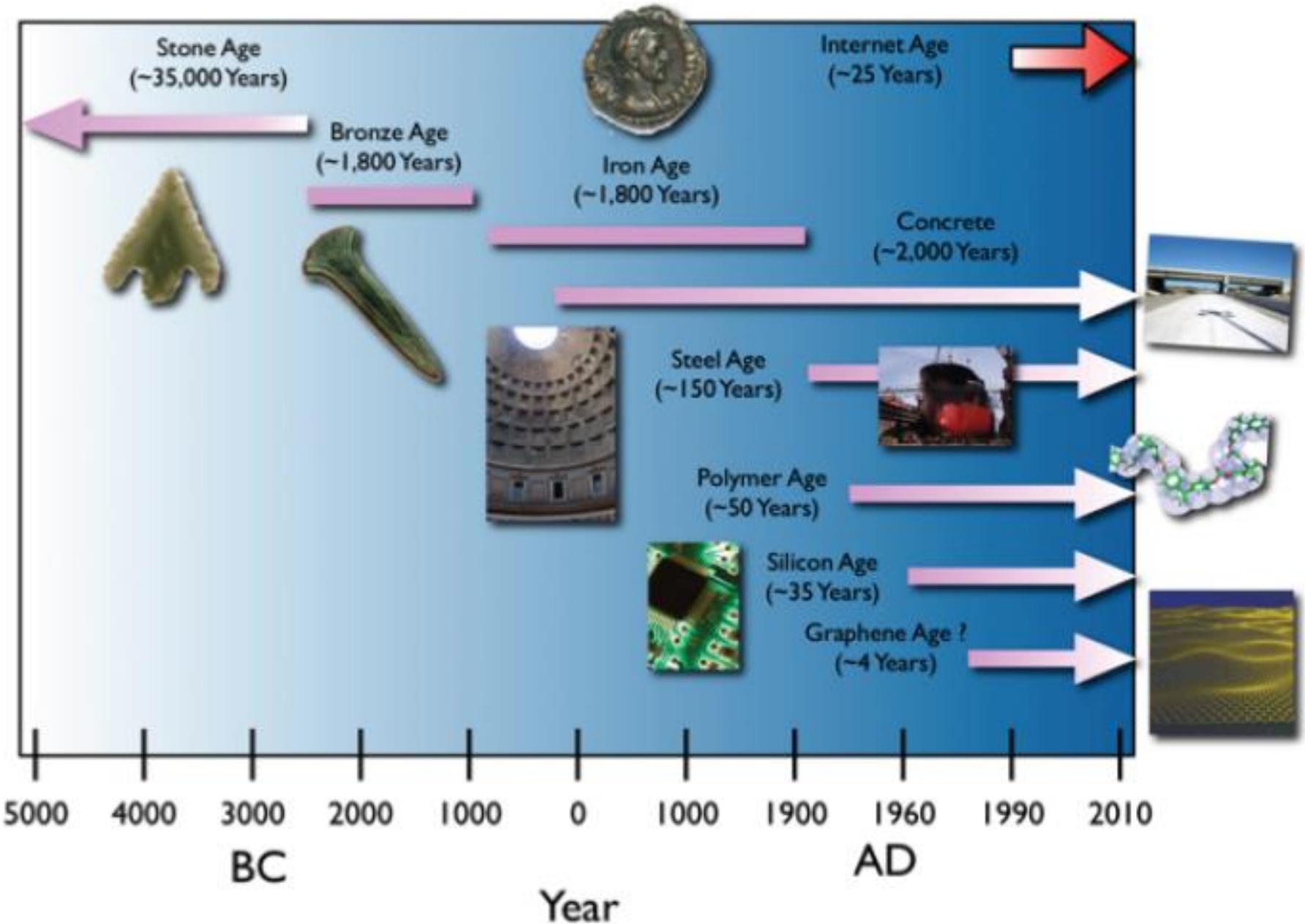
Neutronok a régészettel

Rosta László

MTA Wigner Fizikai Kutatóközpont
Email: rosta.laszlo@wigner.mta.hu

ELFT Vándorgyűlés, Debrecen, 2013. augusztus 22.¹

Az emberiség által használt és ismert anyagok



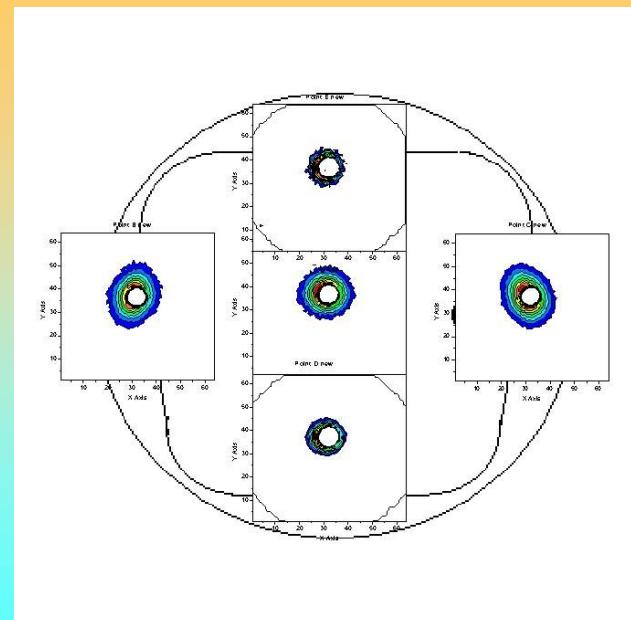
Miért fontosak a neutronok a tudománynak és technológiának

A neutronok fontos szerkezeti, analitikai és topológiai információval szolgálnak az anyagok belsőjéről, tulajdonságairól



Kisszögű neutronszórással a dugattyú különböző pontjain a nanoszerkezeti elváltozásokból (ötvöző elemek kiválása) a mikrorepedések kiidulási gócaira kaptunk információt.

M. Rogante, F. Nicolae, E. Rétfalvi, L.Rosta, Physica. B 358, 224 (2005)



Táguló határok

Soft

*multidisciplinary
condensed matter science*

1990

1980

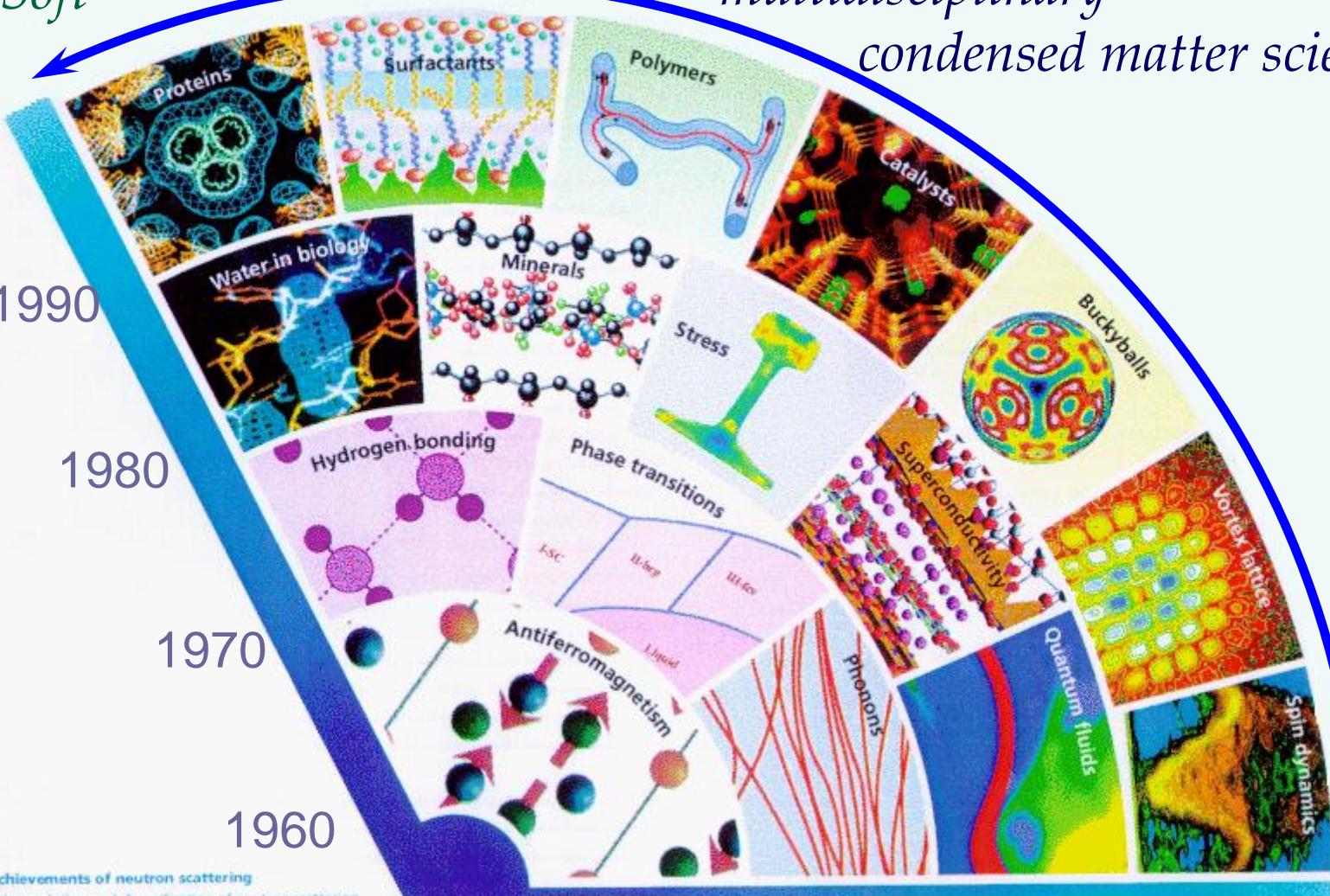
1970

1960

Hard

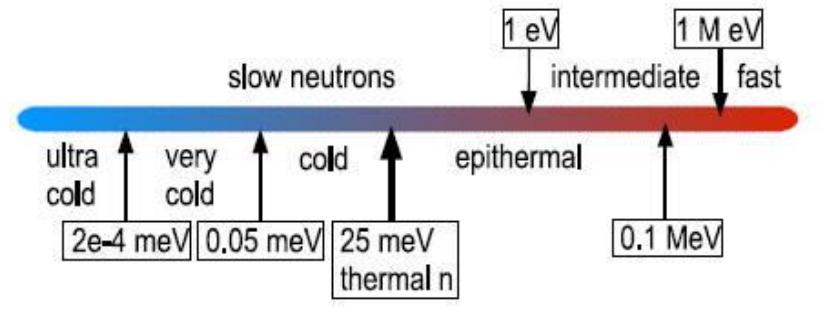
Achievements of neutron scattering

- the evolution and diversification of neutron scattering over the past 40 years



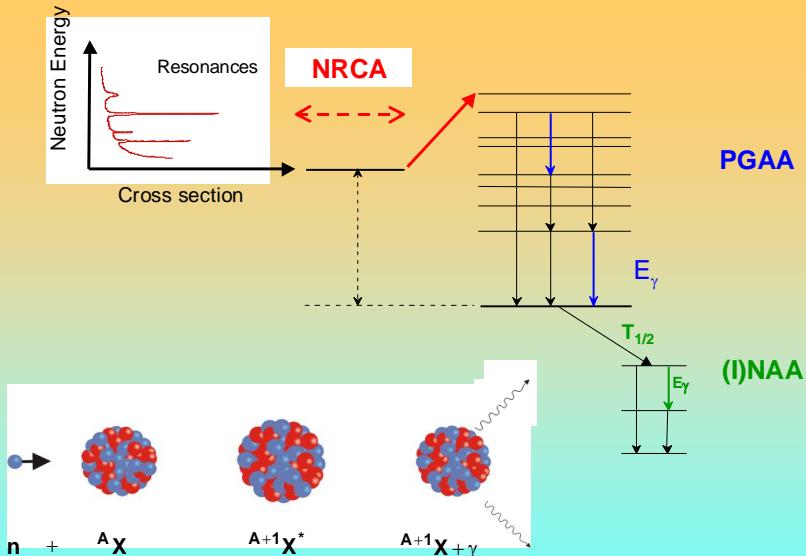
Neutron

- Mass: $m=939 \text{ MeV}/c^2$
- Electric charge: $Q=0$
- Magnetic momentum: $\mu=-1,9 \mu_N$; Spin: $1/2$



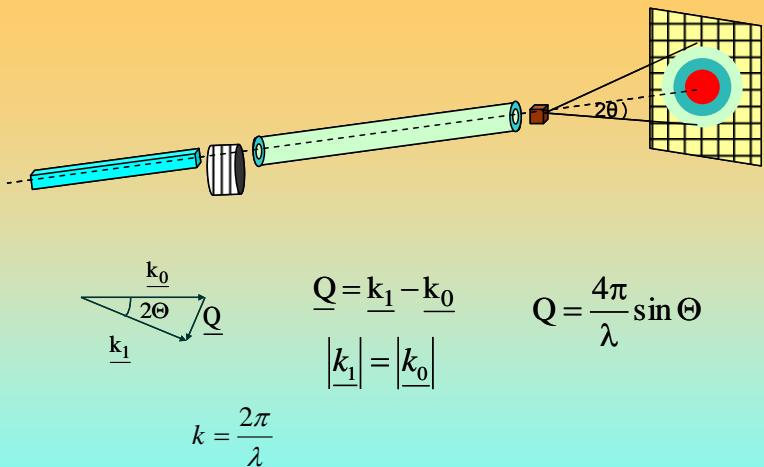
INTERACTIONS WITH MATTER

Radiative capture – (n,γ) reaction



Composition: NRCA, PGAA, INAA

Scattering (elastic or inelastic)



Structure: SANS, TOF-ND

NEUTRONS FULFILL THE REQUIREMENT OF NON-DESTRUCTIVITY!

- As an electrically neutral particle, it can go deep into the sample
- Large objects can be placed in external beams – without sampling
- Induced radioactivity decays fast in most cases

TYPICAL TASKS IN ARCHAEOOMETRY

- Provenance study – identification of raw material source(s) or workshop(s)
- Identification of fakes or imitations
- Survey of the art objects' condition prior to restoration or conservation
- Dating - indirectly

Research Infrastructure offered for C-ERIC

Budapest Research Reactor



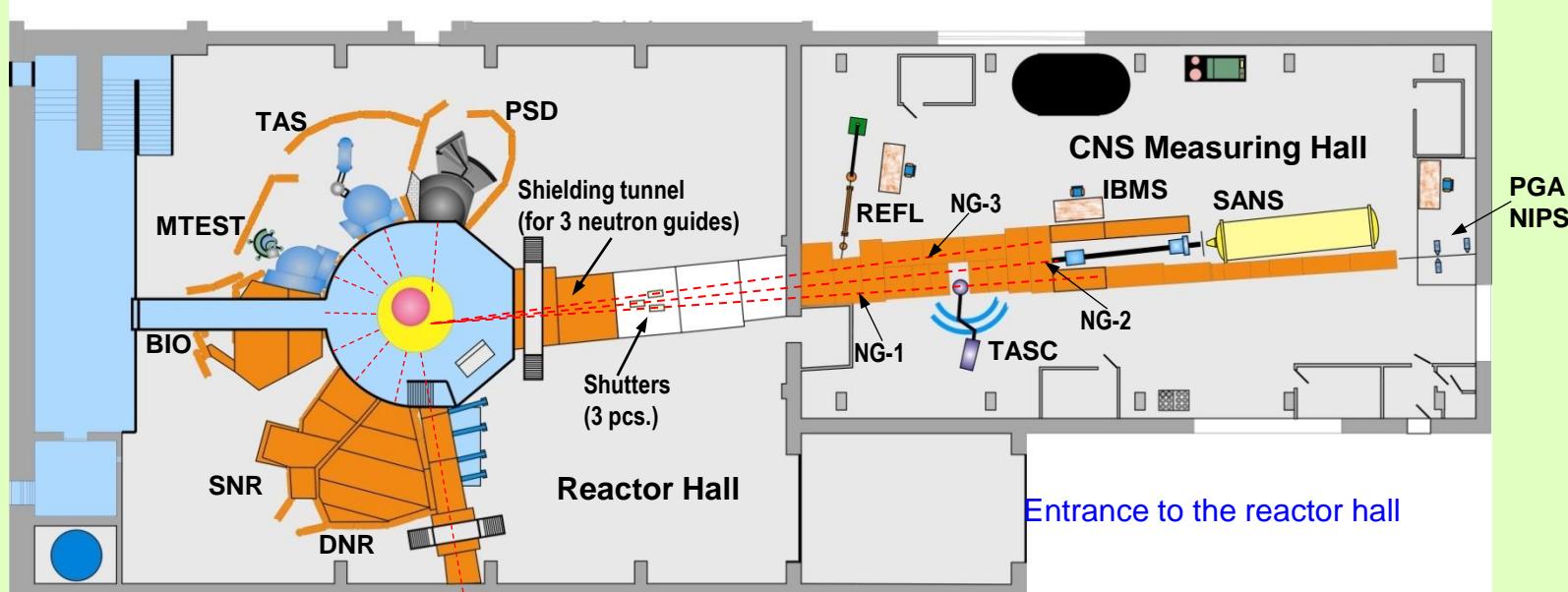
banffy.eszter@mtk.mta.hu

Tank-type
reactor,
moderated and
cooled by light
water

Power: 10 MW

Thermal neutron
flux:
 $2.5 \times 10^{14} \text{ n/cm}^2\text{s}$

A BKR vízszintes neutron-nyaláb berendezései



TOF – Time of flight spectrometer
(under construction)

DNR – Dynamic neutron radiography

SNR – Static neutron radiography

BIO – Port used for biological experiments

MTEST – Material testing diffractometer

TAS – Triple axis spectrometer

PSD – Powder diffractometer

Cold neutron instruments:

REFL – Reflectometer

TASC - TAS – Triple axis spectrometer on CNS

SANS – Small-angle scattering spectrometer

PGAA – Prompt gamma activation analysis

NIPS – Neutron-induced prompt gamma-ray spectrometer

IBMS – In-beam Mössbauer spectrometer
(under construction)

Archaeometry applications at BNC



2000-2003



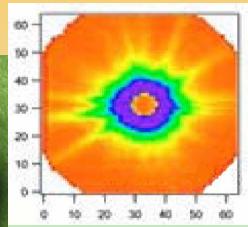
2004-2008



2009-2013



PGAA



TOF-ND



SANS



RADIOGRAPHY

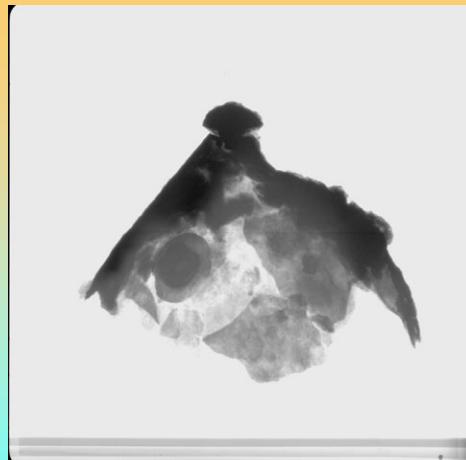


Highlight 2008

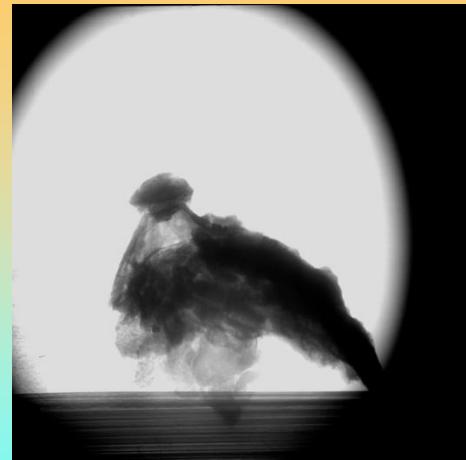
Radiography Inspection of an Archeological Object



Photo of the helmet



X-ray radiography picture (button part)

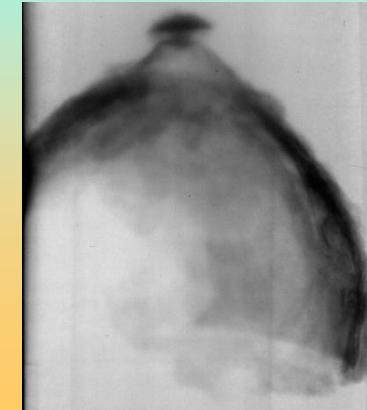


Thermal neutron radiography picture (button part)

The structure of the helmet (from IV. century B.C.) was studied by

- Gamma radiography,
- Thermal neutron radiography,
- Epithermal neutron radiography,
- X-ray radiography.

The inner structure and the hidden decorations of the helmet are shown by the different radiations.



Gamma radiography picture



Epithermal neutron radiography picture

PROMPT GAMMA AKTIVATION ANALYSIS – PGAA

Applicable:

- Bulk composition of any (solid, liquid) sample
- Minimum sample mass ~ 0,1 g
- In principle all chemical elements
Very sensitive: **H, B, Cl, Cd, Nd, Sm, Eu, Gd**
- Detection Limits 0,1 ppm – 1000 ppm



Advantages:

- Non-destructive
- Minimal sample preparation
- Average for the total irradiated volume
- Parts of large objects can be studied
(beam size: 5 mm² – 2X2 cm²)



PGAA – Prompt Gamma Activation Analysis

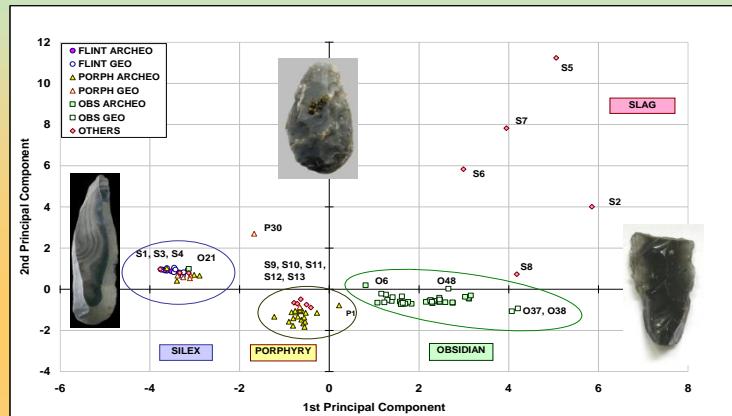


PGAA facility is built on the external cold neutron beam of $10^8 \text{ cm}^{-2} \text{s}^{-1}$
The beam size can vary between
 5mm^2 - 400mm^2

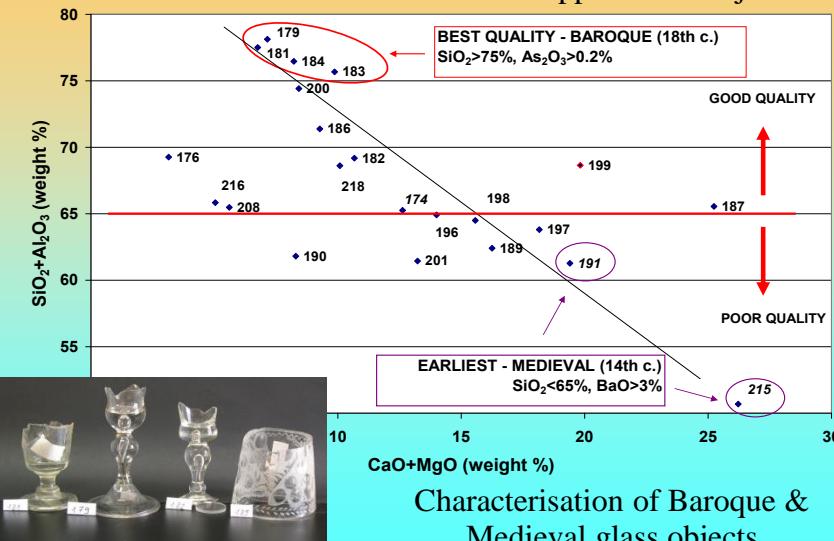
- ✓ Non-destructive nuclear method for determination of bulk elemental composition.
- ✓ Elemental identification is based on the (n, γ) reaction
- ✓ All chemical elements can be measured, with the LOD of 0.1ppm-1000ppm
- ✓ PGAA is extremely sensitive for **H, B, Cl, Cd, Nd, Sm, Eu and Gd.**
- ✓ Spectrum analysis is done by HYPERNET-PC software, using our PGAA library



<http://www.bnc.hu>
contact: Zsolt KASZTOVSZKY
kzsolt@iki.kfki.hu



Characterisation of Prehistoric chipped stone objects



Characterisation of Baroque & Medieval glass objects

APPROXIMATE DETECTION LIMITS FOR THE BUDAPEST PGAA

		Element																																	
		stable isotope							Detection Limit ppm]																										
		atomic weight			σ - capture				σ - scattering			0.01-1																							
												1-10																							
												10-100																							
												100-1000																							
												>1000																							
												no data																							
	H	1	1.00794 0.33261 82.02 b													He	³ 0.00014 ₄ 4.002602 0.007 b 1.34 b																		
Li	6 ⁷ 7 ⁸ 9 ^{2.5} 6.941 70.5 b 1.37 b	Be	9 9.0122 0.0076 b 7.63 b													Ne	²⁰ 9 ¹ 21 ^{0.26} 22 ⁹ 20.1797 0.039 b 2.628 b																		
Na	23 22.98977 0.530 b 3.26 b	Mg	24 ²⁵ 25 ¹⁰ 26 24.305 0.063 b 3.71 b													Ar	³⁶ 38 40 ^{9.8} 39.948 0.675 b 0.683 b																		
K	39 ⁴⁰ 41 ¹ 39.0983 0.1 b 1.96 b	Ca	40 ⁴⁷ 42 ⁴³ 44 46.48 40.078 23.5 b	Sc	45 44.9559 46 ⁴⁷ 47 ⁷ 48 ⁷⁴ 48 ⁹ 50 ⁵	Ti	50 ⁵² 51 ¹ 50.9415 5.08 b 5.10 b 3.05 b 3.49 b	V	50 ⁵² 51 ¹ 50.9961 5.08 b 5.10 b 2.15b	Mn	55 54.9380 55.845 54.66 b 54.66 b 11.62 b	Fe	54 ⁵⁶ 57 ² 58 58.9332 37.18 b 4.49 b 5.6 b	Co	59 58 ⁶⁰ 60 ¹⁶ 61 ¹ 62 ¹⁶ 64 ^{8.8} 58.6934 37.18 b 4.49 b 18.5 b	Ni	58 ⁶⁰ 60 ¹⁶ 61 ¹ 62 ¹⁶ 64 ^{8.8} 58.6934 37.18 b 4.49 b 18.5 b	Cu	63 ⁶⁵ 65 ¹ 63.546 3.78 b 2.75 b 8.03 b	Zn	64 ⁶⁶ 66 ²⁸ 67 ⁴ 65.39 2.75 b 6.38 b	Ga	69 ⁷⁰ 71 ⁴⁰ 69.723 2.20 b 8.60 b	Ge	70 ⁷⁰ 72 ²⁷ 73 ⁸ 74 ³⁷ 76 ⁵ 72.61	As	75 74.9216 4.5 b 5.50 b	Se	76 ⁷⁶ 77 ⁸ 78 ²⁴ 78.96 11.7 b 8.30 b	Br	79 ⁸¹ 81 ⁴⁹ 79.904 6.9 b 5.90 b	Kr	78 ⁸⁰ 82 ¹² 83 ¹² 84 ⁸⁴ 86 ¹⁷ 83.8 25 b 7.68 b		
Rb	85 ⁷² 87 ²⁸ 85.4678 0.38 b 6.8 b	Sr	84 ⁸⁶ 10 ⁸⁷ 88 ⁸³ 87.62 1.28 b 6.25 b	Y	89 90 ⁵² 91 ¹¹ 92 ¹⁷ 94 ¹⁷ 96 ³	Zr	90 ⁹¹ 94 ⁵ 95 ¹⁶ 97 ¹⁰ 98 ²⁴ 99 ¹⁰	Nb	93 92.90638 1.15 b 6.255 b	(Tc)	(98) 96 ¹⁹ 98 ² 99 ¹³ 100 101 ¹⁷ 102 ³² 104	Ru	103 101.07 20 b 6.3 b	Rh	103 102 ¹¹ 104 ¹¹ 105 ²² 102.9055 104.48 b 4.6 b	Pd	107 ¹⁰² 109 ⁴⁸ 106 ¹⁰² 108 ²⁷ 110 ¹² 106.42 6.8 b 4.48 b	Aq	106 ¹⁰⁸ 110 ¹¹¹ 112 ¹¹³ 114 ¹¹⁶ 112.411	Cd	113 ⁴ 115 ³⁶ 114.818 6.5 b	In	113 ⁴ 115 ³⁶ 114.818 6.5 b	Sn	112 ¹¹⁴ 115 ¹¹⁸ 117 ¹¹⁶ 119 ¹¹⁹ 120 ¹²² 128 ¹³⁰ 118.71	Sb	121 ⁵⁷ 123 ⁴³ 121.76 4.91 b 3.90 b	Te	120 ¹²² 123 ¹²⁴ 125 ¹²⁶ 128 ¹³⁰ 127.6 4.32 b	I	127 126.90447 6.15 b 3.81 b	Xe	124 ¹²⁶ 128 ¹²⁹ 130 ¹³¹ 132 ¹³² 134 ¹³⁶ 131.29 23.9 b -		
Cs	133 132.90545 29.0 b 3.90 b	Ba	130 132 134 35 136 137 138 37 137.327 1.1 b 3.38 b	La	138 139 ⁹⁹ 138.9055 8.97 b 9.66 b	Hf	174 176 ⁵ 177 ¹⁰ 178 ²¹ 179 ¹⁴	Ta	180 181 ⁹⁹ 180.9497 20.6 b 6.01 b	W	180 182 ²⁶ 183 ¹⁴ 184 ³¹ 186 ²⁹	Re	185 ³⁷ 187 ⁶³ 184 188 187 ¹⁹ 192 ²¹	Os	184 188 187 ¹⁹ 188 ¹⁴ 189 ¹⁹ 190 ¹ 192 ²¹	Ir	191 ³⁷ 193 ⁶³ 190 192 ¹ 194 ¹¹ 192 ²¹	Pt	190 192 ¹ 194 ¹¹ 195 ³⁴ 196 ²⁵ 195 ¹	Au	197 196 198 ¹⁹⁹ 200 ²⁰¹ 202 ²⁰² 204	Hg	196 198 ¹⁹⁹ 200.59 372.3 b 26.8 b	Tl	203 ³⁰ 205 ⁷⁰ 204.3833 3.43 b 9.89 b	Pb	204 ¹ 206 ²⁴ 207 ²² 208 ⁵² 207.2	Bi	209 208.98038 0.0338 b 9.156 b	(Po)	(209)	(At)	(210)	(Rn)	(222)
(Fr)	(223)	(Ra)	(226)	(Ac)	(227)	104	105	106																											
	-		-			12.8 b 13 b																													

Ce	136 138 140 ⁸⁹ 142 ¹¹ 140.915 0.63 b 2.94b	Pr	141 140.90765 11.5 b 2.66 b	Nd	142 ¹⁴³ 144 ¹⁴ 146 ¹⁴⁸ 150 ¹ 144.24 51 b	(Pm)	(145) 168.4 b 21.3 b	Sm	144 ¹⁴⁵ 146 ¹⁴ 151 ¹⁵² 154 ¹ 150.36 92.2 b	Eu	151 ¹⁵² 153 ⁵ 152.153 ⁵ 151.965 9.2 b	Gd	152 154 155 ¹ 157 ¹⁵⁸ 160 ¹ 157.25 97.0 b	Tb	159 158.92534 23.4 b 6.84 b	Dy	165 162 163 ¹⁶⁴ 162.5 99.6 b 90.3 b	Ho	165 164 ² 166 ³³ 167 ²³ 168 ⁴⁷ 170 ¹⁵ 8.7 b	Er	169 164 165 166 ³³ 167 ²³ 168 ⁴⁷ 173.04 167.26 159 b 6.38 b	Tm	169 168 170 171 ¹⁷² 173 ¹⁷⁴ 176 ¹ 173.04 100 b 6.38 b	Yb	168 170 171 ¹⁷² 173 ¹⁷⁴ 176 ¹ 173.04 34.8 b 23.4 b	Lu	175 ⁹⁷ 176 ³ 174 976 7.2 b
Th	232 232.03805 7.37 b 13.36 b	(Pa)	(231) 200.6 b 10.5 b	U	235 ⁹⁷² 238 ⁹⁹ 238.0289 7.57 b 8.9 b	(Np)	(239) 175.9 b 14.5 b	(Pu)	(244) 1017.3 b 7.7 b	(Am)	(243) -	(Cm)	(247) -	(Bk)	(247) -	(Cf)	(251) -	(Es)	(252) -	(Fm)	(257) -	(Md)	(258) -	(No)	(259) -	(Lr)	(261) -

TIME OF FLIGHT NEUTRON DIFFRACTION – TOF-ND



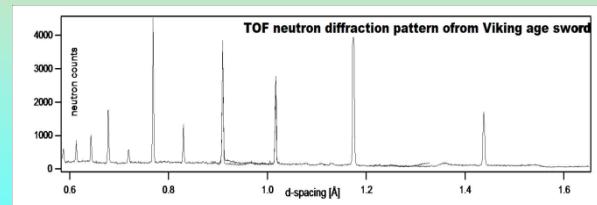
Applicable:

- To study monocrystal or polycrystal structure
- Strain analysis
- Texture analysis
- To identify phases



Advantages:

- Non-destructive
- Minimal sample preparation
- Average for the total irradiated volume
- Parts of large objects can be studied
(beam size: $3 \text{ cm}^2 - 2,5 \times 10 \text{ cm}^2$)

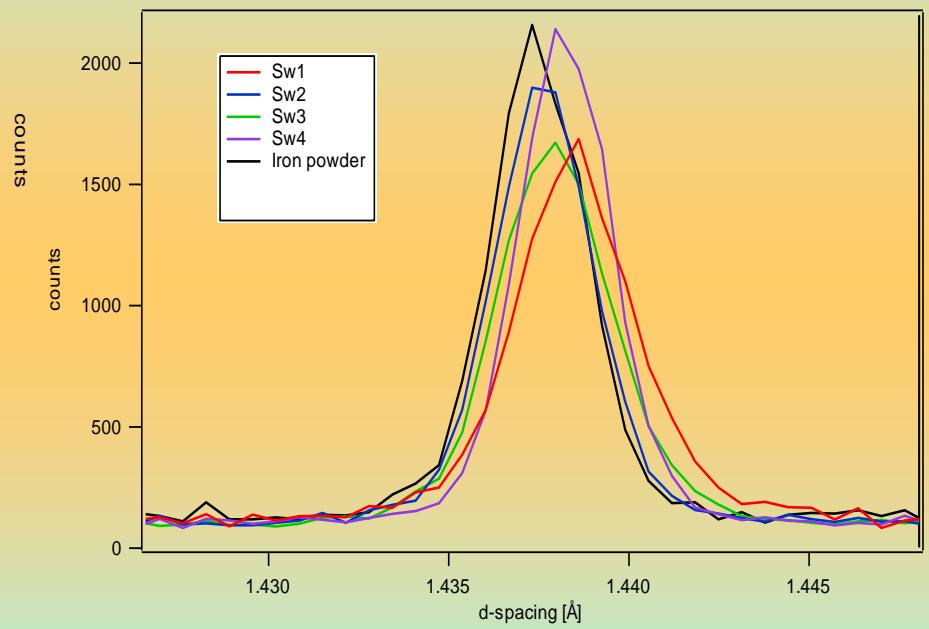
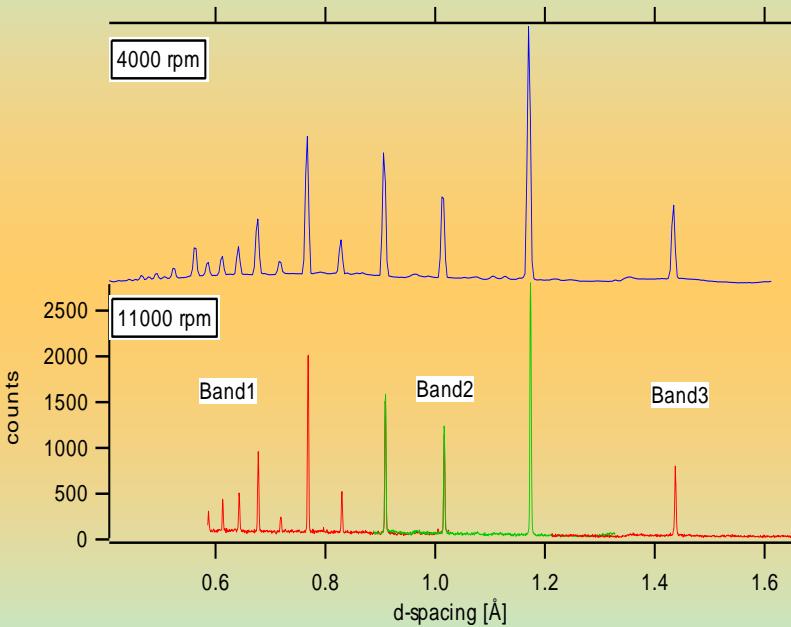


The secret of Viking arms

Four – believed – medieval swords had been studied.

Sword1 strongly corroded but together with **Sword2** were visibly Damascus blades, certificated archeological objects. **Sword3** and **Sword4** were in good state but not certificated.

High resolution TOF diffraction: 150 spectra

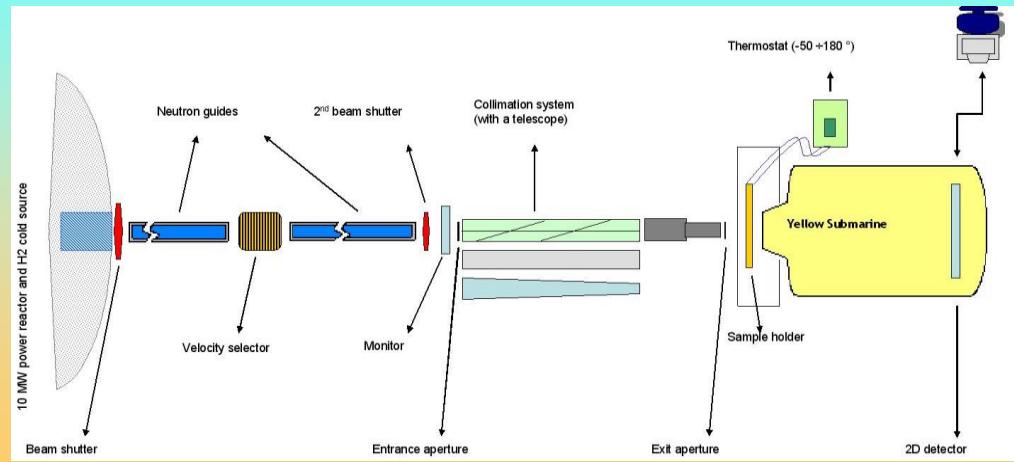


- Phase composition. (For steel phases as ferrite, cementite, martensite and non-steel phases).
- The degree of alloying of the main phase.
- The total carbon content (using the two previous information)
- Texture analyses (preferred orientations of the crystallites).
- Average internal stress and dislocation density.

Some conclusions:

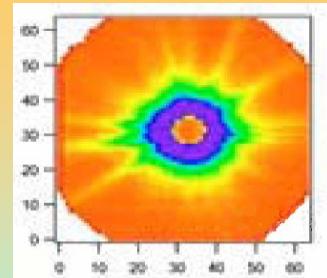
- Important and equal cementite content
- Inhomogeneous precipitate distribut.
- The tensile strength was nearly same
- *Except for 1 sword - decorated*

SMALL ANGLE NEUTRON SCATTERING – SANS



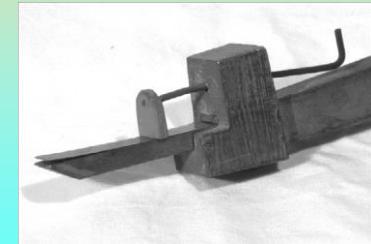
Applicable:

- To study inhomogeneities 1-100 nm scale
- To determine pore size
- To study anisotropy, precipitates in metals or in minerals
- To study inhomogeneities, porosity in ceramics, stones

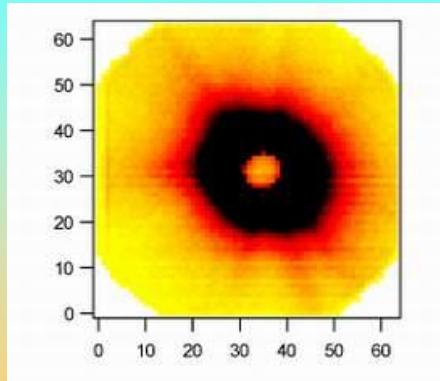


Advantages:

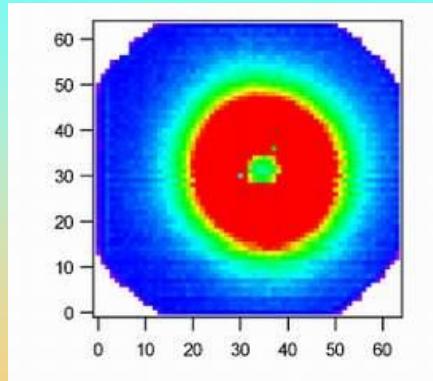
- Non-destructive
- Minimal sample preparation
- Average for the total irradiated volume
- Parts of large objects can be studied
(beam size: mm² – 4X4 cm²)



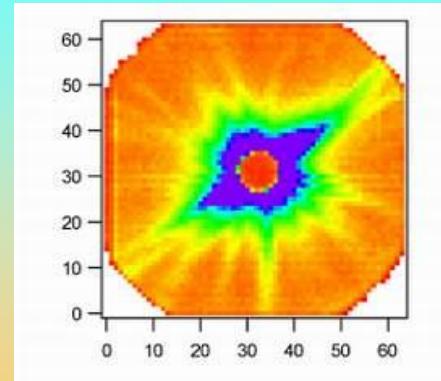
Marble samples from different mines



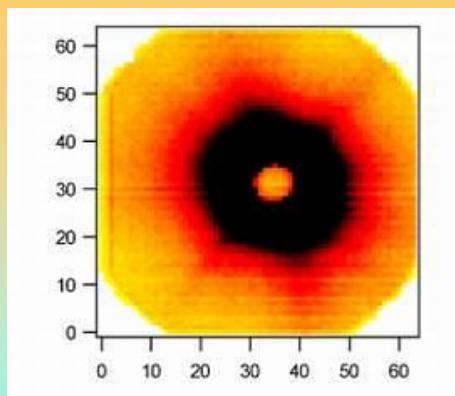
Rimski 2,
Hungary



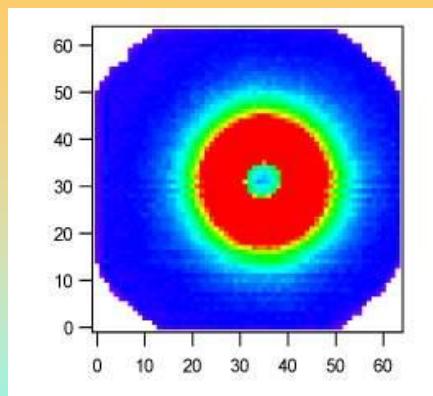
PK1,
Slovenia



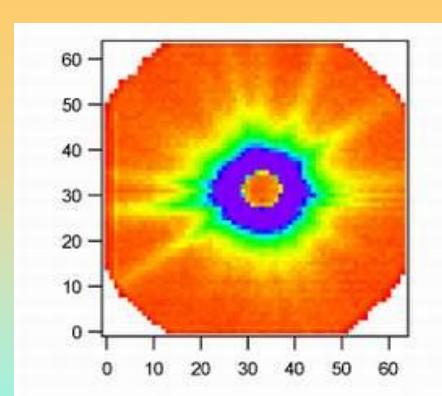
K7, Turkey



Rimski 3,
Hungary



PK3,
Slovenia



K9, Turkey

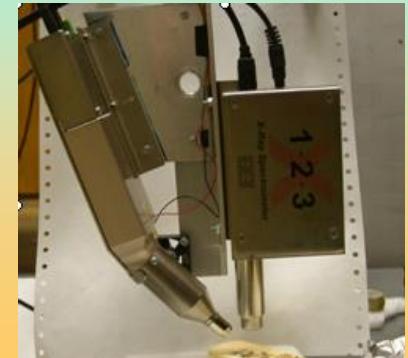
anisotropic distribution of nanoscale pores or precipitates

X-RAY SPECTROSCOPY – PIXE, XRF



Applicable:

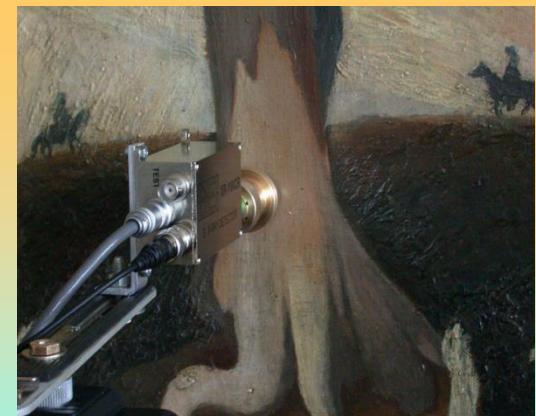
- For near-surface analysis 10-500 µm
- Detection Limits 50-1000 ppm, Al-U



Advantages:

PIXE

- Non-destructive
- 3D positioning (even for large objects)
- Minimal sample preparation
- Penetration depth 8-20 µm
- Beam size: 1-2 mm²



XRF

- Non-destructive
- Fast (in situ) analysis
- Penetration depth 20-170 µm
- Beam size : 25 mm²



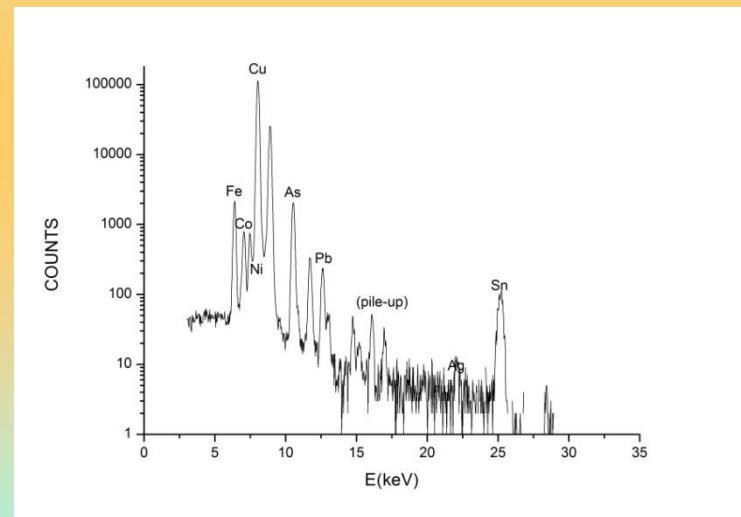
External beam PIXE contribution to the CHARISMA project

Bronze-Age Usage and Development of Defensive Armour in Eastern Europe

Project leader: Marianne Mödlinger,
Landesmuseum Kärnten, Klagenfurt, Austria



A bronze helmet from Northern Hungary facing to the external proton beam



A typical PIXE spectrum



NUCLEAR TECHNIQUES IN RESEARCH FOR CULTURAL HERITAGE

László Rosta, Zoltán Szőkefalvi-Nagy, Zsolt Kasztovszky and
Zita Szikszai

CHARISMA

Cultural Heritage Advanced Research Infrastructures: Synergy
for a Multidisciplinary Approach to Conservation/Restoration

Project co-funded by the European Commission within the action 'Research
Infrastructures' of the 'Capacities' Programme - GA FP7 228330



2009 - 2013



**Single access & joint access
service supported**

Transnational access

**charisma**

Cultural Heritage Advanced
Research Infrastructures:
Synergy for a Multidisciplinary
Approach to Conservation/Restoration



FIXLAB_ PLATFORM B

BUDAPEST-DEBRECEN



ATOMKI-HAS, DEBRECEN



The CHARISMA TNA programme in ATOMKI



Scanning ion microprobe

Techniques:
**PIXE, PIGE, RBS with focused ion
beams (+XRF)**

Trace element level composition
and distribution

Beam size: $1\mu\text{m} \times 1\mu\text{m}$

PIXE is applied in all projects:
Elements: C-U (quantitative: O-U)
Typical det. limits: 10-100 ppm



PROVENANCE STUDY OF LAPIS LAZULI

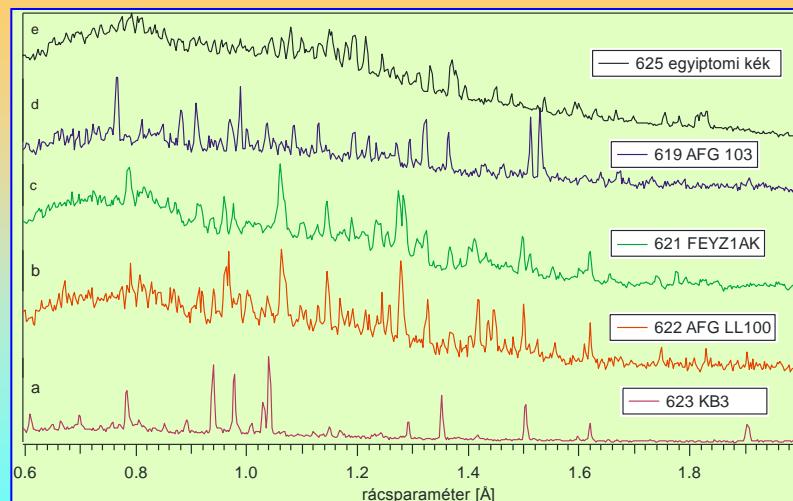
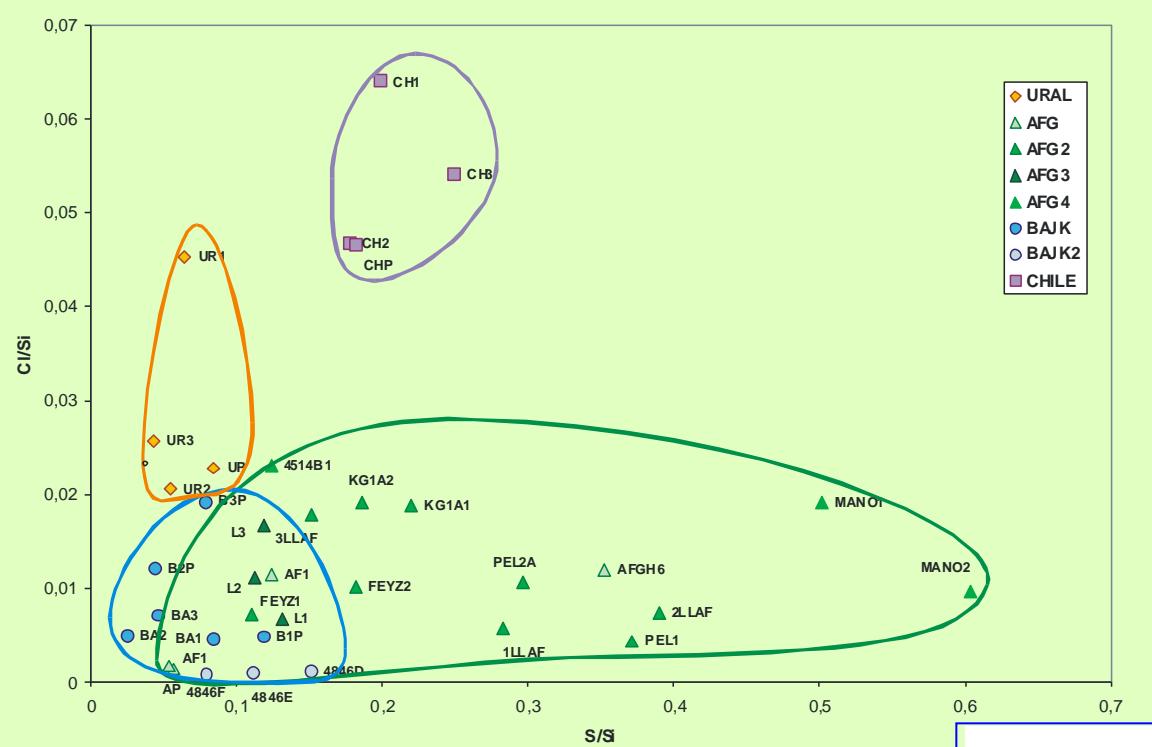
BNC – ATOMKI – Tübingen University

Project leader: Judit Zöldföldi

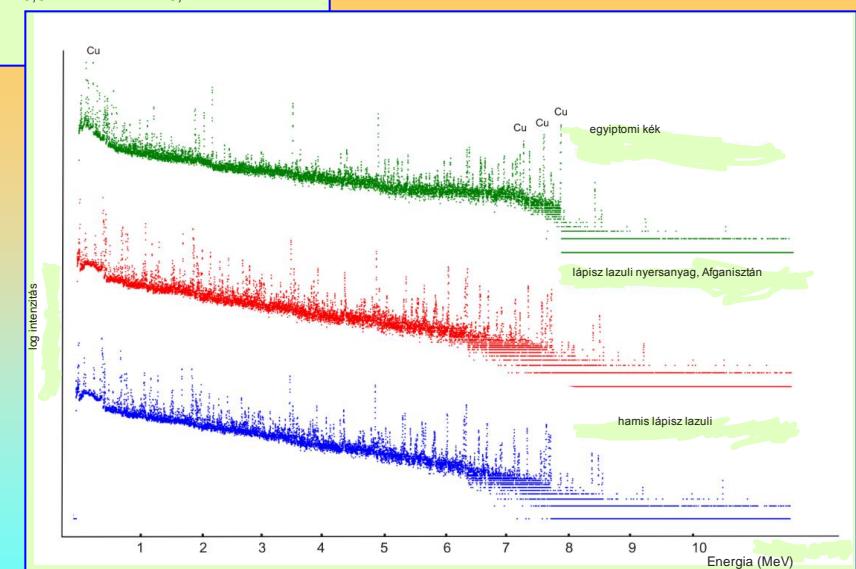


- A few geological occurrences in the World
(Ural, Chile, Afghanistan, Lake Bajkal)
- **Main mineral:** Lazurit / $(\text{Na}, \text{Ca})_{7-8}(\text{Al}, \text{Si})_{12}\text{O}_{24}[(\text{SO}_4)\text{Cl}_2(\text{OH})_2]$
- **AIM:** Identification of raw materials, provenance of art objects
- **PGAA:** H, Na, Mg, Al, Si, K, Ca, Ti, Mn, Fe, S, Cl

Characterisation of raw materials with PGAA



Fake identification with TOF-ND



Fake identification with PGAA



PROVENANCE STUDY OF LAPIS LAZULI

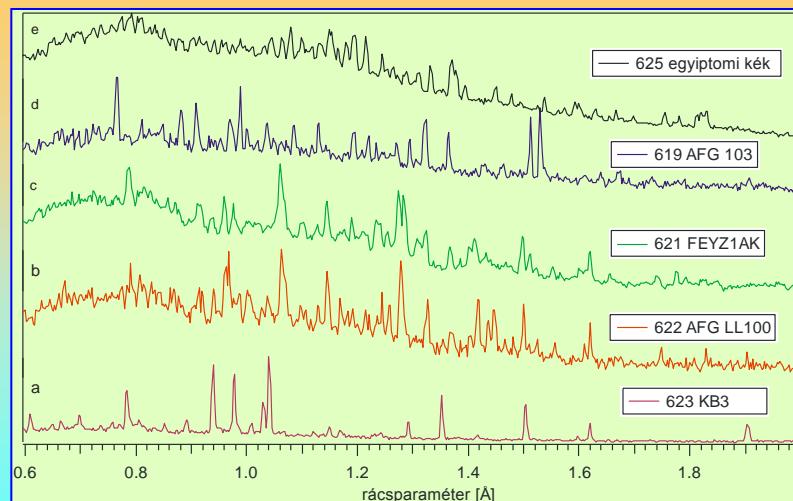
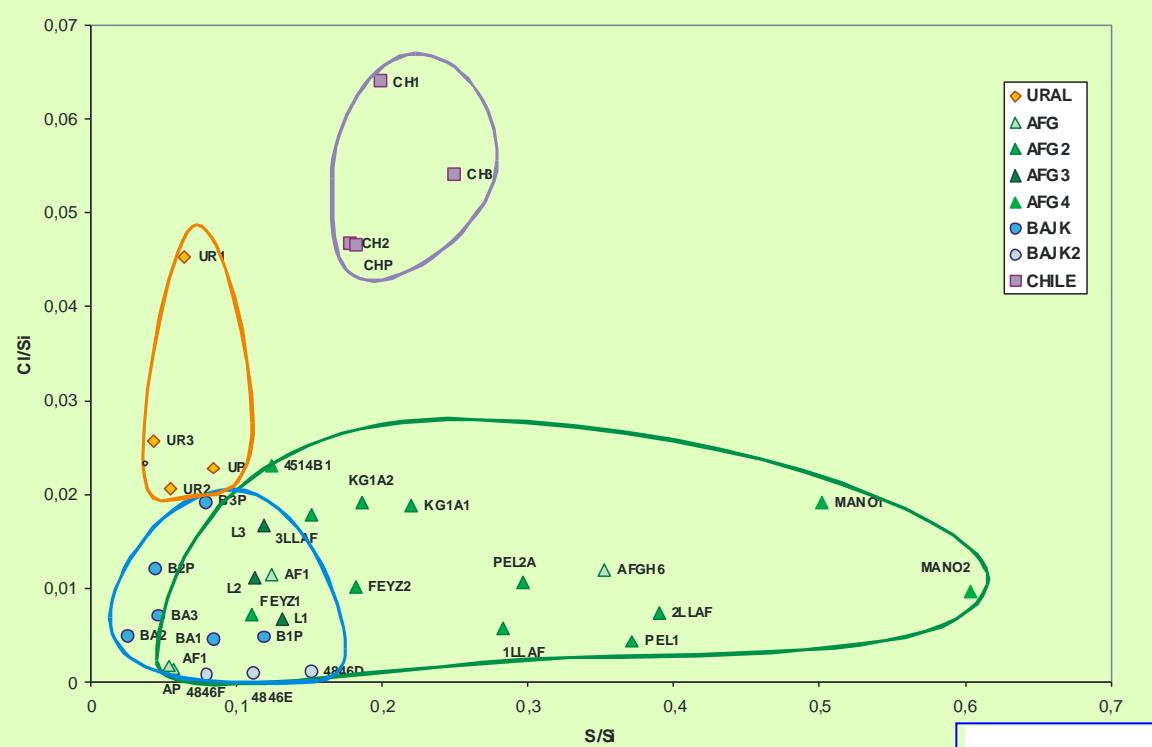
BNC – ATOMKI – Tübingen University

Project leader: Judit Zöldföldi

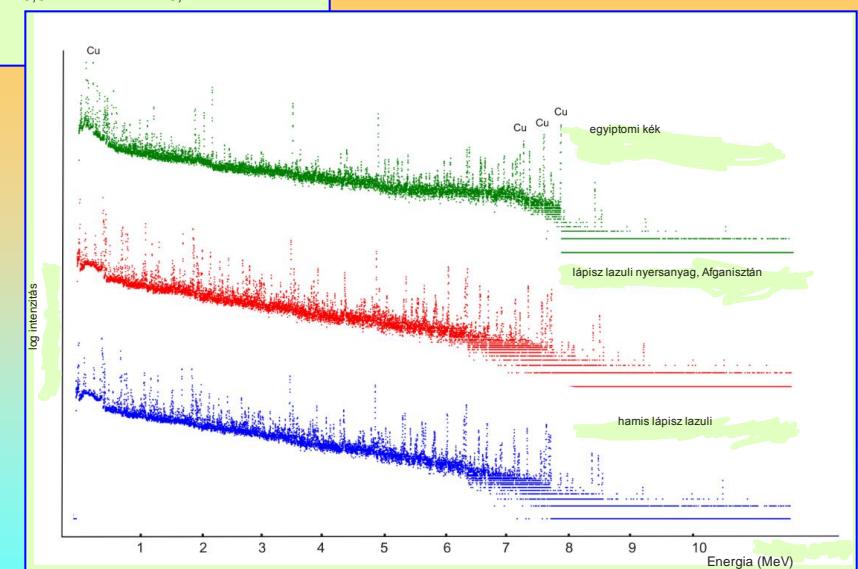


- A few geological occurrences in the World
(Ural, Chile, Afghanistan, Lake Bajkal)
- **Main mineral:** Lazurit / $(\text{Na}, \text{Ca})_{7-8}(\text{Al}, \text{Si})_{12}\text{O}_{24}[(\text{SO}_4)\text{Cl}_2(\text{OH})_2]$
- **AIM:** Identification of raw materials, provenance of art objects
- **PGAA:** H, Na, Mg, Al, Si, K, Ca, Ti, Mn, Fe, S, Cl

Characterisation of raw materials with PGAA



Fake identification with TOF-ND



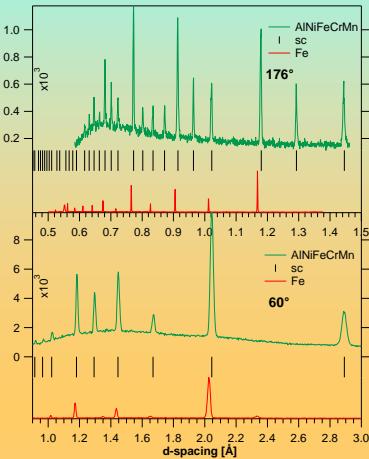
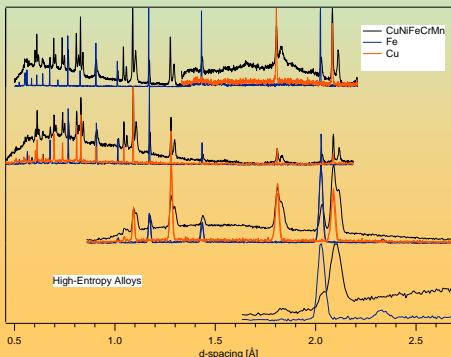
Fake identification with PGAA

TOF - Time of Flight Neutron Diffraction

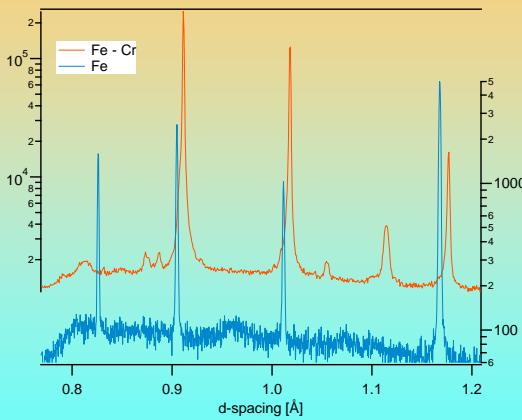


Metallurgy

High-entropy alloys

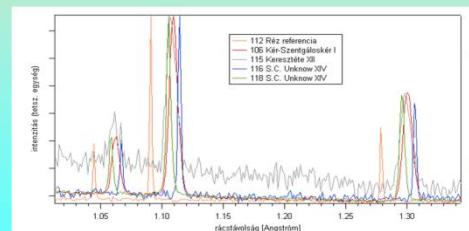


Fe-Cr system



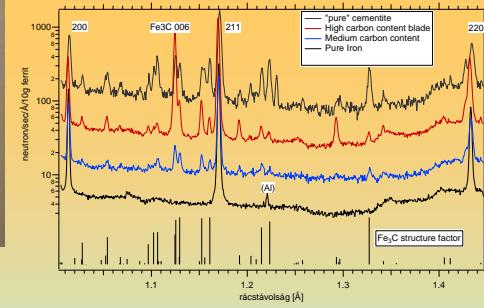
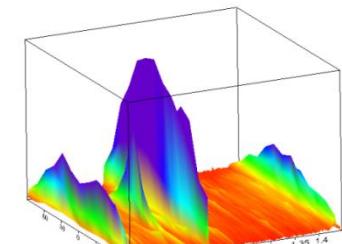
- Phase analysis
- Structure determination
- Texture and stress analysis

Bronze artefacts

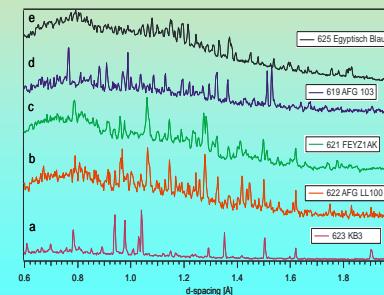


Archaeometry

Carbon steel blades



Lapis lazuli



Proof of meteoritic origin of mankind's earliest iron artefacts, 3200 BC, by neutron and X-ray techniques

Principal Proposer: Thilo Rehren – UCL London



A predynastic cemetery was excavated near Gerzeh by G.A. Wainwright and J.P. Bushe-Fox in 1911

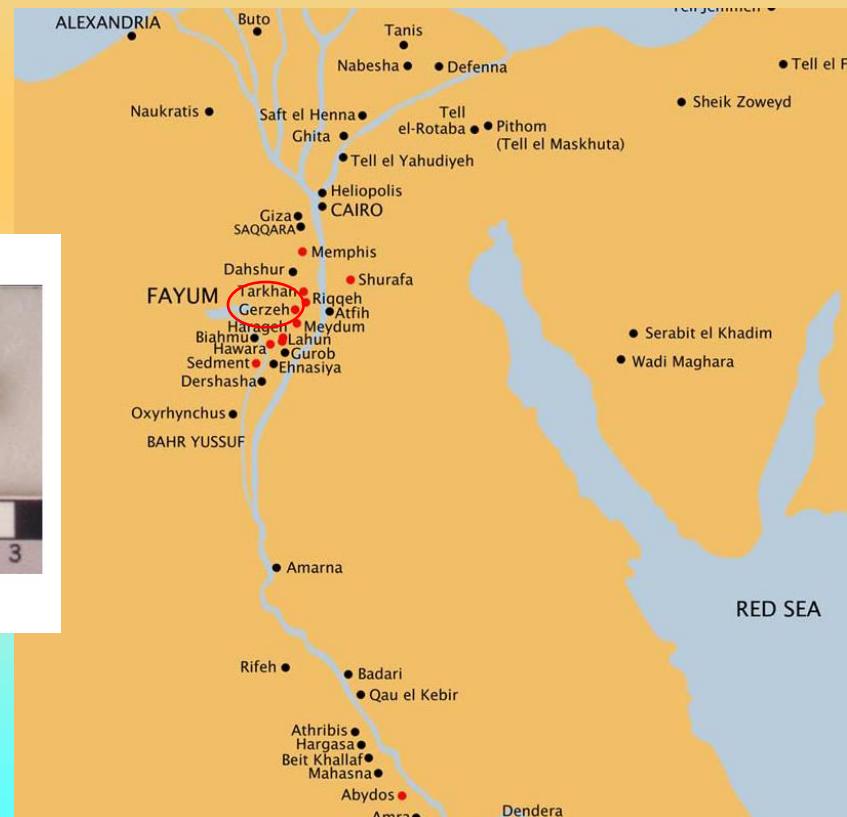
- 3 iron beads were investigated by non-destructive techniques (**NR**, **TOF-ND**, **PGAA**, **PIXE**)
- The objective was to determine the nature of the iron from which these earliest iron beads are made - can we demonstrate that they are meteoritic in origin, as has been speculated based on their early date?
- Meteoritic iron has several characteristics that distinguish it from smelted iron. Most prominent are the large crystal grain size, elevated bulk concentrations of **Ni** (1-10 wt%), **Co** (1000-10000 ppm) and **Ge** (200-400 ppm)

Properties of The Petrie Museum of Egyptian Archaeology, London



Fig. 1: Beads UC10738 (left), UC10739 (centre) and UC10740 (right). Scale in cm.

One of the beads had been analysed in the 1920s and found to contain about 7.5 wt% Ni



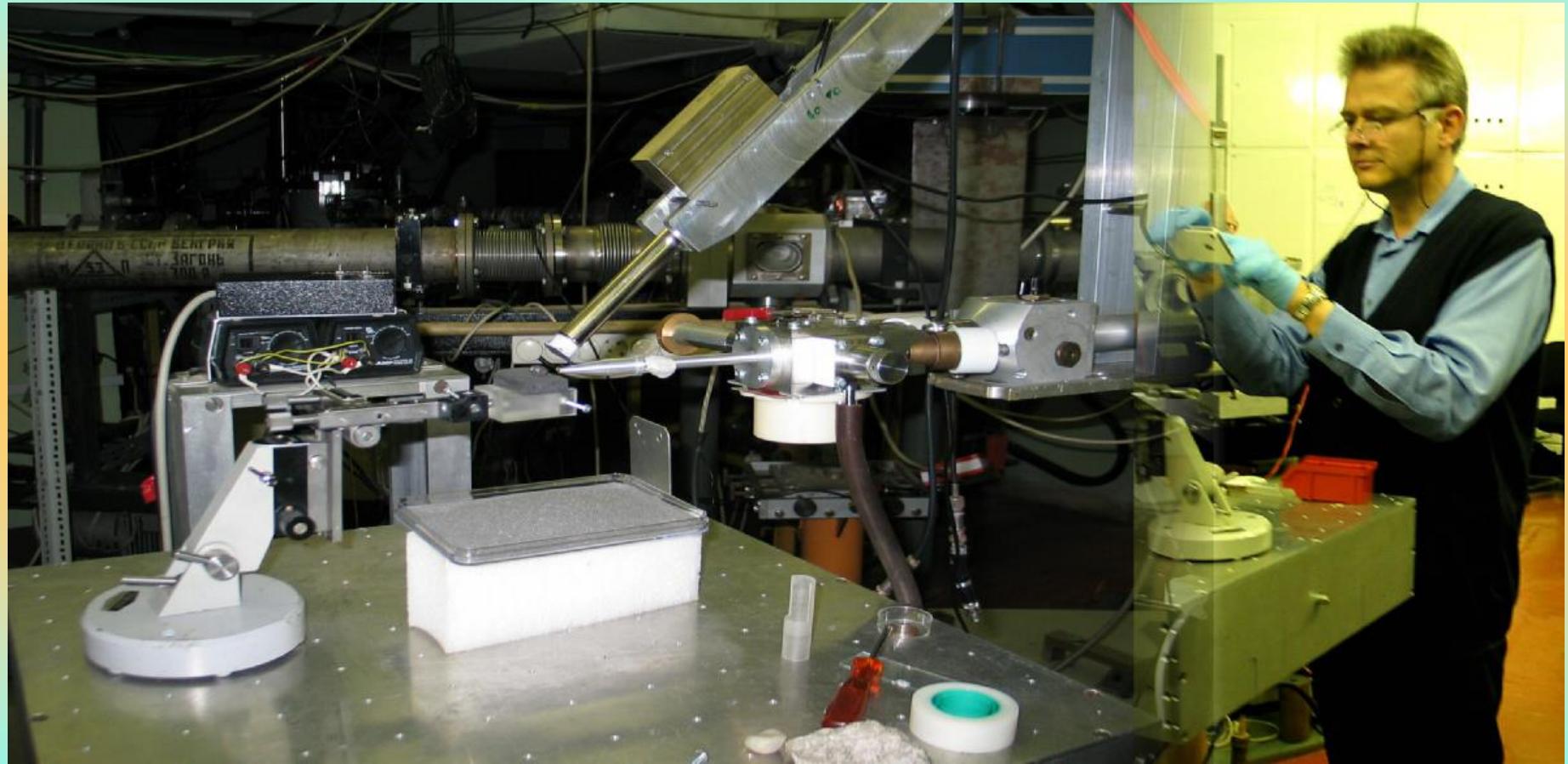
PGAA

Zsolt Kasztovszky, Boglárka Maróti & Tamás Belgya

Spectr. Nr.	578		579		586		580		589		588	
Sample code	UC10738		UC10739		UC10740		CdC3C		28848/12		28848/1	
Element	Conc. / wt%	Abs. Unc. +/-										
H	1.65	0.03	1.58	0.03	2.03	0.03	0.114	0.003	1.16	0.03	1.36	0.03
B	0.0473	0.0009	0.0575	0.0010	0.0810	0.0012	<D.L.		0.00172	0.00004	0.00465	0.00010
Na	0.13	0.01	0.23	0.02	0.20	0.01	<D.L.		0.059	0.004	0.090	0.012
Mg	0.66	0.09	<D.L.		0.46	0.04	<D.L.		0.37	0.06	0.47	0.06
Al	0.18	0.07	0.31	0.02	0.10	0.03	<D.L.		0.12	0.02	0.06	0.02
Si	1.5	0.1	3.0	0.1	1.3	0.05	<D.L.		0.6	0.04	0.2	0.06
P	0.8	0.2	0.6	0.1	1.0	0.1	0.24	0.05	<D.L.		<D.L.	
S	0.2	0.02	0.2	0.01	0.2	0.01	0.11	0.01	0.063	0.007	<D.L.	
Cl	0.709	0.017	0.625	0.011	0.806	0.015	0.0050	0.0001	0.118	0.003	0.167	0.004
K	0.028	0.002	0.077	0.003	0.080	0.005	<D.L.		0.023	0.003	0.021	0.004
Ca	0.48	0.03	0.55	0.02	0.67	0.03	<D.L.		0.80	0.03	0.28	0.02
Ti	0.016	0.002	0.047	0.002	0.009	0.001	<D.L.		<D.L.		<D.L.	
Mn	0.023	0.003	0.0160	0.0004	0.050	0.001	<D.L.		0.008	0.0005	0.027	0.0007
Fe	50.2	0.4	48.7	0.4	48.5	0.3	64.1	0.2	60.2	0.2	60.0	0.2
Co	0.203	0.006	0.237	0.008	0.170	0.006	0.284	0.010	<D.L.		<D.L.	
Ni	3.55	0.10	4.10	0.10	2.75	0.06	4.88	0.15	<D.L.		<D.L.	
Nd	<D.L.		<D.L.		0.002	0.0005	<D.L.		<D.L.		<D.L.	
Sm	0.00002	0.000002	0.00002	0.000001	<D.L.		<D.L.		<D.L.		<D.L.	
Gd	<D.L.		0.000023	0.000003	<D.L.		<D.L.		<D.L.		<D.L.	
O (calculated)	39.6	0.1	39.7	0.1	41.6	0.1	30.3	0.1	36.5	0.1	37.3	0.1

PGAA showed that the beads consist predominantly of Fe and O in broadly similar amounts, which is consistent with their corroded state. Of more interest, the beads contain 2.8-4.1 wt% Ni, 0.6-1.0 wt% P, and 1700-2400 ppm Co. Ge was below the D.L.

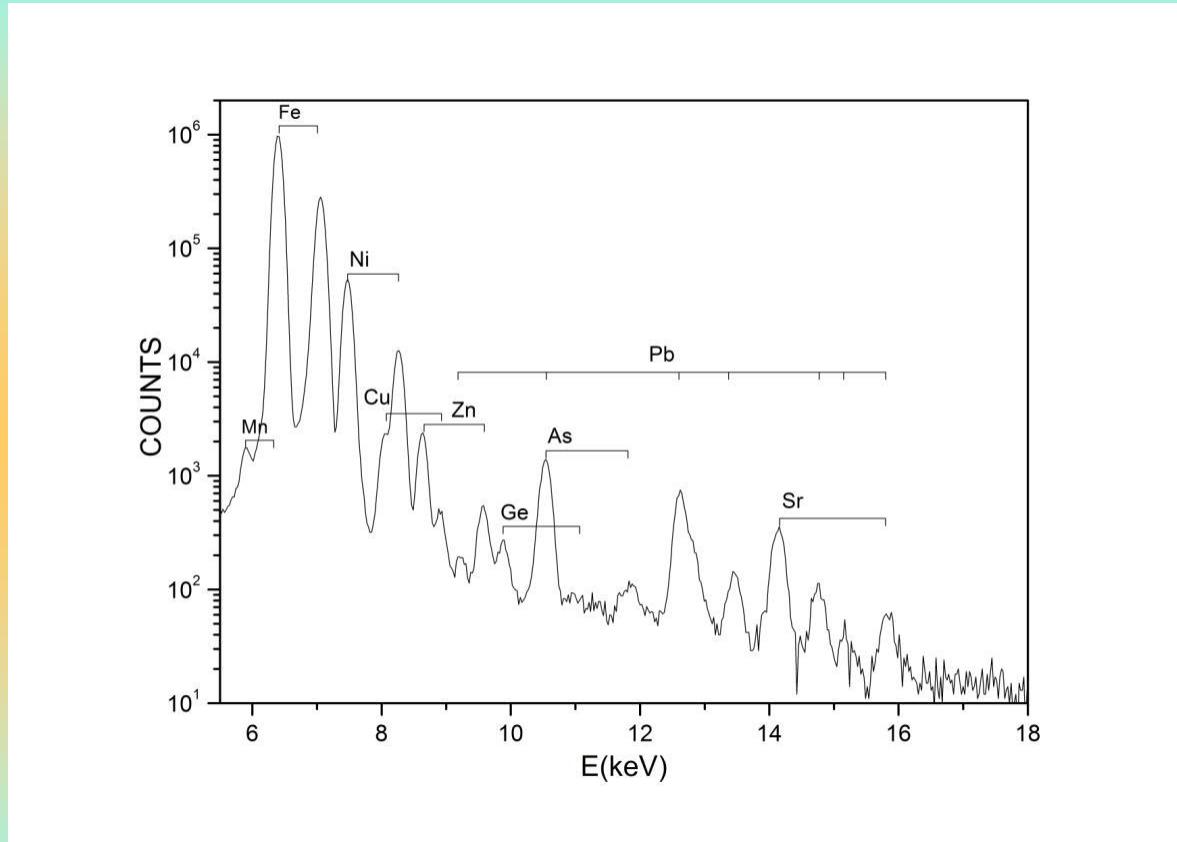
Fontos bizonyítékként a csillebéri gyorsítónál üzemelő röntgen-emissziós berendezéssel (PIXE) a germánium jelenlétét is sikerült kimutatni.



Prof. Thilo Rehnen (University College London) az egyik vasgyöngy beállítását figyeli csillebéri protongyorsító röntgen-emissziós mérőállomásánál (MTA Wigner FK).

PIXE

Imre Kovács & Zoltán Szőkefalvi-Nagy



- PIXE analysis of the beads' surfaces confirmed the presence of **Fe** as the main element, followed by **Ni** at an estimated 5 wt%, and the light elements from the soil. Individual spots have different concentrations of **Cu**, **Pb**, **As**, **Zn** and **Mn**. Two of the beads showed spots with **Ge**, estimated to be at 30 ppm, and reaching up to 100 ppm.

TOF-ND

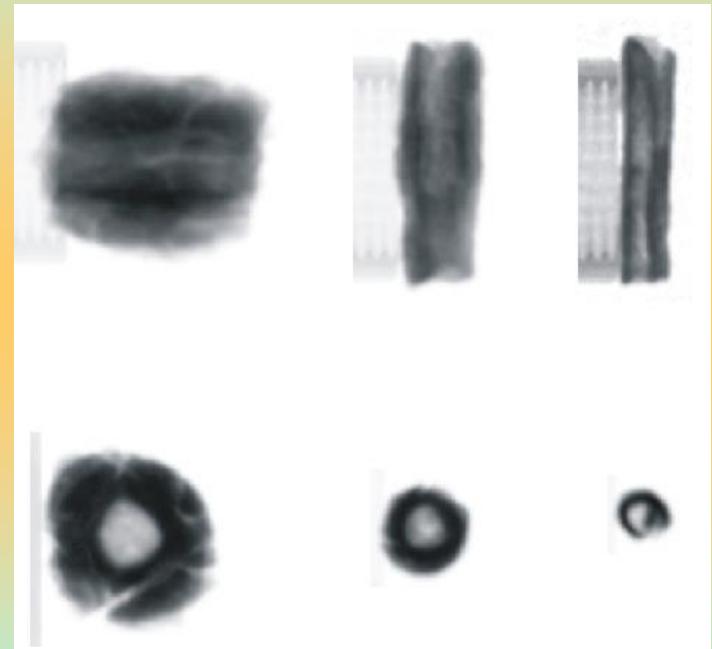
György Káli & László Rosta

- By ToF-ND testing for grain size and crystal lattice structure of any metallic phases present in the beads, no metallic form of iron was found. No definite Bragg peaks were observed, consequently they should consist of a larger number of low symmetry crystalline phases (probably with non-uniform chemical compositions, as oxides), imperfectly crystallized or amorphous compounds
- This is considered typical for the corrosion products of iron

NEUTRON RADIOGRAPHY

Zoltán Kis & László Szentmiklósi

- Neutron radiography revealed the original shapes and bulk morphology of the artefacts
Details of their manufacture can be deducted.
- All three artefacts have a central hole along their long axis, not visible during visual inspection due to their corrosion. It demonstrate that the beads were made from rolled iron sheet, with areas of overlapping metal visible at the centre of the seam UC10740.
- This would have required repeated hammering with intermittent annealing.



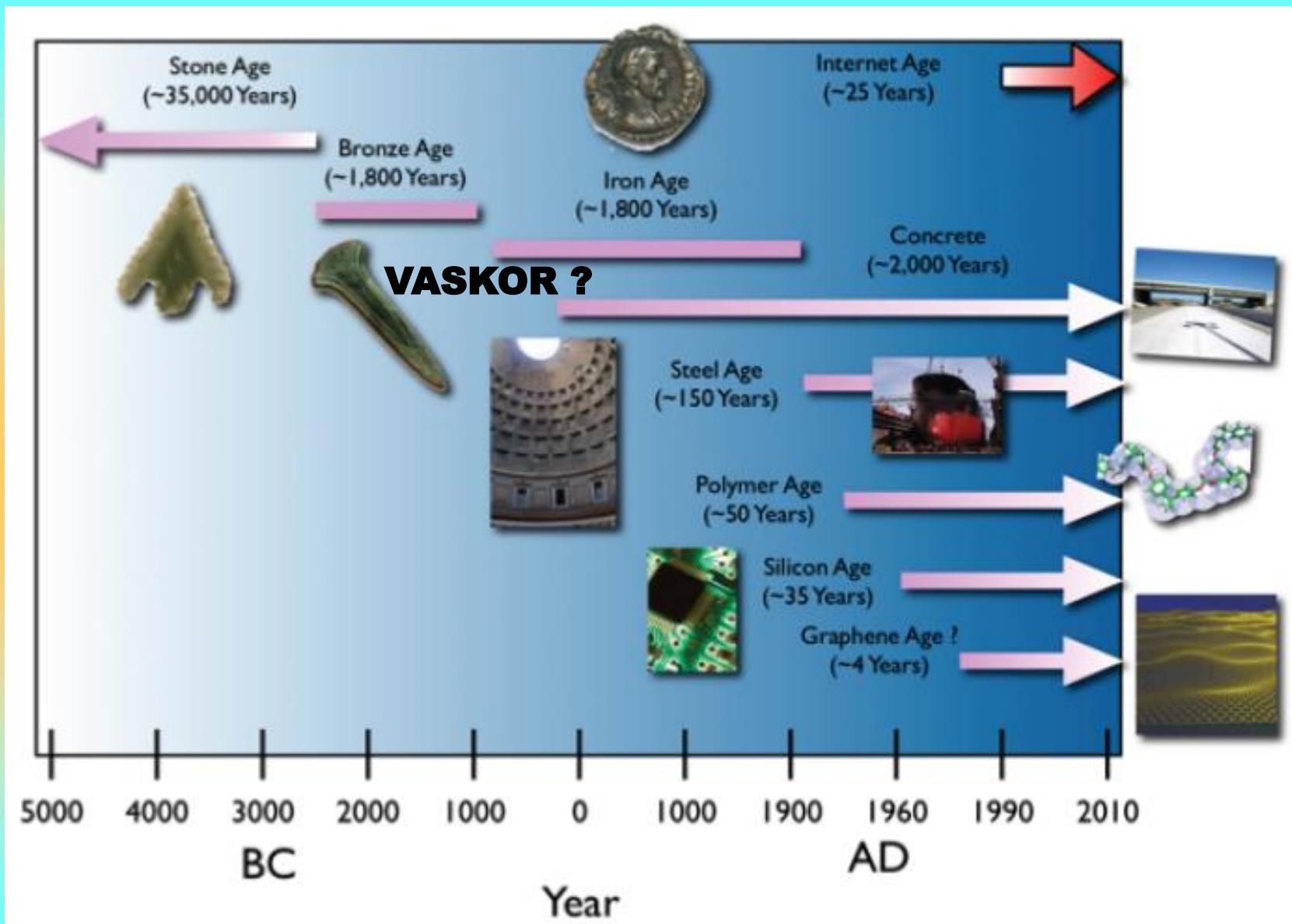
CONCLUSIONS

- Serendipity was a key factor in this investigation

"happy accident" of finding something good or useful while not specifically searching for it.

- We provided positive proof of a meteoritic origin of these beads, strengthening the argument that these are indeed the earliest known examples of iron metal worked by humans made from a material much more difficult to work.
- Composition and manufacturing technique rule out a sub-recent origin of the beads, confirming that they are not later intrusions into Gerzeh tombs, but indeed humankind's oldest known iron artefacts.

Mikor is kezdődött a vaskor ???



Új kihívás: a Viking fegyverek titka

Gazdag leletanyag a Kárpát-medencében.



Szent István (1000-1038)

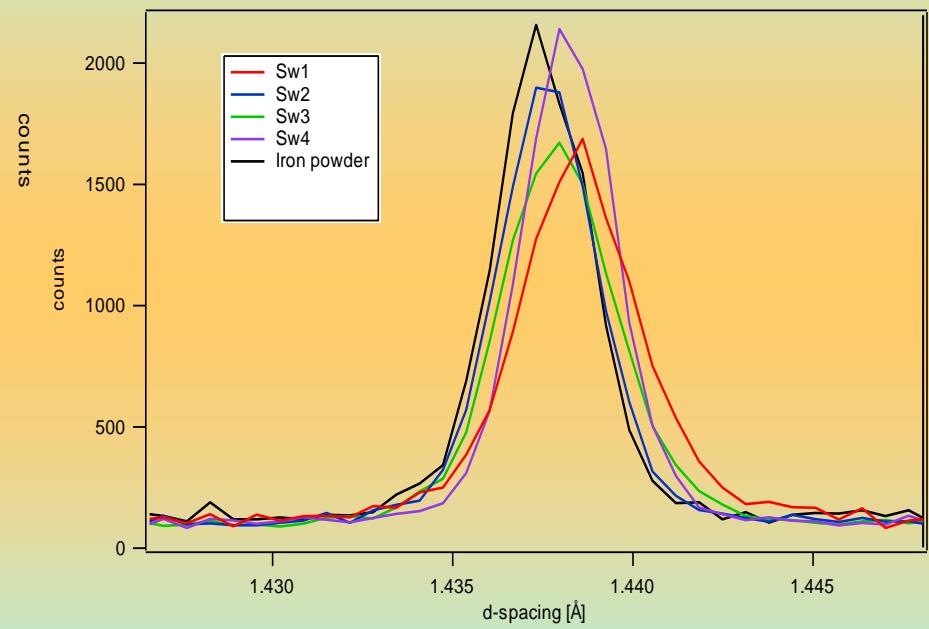
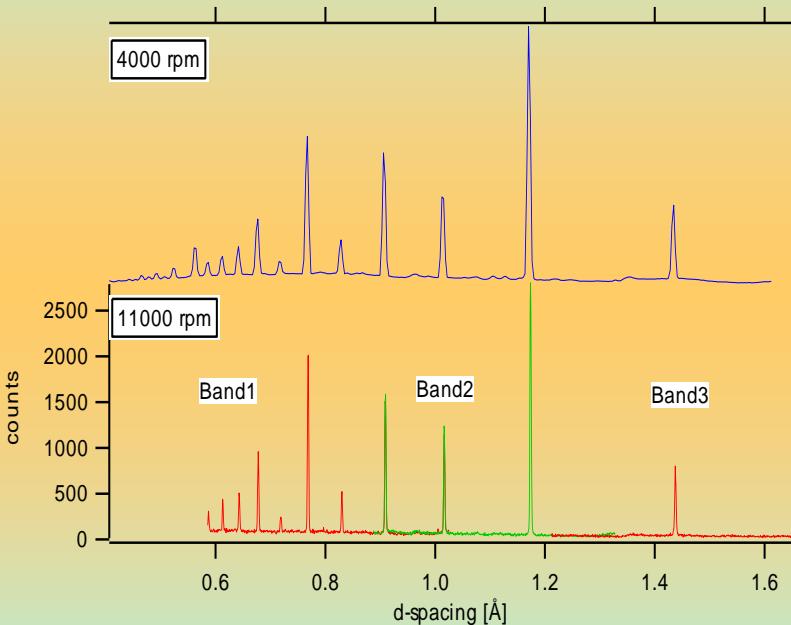


Új kihívás: a Viking fegyverek titka

Four – believed – medieval swords had been studied.

Sword1 strongly corroded but together with **Sword2** were visibly Damascus blades, certificated archeological objects. **Sword3** and **Sword4** were in good state but not certificated.

High resolution TOF diffraction: 150 spectra



- Phase composition. (For steel phases as ferrite, cementite, martensite and non-steel phases).
- The degree of alloying of the main phase.
- The total carbon content (using the two previous information)
- Texture analyses (preferred orientations of the crystallites).
- Average internal stress and dislocation density.

Some conclusions:

- Important and equal cementit content
- Inhomogeneous precipitate distribut.
- The tensile strength was nearly same
- *Except for 1 sword - decorated*

Új kihívás: a Viking fegyverek titka



Koronázási szimbólumok

A történészek kérdése:

Melyik is István Király valódi kardja, és ez(ek) tényleg viking kardok?

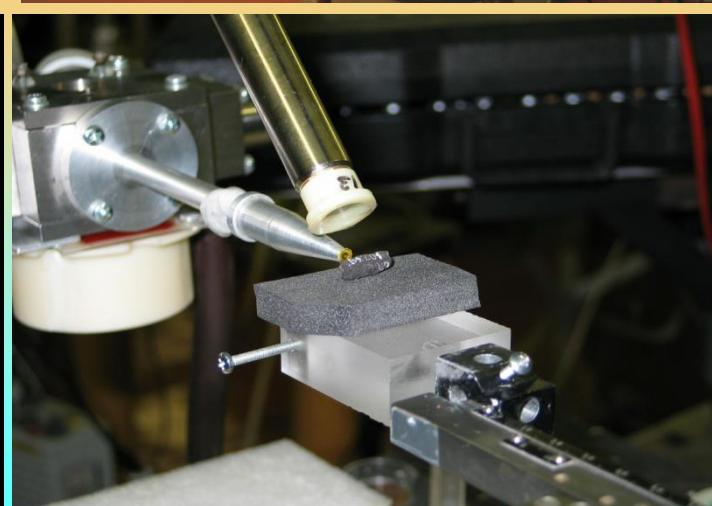
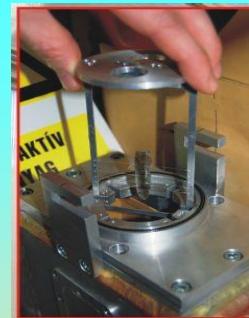
**A válasz
természettudományos
megközelítést igényel
pl.nanodiagnosztika
neutronokkal**

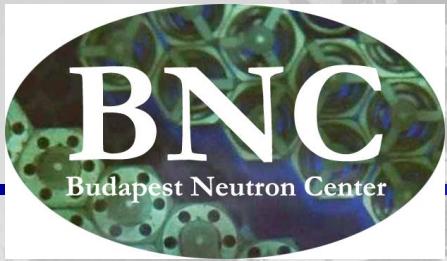
Szent István kardja (1356 óta Prágában, ma a Szt. Vitus székesegyház múzeumában)

Egyedülálló nagyműszer együttes a csillebéri kutatóközpontban

Neutronendiffrakció
Kisszögű szórás
Neutron/gamma
radiográfia

PGAA és PIXE





A neutronok régészeti alkalmazása előtt nagy jövő áll



Köszönöm a figyelmet!

