



HELLENIC REPUBLIC

**National and Kapodistrian
University of Athens**

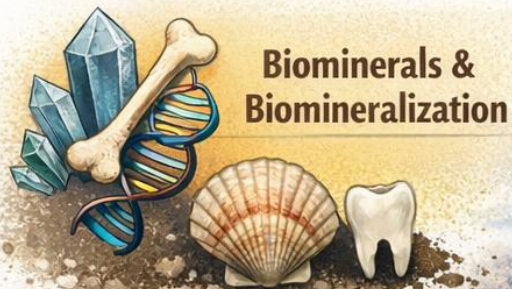
— EST. 1837 —

Introduction to Biomineralogy and Medical Geology

Prof. A. Godelitsas

- Basics of medical mineralogy / geochemistry and geology
- Biominerals and biomineralization
- Volcanic ash and Saharan dust
- Radioactivity
- Asbestos minerals and surface reactivity (Fenton cycle)
- Characterization of asbestos in building materials using laser-based *in-situ* techniques (laser μ -Raman, LIBS)

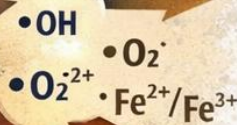
Medical Mineralogy & Environmental Geoscience



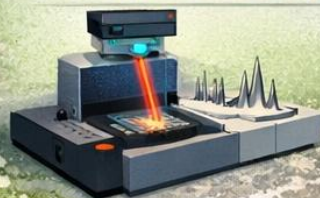
Volcanic Ash & Saharan Dust



Asbestos Minerals & Fenton Cycle



Laser-Based Analysis



IUPAC Periodic Table of the Elements

1 1 H hydrogen 1.0080 ± 0.0002																								2 2 He helium 4.0026 ± 0.0001																																																																																																																																																																																															
3 3 Li lithium 6.94 ± 0.06												4 4 Be beryllium 9.0122 ± 0.0001																																																																																																																																																																																																											
11 11 Na sodium 22.990 ± 0.001												12 12 Mg magnesium 24.305 ± 0.002																																																																																																																																																																																																											
19 19 K potassium 39.098 ± 0.001												20 20 Ca calcium 40.078 ± 0.004												21 21 Sc scandium 44.956 ± 0.001												22 22 Ti titanium 47.867 ± 0.001												23 23 V vanadium 50.942 ± 0.001												24 24 Cr chromium 51.996 ± 0.001												25 25 Mn manganese 54.938 ± 0.001												26 26 Fe iron 55.845 ± 0.002												27 27 Co cobalt 58.933 ± 0.001												28 28 Ni nickel 58.693 ± 0.001												29 29 Cu copper 63.546 ± 0.003												30 30 Zn zinc 65.38 ± 0.02												31 31 Ga gallium 69.723 ± 0.001												32 32 Ge germanium 72.630 ± 0.008												33 33 As arsenic 74.922 ± 0.001												34 34 Se selenium 78.971 ± 0.008												35 35 Br bromine 79.904 ± 0.003												36 36 Kr krypton 83.798 ± 0.002											
37 37 Rb rubidium 85.468 ± 0.001												38 38 Sr strontium 87.62 ± 0.01												39 39 Y yttrium 88.906 ± 0.001												40 40 Zr zirconium 91.224 ± 0.002												41 41 Nb niobium 92.906 ± 0.001												42 42 Mo molybdenum 95.95 ± 0.01												43 43 Tc technetium [97]												44 44 Ru ruthenium 101.07 ± 0.02												45 45 Rh rhodium 102.91 ± 0.01												46 46 Pd palladium 106.42 ± 0.01												47 47 Ag silver 107.87 ± 0.01												48 48 Cd cadmium 112.41 ± 0.01												49 49 In indium 114.82 ± 0.01												50 50 Sn tin 118.71 ± 0.01												51 51 Sb antimony 121.76 ± 0.01												52 52 Te tellurium 127.60 ± 0.03												53 53 I iodine 126.90 ± 0.01												54 54 Xe xenon 131.29 ± 0.01											
55 55 Cs caesium 132.91 ± 0.01												56 56 Ba barium 137.33 ± 0.01												57-71 lanthanoids												72 72 Hf hafnium 178.49 ± 0.01												73 73 Ta tantalum 180.95 ± 0.01												74 74 W tungsten 183.84 ± 0.01												75 75 Re rhenium 186.21 ± 0.01												76 76 Os osmium 190.23 ± 0.03												77 77 Ir iridium 192.22 ± 0.01												78 78 Pt platinum 195.08 ± 0.02												79 79 Au gold 196.97 ± 0.01												80 80 Hg mercury 200.59 ± 0.01												81 81 Tl thallium 204.38 ± 0.01												82 82 Pb lead 207.2 ± 1.1												83 83 Bi bismuth 208.98 ± 0.01												84 84 Po polonium [209]												85 85 At astatine [210]												86 86 Rn radon [222]											
87 87 Fr francium [223]												88 88 Ra radium [226]												89-103 actinoids												104 104 Rf rutherfordium [267]												105 105 Db dubnium [268]												106 106 Sg seaborgium [269]												107 107 Bh bohrium [270]												108 108 Hs hassium [269]												109 109 Mt meitnerium [277]												110 110 Ds darmstadtium [281]												111 111 Rg roentgenium [282]												112 112 Cn copernicium [285]												113 113 Nh nihonium [286]												114 114 Fl flerovium [290]												115 115 Mc moscovium [290]												116 116 Lv livermorium [293]												117 117 Ts tennessine [294]												118 118 Og oganeson [294]											

Key:
atomic number
Symbol
name
abridged standard
atomic weight



INTERNATIONAL UNION OF
PURE AND APPLIED CHEMISTRY

57 La lanthanum 138.91 ± 0.01	58 Ce cerium 140.12 ± 0.01	59 Pr praseodymium 140.91 ± 0.01	60 Nd neodymium 144.24 ± 0.01	61 Pm promethium [145]	62 Sm samarium 150.36 ± 0.02	63 Eu europium 151.96 ± 0.01	64 Gd gadolinium 157.25 ± 0.03	65 Tb terbium 158.93 ± 0.01	66 Dy dysprosium 162.50 ± 0.01	67 Ho holmium 164.93 ± 0.01	68 Er erbium 167.26 ± 0.01	69 Tm thulium 168.93 ± 0.01	70 Yb ytterbium 173.05 ± 0.02	71 Lu lutetium 174.97 ± 0.01
89 Ac actinium [227]	90 Th thorium 232.04 ± 0.01	91 Pa protactinium 231.04 ± 0.01	92 U uranium 238.03 ± 0.01	93 Np neptunium [237]	94 Pu plutonium [244]	95 Am americium [243]	96 Cm curium [247]	97 Bk berkelium [247]	98 Cf californium [251]	99 Es einsteinium [252]	100 Fm fermium [257]	101 Md mendelevium [258]	102 No nobelium [259]	103 Lr lawrencium [262]

For notes and updates to this table, see www.iupac.org. This version is dated 4 May 2022.
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REVIEWS in
MINERALOGY
Volume 28

HEALTH EFFECTS OF MINERAL DUSTS

George D. Guthrie, Jr.,
Brooke T. Mossman, *Editors*



Series Editor: Paul H. Ribbe
MINERALOGICAL SOCIETY OF AMERICA

by Charlotte A. Bowman¹, Peter T. Bobrowsky², and Olle Selinus³

Medical geology: new relevance in the earth sciences

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² Geological Survey of Canada, Ottawa, Canada

³ Geological Survey of Sweden, Uppsala, Sweden



Short Courses and Workshops

Medical Mineralogy and Geochemistry Fall, 2006

Short Course organizers: Nita Sahai, University of Wisconsin, Madison, WI and Martin A. Schoonen, State University of New York - Stony Brook, Stony Brook, NY .
meeting: Fall 2006 American Geophysical Union, San Francisco, California
sponsors: Mineralogical Society of America and The Geochemical Society

The Emergent Field of Medical Mineralogy and Geochemistry

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Yale University
New Haven, Connecticut, 06520-8109, U.S.A.
e-mail: catherine.skinner@yale.edu*

**19th GENERAL MEETING OF THE
INTERNATIONAL MINERALOGICAL ASSOCIATION**

Expansion to Nano, Bio and Planetary Worlds



IMA2006-Kobe, Japan July 23-28, 2006
at International Conference Center Kobe



Scientific Program

26. Environmental and medical mineralogy (ICAM, WGEM):
Anhuai Lu (Peking Univ.), Mihaly Posfai (Univ. of Veszprem),
Tsutomu Sato*(Kanazawa Univ.), David J. Vaughan (Univ. of
Manchester), Roy Wogelius (Univ. of Manchester)

Olle Selinus
Brian Alloway
José A. Centeno
Robert B. Finkelman

Ron Fuge
Ulf Lindh
Pauline Smedley
Editors



Essentials of Medical Geology

Revised Edition



2013

 Springer



Malcolm Siegel · Olle Selinus
Robert Finkelman *Editors*

Practical Applications of Medical Geology

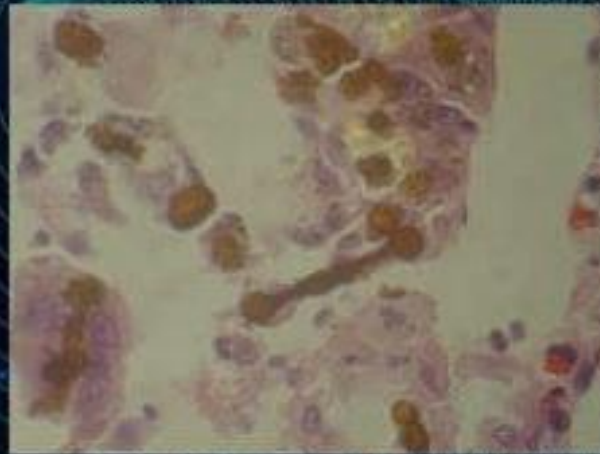
2021

 Springer

Asbestos

**Risk Assessment, Epidemiology,
and Health Effects**

THIRD EDITION



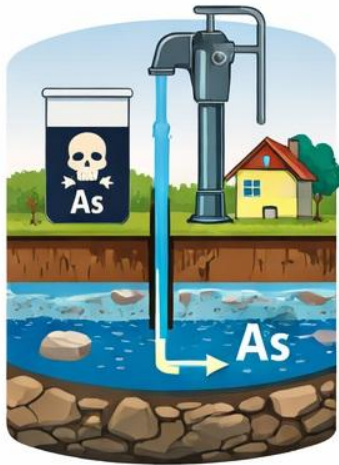
**Edited by Michele Carbone,
Ronald F. Dodson, Harvey Pass,
and Haining Yang**

2025



CRC Press
Taylor & Francis Group

- High arsenic concentrations in groundwater are associated with an increased risk of cancer.
- Low iodine levels in soils may lead to iodine deficiency and related thyroid disorders.
- Desert dust exposure can contribute to respiratory problems.
- Radon gas emanating from certain rock types is linked to an elevated risk of lung cancer.
- Naturally occurring asbestos minerals, when disturbed and inhaled, are associated with serious respiratory diseases, including Asbestosis and Mesothelioma.



**Arsenic in
Groundwater**



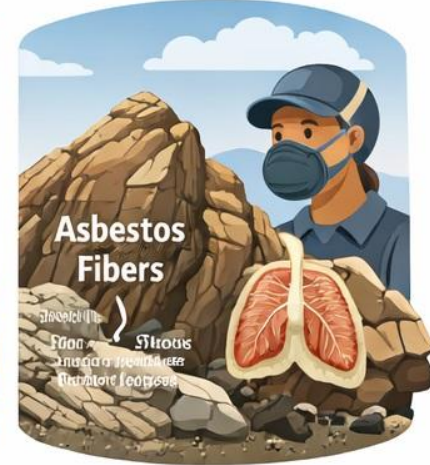
**Iodine
Deficiency in Soil**



**Desert
Dust**

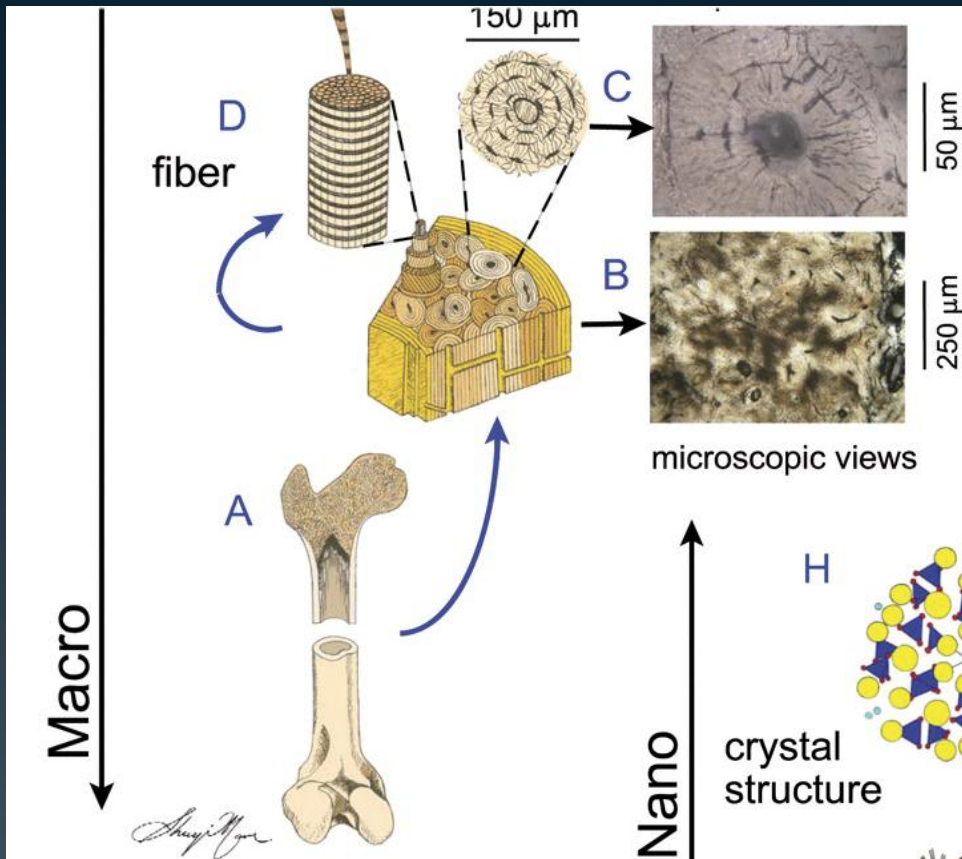


Radon Gas

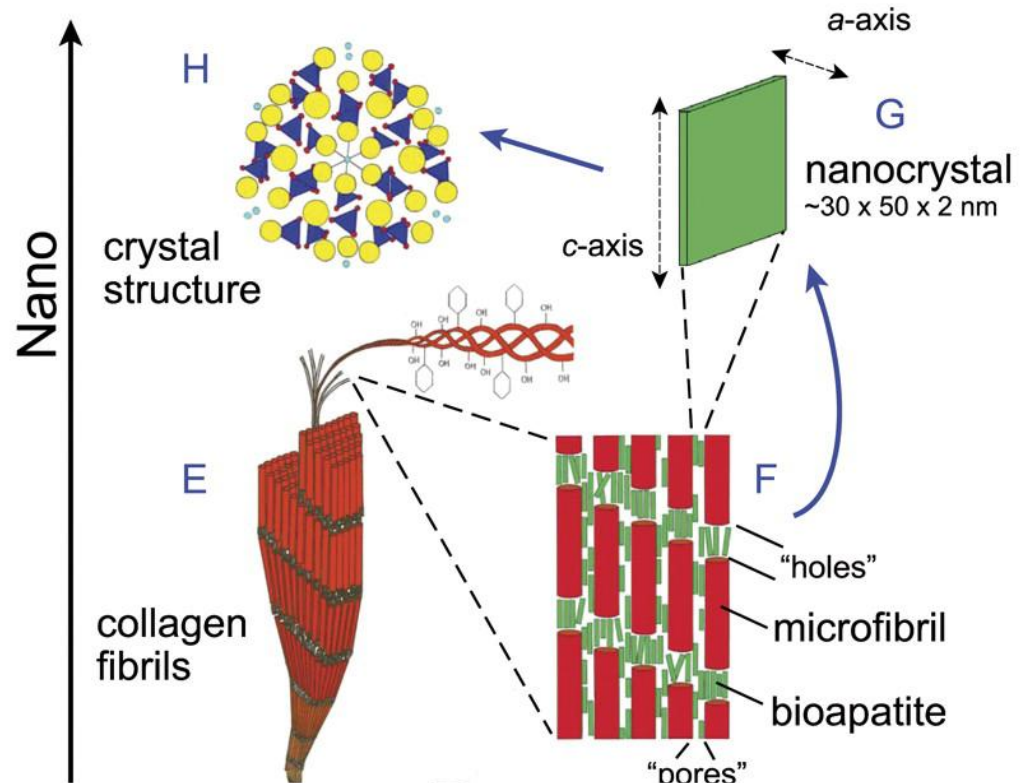


**Asbestos
Exposure**

Biomaterials and biomineralization

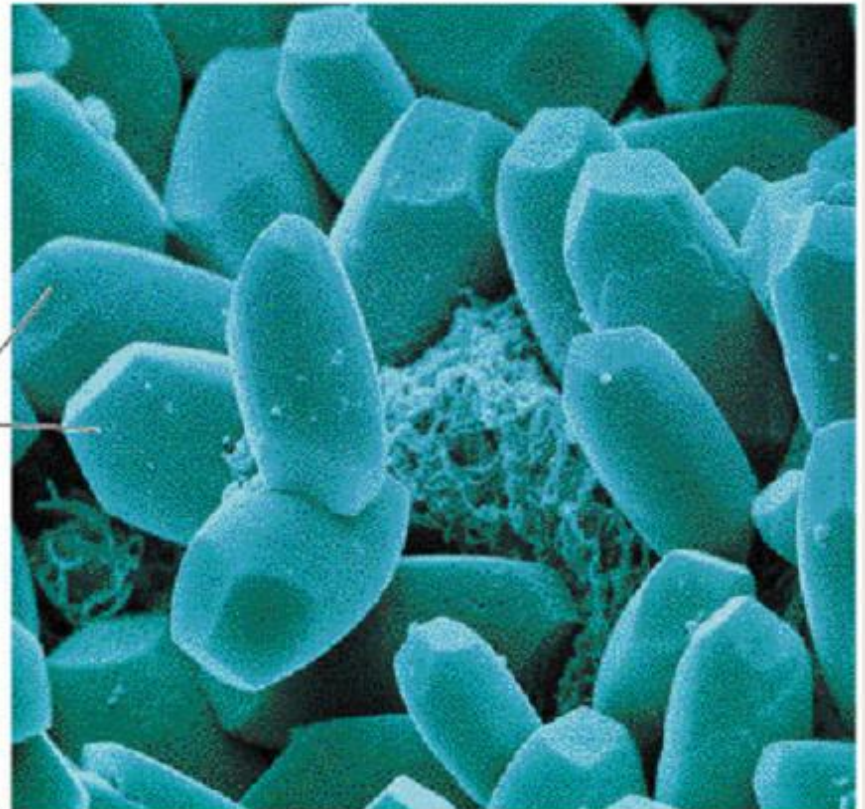
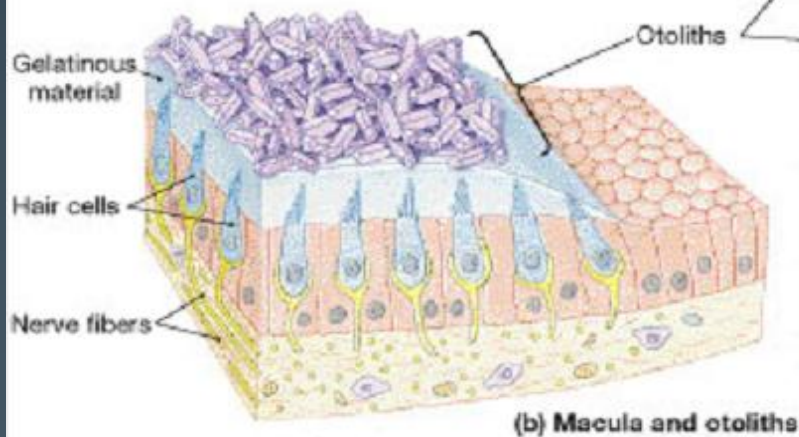
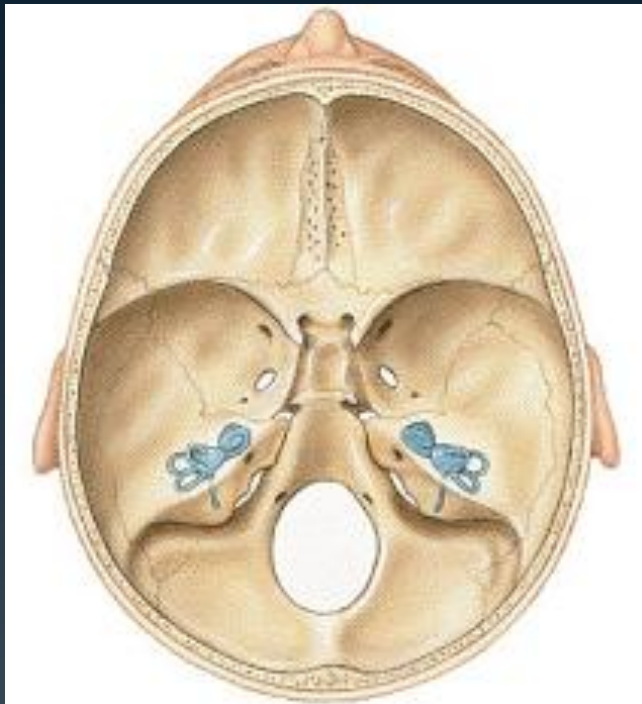


Pasteris et al.,
Elements 2008



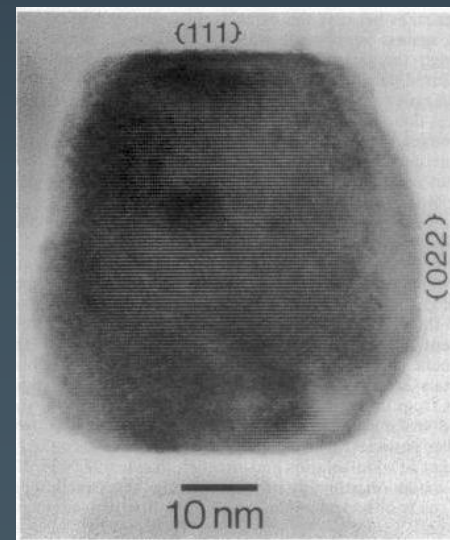
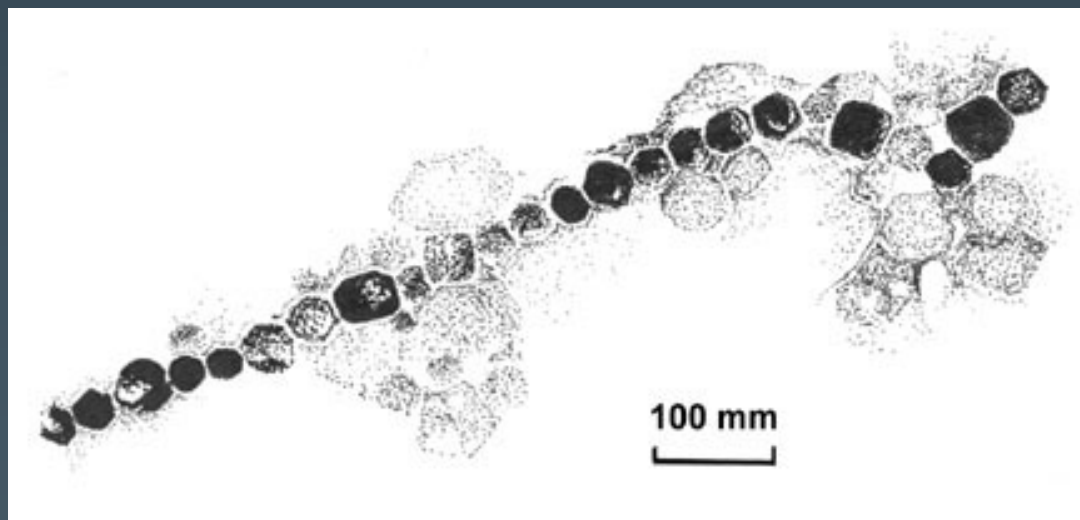
OTOLITES

Calcite *microcrystals*

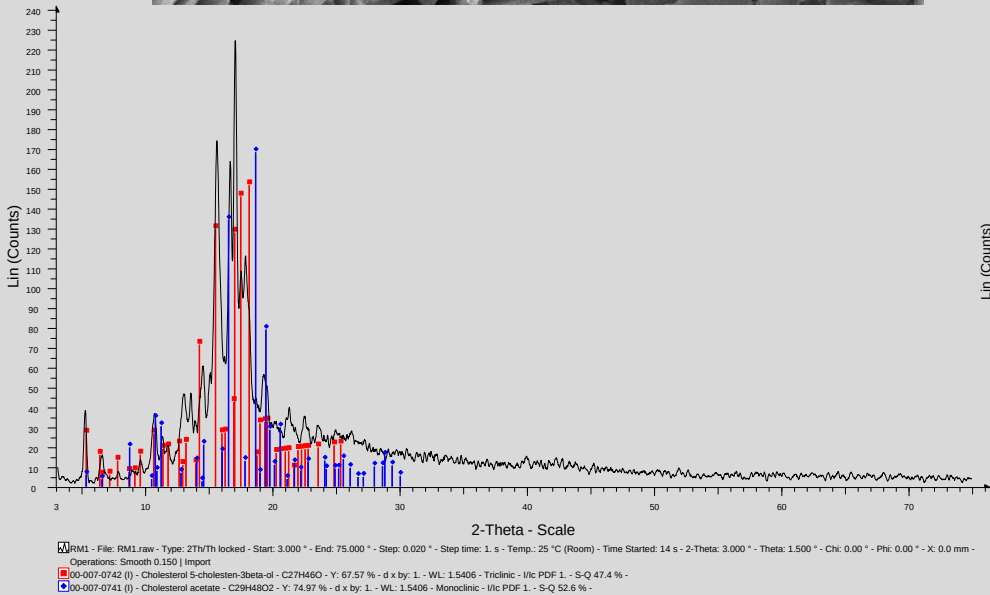
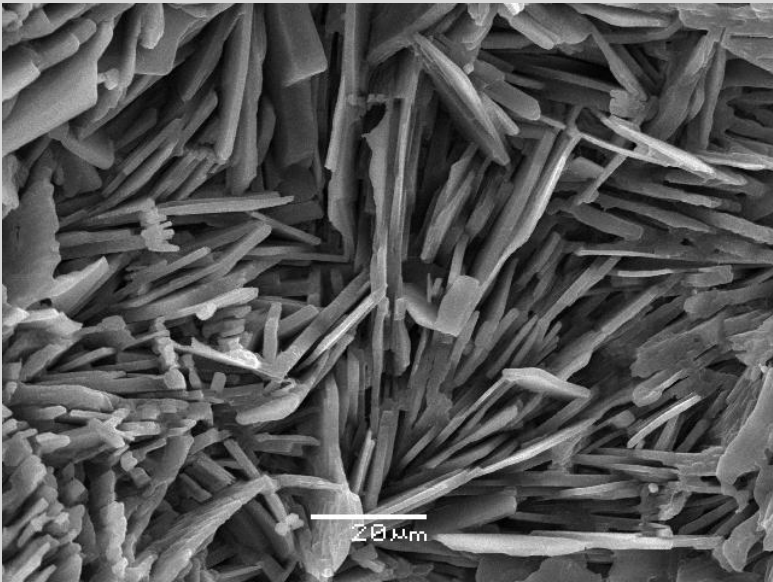




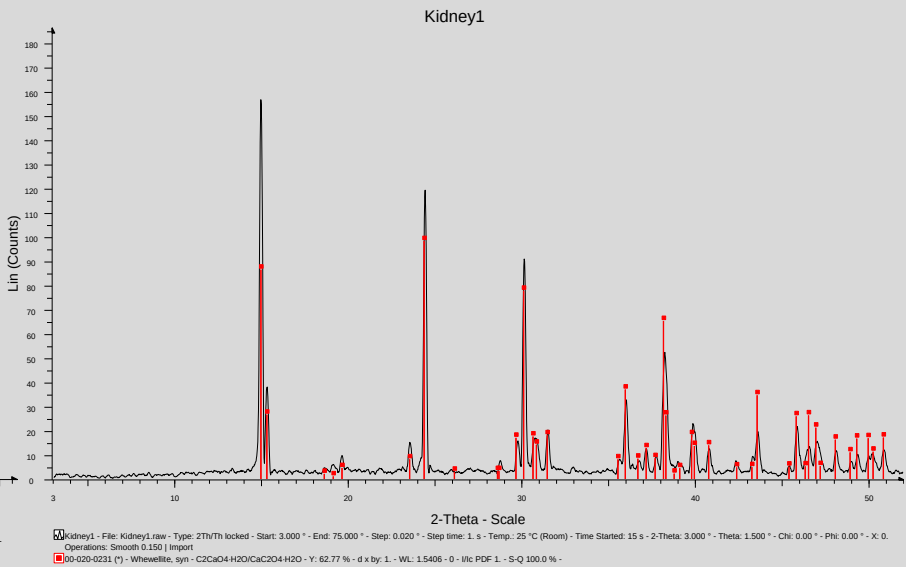
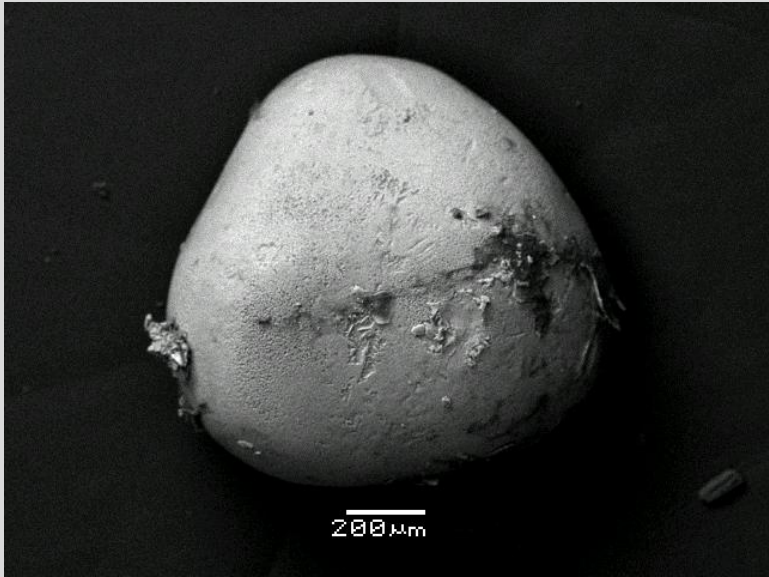
Magnetite *nanocrystals* Fe_3O_4



GALLSTONES



KIDNEY STONES

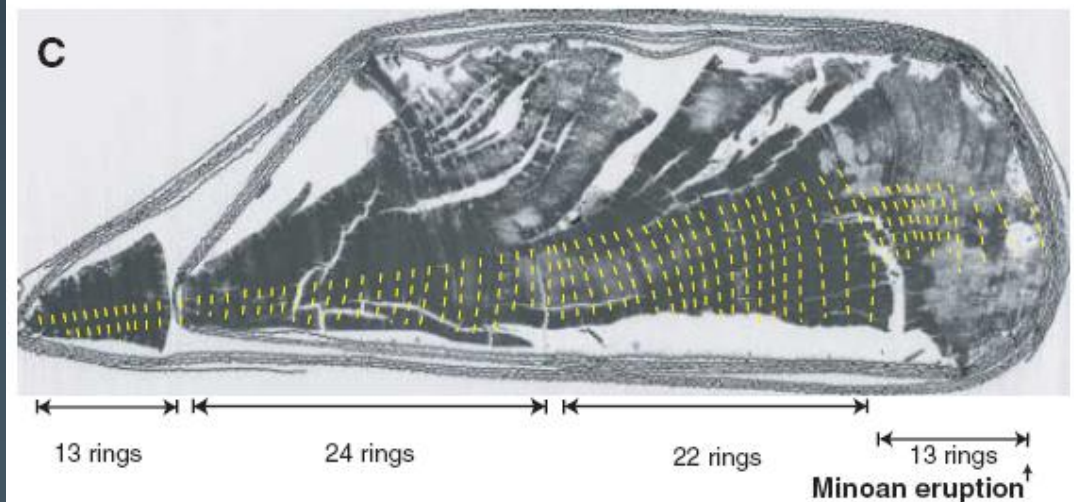
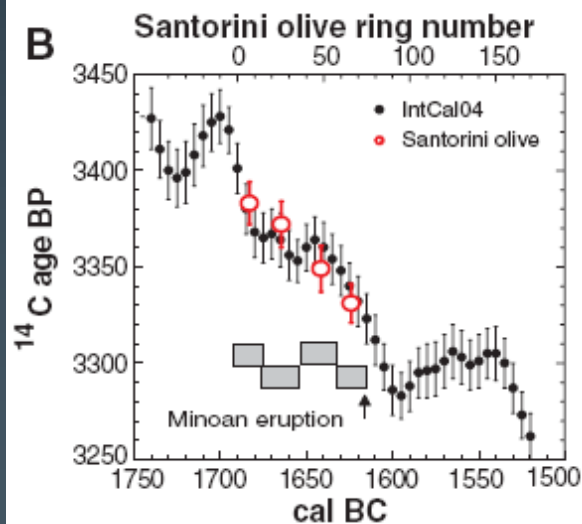


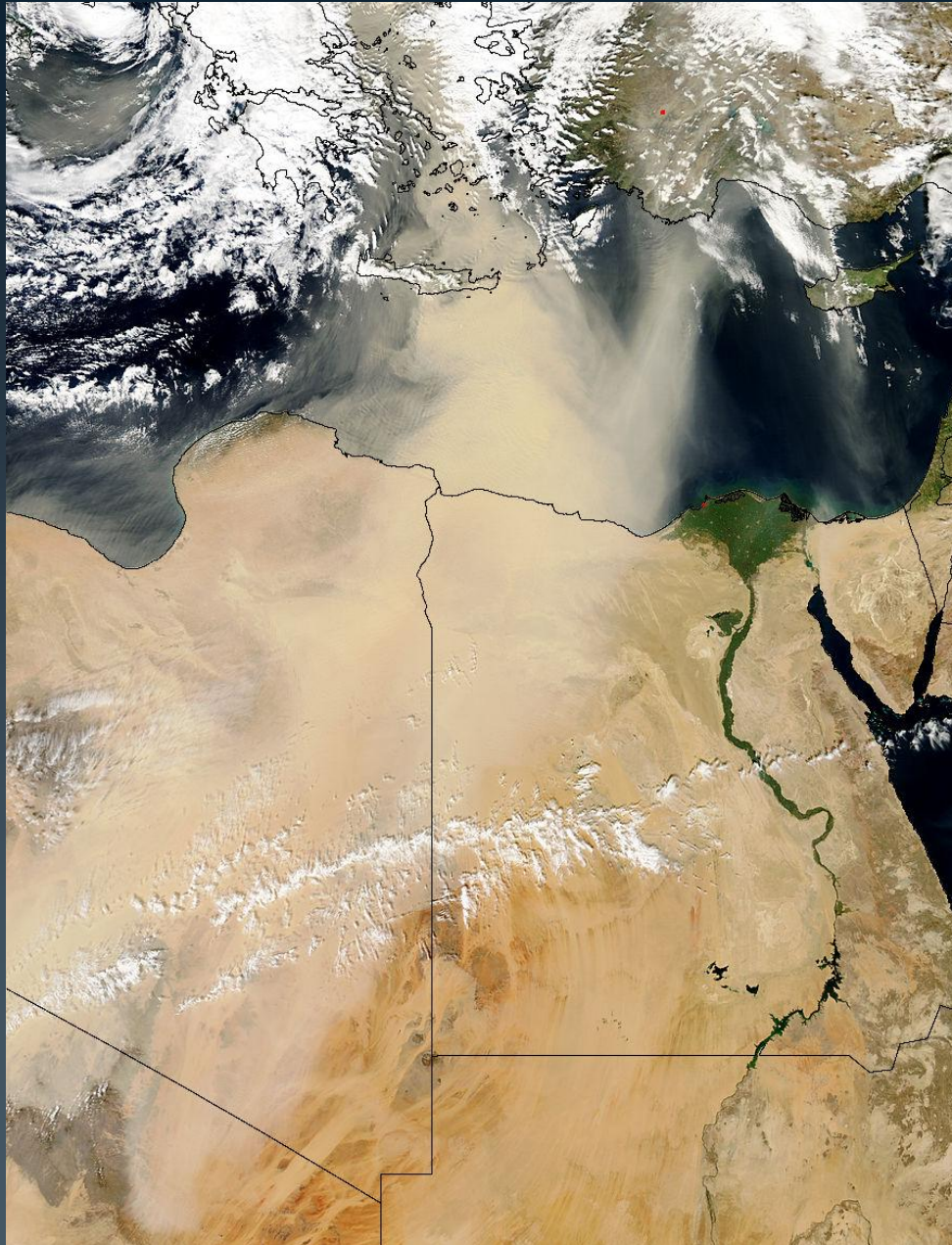


1939

Santorini Eruption Radiocarbon Dated to 1627–1600 B.C.

Walter L. Friedrich,^{1*} Bernd Kromer,² Michael Friedrich,^{2,3} Jan Heinemeier,⁴
Tom Pfeiffer,¹ Sahra Talamo²

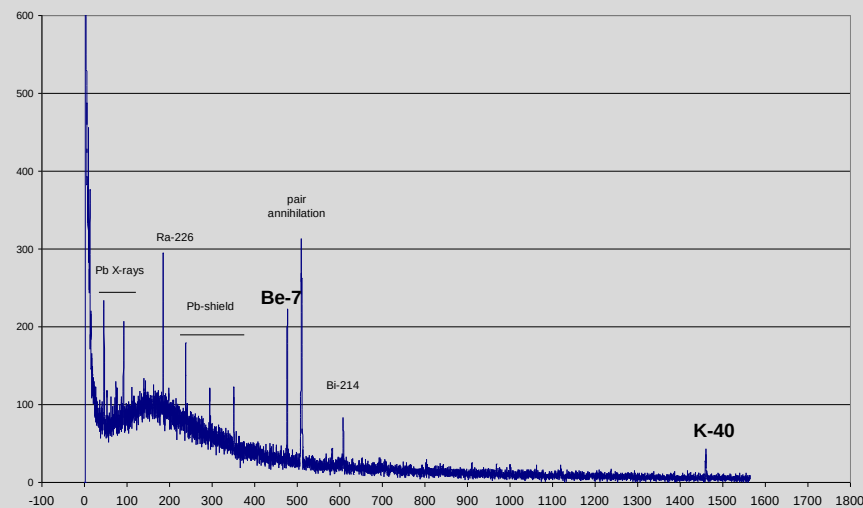
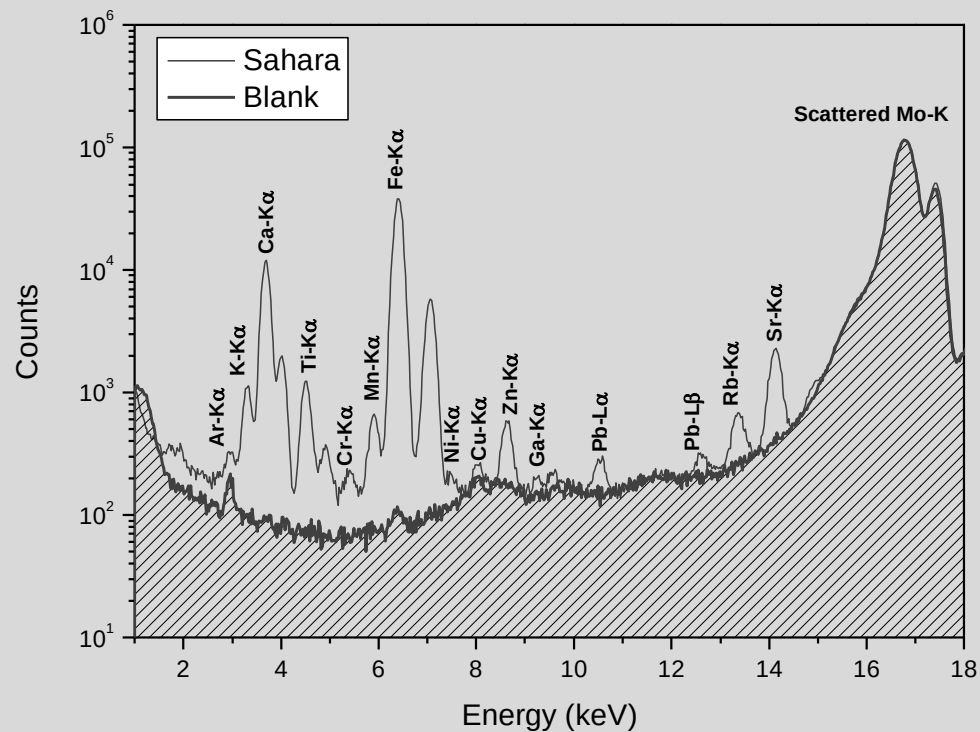
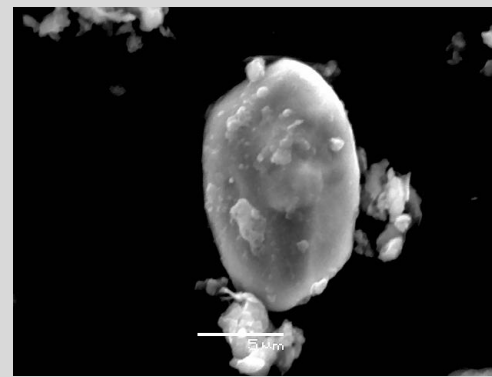
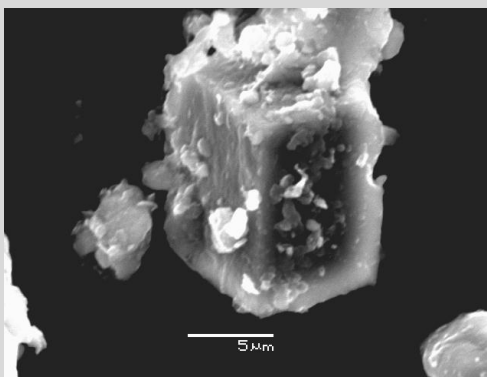
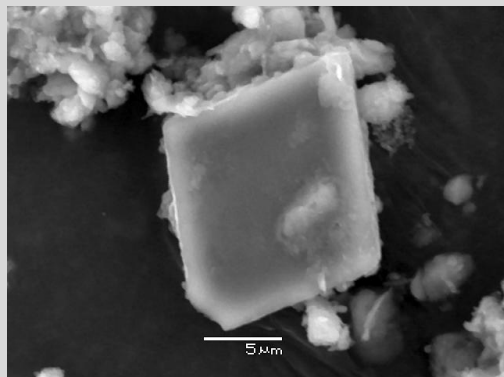




SAHARAN DUST & COLOURED RAIN (MUD RAIN)

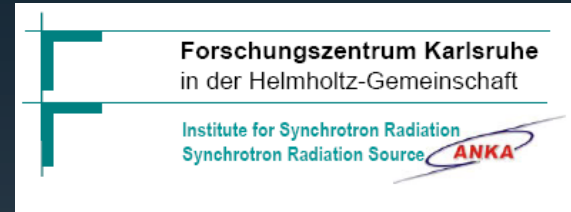
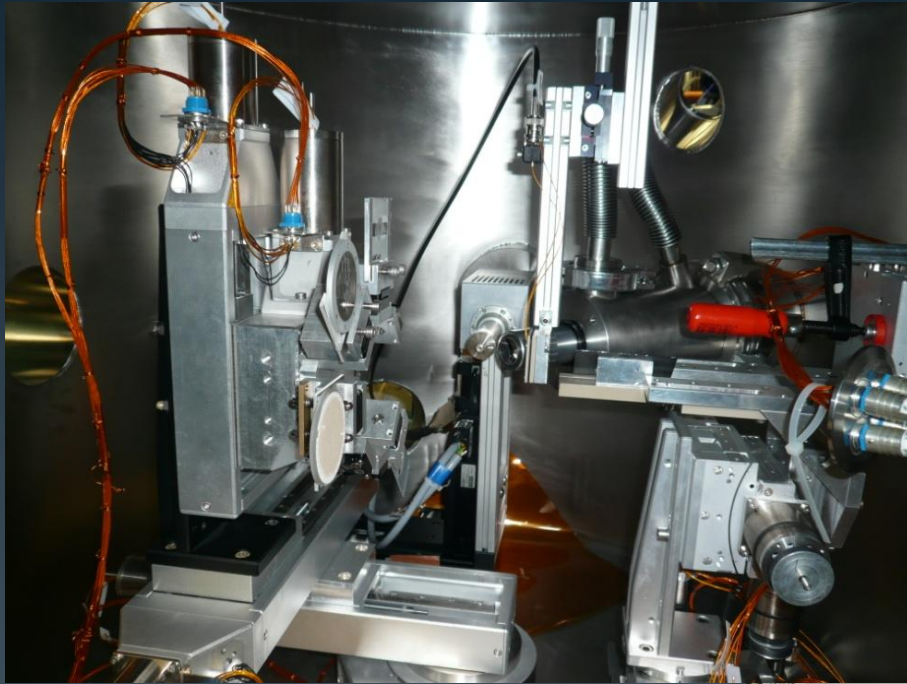


SAHARAN DUST

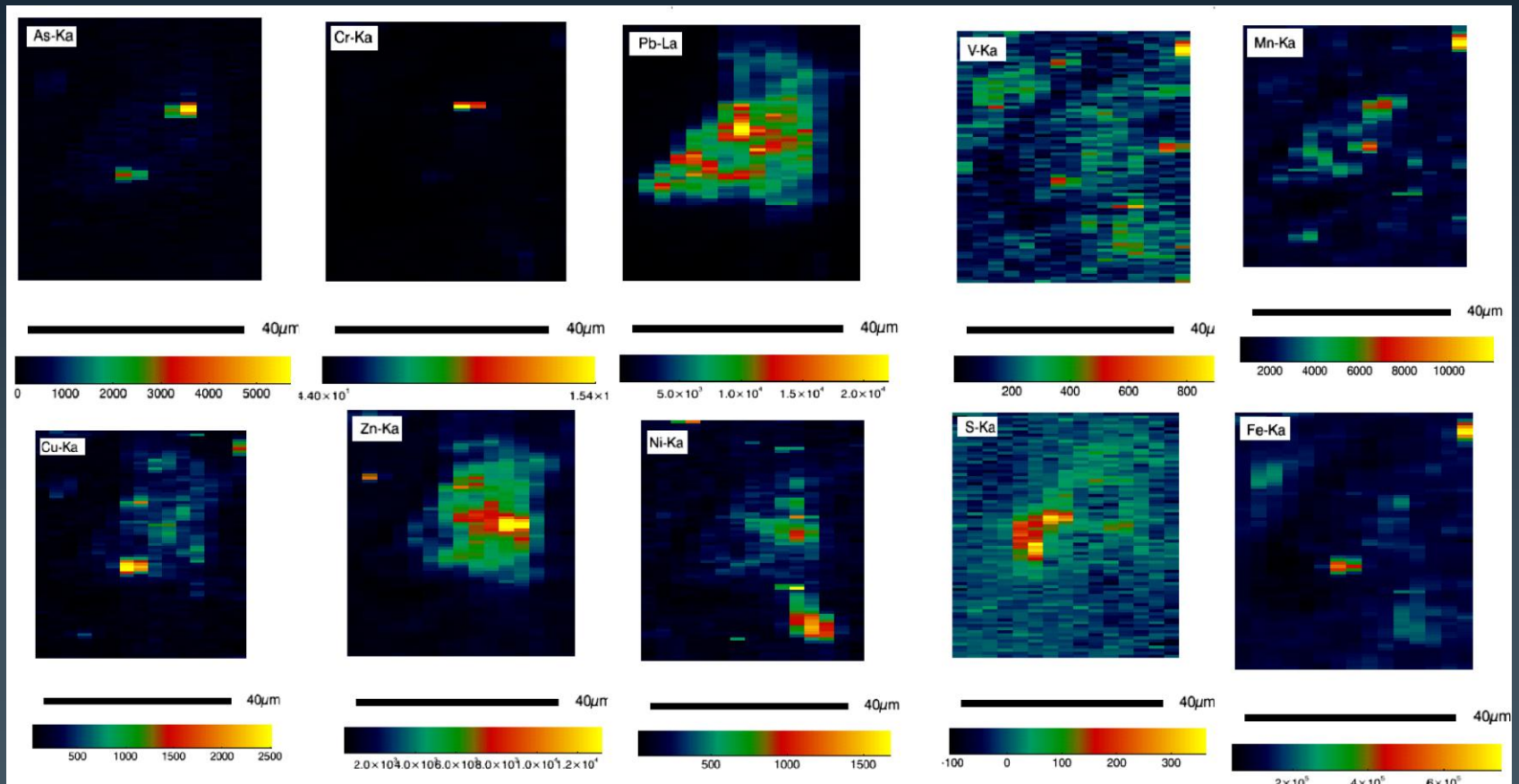


**Godelitsas et al.,
Goldschmidt 2011 (Prague)**

SR μ -XRF (FLUO beamline, ANKA Synchrotron)



SR μ -XRF (FLUO beamline, ANKA Synchrotron)



Godelitsas et al., Goldschmidt 2011 (Prague)

Key: atomic number Symbol name abridged standard atomic weight



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Isotope	Type	Half-life	Notes
Hydrogen-3 (³ H, tritium)	Light, radioactive	12.3 years	Produced by cosmic rays; exists in trace amounts in nature
Beryllium-7 (⁷ Be)	Alkaline earth metal	53.2 days	Produced by cosmic ray spallation in the atmosphere; trace amounts in air and rain; not primordial
Beryllium-10 (¹⁰ Be)	Alkaline earth metal	1.39 × 10 ⁶ years	Produced by cosmic ray spallation in the atmosphere; trace amounts in minerals, rocks, and ice cores; used in geochronology
Carbon-14 (¹⁴ C)	Light, radioactive	5,730 years	Formed by cosmic rays in the atmosphere; used in radiocarbon dating
Aluminium-26 (²⁶ Al)	Metal	7.17 × 10 ⁵ years	Cosmic ray spallation of Si in rocks; used in surface exposure dating
Chlorine-36 (³⁶ Cl)	Halogen	3.01 × 10 ⁵ years	Produced cosmogenically and by neutron activation of Cl-35 in rocks; trace amounts in minerals; used in dating
Argon-39 (³⁹ Ar)	Noble gas	269 years	Trace amounts in atmosphere and rocks; produced by cosmic rays and K-40 decay
Sodium-22 (²² Na)	Metal	2.6 years	Produced by cosmic ray interaction with Ar in the atmosphere; short-lived tracer
Potassium-40 (⁴⁰ K)	Alkali metal	1.25 × 10 ⁹ years	Naturally present in minerals; small radioactive fraction of potassium
Titanium-44 (⁴⁴ Ti)	Metal	60 years	Produced by cosmic ray spallation on Ca and Ti in meteorites
Manganese-53 (⁵³ Mn)	Metal	3.7 × 10 ⁶ years	Produced by cosmic ray spallation of Fe; used in meteorite studies and surface exposure dating
Rubidium-87 (⁸⁷ Rb)	Alkali metal	4.88 × 10 ¹⁰ years	Half-life longer than Earth's age and over 3 times the age of the universe; <i>practically stable</i> ; ~28% of natural Rb

Technetium-97 (⁹⁷ Tc)	Metal	4.21 × 10 ⁶ years	Produced by neutron capture in U ores; exists only in trace amounts today
Tellurium-128 (¹²⁸ Te)	Metalloid	~2.2 × 10 ²⁴ years	Half-life longer than Earth's age and the age of the universe; <i>practically stable</i> ; ~31.7% of natural Te
Promethium-147 (¹⁴⁷ Pm)	Lanthanide metal	2.62 years	Produced naturally in extremely small traces as a fission product of U-238 in U-rich minerals
Samarium-147 (¹⁴⁷ Sm)	Lanthanide metal	1.06 × 10 ¹¹ years	Half-life far longer than both the Earth and Universe.; <i>practically stable</i> ; ~15% of natural Sm
Thallium-208 (²⁰⁸ Tl)	Metal	3.05 minutes	Part of Th-232 decay chain (Pb-212 → Tl-208 → Po-208 → Pb-208); transient in Th-rich minerals
Lead-210 (²¹⁰ Pb)	Metal	22.3 years	Part of U-238 decay chain; found in soil, sediments, and air via radon decay
Lead-212 (²¹² Pb)	Metal	10.6 hours	Part of Th-232 decay chain; present in thorium-bearing rocks
Lead-214 (²¹⁴ Pb)	Metal	26.8 minutes	Part of U-238 decay chain via Rn-222; very short-lived
Bismuth-209 (²⁰⁹ Bi)	Metal	1.9 × 10 ¹⁹ years	Half-life longer than Earth's age and the age of the universe; <i>practically stable</i> ; ~100% of natural Bi
Bismuth-210 (²¹⁰ Bi)	Metal	5.01 days	Part of U-238 decay chain (²¹⁰ Pb → ²¹⁰ Bi → ²¹⁰ Po); short-lived
Bismuth-212 (²¹² Bi)	Metal	60.55 minutes	Part of Th-232 decay chain; short-lived
Bismuth-214 (²¹⁴ Bi)	Metal	19.9 minutes	Part of U-238 decay chain; short-lived
Polonium isotopes (e.g., ²¹⁰ Po)	Post-transition metal	138 days	Part of U-238 decay chain; short-lived
Astatine isotopes (e.g., ²¹¹ At)	Halogen	7.2 hours	Very short-lived; trace amounts in nature
Radon isotopes (e.g., ²²² Rn)	Noble gas	3.8 days	Produced by Ra decay (U-238 chain); occurs in soil and rocks
Francium isotopes (e.g., ²²³ Fr)	Alkali metal	22 minutes	Extremely rare; from decay chains
Radium isotopes (e.g., ²²⁶ Ra)	Alkaline earth metal	1,600 years	Decay products of U-238
Actinium-227 (²²⁷ Ac)	Actinide metal	21.77 years	Part of U-235 decay chain; trace amounts
Actinium-228 (²²⁸ Ac)	Actinide metal	6.15 hours	Part of Th-232 decay chain (Ra-228 → Ac-228 → Th-228); transient in Th-rich minerals

Thorium-228 (^{228}Th)	Actinide metal	1.91 years	Short-lived decay product of Ra-224 in the Th-232 decay chain; transient in Th-rich minerals
Thorium-230 (^{230}Th)	Actinide metal	7.538×10^4 years	Radioactive decay product of U-234; trace amounts in uranium ores and sediments
Thorium-232 (^{232}Th)	Actinide metal	1.41×10^{10} years	Major primordial radionuclide
Protactinium-231 (^{231}Pa)	Actinide metal	32,760 years	Part of U-235 decay chain; trace amounts
Protactinium-234 (^{234}Pa)	Actinide metal	6.7 hours (Pa-234m: 1.17 minutes)	Daughter of U-238 decay chain (U-238 $\rightarrow$ Th-234 $\rightarrow$ Pa-234 $\rightarrow$ U-234); exists transiently in uranium ores; very short-lived
Uranium-234 (^{234}U)	Actinide metal	2.455×10^5 years	Alpha emitter; part of U-238 decay chain (U-238 $\rightarrow$ Th-234 $\rightarrow$ Pa-234m $\rightarrow$ U-234 $\rightarrow$ Th-230); found in uranium ores; ~0.0055% of natural uranium
Uranium-235 (^{235}U)	Actinide metal	7.04×10^8 years	Minor primordial uranium isotope
Uranium-238 (^{238}U)	Actinide metal	4.47×10^9 years	Major primordial uranium isotope
Plutonium-244 (^{244}Pu)	Actinide metal	8×10^7 years	Trace primordial isotope from nucleosynthesis; not from U/Th decay

The Karlsruhe Nuclide Chart

A nuclide chart is a two dimensional representation of the nuclear and radioactive properties of all known atoms. A nuclide is the generic name for atoms characterized by the constituent protons and neutrons. The nuclide chart arranges nuclides according to the number of protons (vertical axis) and neutrons (horizontal axis) in the nucleus. Each nuclide in the chart is represented by a box containing the element symbol and mass number, half-life, decay types and decay energies, etc.

"Magic" numbers

In nuclear physics, a magic number is a number of protons or neutrons (e.g. 2, 8, 20, 28, 50, 82, 126) which give rise to a complete shell in the atomic nucleus. Lead 208 for example, which consists of 82 protons and 126 neutrons, is called "doubly magic" since both the proton and neutron numbers are "magic".

Number of protons (Z)

Number of neutrons (N)

N=28

Z=20 Calcium

Lead Z=82

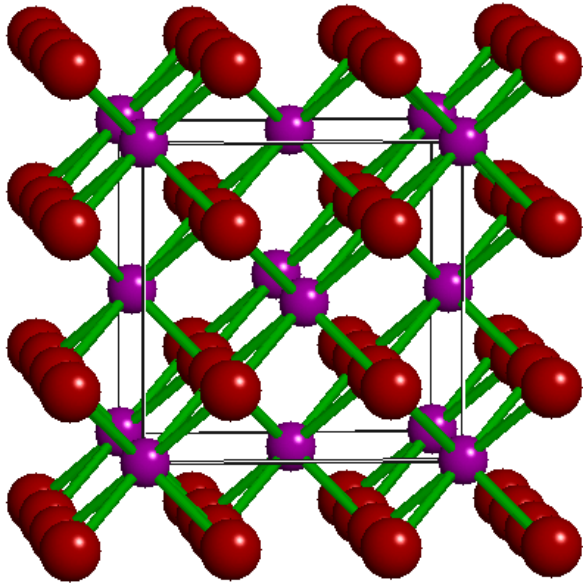
N=126

Examples of the nuclide box structure

Th 232 100 1.40 · 10 ¹⁰ a α 4.012, 3.947... γ (64...), e ⁻ , sf α 7.37, σ 3E-6	Ac 226 29.37 h β ⁻ 0.9, 1.1 α 5.40 γ 230, 158, 254 186...
Ra 225 14.9 d β ⁻ 0.3, 0.4 γ 40, e ⁻	Bi 207 31.55 a e ⁻ , β ⁺ ... γ 570, 1064 1770...
Cs 135 53 m 2.3 · 10 ⁶ a IT 846 γ 787 β ⁻ 0.3 no γ g α 8.3	Rn 219 3.96 s α 6.819, 6.553 6.425... γ 271, 402...

Black squares represent stable atoms. Other colours indicate the modes of radioactive decay, e.g. by emission of alpha particles (α), beta particles (β), neutrons (n), etc.

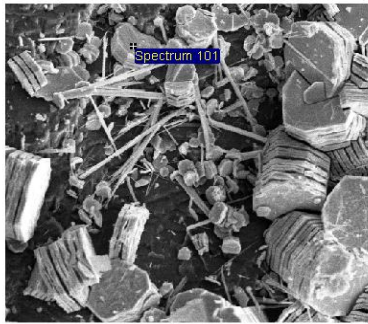
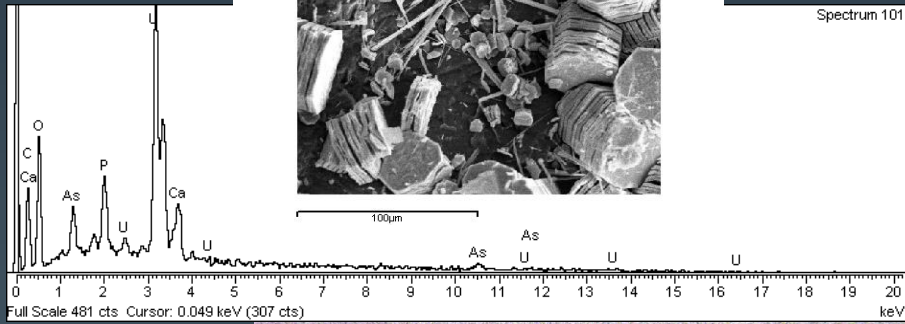
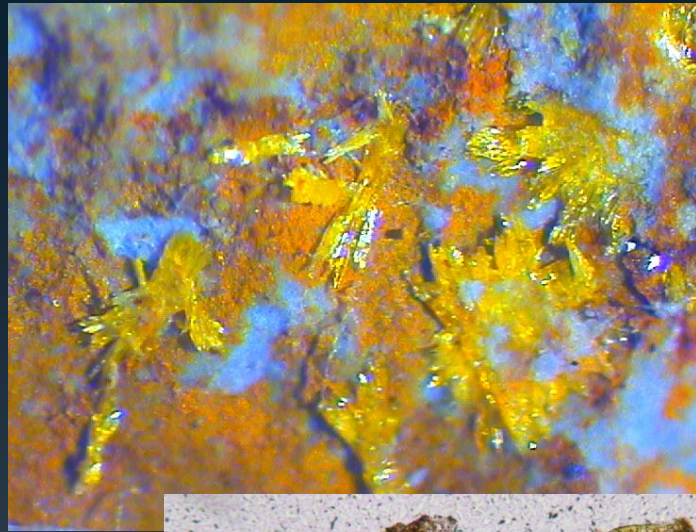
stable	p	α	ε β ⁺	IT	β ⁻	sf	CE	n
--------	---	---	---------------------	----	----------------	----	----	---



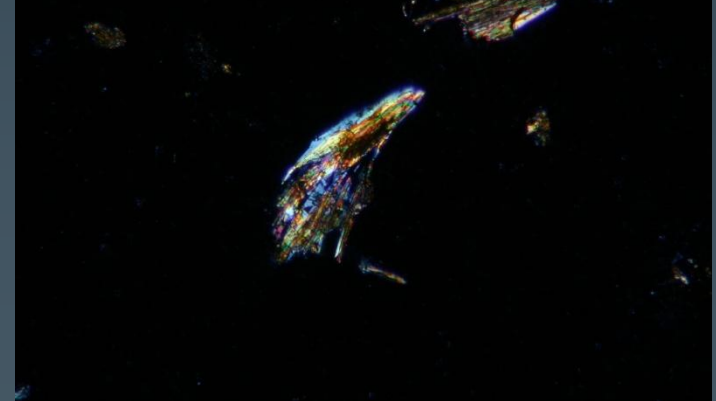
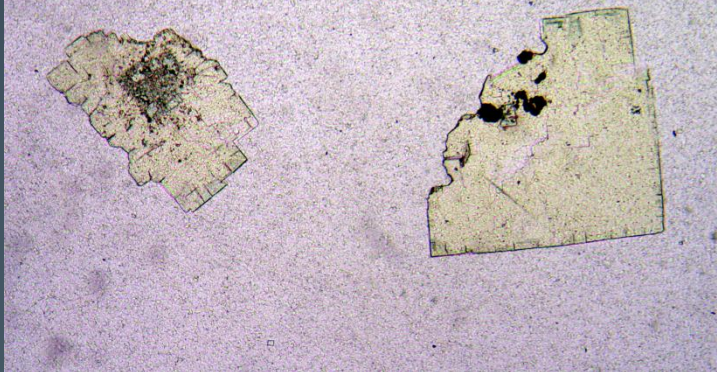
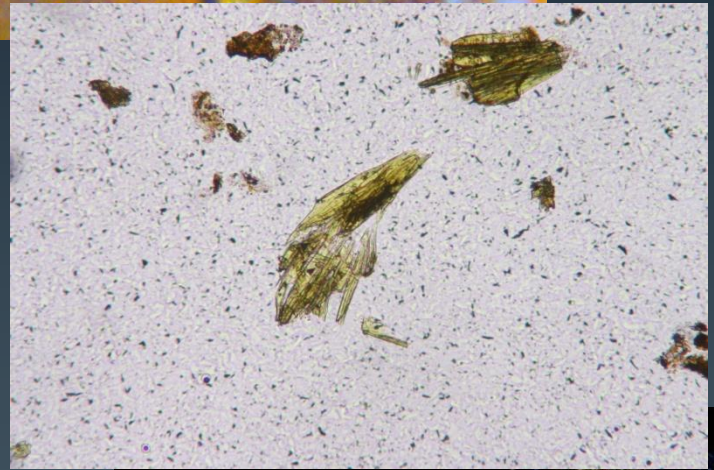
URANINITE: UO_2



PITCHBLEND: $\text{UO}_2 + \text{UO}_3 + \text{Th} + \text{REE}$



Spectrum 101



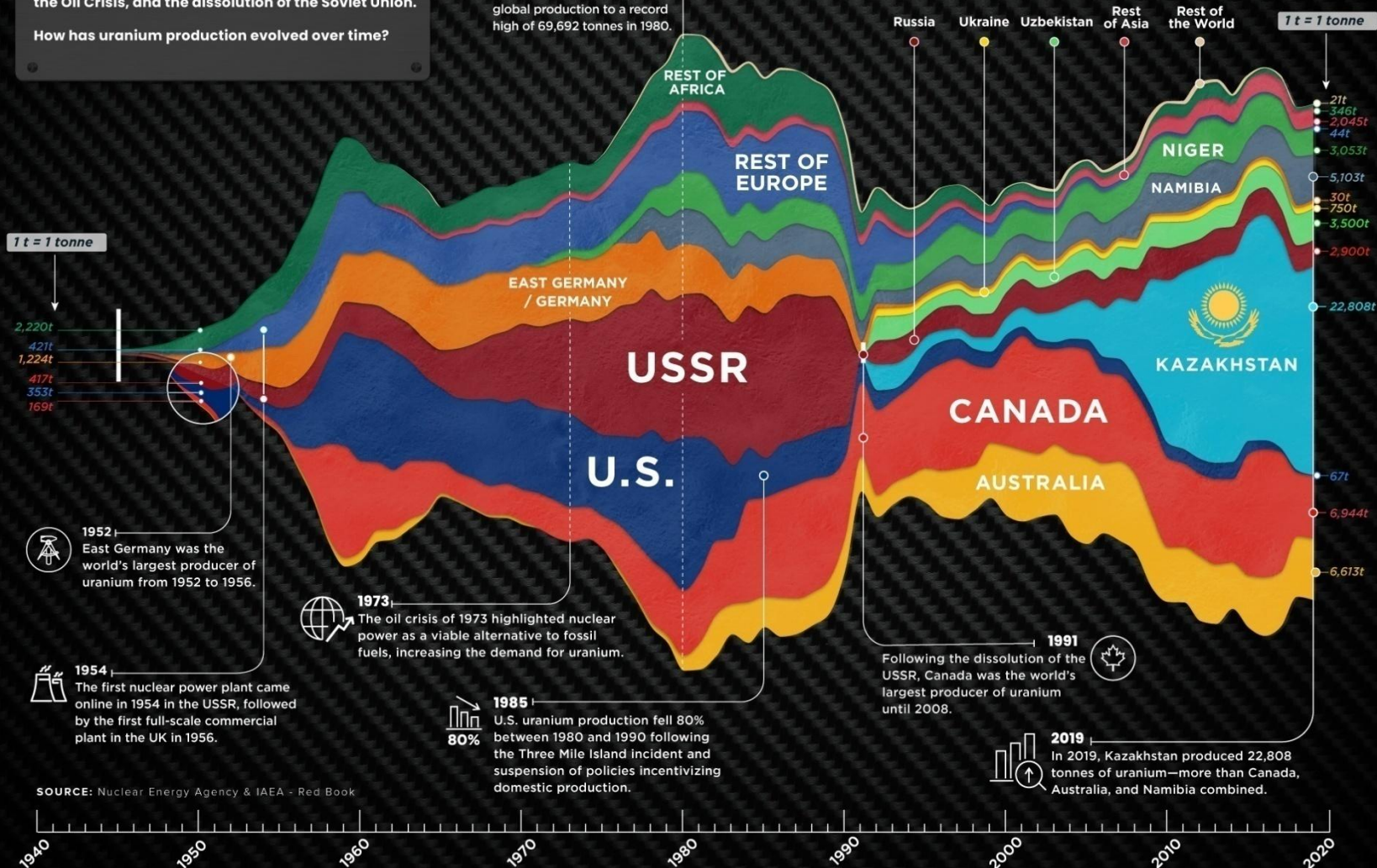
70 YEARS OF URANIUM PRODUCTION VISUALIZED

Throughout history, uranium production has been influenced by world events, including the Cold War, the Oil Crisis, and the dissolution of the Soviet Union.

How has uranium production evolved over time?



1980
Uranium production in the U.S. and USSR peaked during the Cold War, driving global production to a record high of 69,692 tonnes in 1980.



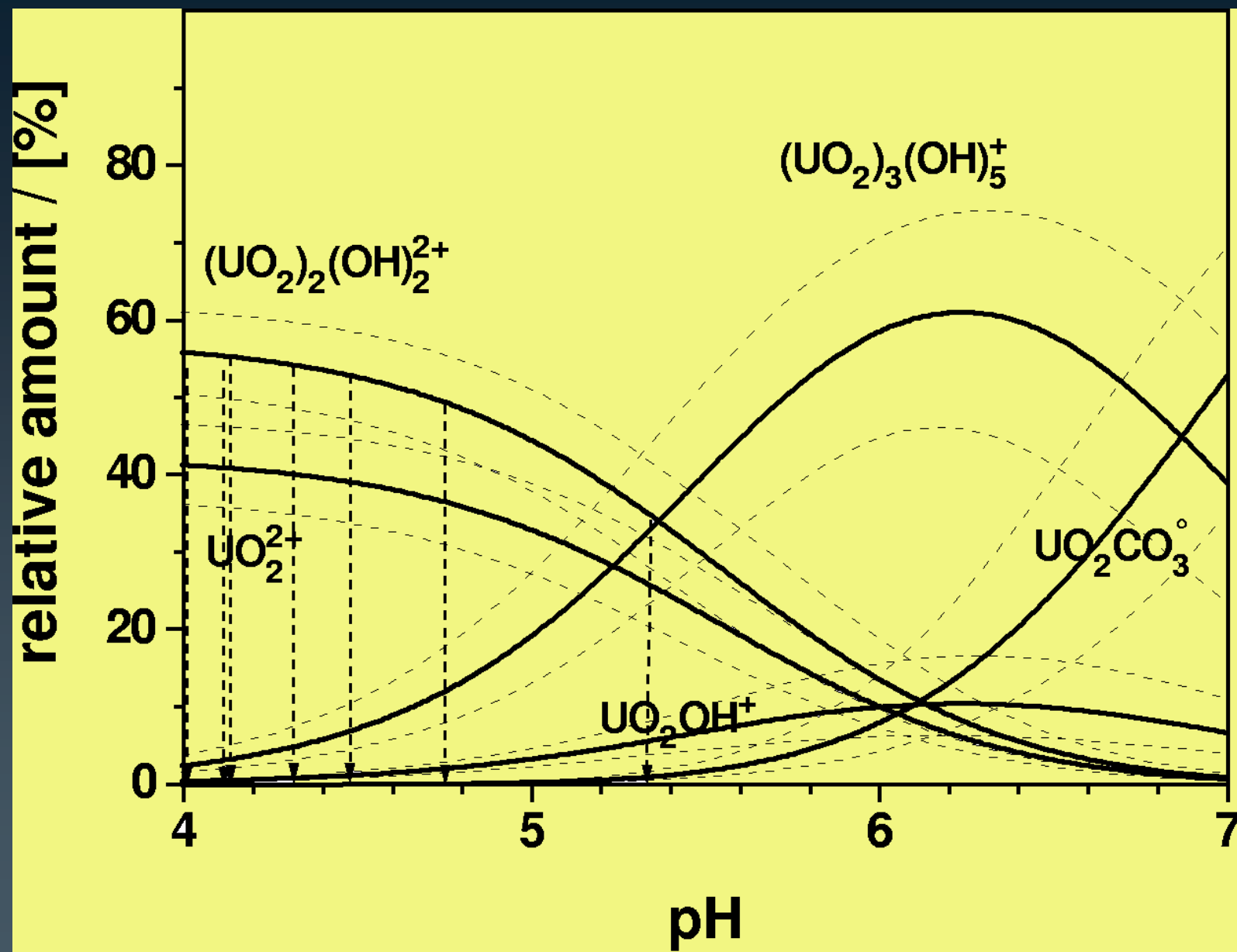
SOURCE: Nuclear Energy Agency & IAEA - Red Book

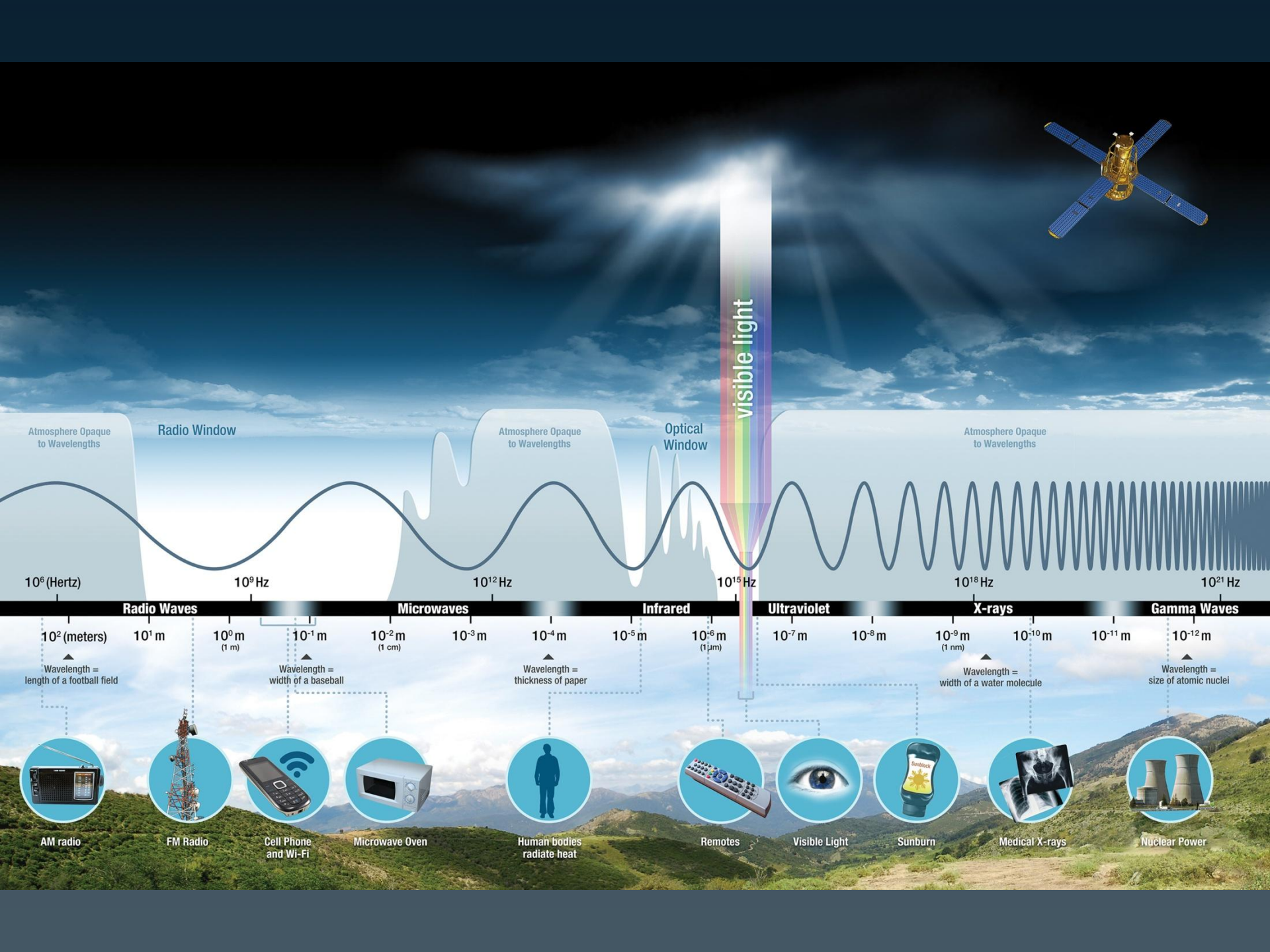


The Cigar Lake Project is the world's highest-grade U mine ((average grade 15% U_3O_8 , the highest in the world; since 2015), located in northern Saskatchewan, Canada, operated by Cameco Corporation. It produces roughly 11% of global annual U demand. Mining at Cigar lake takes place 480 m below the surface. The ore mined at Cigar Lake is processed at the McClean Lake Mill. The mill can produce ~10000 tonnes of yellowcake (U concentrate) annually and total production of ~8.16 tonnes of U_3O_8 .



	Th	U	Np	Pu	Am
+6		$(\text{UO}_2)^{2+}$		$(\text{PuO}_2)^{2+}$	
+5			$(\text{NpO}_2)^+$	$(\text{PuO}_2)^+$	
+4	Th^{4+}	U^{4+}	Np^{4+}	Pu^{4+}	
+3				Pu^{3+}	Am^{3+}

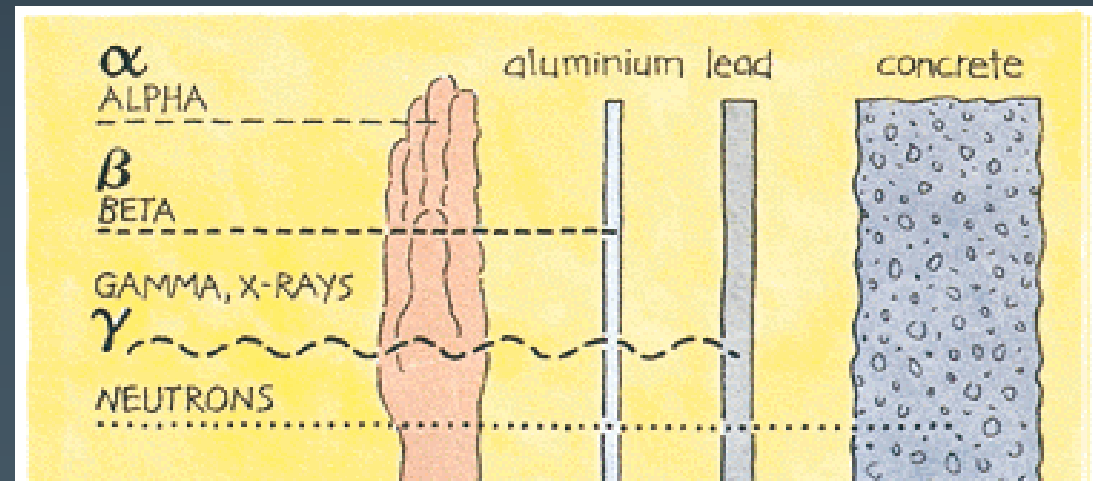
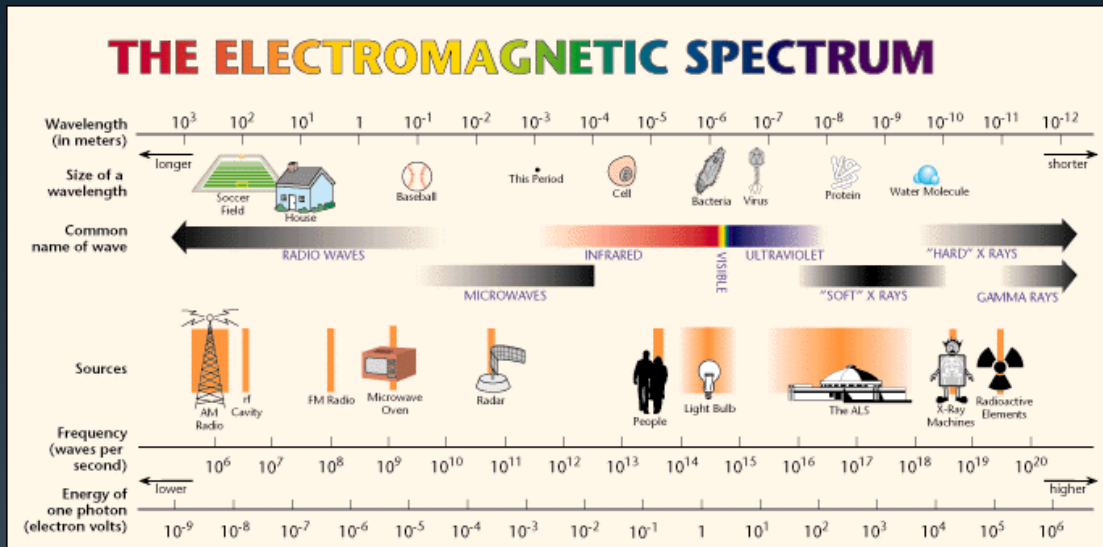




URANIUM 238 (U238) RADIOACTIVE DECAY

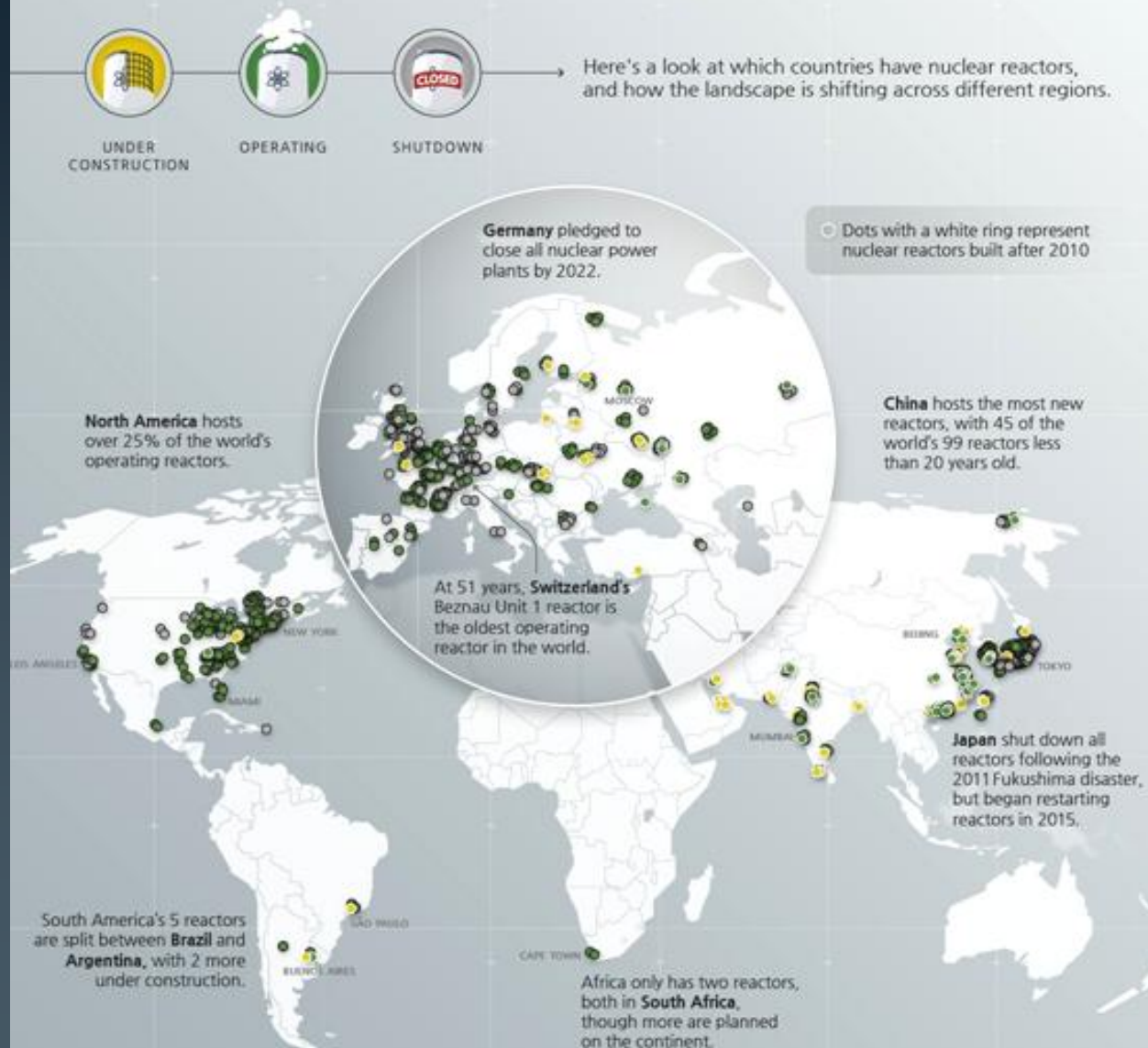
type of radiation	nuclide	half-life
α	uranium-238	4.47 billion years
	thorium-234	24.1 days
β	protactinium-234m	1.17 minutes
β	uranium-234	245000 years
α	thorium-230	8000 years
α	radium-226	1600 years
α	radon-222	3.823 days
α	polonium-218	3.05 minutes
α	lead-214	26.8 minutes
β	bismuth-214	19.7 minutes
β	polonium-214	0.000164 seconds
α	lead-210	22.3 years
β	bismuth-210	5.01 days
β	polonium-210	138.4 days
α	lead-206	stable

RADIOACTIVITY



THE WORLD'S NUCLEAR REACTOR LANDSCAPE

Some countries see nuclear energy as an environmental danger.
Others are embracing it as a climate-change fighting solution.



^{238}U ($\sim 99.27\%$) ^{235}U (0.72 %)

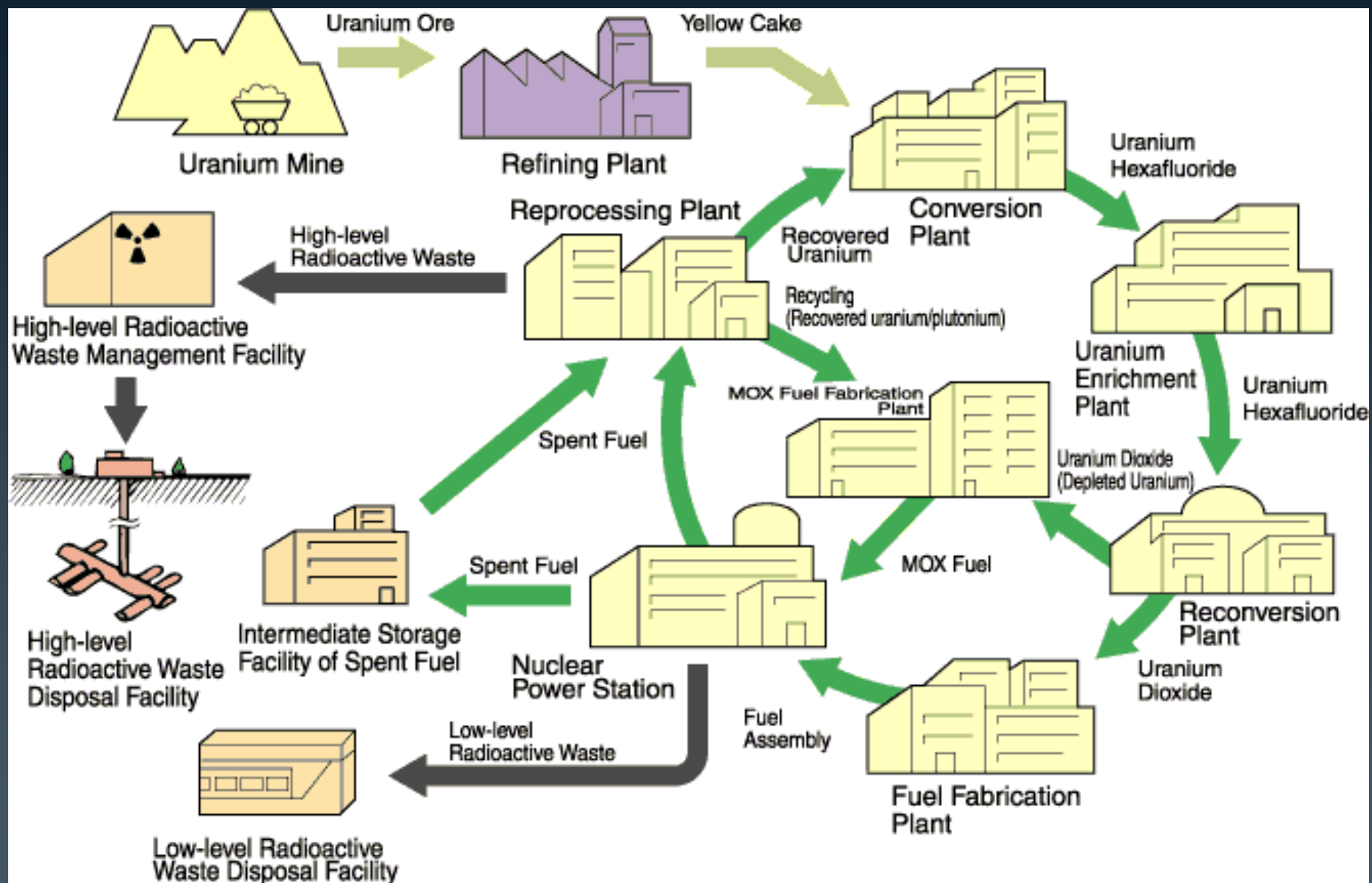
! DEPLETED URANIUM !

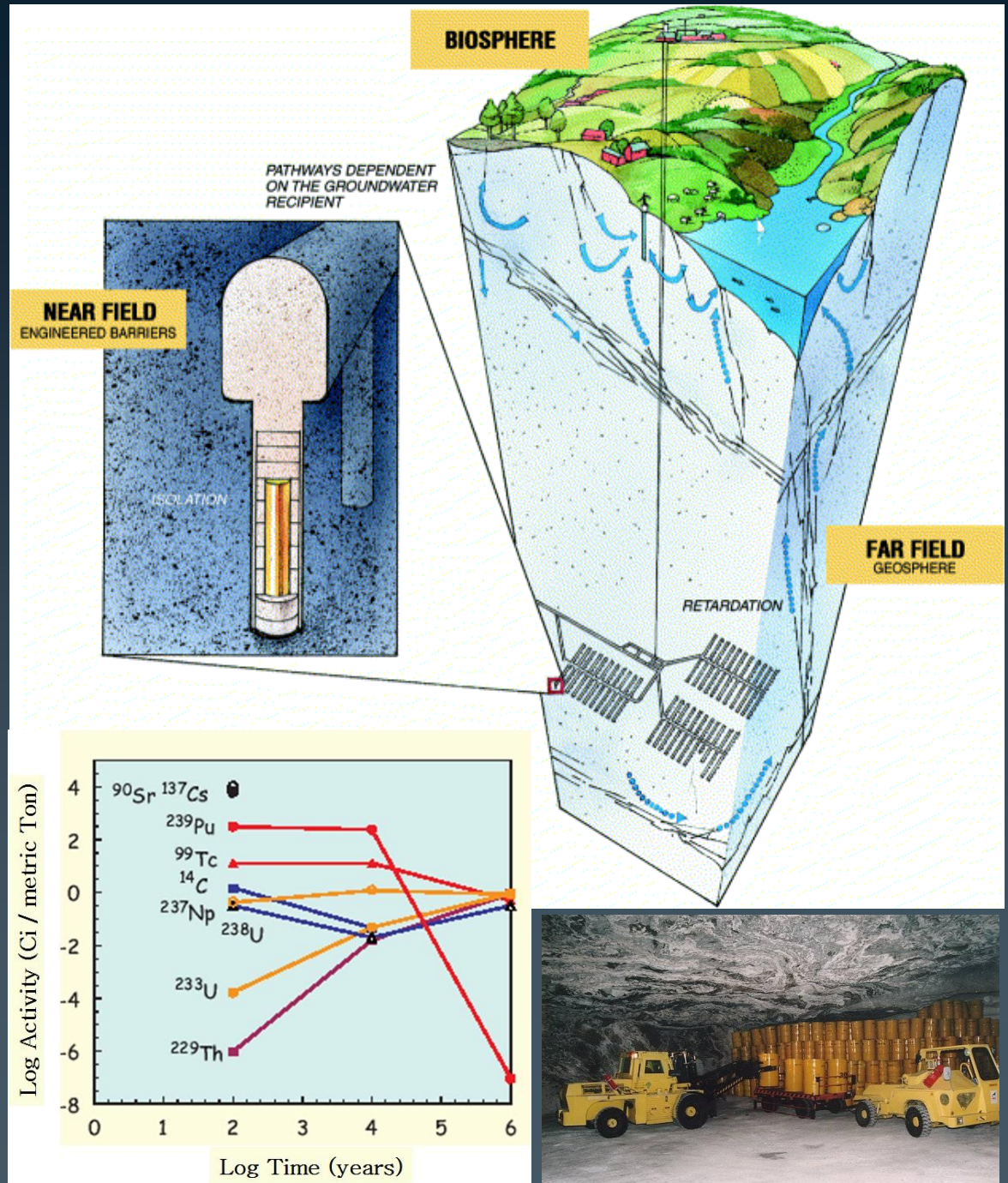


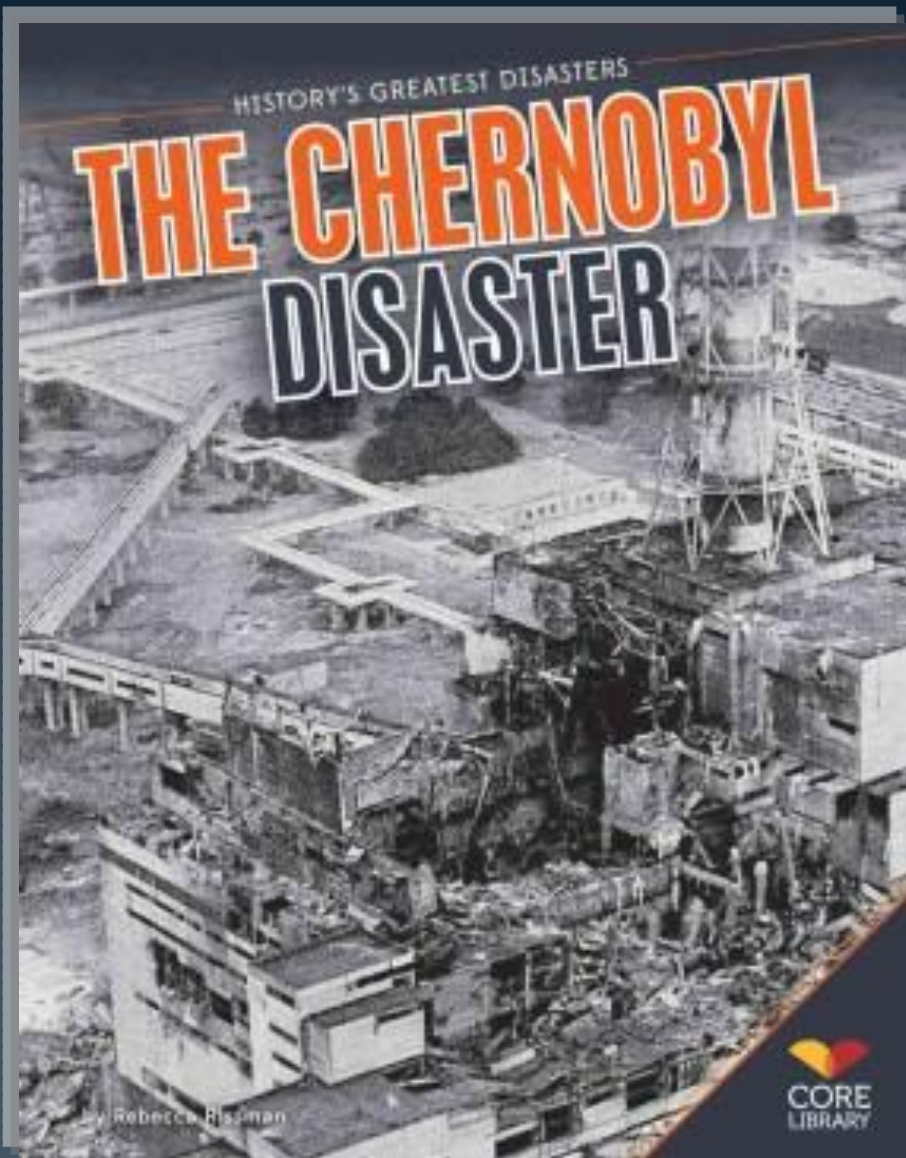


Schoepite, $[(\text{UO}_2)_8\text{O}_2(\text{OH})_{12}](\text{H}_2\text{O})_{12}$,
transforms slowly in air at ambient
temperature to
Metaschoepite, $\text{UO}_3 \cdot n\text{H}_2\text{O}$,
and crystals commonly contain an intergrowth
of both minerals









On 26 April 1986, reactor no.4 of the Chernobyl Nuclear Power Plant, located near Pripyat, Ukrainian SSR, Soviet Union (later Ukraine), exploded.

Short-term danger (days–weeks):

^{131}I , ^{133}Xe , ^{132}Te

Medium-term (years):

^{134}Cs

Long-term (decades+):

^{137}Cs , ^{90}Sr

Ultra-long-term (localized):

Pu isotopes

Cesium-133 (^{133}Cs)

Status: The only stable, naturally occurring cesium isotope

Abundance: ~**100% of natural cesium**

Half-life: Stable (does not decay)

Origin: Primordial (formed in stellar nucleosynthesis before the Solar System formed)

Cesium-134 (^{134}Cs)

Half-life: ~2 years

Radiation: Beta + gamma

Role: Important in the first decade after release, then mostly disappears

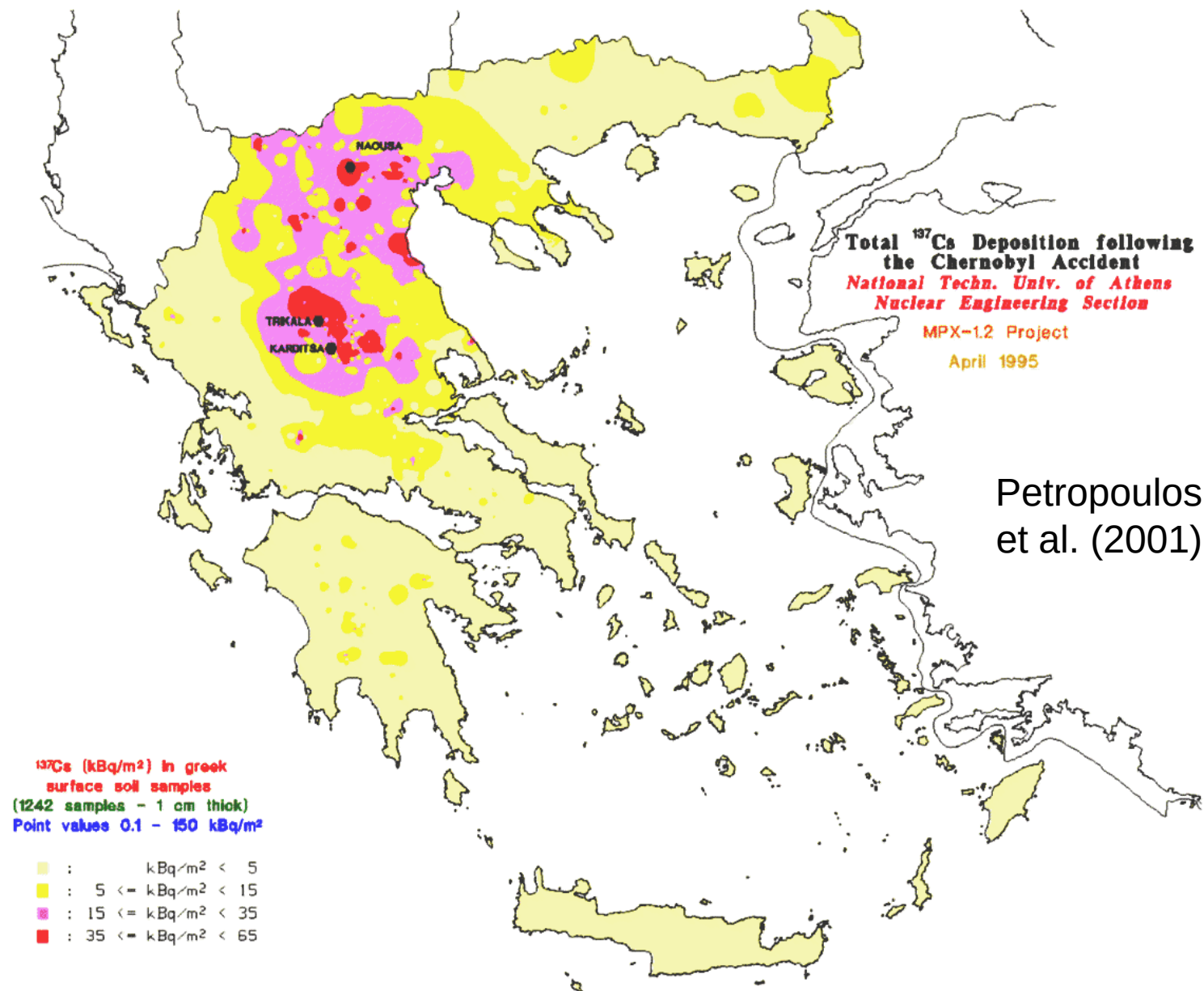
Cesium-137 (^{137}Cs)

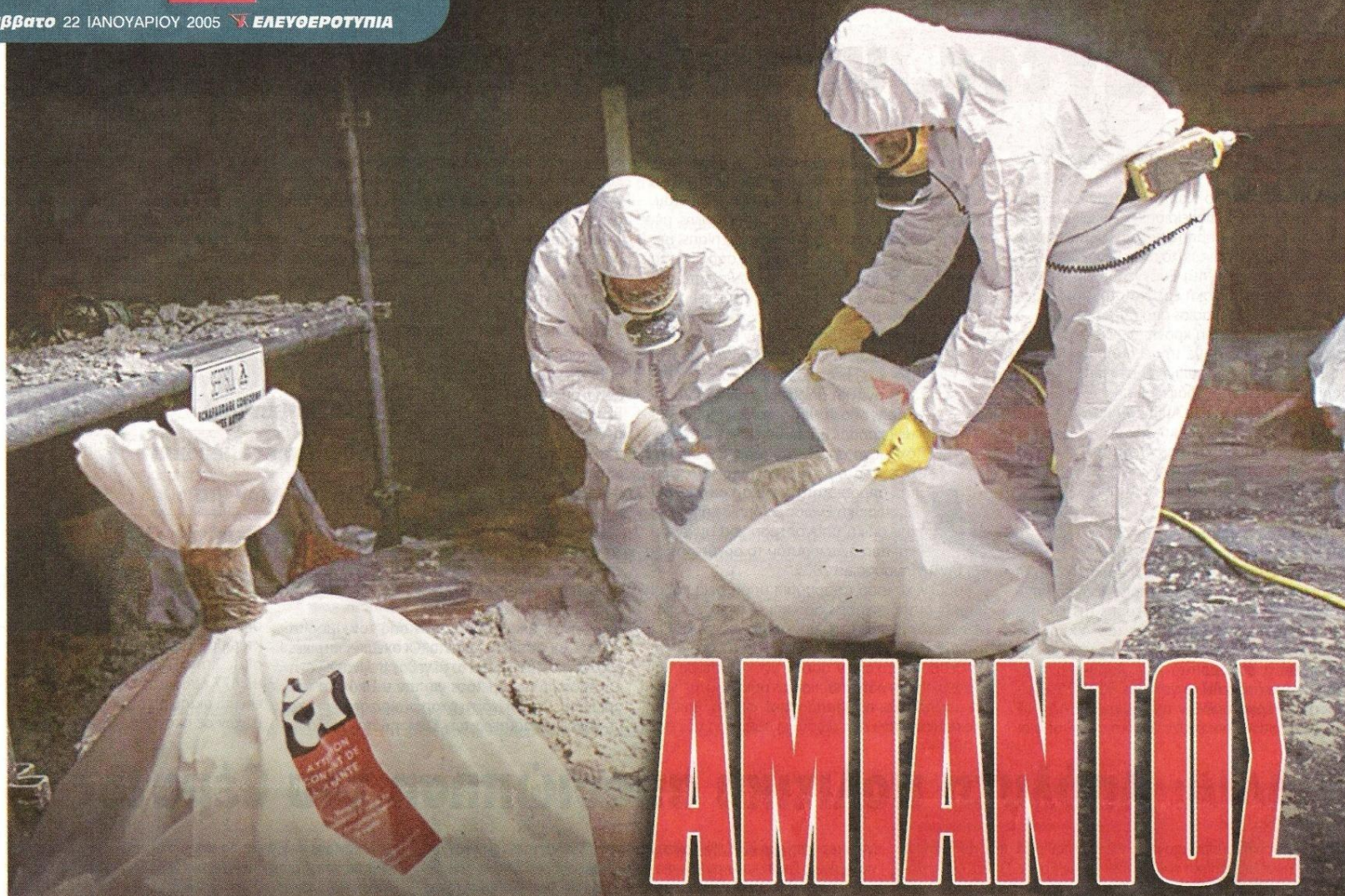
Half-life: ~30 years

Radiation: Beta + gamma

Decay: Turns into Ba-137m, which emits strong gamma radiation

□ This gamma radiation is what makes ^{137}Cs easy to detect—and dangerous at a distance. **Very hazardous radionuclide that spread across Europe.**

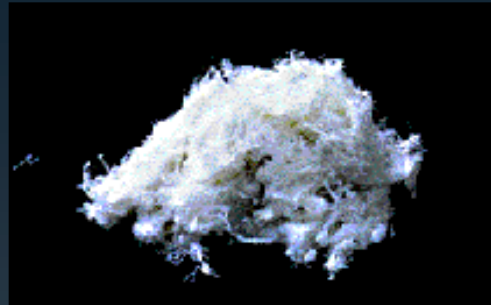




AMIANTOS

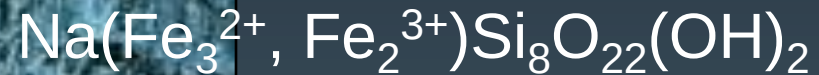
- Chrysotile

“White” asbestos



- Crocidolite

“Blue” asbestos



- Amosite

“Brown” asbestos



- Tremolite

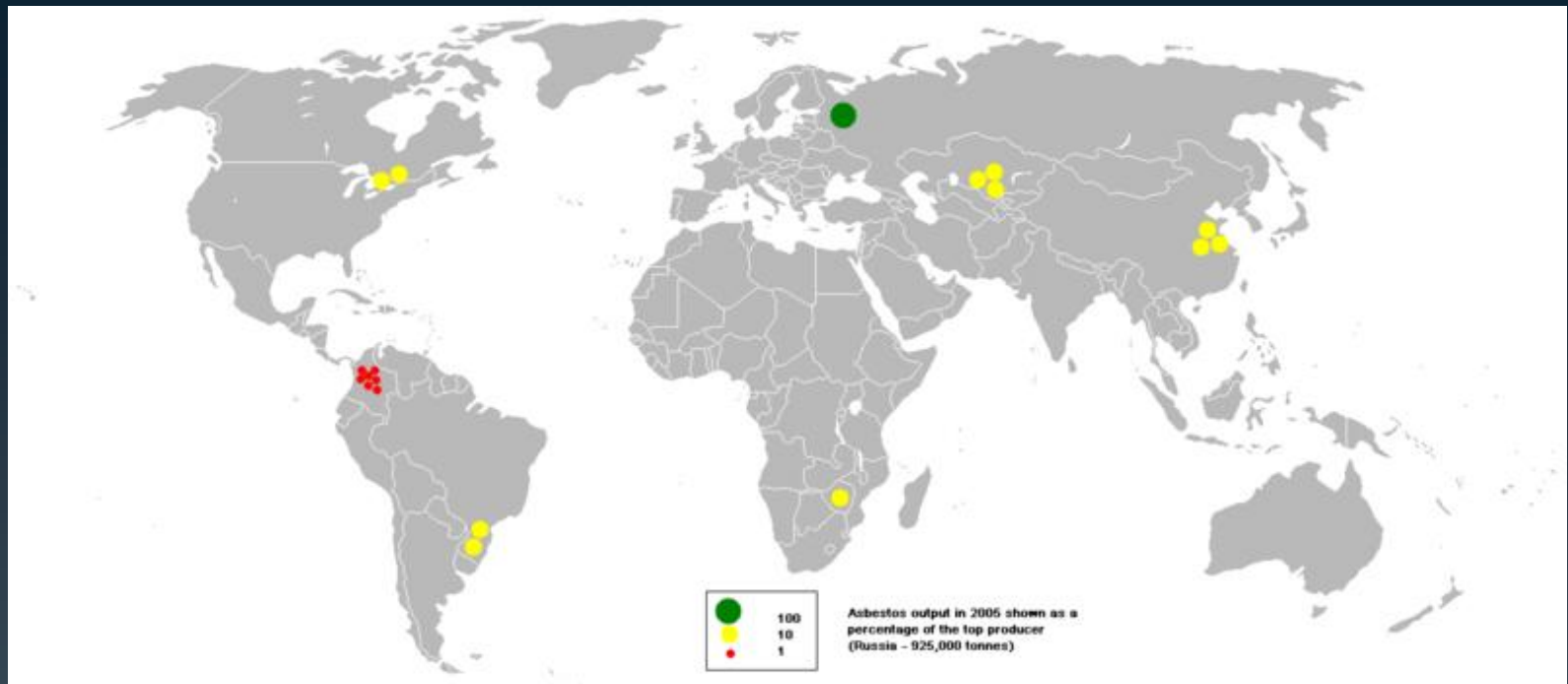


- Actinolite



- Anthophyllite

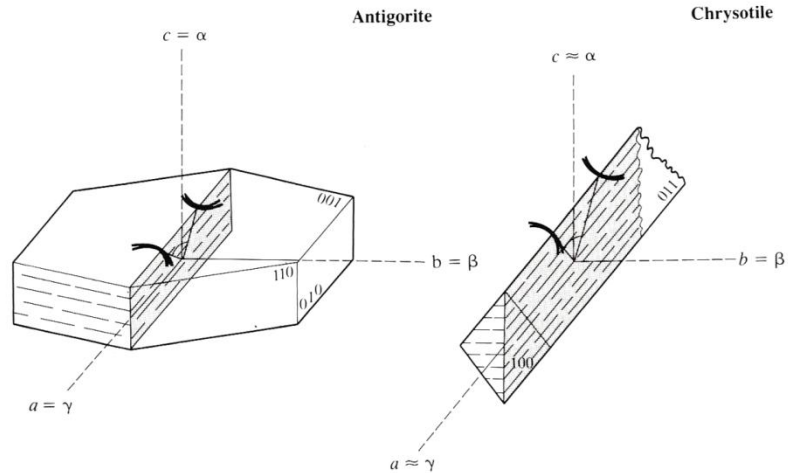




Serpentine $\text{Mg}_3\text{Si}_2\text{O}_5(\text{OH})_4$

monoclinic
0.57:1:1.31, $\beta = 93^\circ$

Serpentine includes a variety of minerals, one fibrous (**chrysotile**) and two tabular (**lizardite** and **antigorite**)

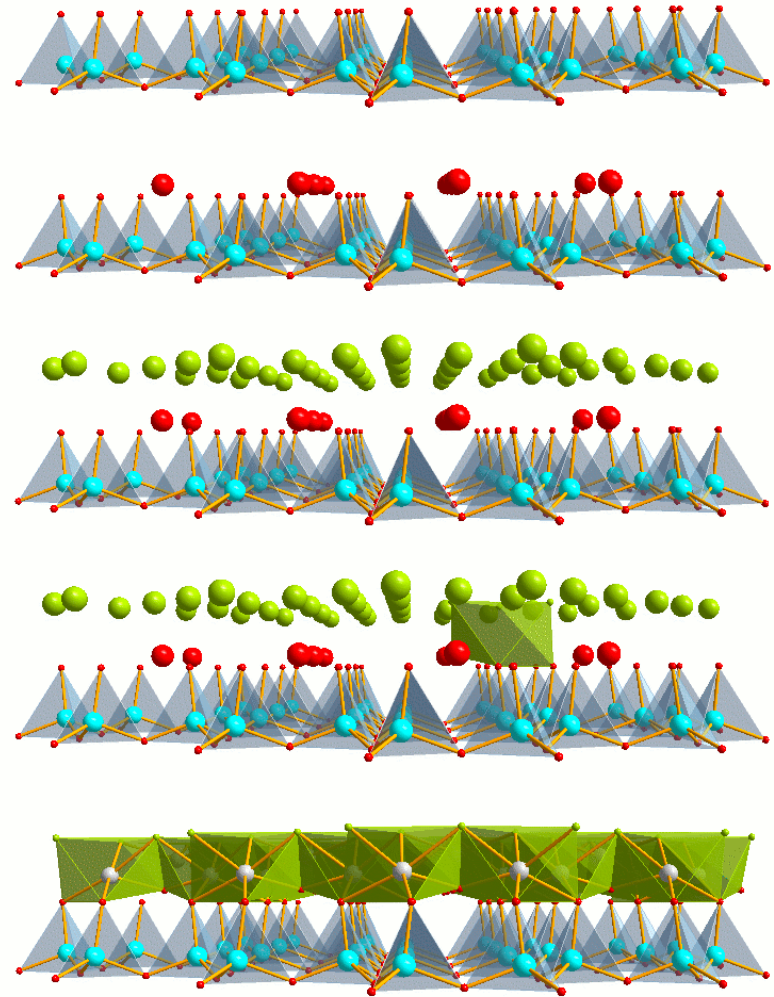


	Chrysotile	Lizardite	Antigorite
n_a	1.53–1.55	1.54–1.55	1.56–1.57
n_β	—	—	1.57
n_γ	1.55–1.56	1.55–1.56	1.56–1.57
δ	0.013–0.017	0.006–0.008	0.004–0.007
$2V_a$	variable – ve	?	37° – 61° – ve
OAP	parallel to (010)	?	parallel to (010)
D	2.55	2.55	2.6
H	$2\frac{1}{2}$	$2\frac{1}{2}$	2 – $3\frac{1}{2}$

COLOUR Colourless to pale green.

HABIT Chrysotile is fibrous elongated parallel to the a crystallographic axis, and lizardite and antigorite are both flat, tabular crystals.

CLEAVAGE Chrysotile has a fibrous cleavage, and lizardite a basal cleavage.



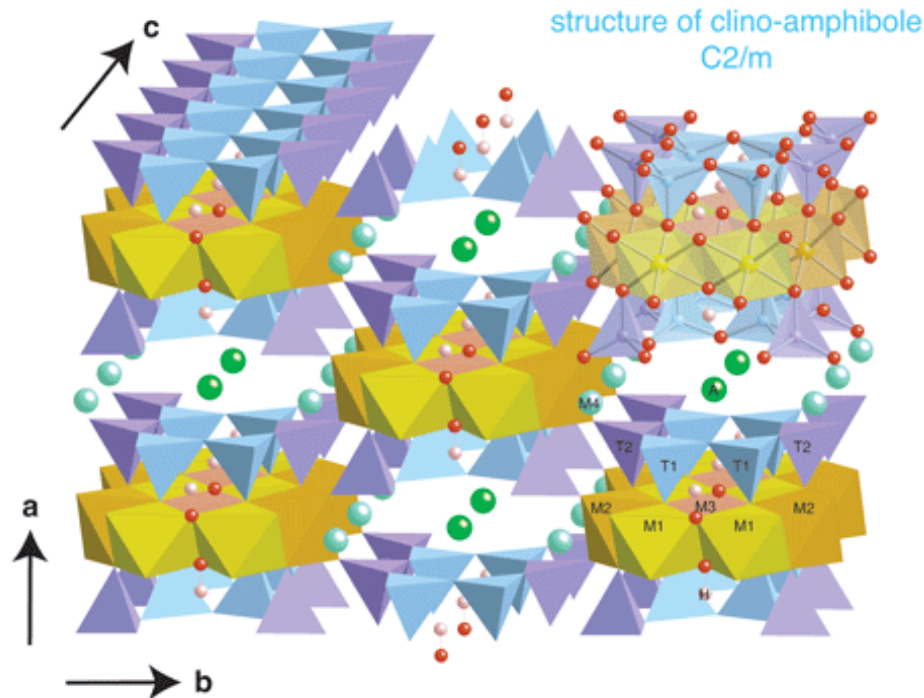
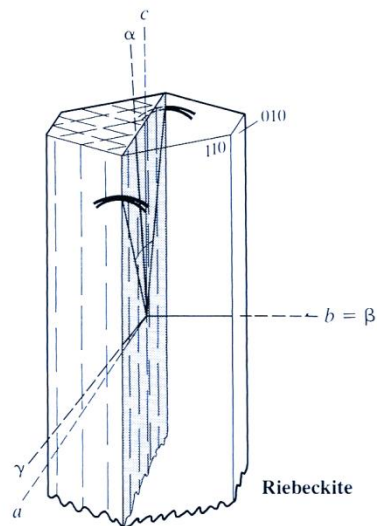
$n_a = 1.606\text{--}1.701$
 $n_\beta = 1.622\text{--}1.711$
 $n_\gamma = 1.627\text{--}1.717$
 $\delta = 0.008\text{--}0.022$

$2V_a = 0^\circ\text{--}50^\circ$ (–ve) glaucophane

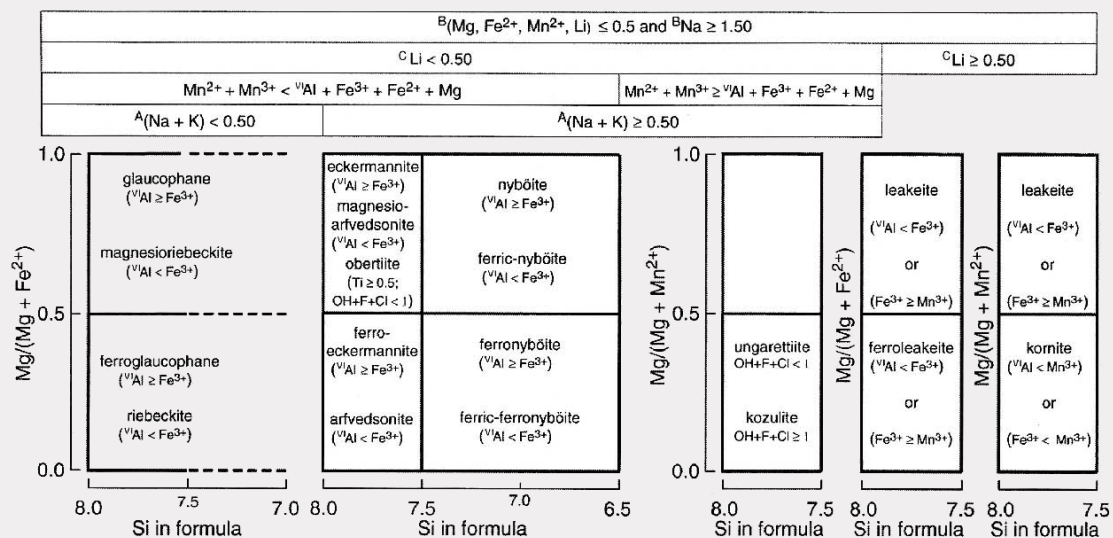
$2V_a = 0^\circ\text{--}90^\circ$ (–ve) riebeckite

OAP is parallel to (010) in glaucophane and riebeckite but is perpendicular to (010) in crossite, an intermediate variety

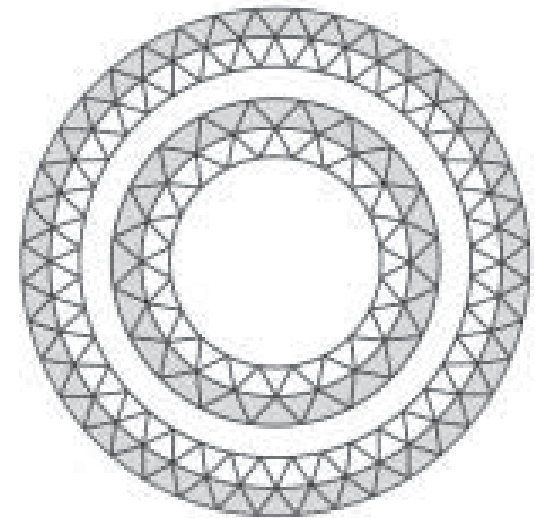
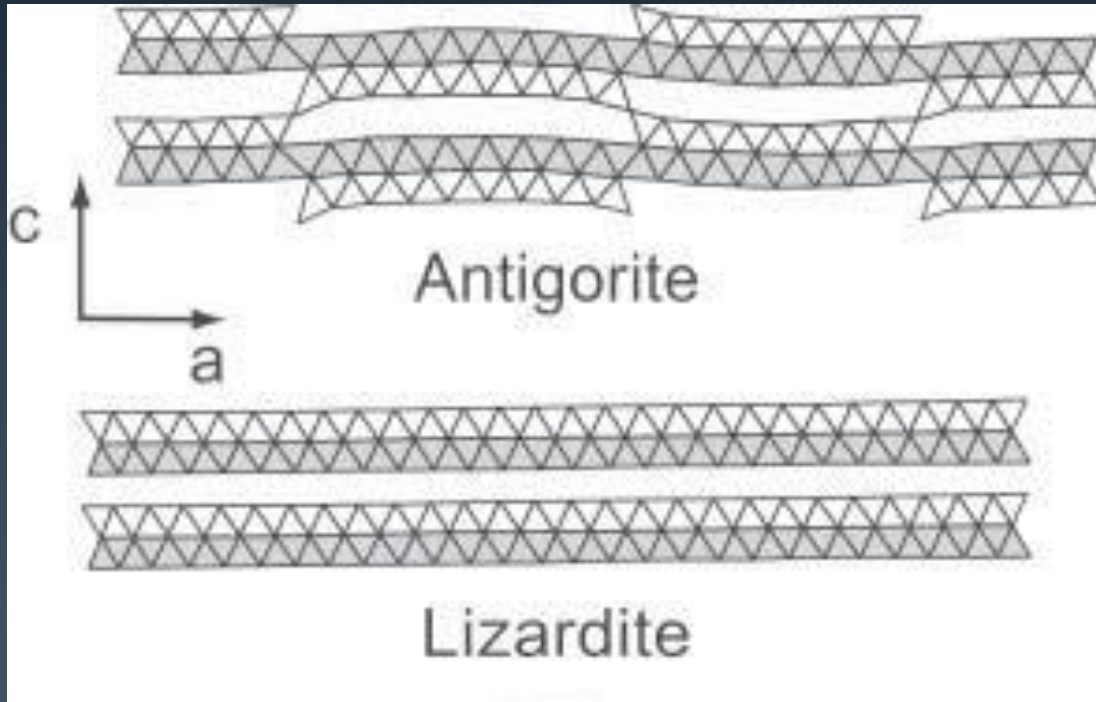
$D = 3.02\text{--}3.43$ $H = 6$ (glaucophane), 5 (riebeckite)



Sodic Amphiboles



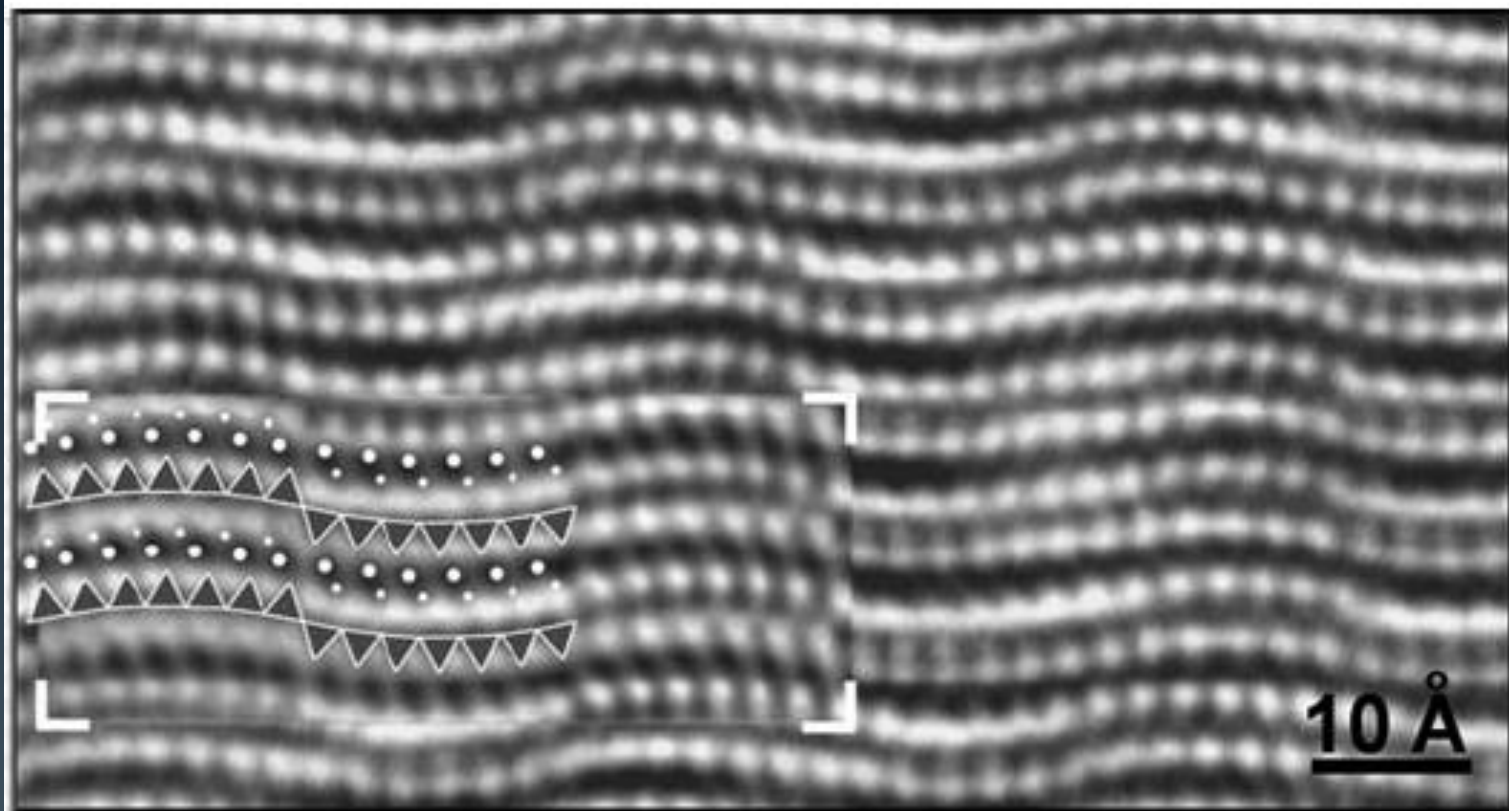
SERPENTINE POLYMORPHS



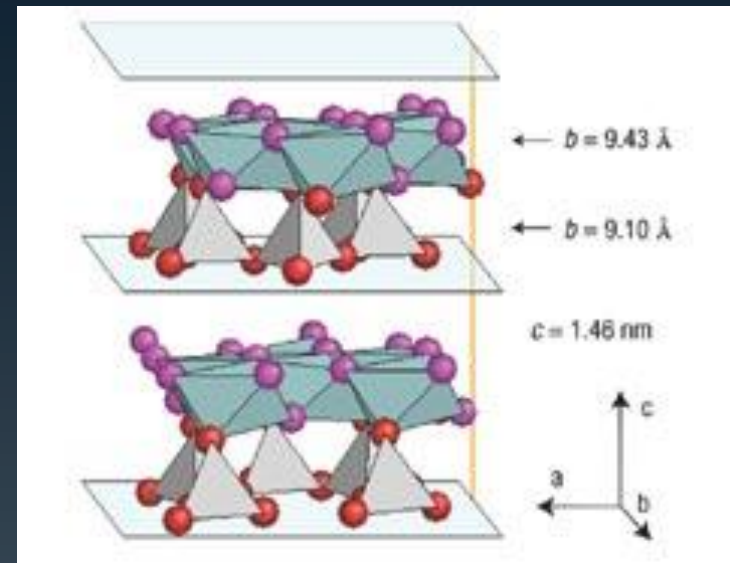
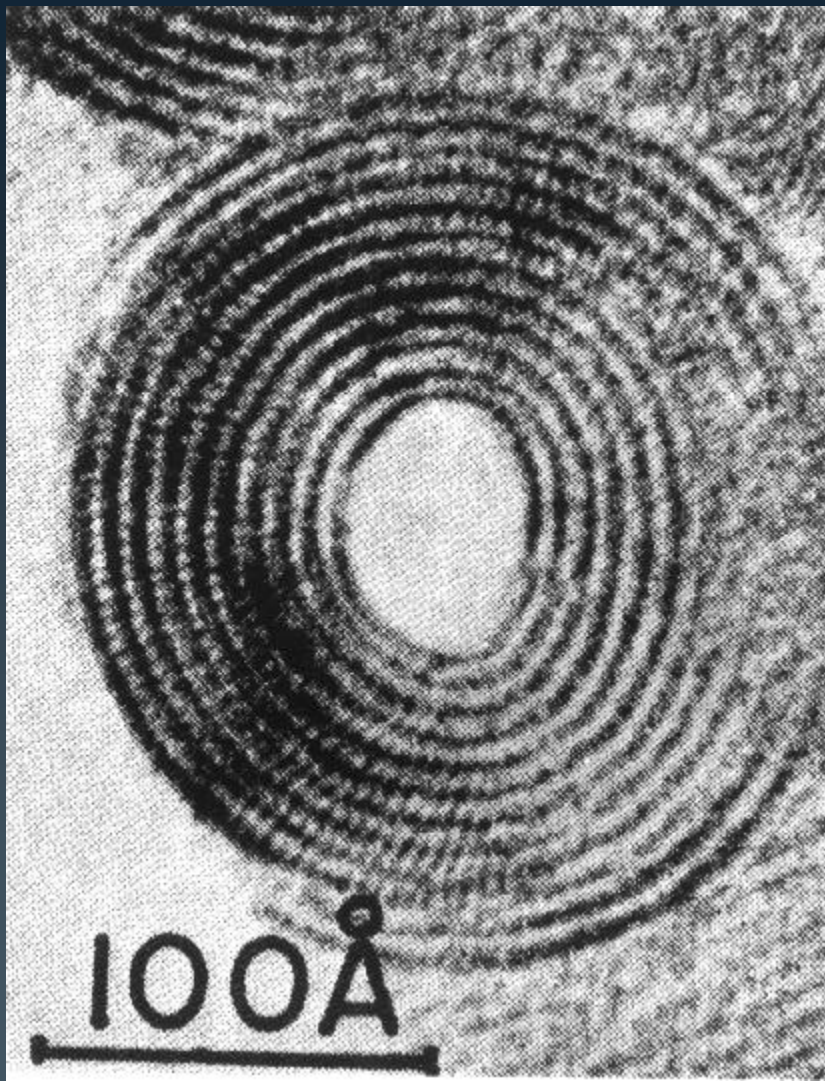
Chrysotile



 Tetrahedral Sheet
 Octahedral Sheet

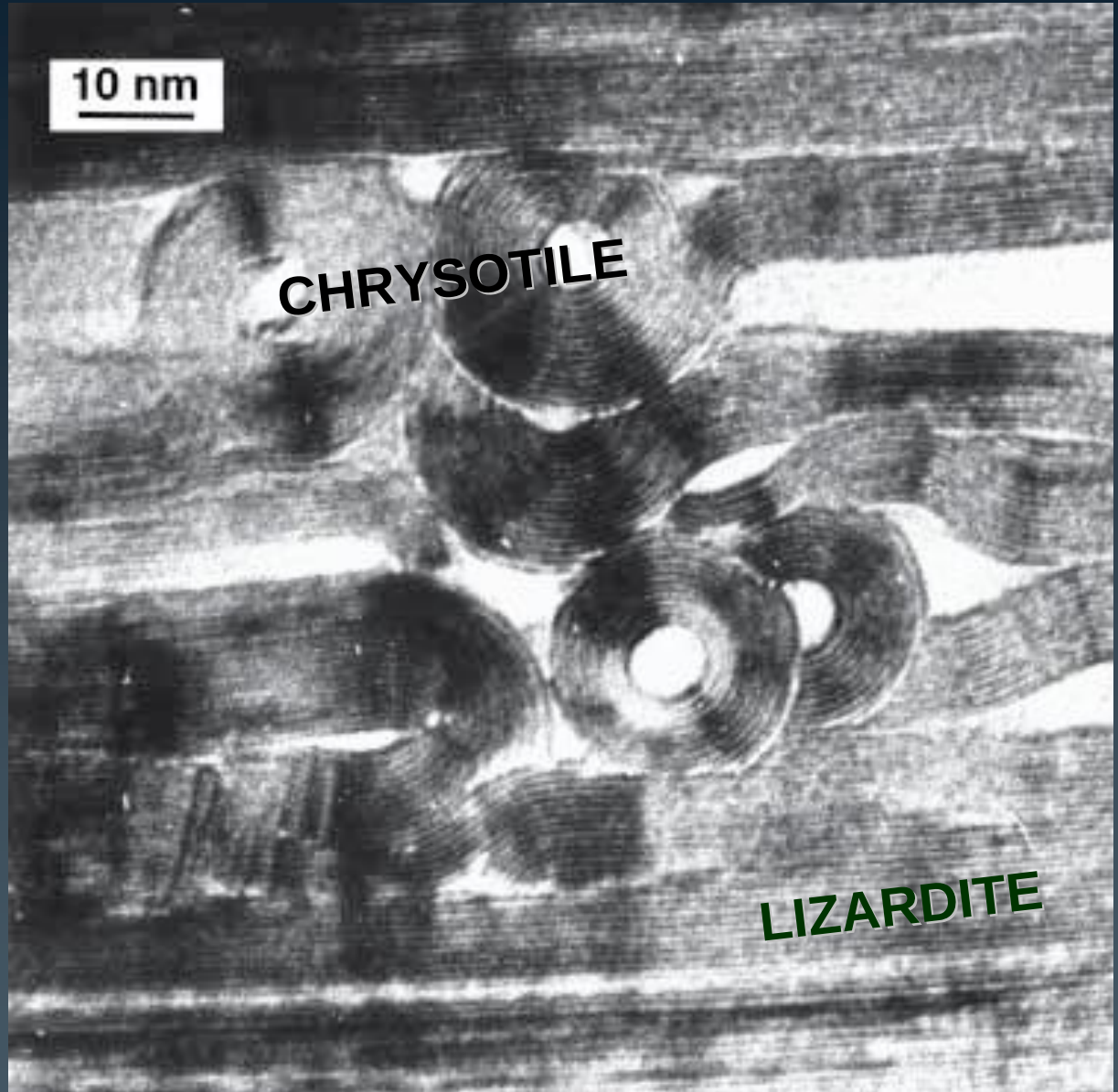


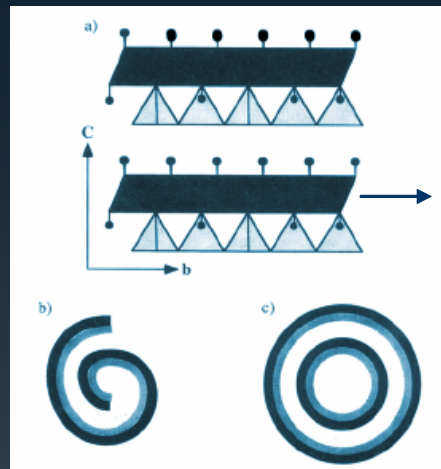
Experimental and simulated (inserted) [010] HRTEM images of antigorite ($m = 14$). A sketch indicates the tetrahedral sheets (triangles) and Mg positions (larger white spots), hydroxyls are small white dots.



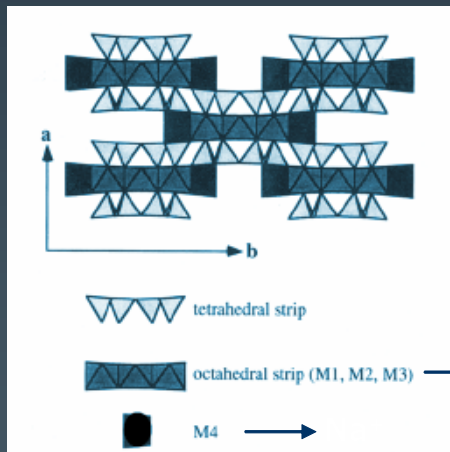
Transmission Electron
Micrograph of chrysotile.
**Misfit between the smaller
Si-rich tetrahedral sheet
and larger Mg-rich
octahedral sheet results in
curl** (Yada, K., 1971, *Acta
Cryst.*, A27 659-664)

Transformation
of
LIZARDITE
to
CHRYSOTILE
in
*nanoscale
(nano-
intergrowths)*

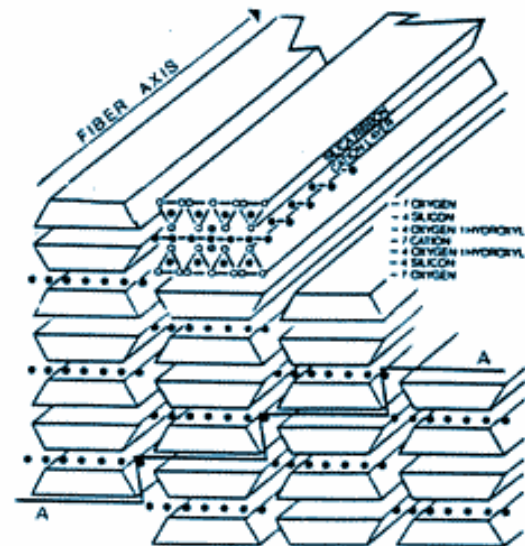
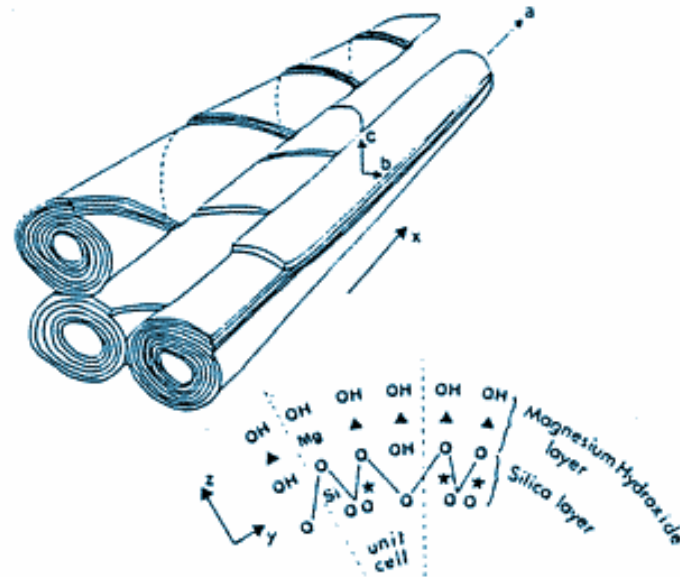




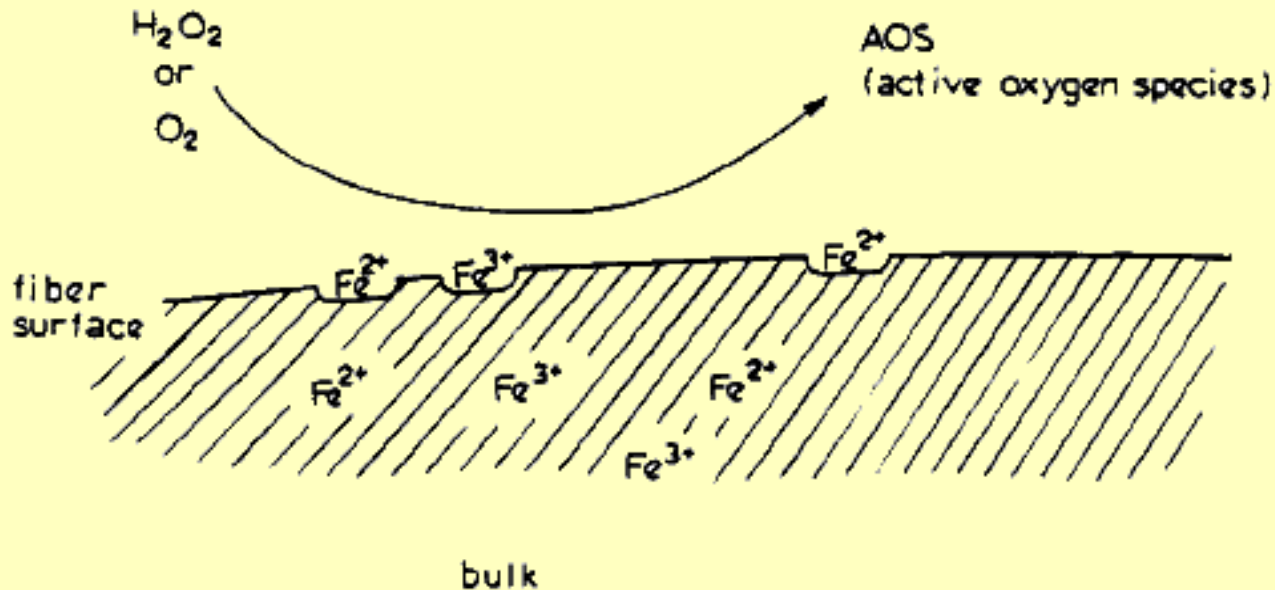
CHRYSOTILE (SERPENTINE ASBESTOS)



CROCIDOLITE (AMPHIBOLE ASBESTOS)



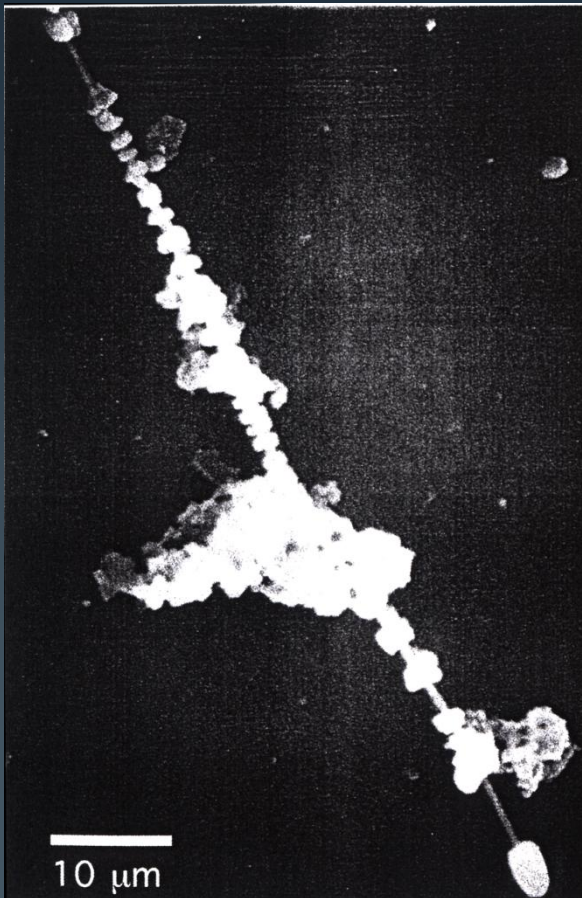
Fenton Chemistry



The surface reactivity scheme proposed by Fubini and associates depicting the occurrence of both Fe(II) and Fe(III) on the surface and in the interior of the mineral fibers.

Hardy and Aust: Iron in Asbestos Chemistry and Carcinogenicity.
Chem. Rev. 95 (1995) 97-118.

Fenton Chemistry



Ferrihydrite

see:

Hochella Jr. *Mineral. Mag.*, 66(5)
(2002) 627-652.

Shen et al. *Chem. Res. Toxicol.*, 13
(2000) 913-921.

Asbestos in building materials ...

- Characterization
ex-situ and in-situ
(portable equipments)

- Removal and disposal

Ex-situ and in-situ characterization in building materials

Determination of asbestos minerals
and phase identification (serpentine
polymorphs, amphiboles)

Ex-situ and in-situ characterization of asbestos in building materials

- ✓ MICROSCOPIC TECHNIQUES
(Optical microscope, SEM, TEM)
- ✓ SPECTROSCOPIC TECHNIQUES
(Laser- μ Raman, IR, LIBS)

Anagnostopoulos et al. (2009)



SAMPLES FROM BUILDING MATERIALS (CEM)



REFERENCE MATERIALS



Chrysotile (CHR), Crocidolite (CRD) from U.I.C.C. (Union International Contre le Cancer), see also *Free Radical Biology and Medicine*, 20(6) (1996) 853-858



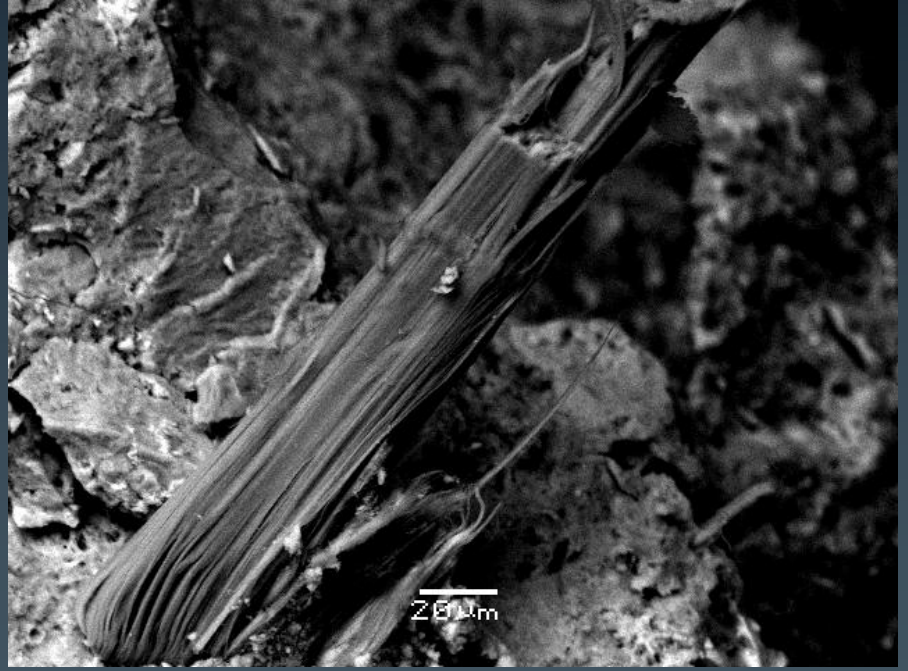
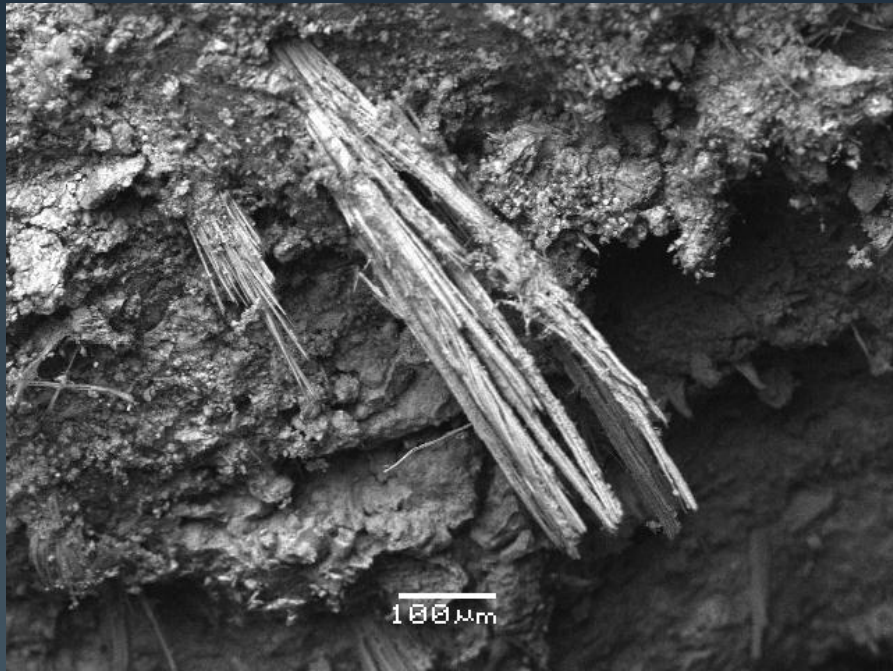
Chrysotile from
Zidani asbestos
deposit, N.
Greece (ZID)

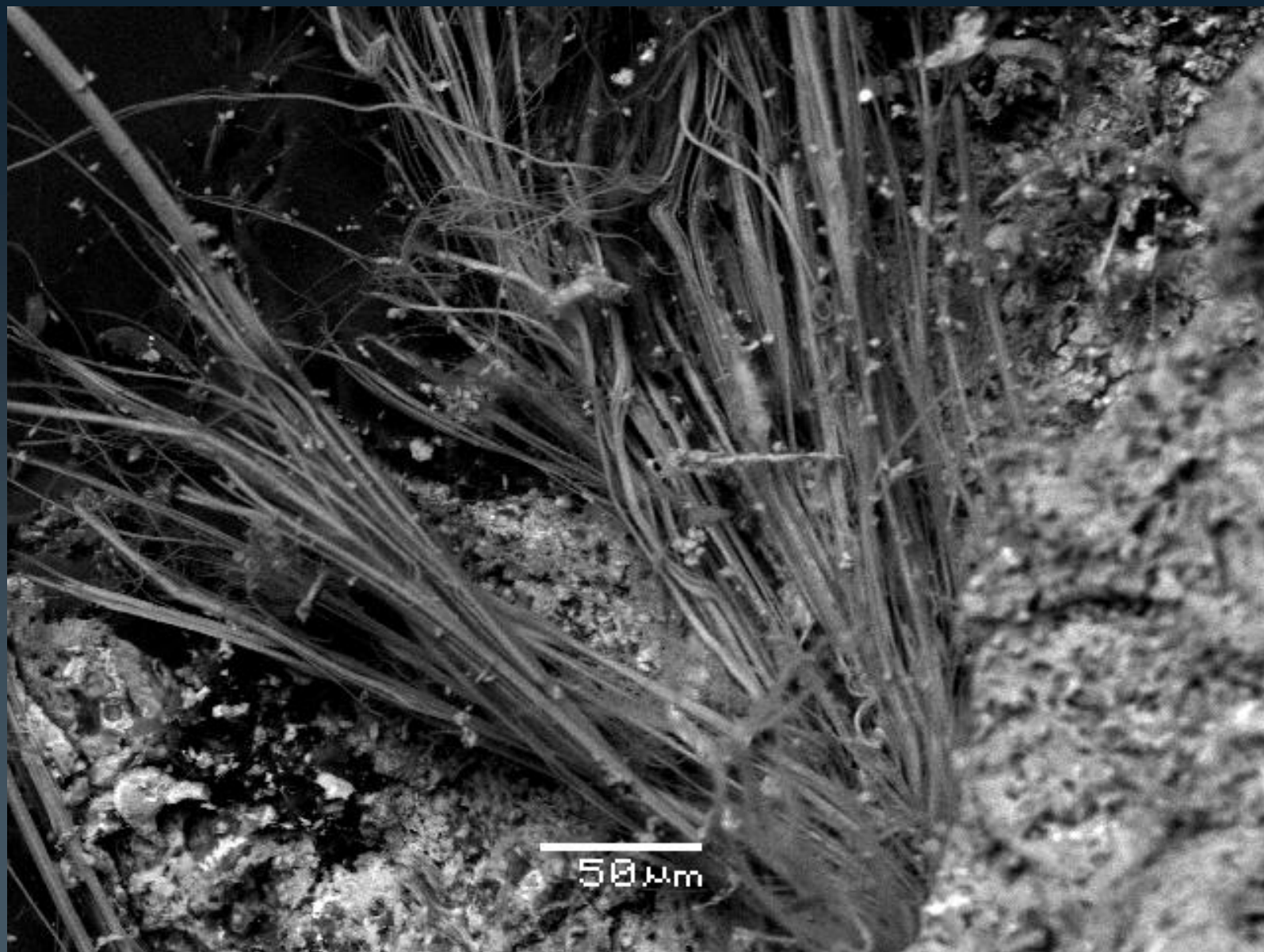
ZIDANI ASBESTOS DEPOSIT, N. GREECE (abandoned mine)

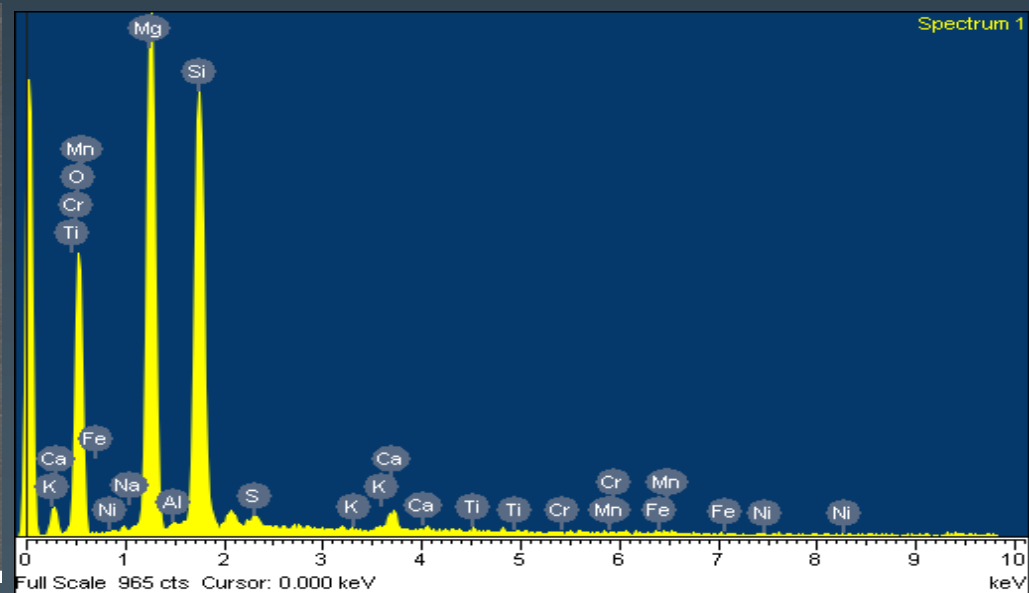
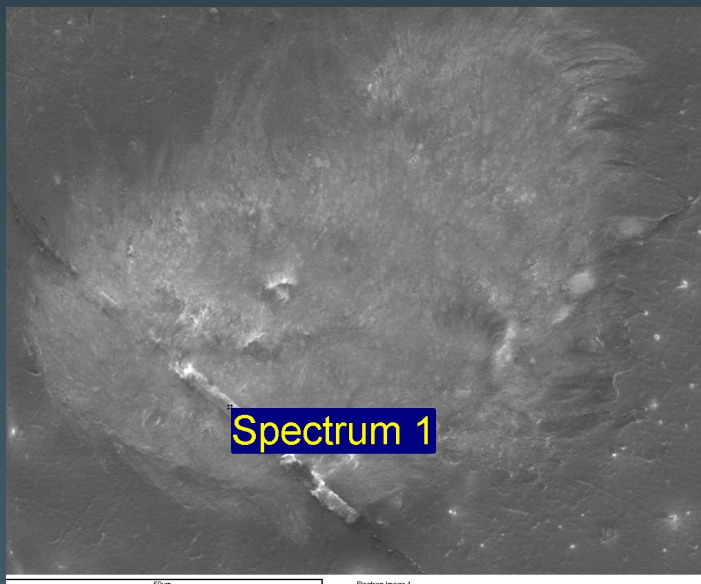
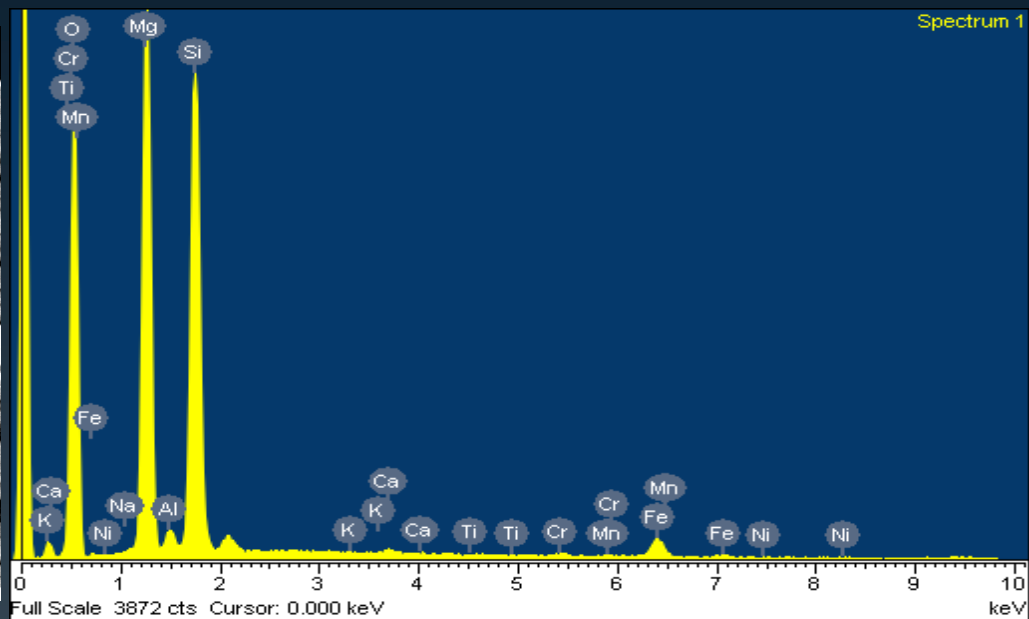
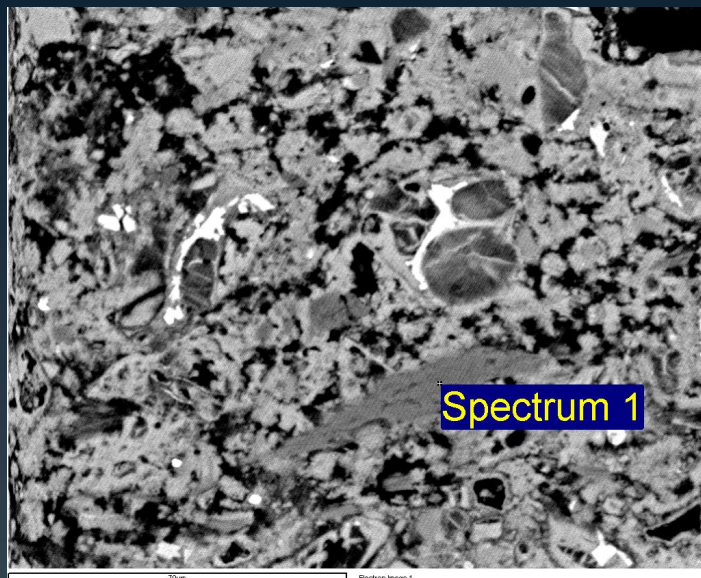


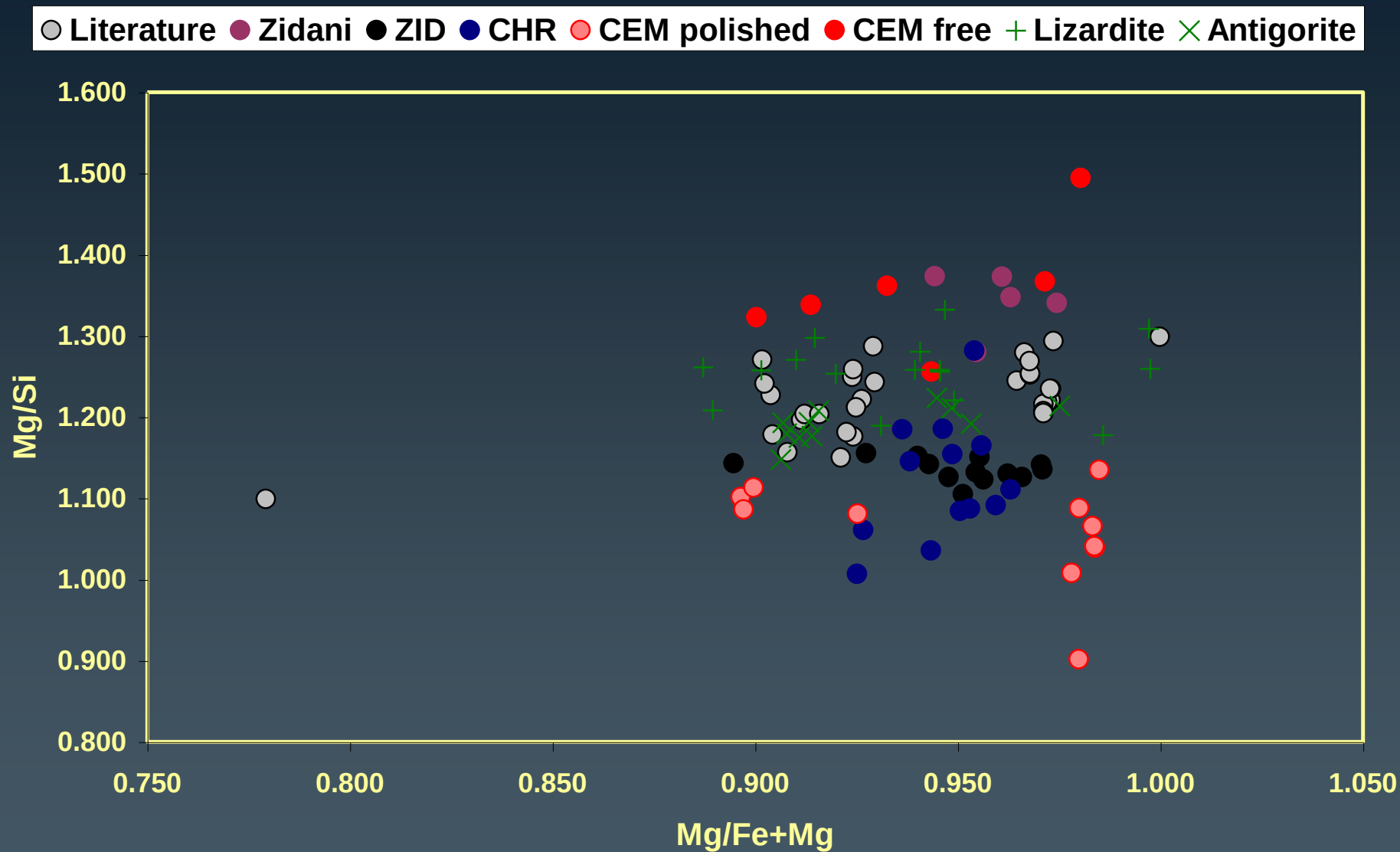
SEM-EDS

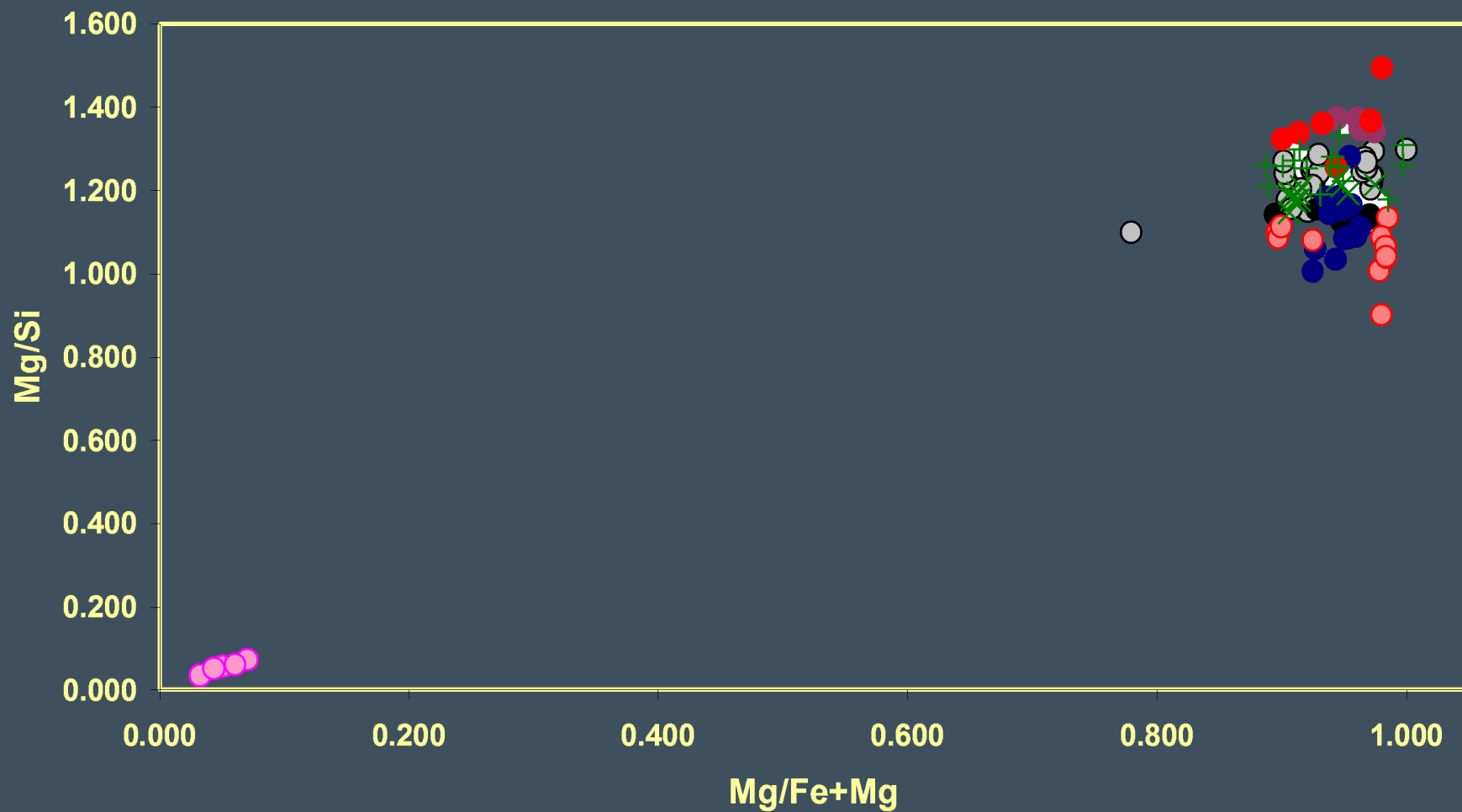




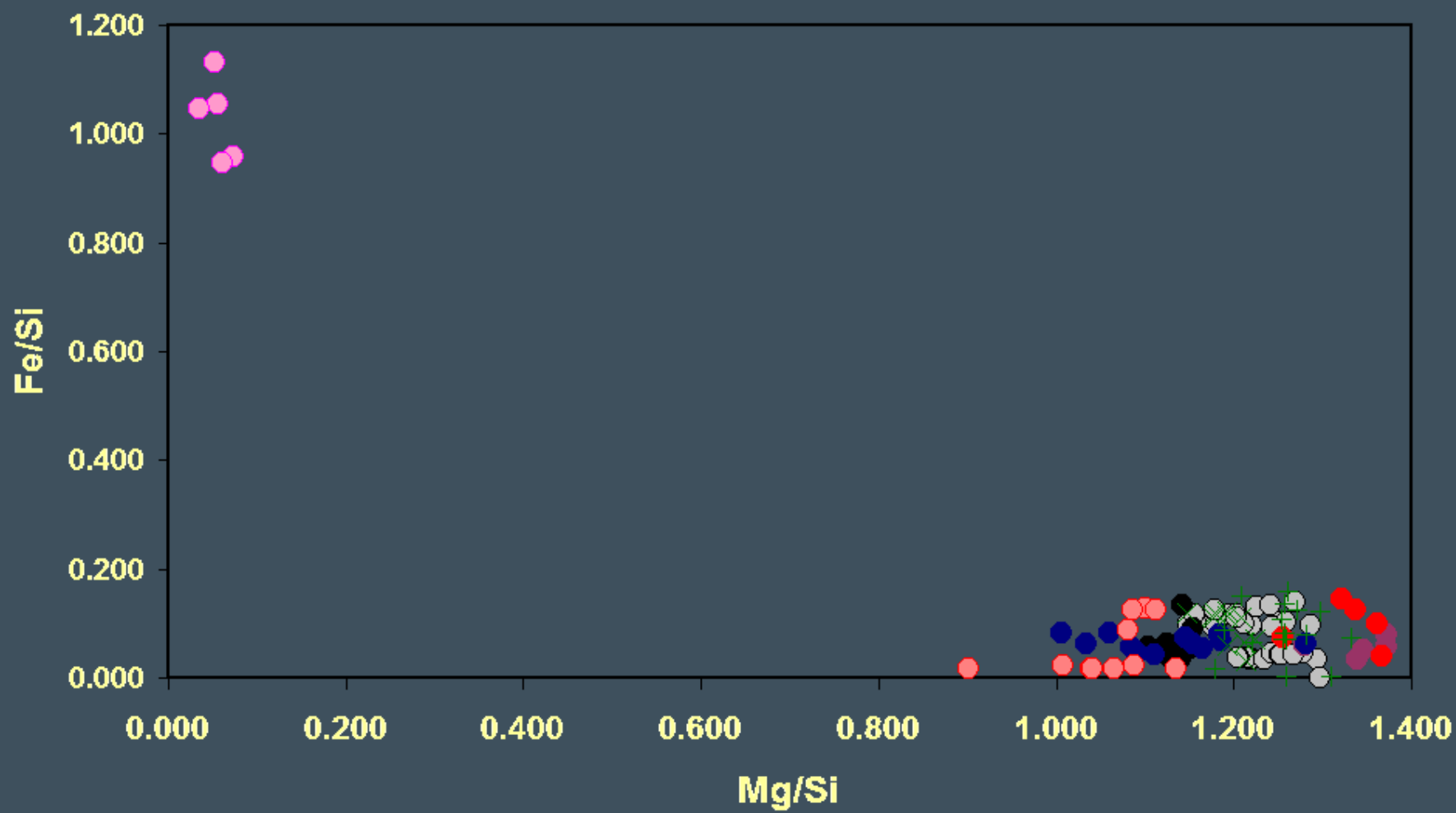


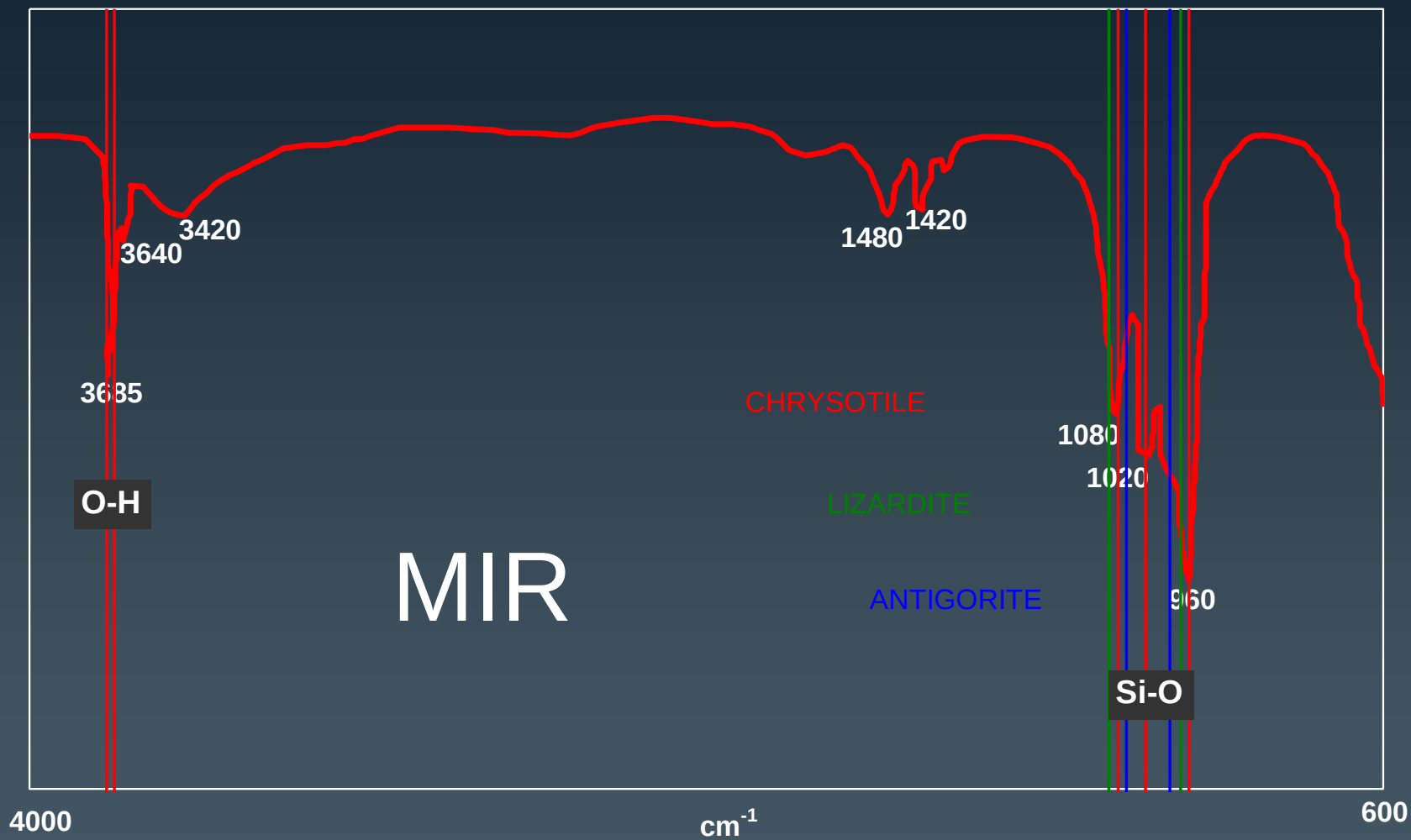


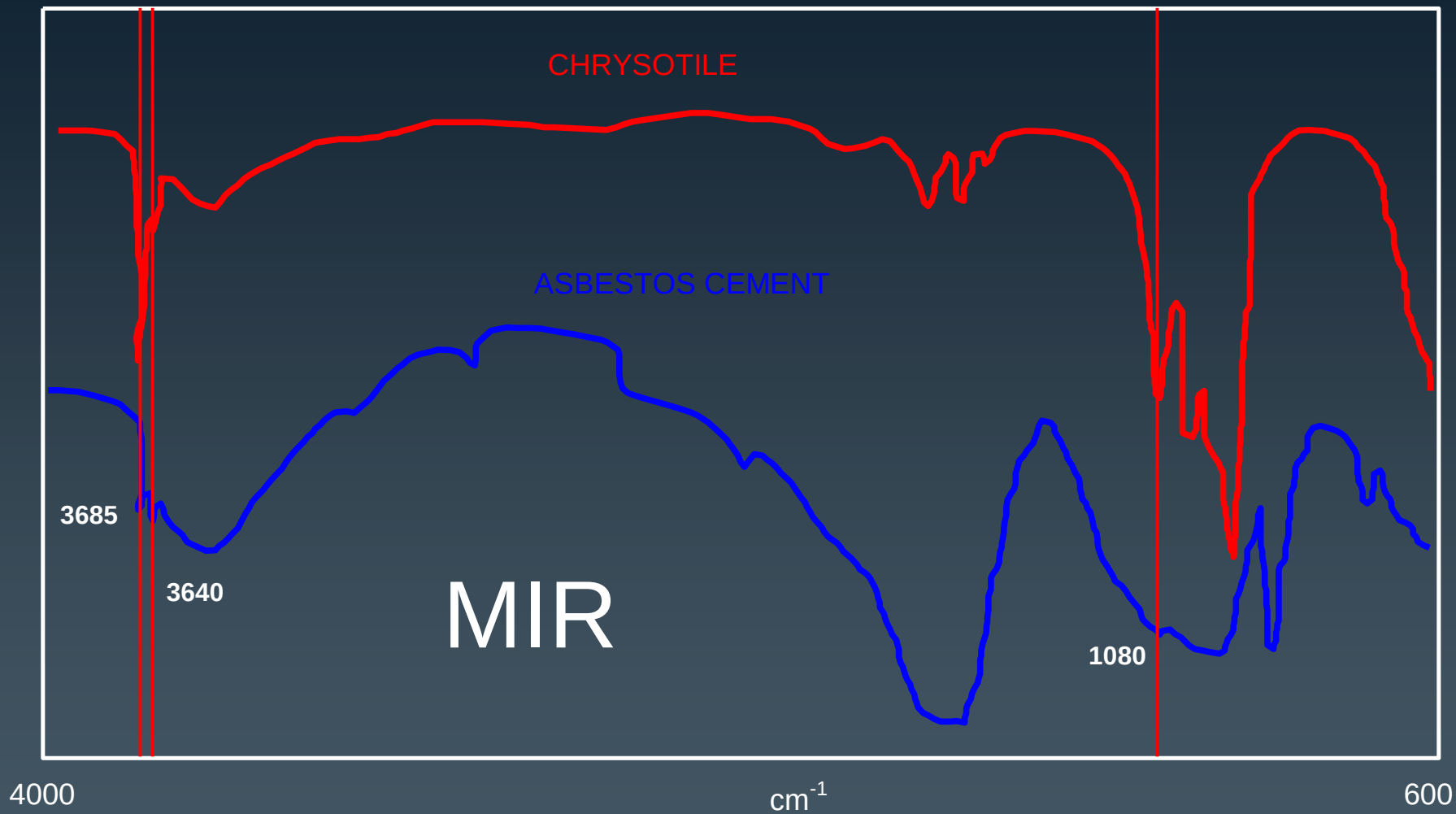




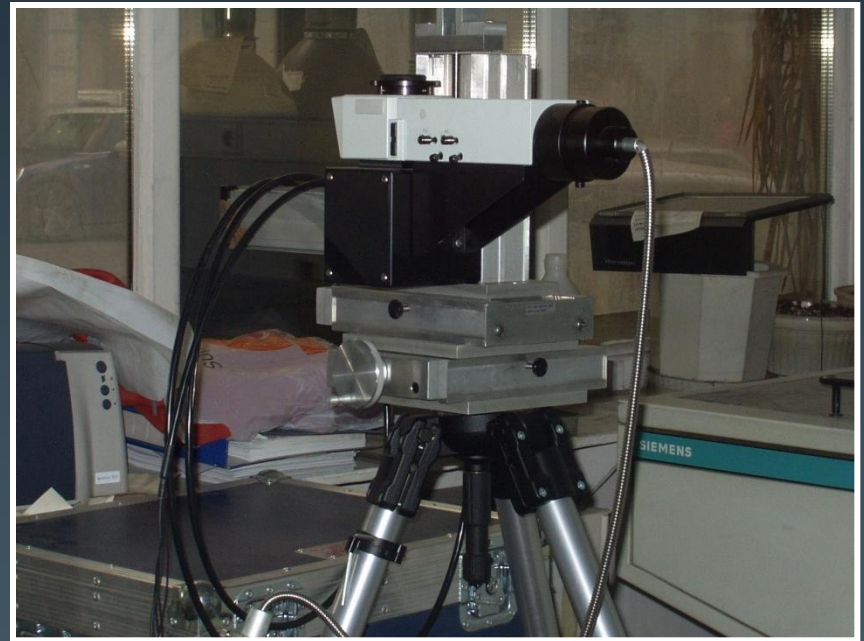
○ Literature ● Zidani ● ZID ● CHR ● CEM polished ● CEM free × Antigorite + Lizardite ● CRD



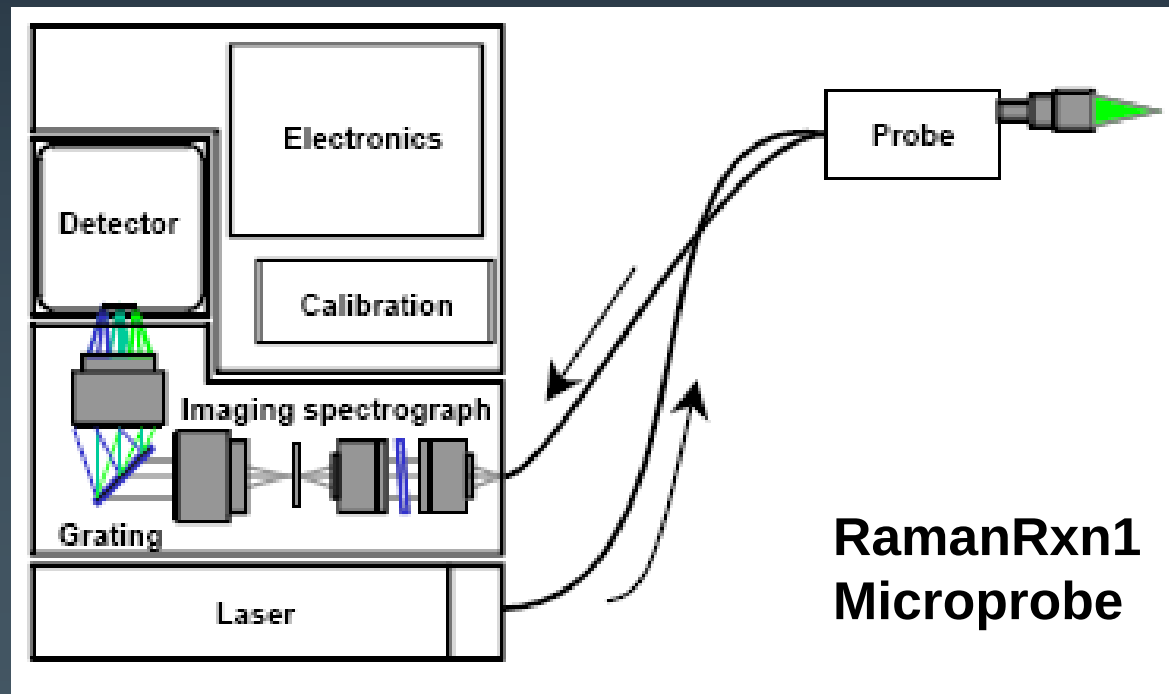


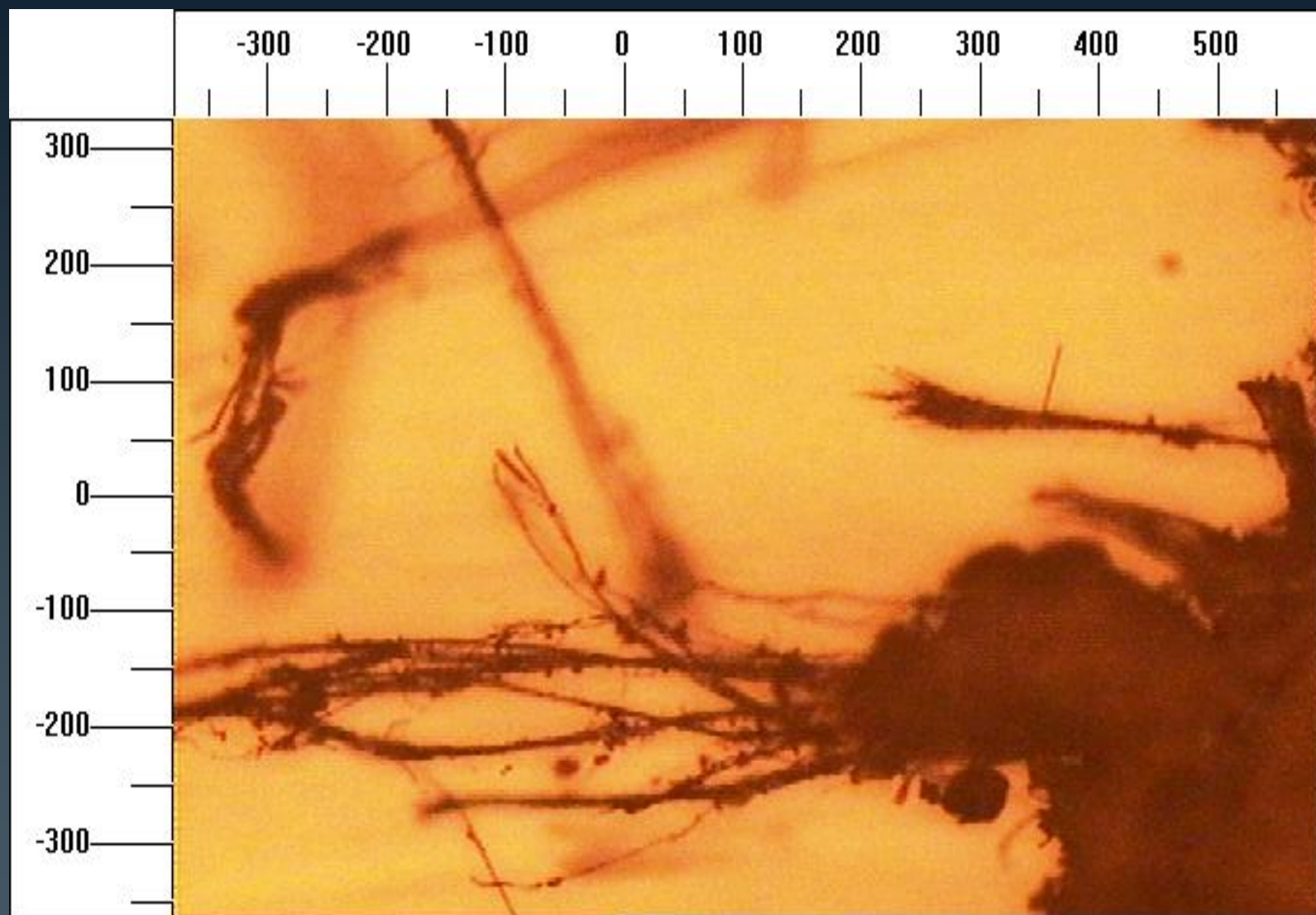


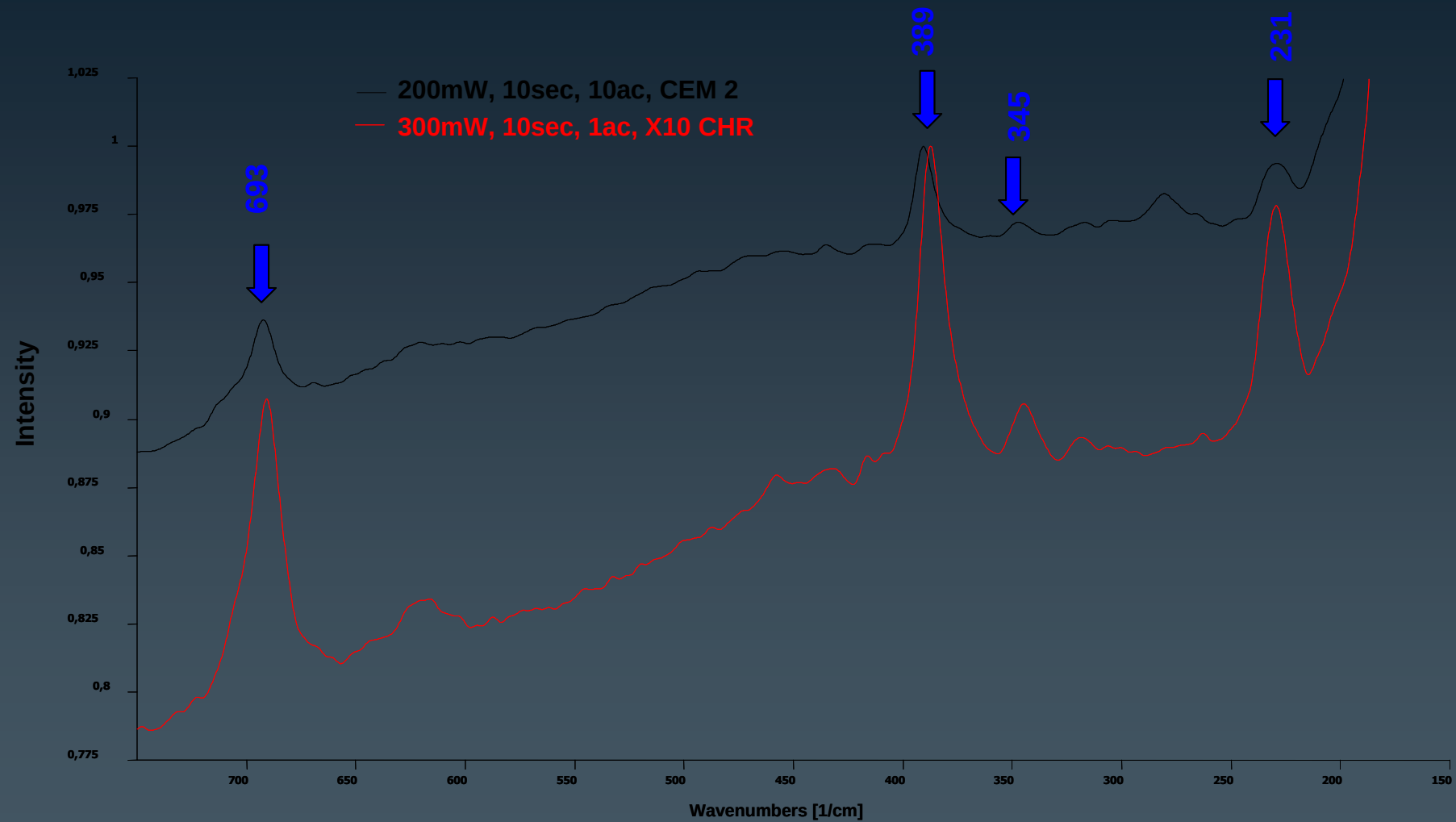
Laser- μ Raman (Raman microprobe)

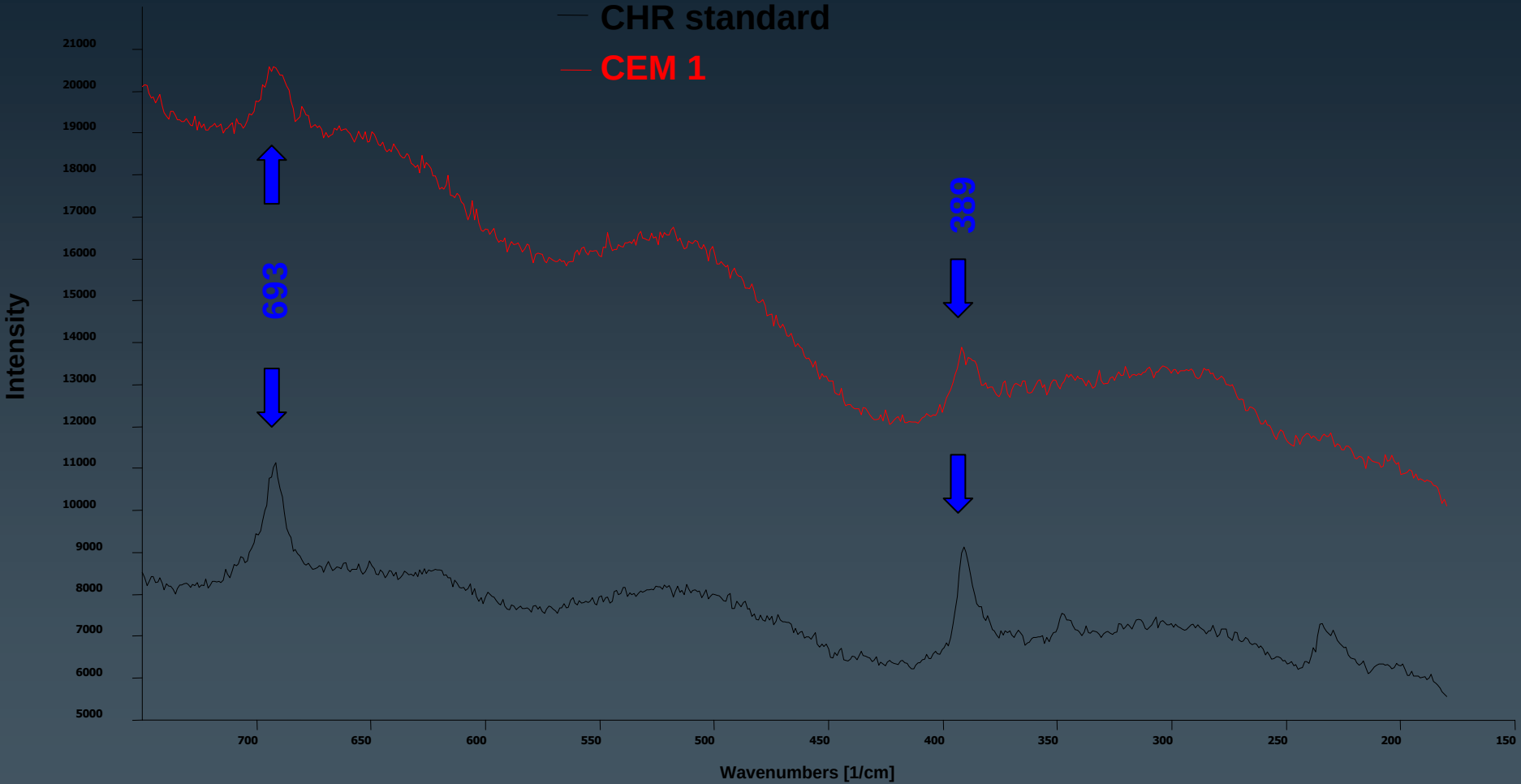


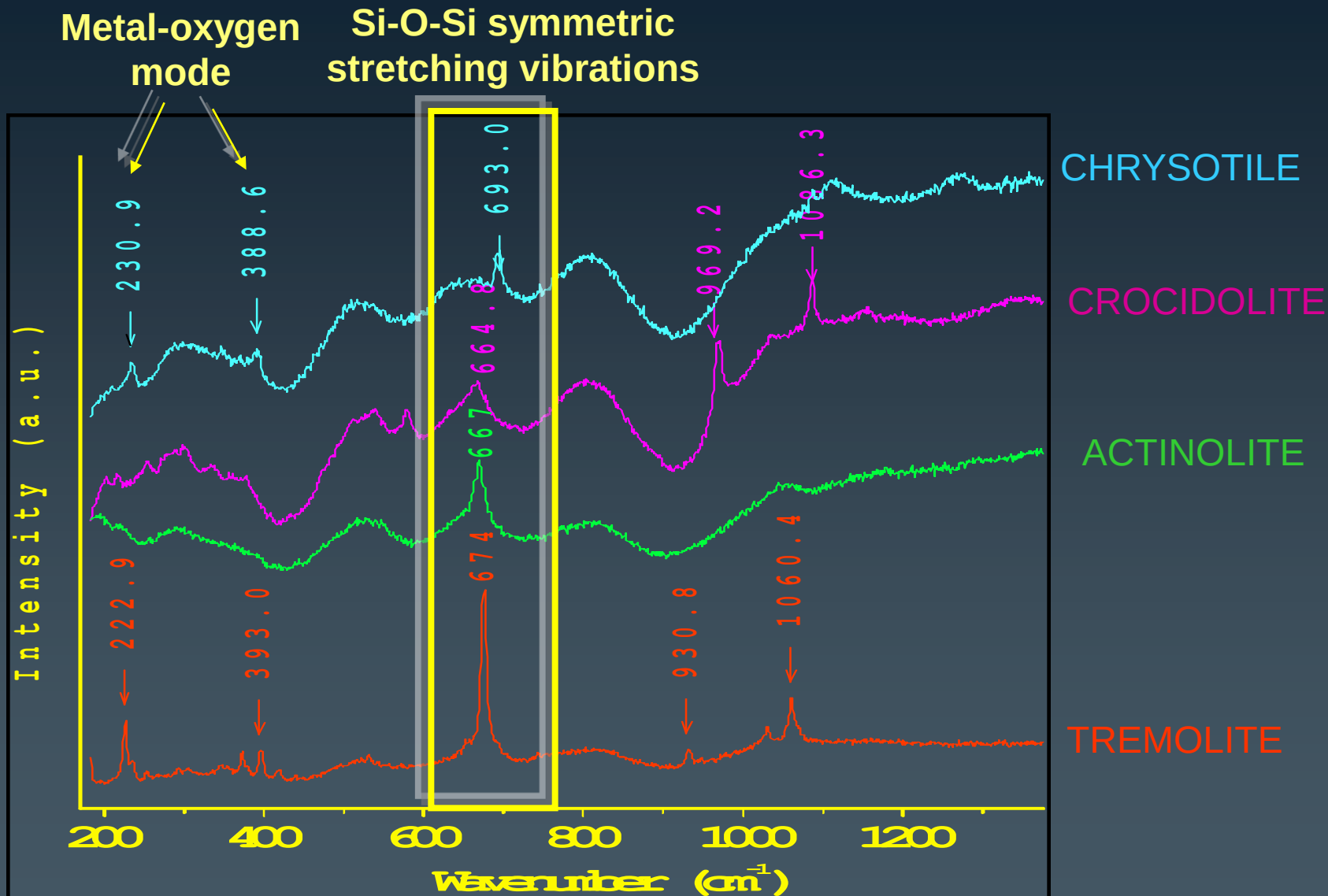
In-situ Laser μ -Raman portable Raman microprobe

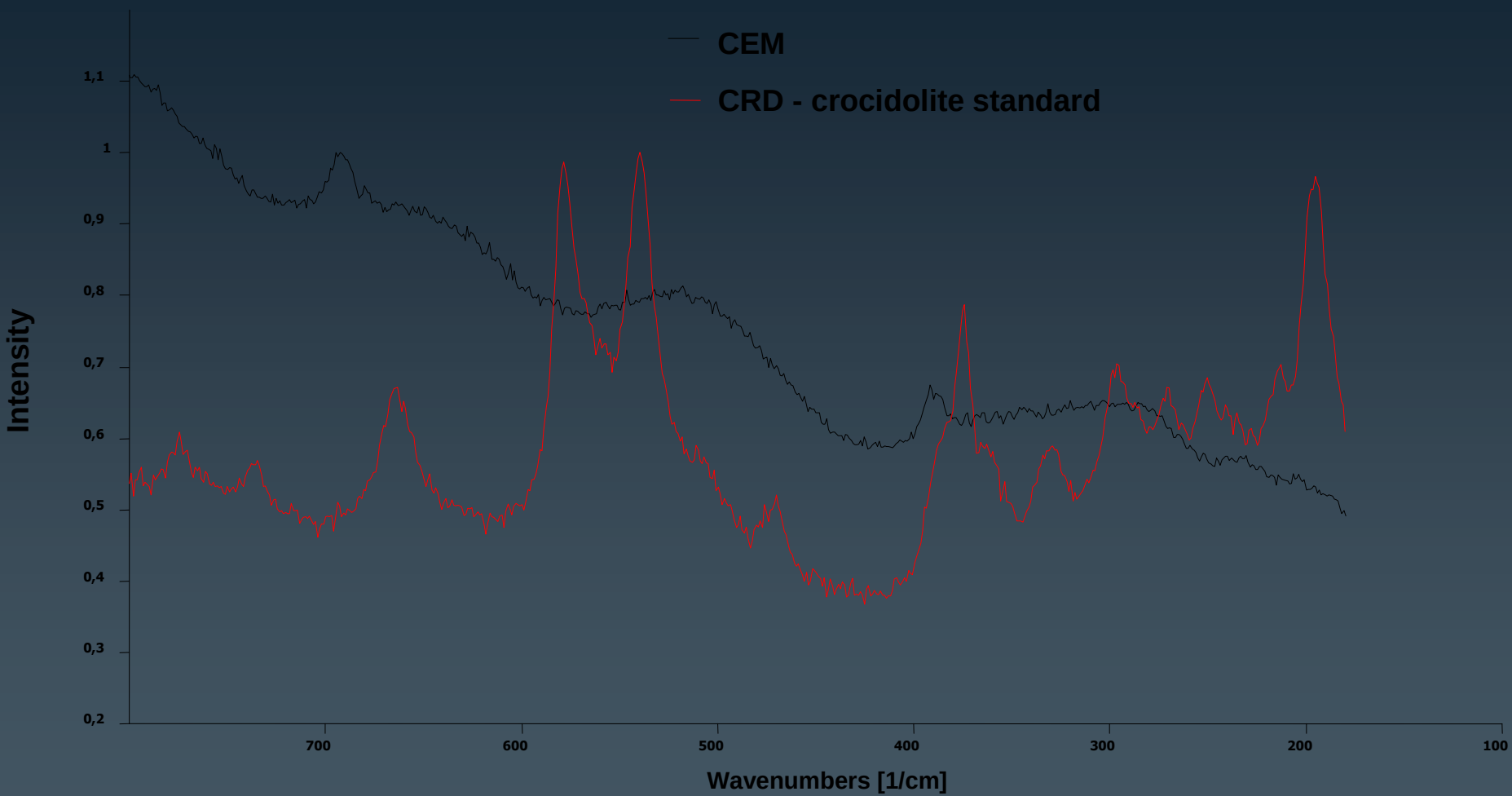


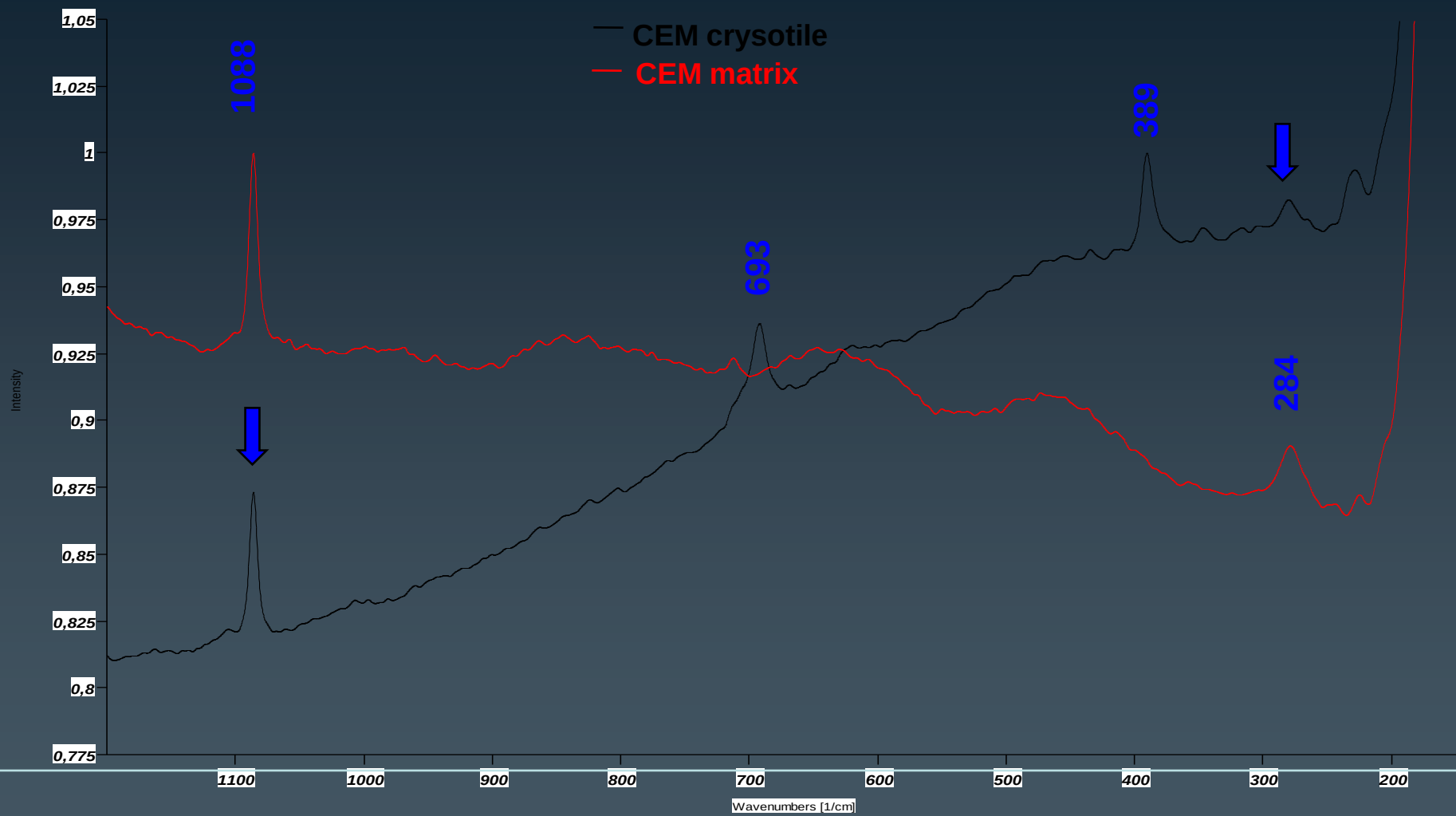




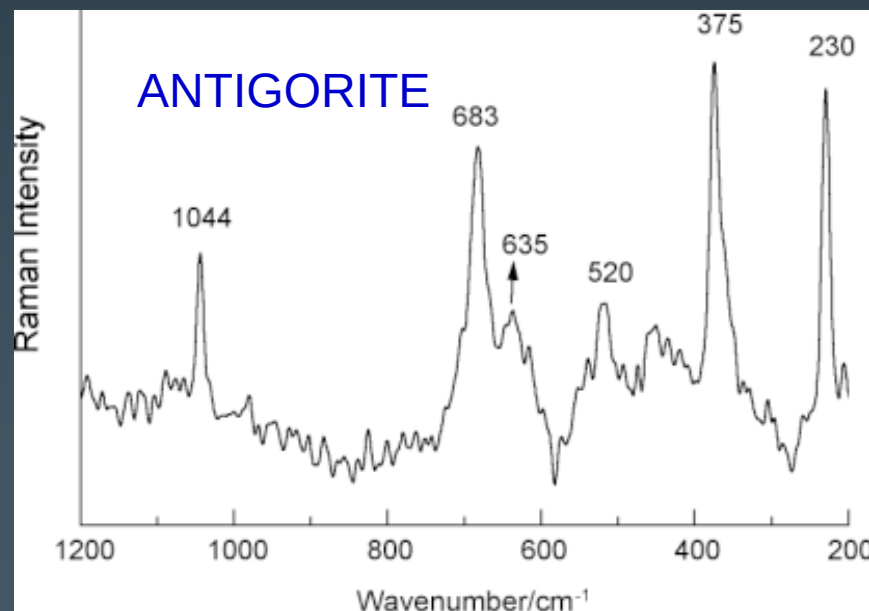
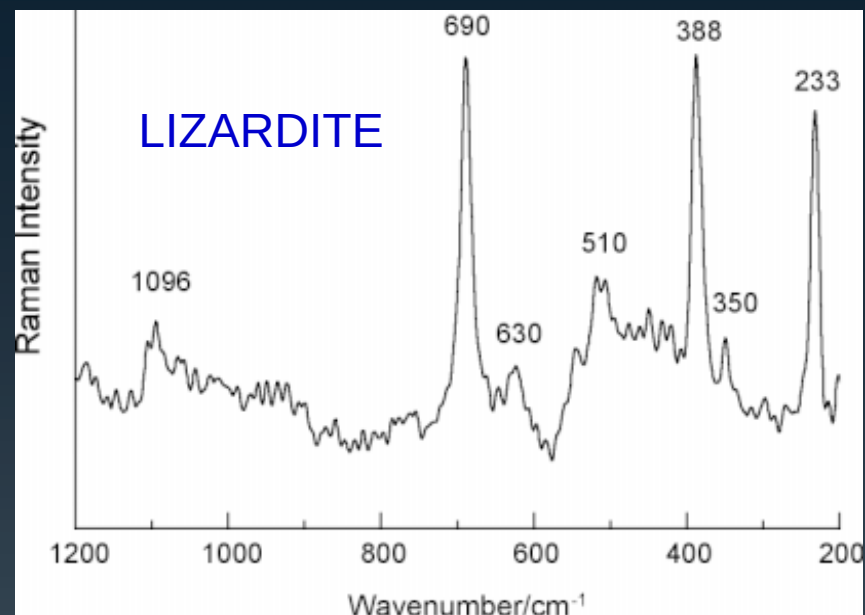
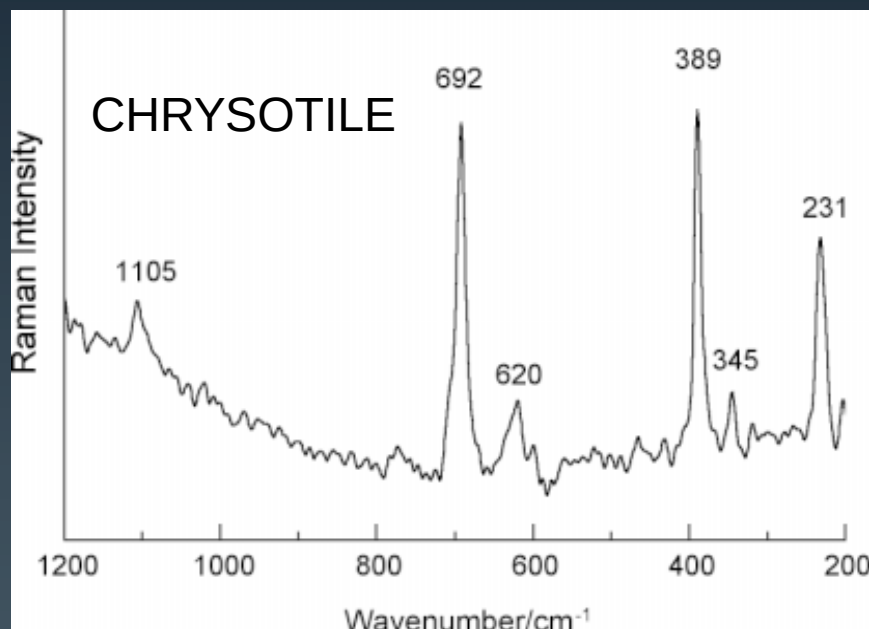








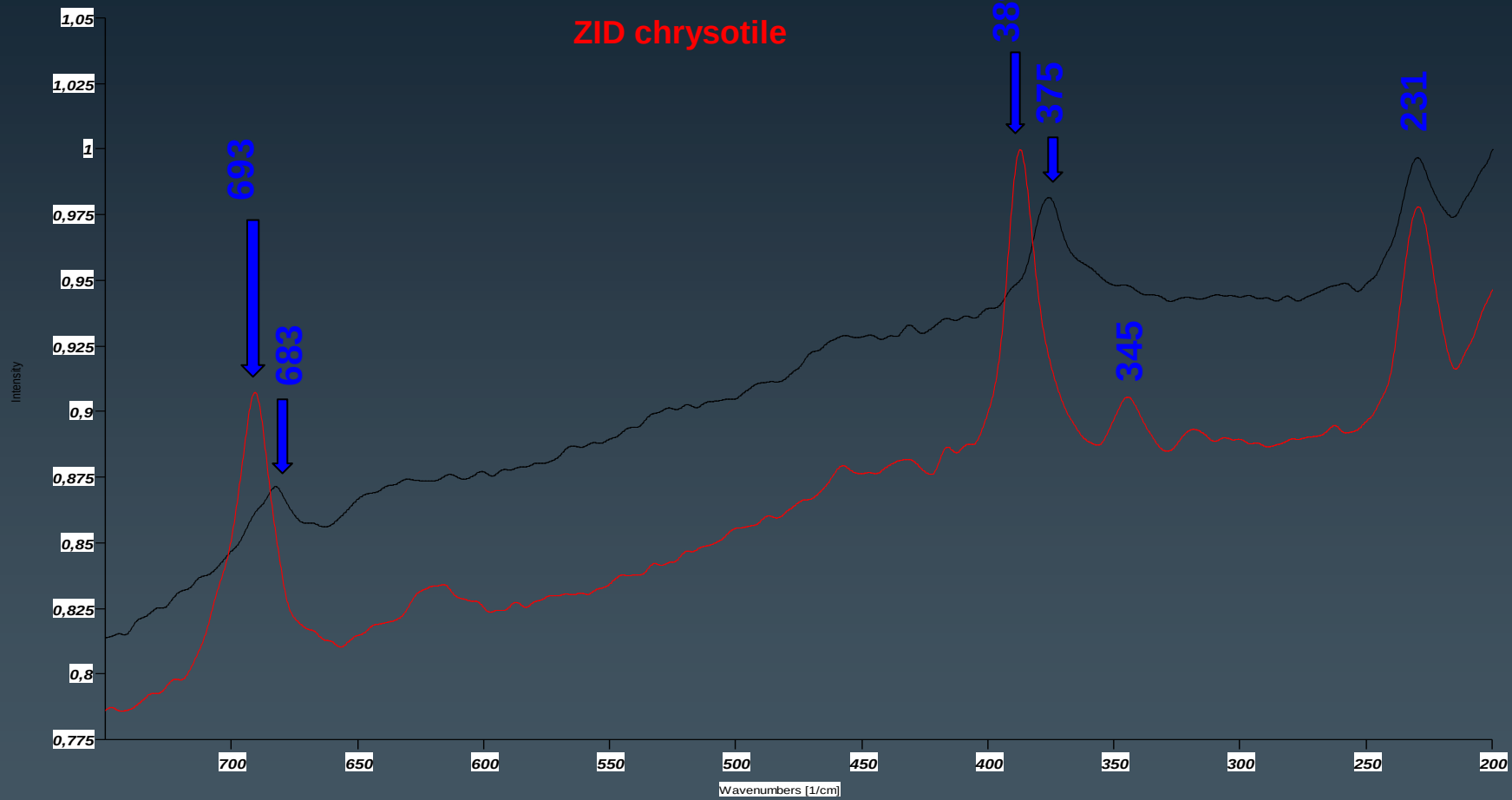
Serpentine polymorphs



Rinaudo et al.,
Can. Mineral. 2003

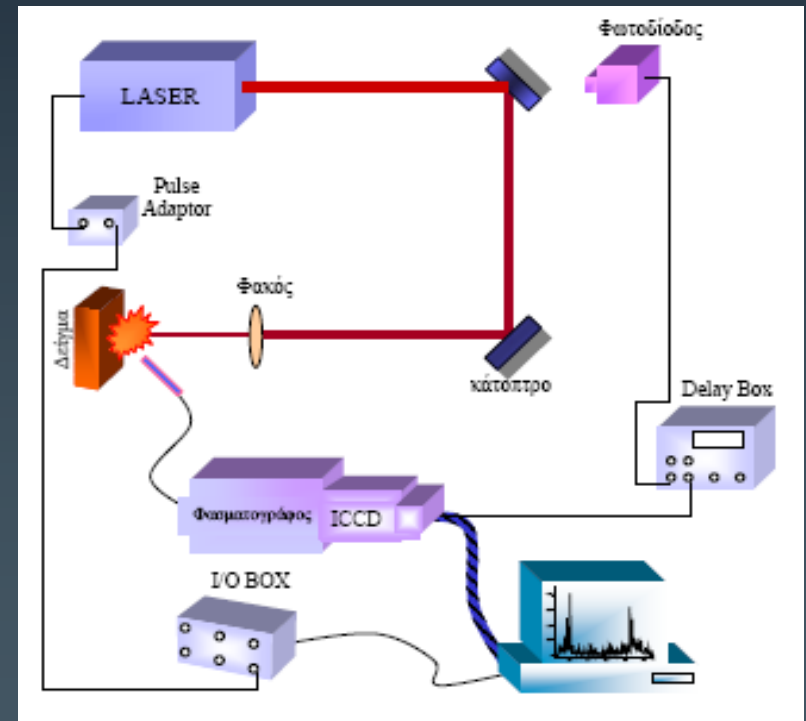
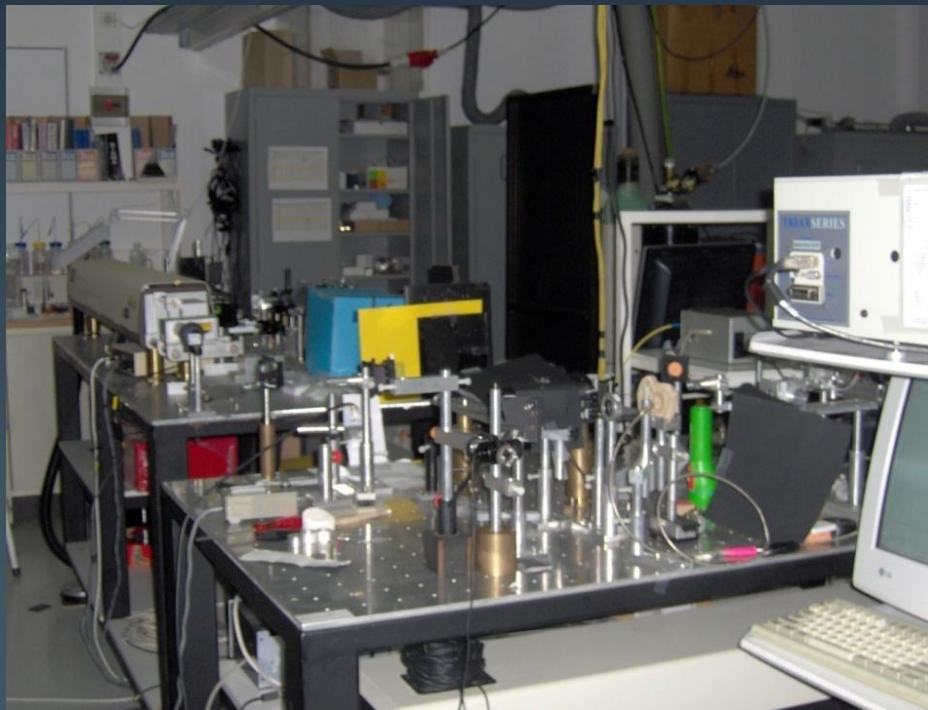
ZID antigorite

ZID chrysotile

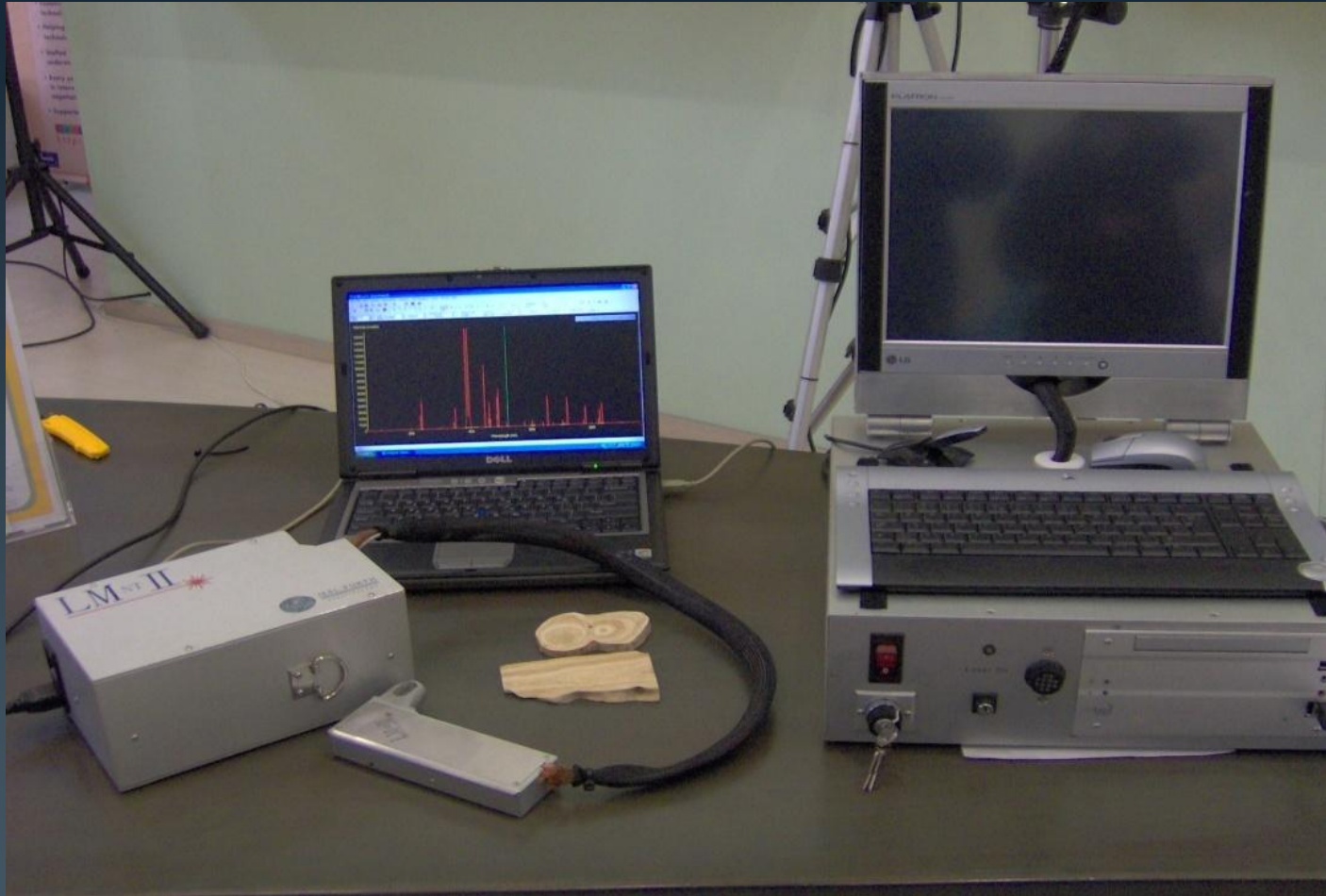


LIBS

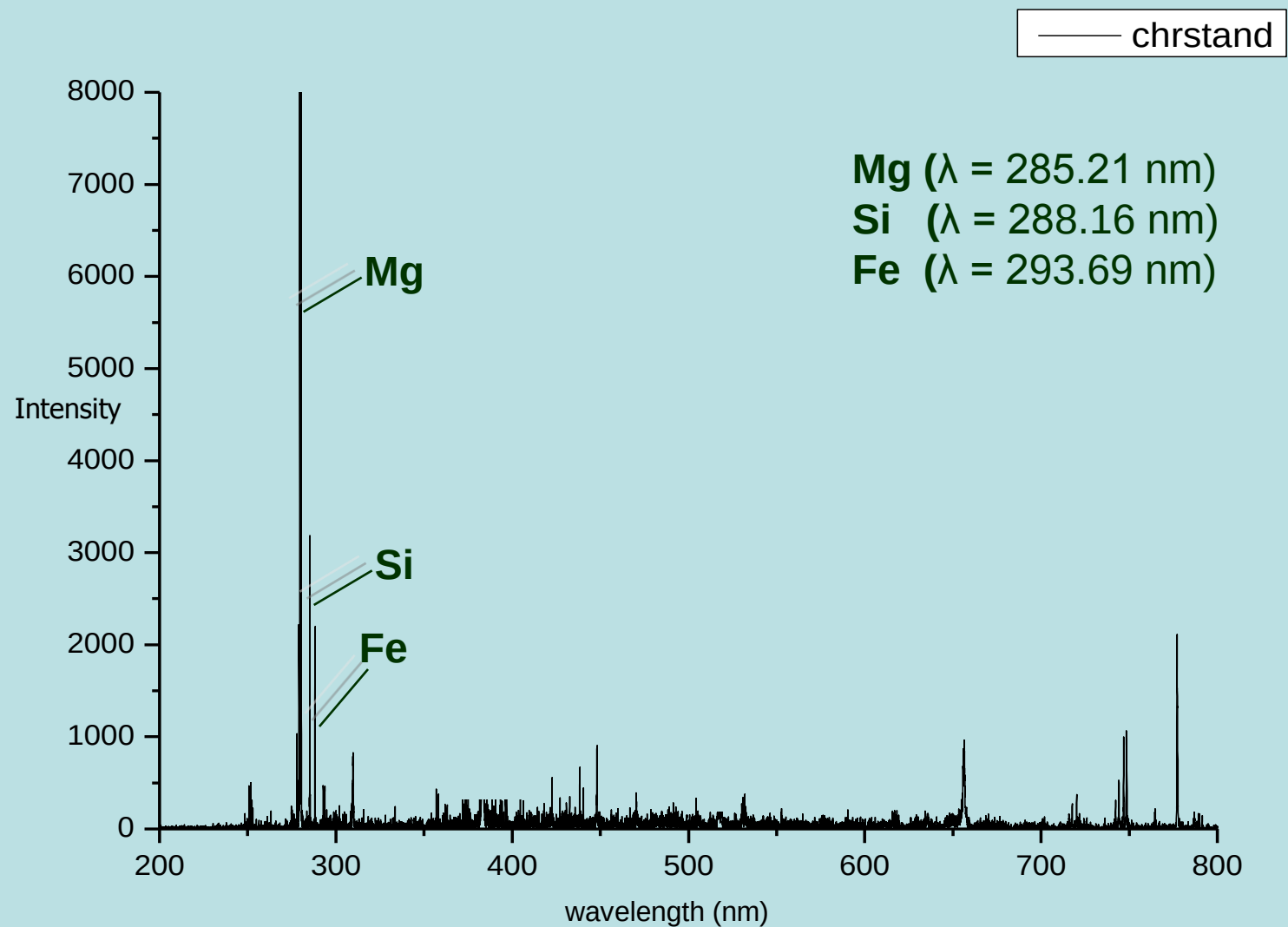
(Laser-induced breakdown Spectroscopy)



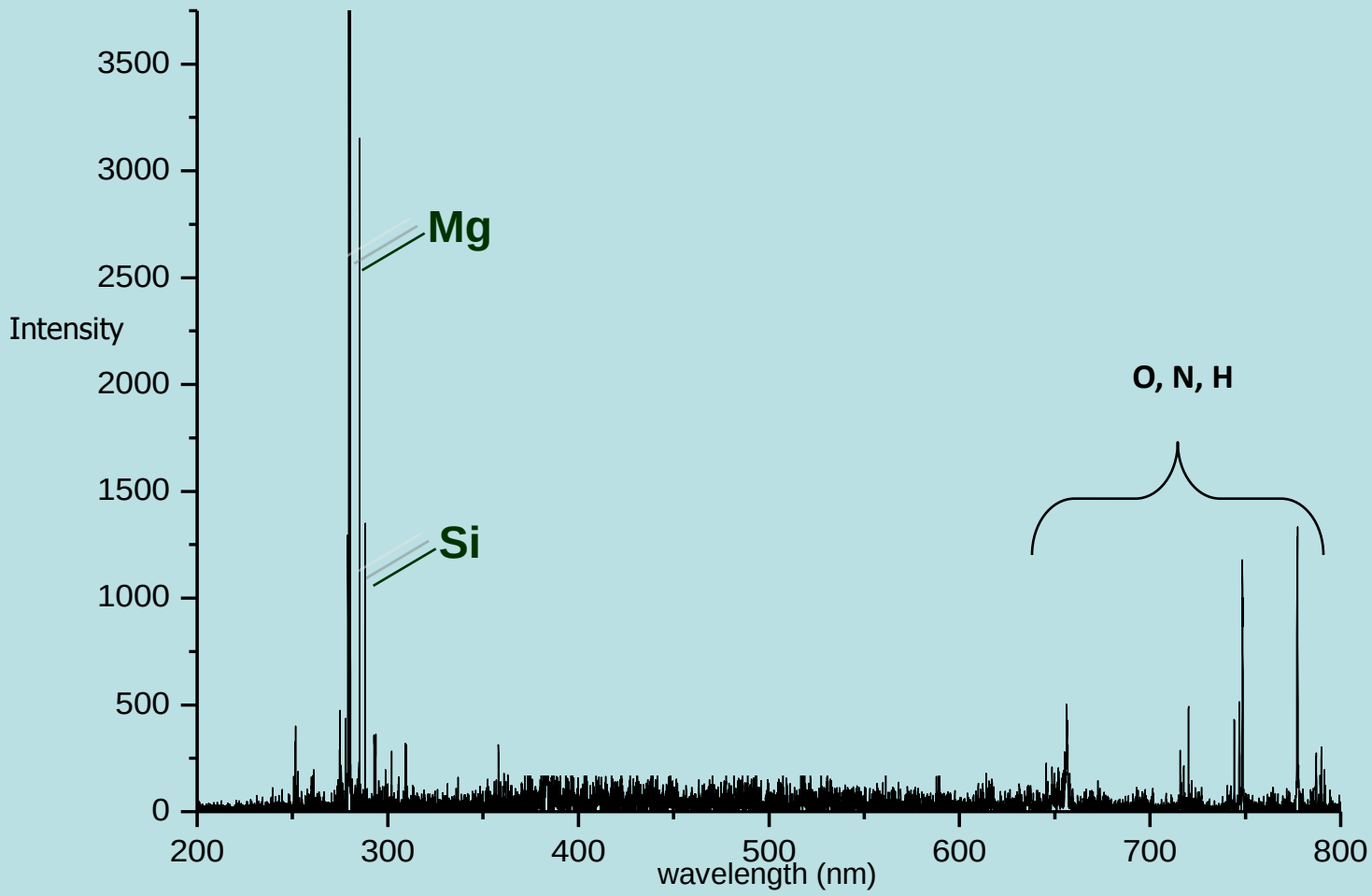
portable LIBS microprobe

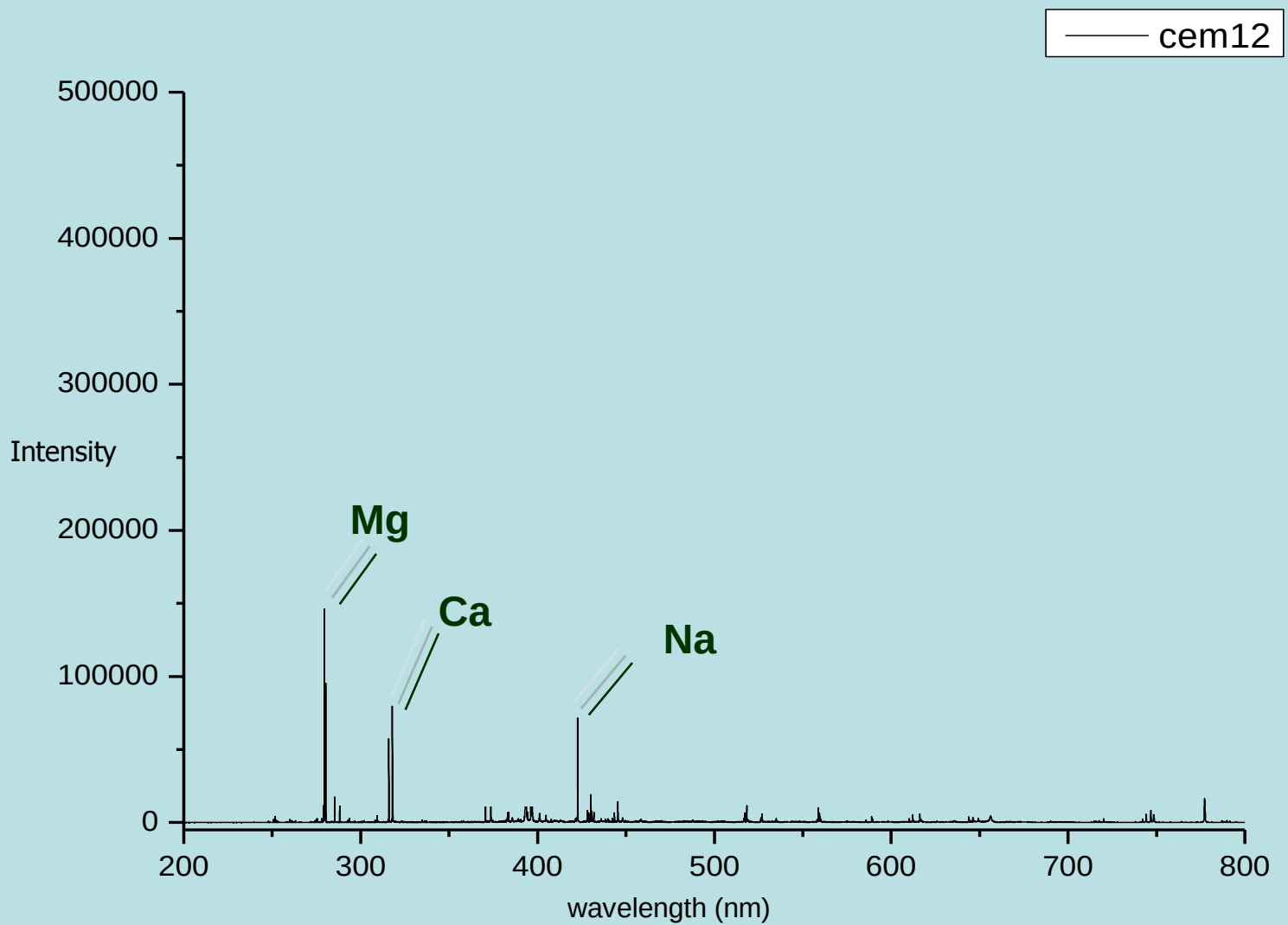


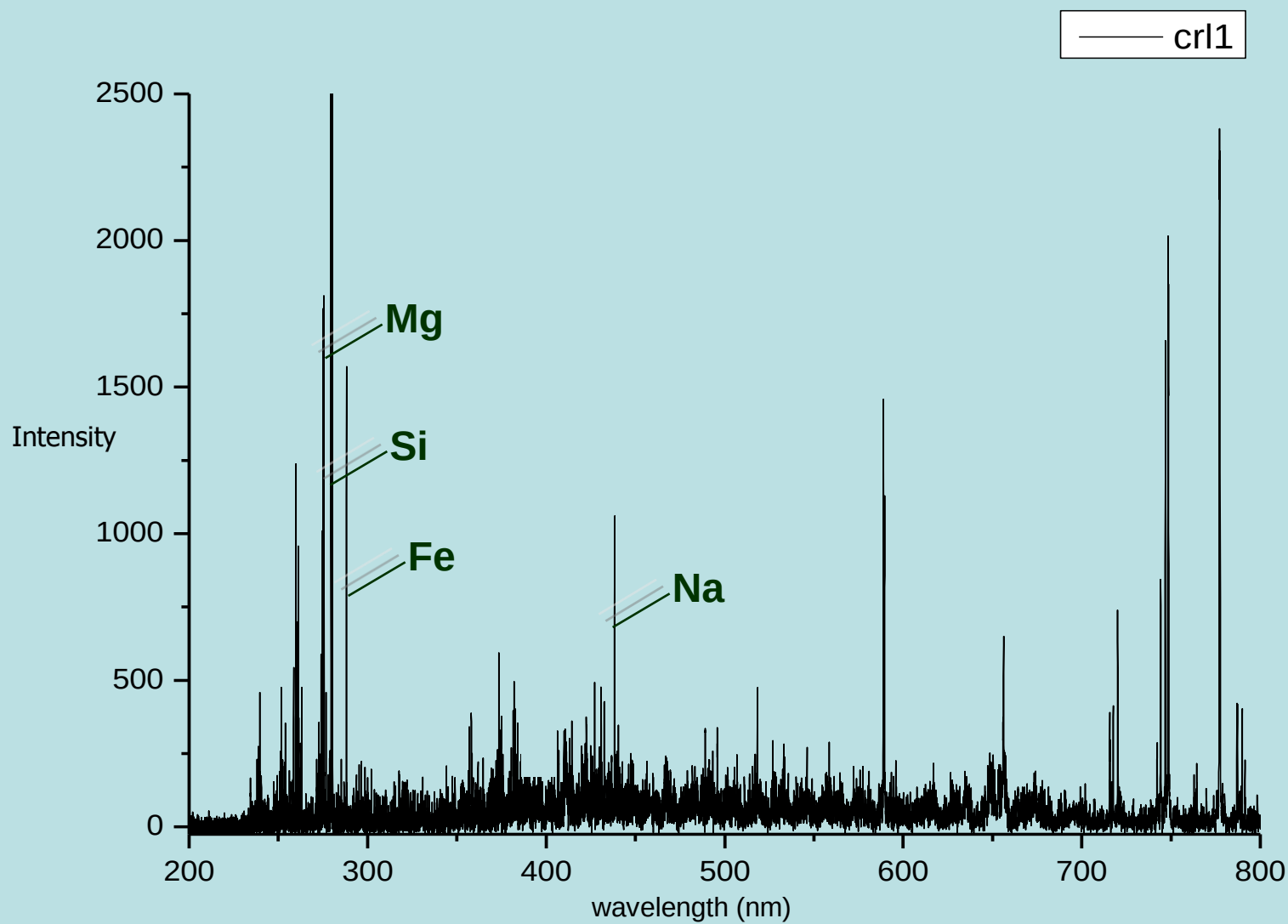
Institute of Electronic Structure
and Laser (Crete, Greece)

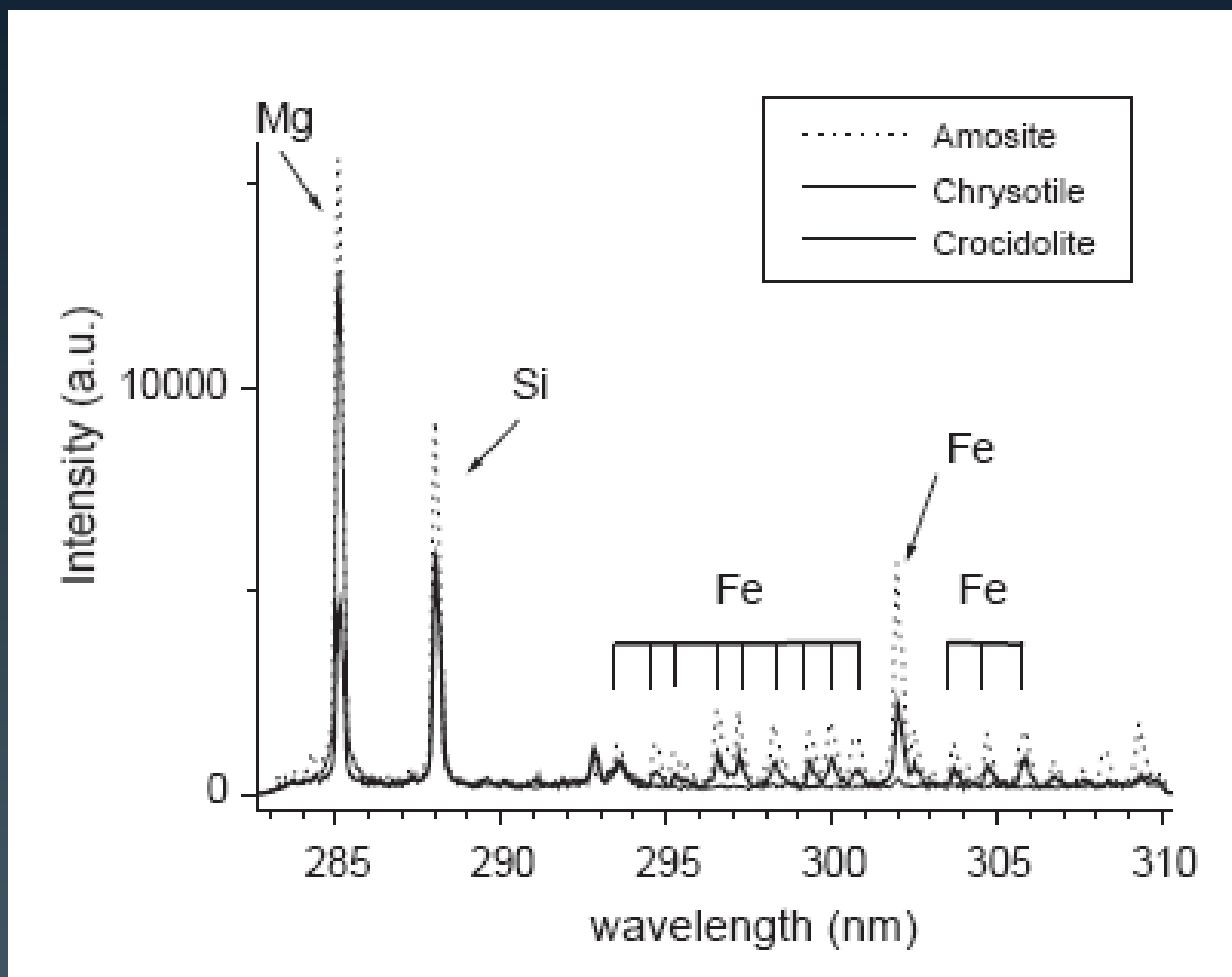


— zidwhite2





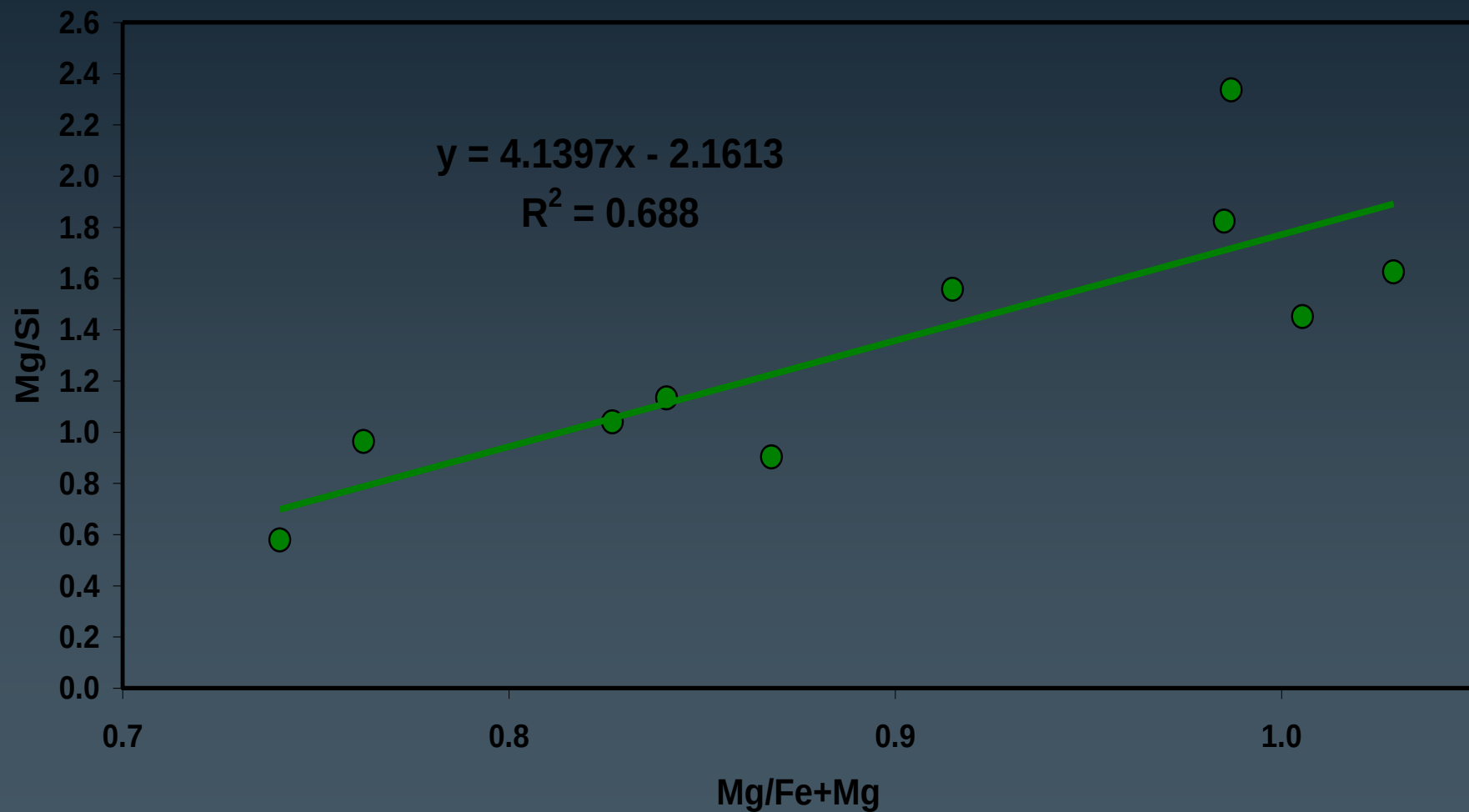




Caneve et al., *Spectrochim. Acta* 2005

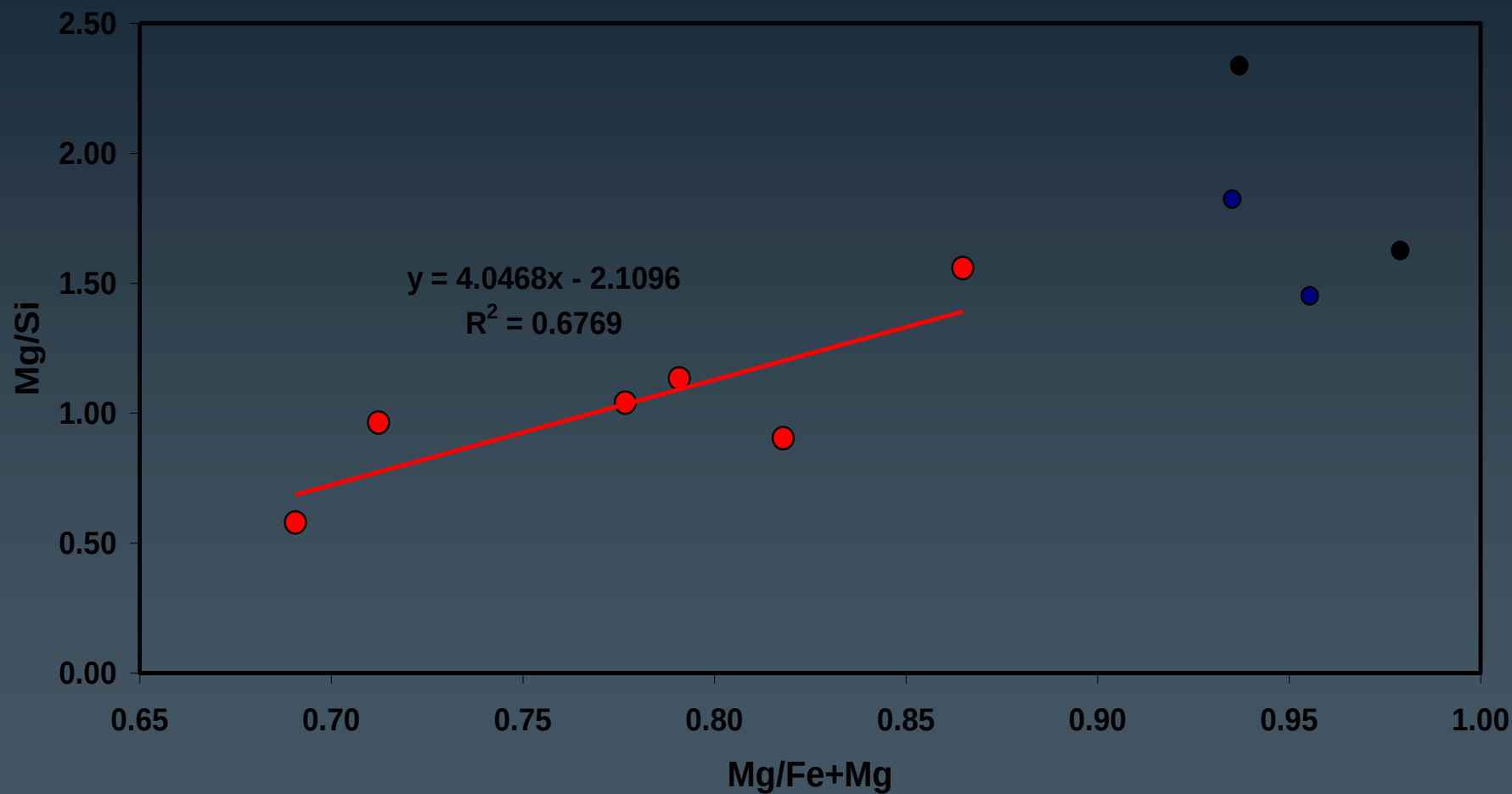
LIBS Ratios

● CHRYSOTILES — Linear (CHRYSOTILES)



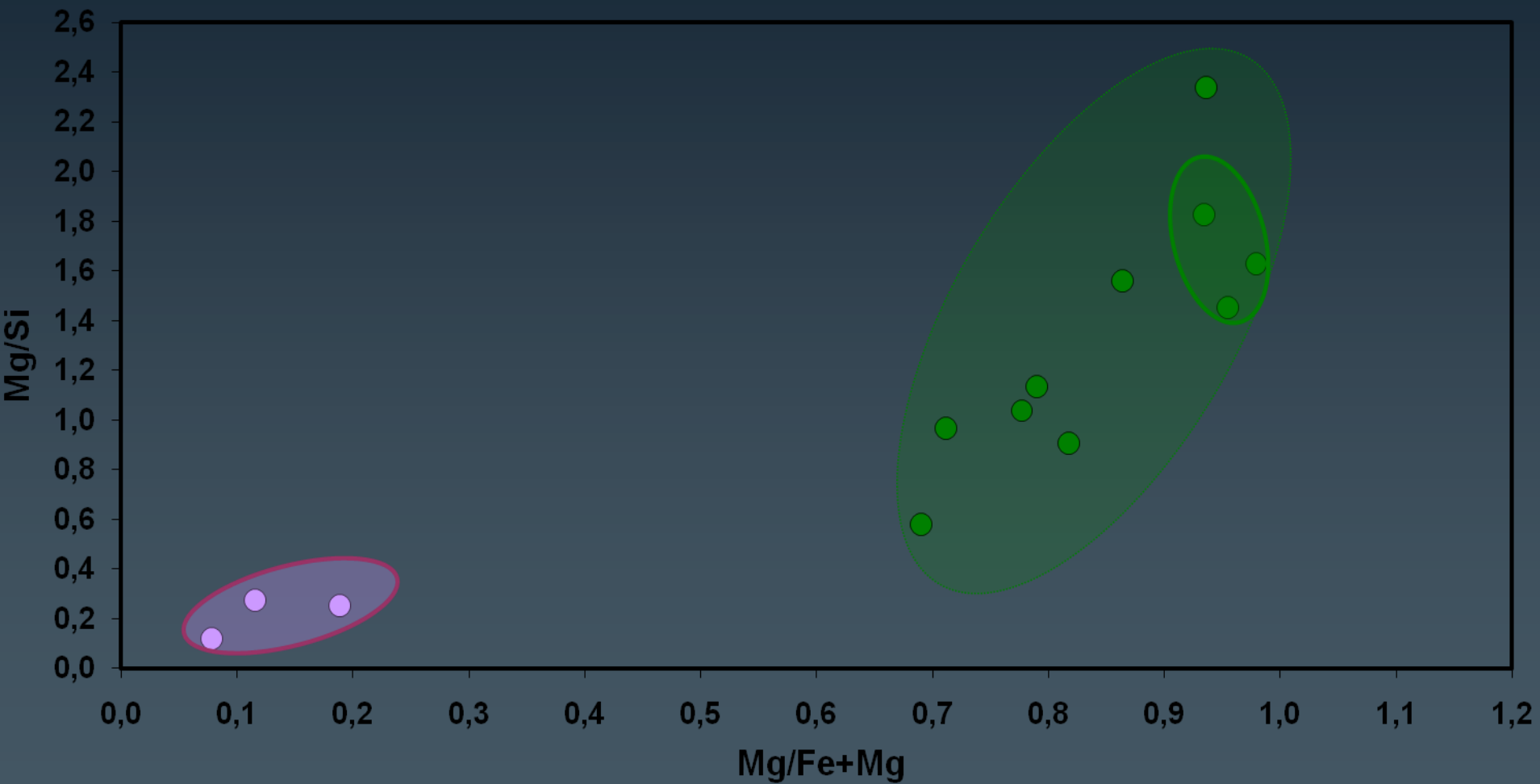
LIBS Ratios

● CHR ● ZID ● CEM



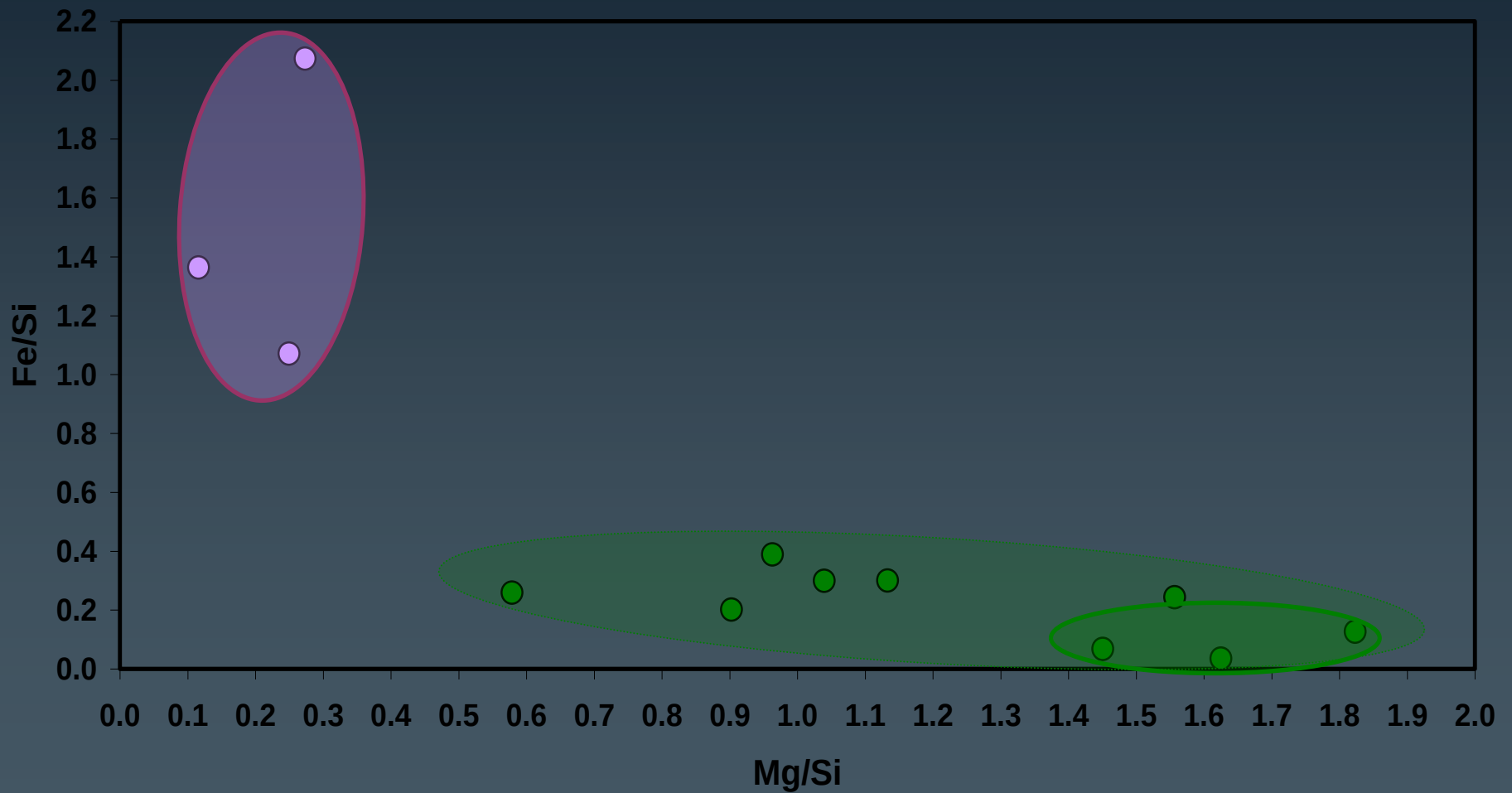
LIBS Ratios

● CHRYSOTILES ● CROCIDOLITE



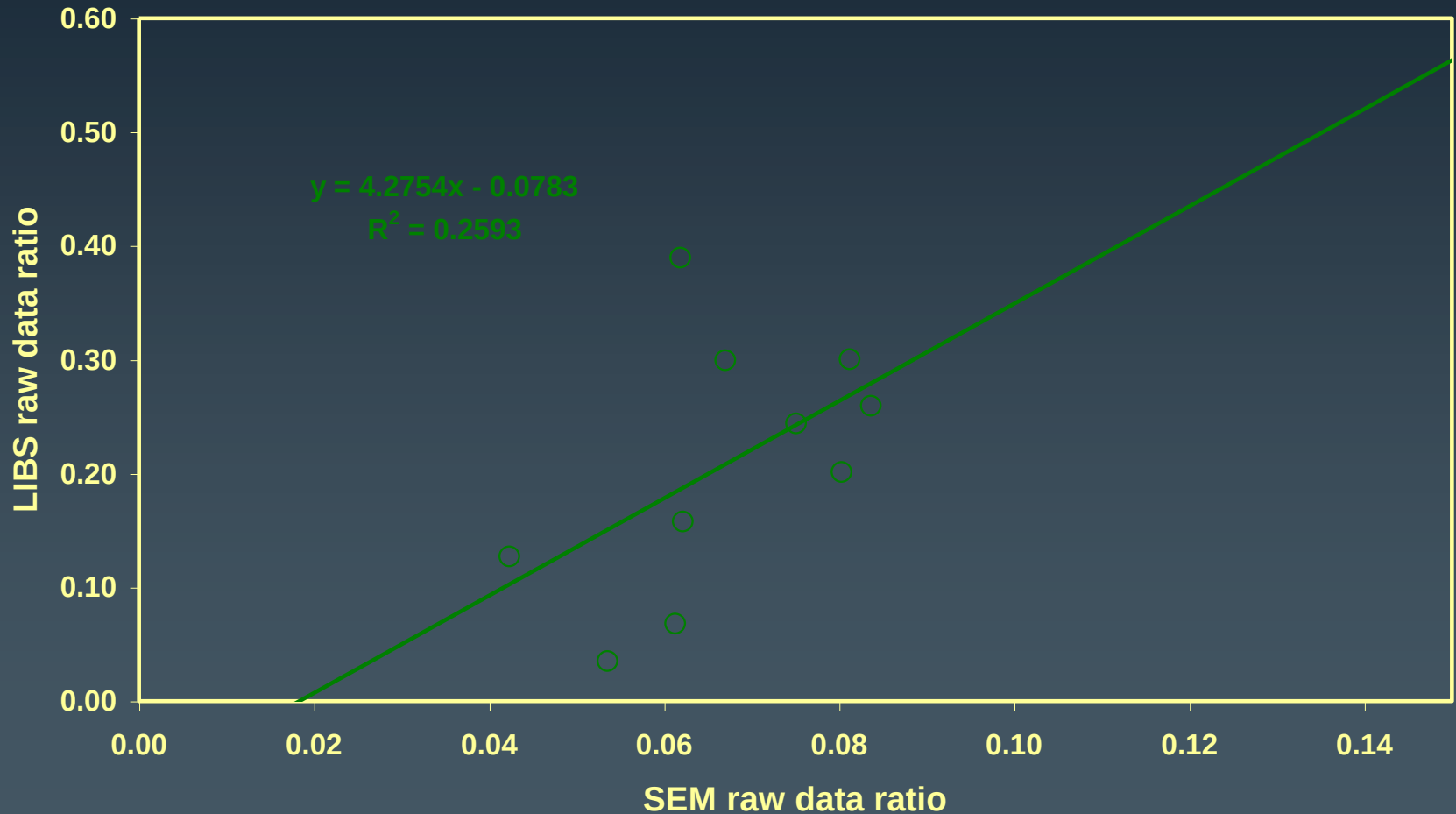
LIBS Ratios

● CHRYSOTILES ● CROCIDOLITE



Correlation SEM-EDS / LIBS

○ Fe/Si CHRYSOTILES — Linear (Fe/Si CHRYSOTILES)



Research Article

Identification of Asbestos Using Laser-Induced Breakdown Spectroscopy: A Viable Alternative to the Conventional Approach?

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Laser-induced breakdown spectroscopy has been performed on isolated samples of six types of asbestos—Chrysotile, Crocidolite, Amosite, Anthophyllite, Actinolite, and Tremolite—with analysis of optical emission in the visible region of the spectrum. The principal elements of Mg, Fe, Si, Na, and Ca have all been identified. By examining peak intensity ratios of these elements it is possible to identify the type of asbestos under examination solely from internal examination of the sample spectra. LIBS offers some significant advantages of speed of analysis and removal of subjectivity with potential for on-site rapid analysis.



**Centro Interdipartimentale per lo Studio degli
Amianti e di altri Particolati Nocivi "Giovanni
Scansetti"**

Article

Portable Raman Spectrometer for In Situ Analysis of Asbestos and Fibrous Minerals

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Featured Application: Portable Raman can detect asbestos and asbestos-like minerals in the field.