Perspectives in Astrobiology:
Microfossils in Carbonaceous Meteorites

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Modern Trends in Radiobiology and Astrobiology

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Perspectives in Astrobiology

INTRODUCTION

Fundamental Question of Astrobiology:

Is Life Restricted to the Planet Earth
or more widely distributed across the Cosmos?

Recent Discoveries Have Invalidated Long-Held Paradigms about Origin, Distribution And Evolution of Life on Earth and Provided New Perspectives in Astrobiology

Perspectives in Astrobiology

Recent Space Missions Show Water, Biogenic Elements, Energy & Organics Widely Distributed Throughout the Universe

Advanced Scanning Electron Microscopy, Stable Isotope and Radiochemical Neutron Activation Analysis Studies Reveal Carbonaceous Meteorites Contain Extraterrestrial Organics, Exotic Minerals and Rare Earth Elements and Embedded Microfossils of Recognizable Prokaryotic & Eukaryotic Life Forms

Perspectives in Astrobiology

Life as Chemistry

All known Life Requires Co-Existence of:

- Water (Liquid, Solid or Gas)
- Energy (Light, Chemicals, Food)
- Biogenic Elements (~20 are Life-Critical)

Major Biogenic Elements: (C, H, O, N, P, S)

Minor Biogenic Elements: (Na, K, Mg, Ca, Cl)

Trace Elements:(Mn, Fe,Co, Cu, Zn, B, Al, V, Mo, I)

Needed for Energy, Metabolism, Reproduction and Construction of Life-Critical Biomolecules, Amino Acids ,Proteins, DNA, RNA, ATP & Cells

Perspectives in Astrobiology

Life as Physics

Carl Woese&N. Goldenfeld (2010) New Perspective-

Life as Branch of Condensed Matter Physics like Superconductivity "Emergent Phenomena in Systems Far Out of Equilibrium Governed by Laws of Physics" -

Self-Propelled Entities Creating Large Scale Structures & Movements (Active Matter) – Motility

Complexity is Key: Non-Equilibrium Statistical Mechanics

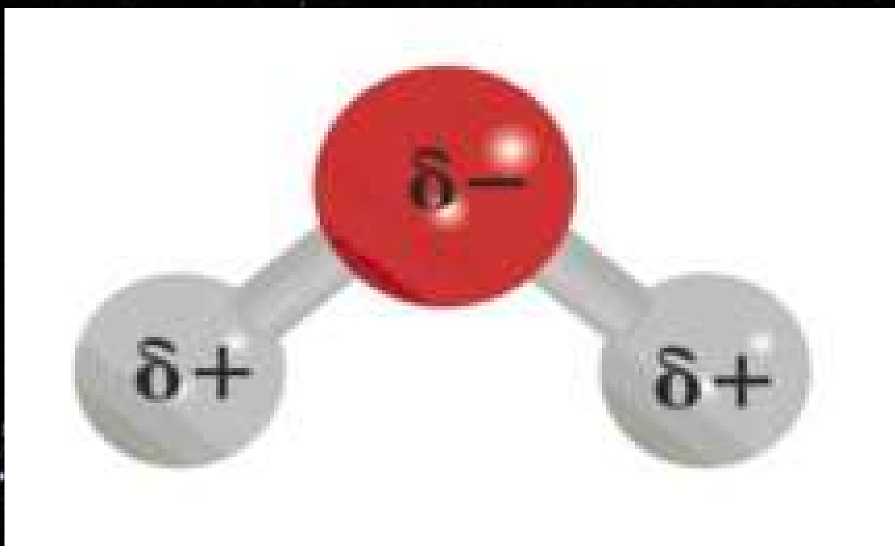
Main Dynamical Modes are Collective (Swarming)

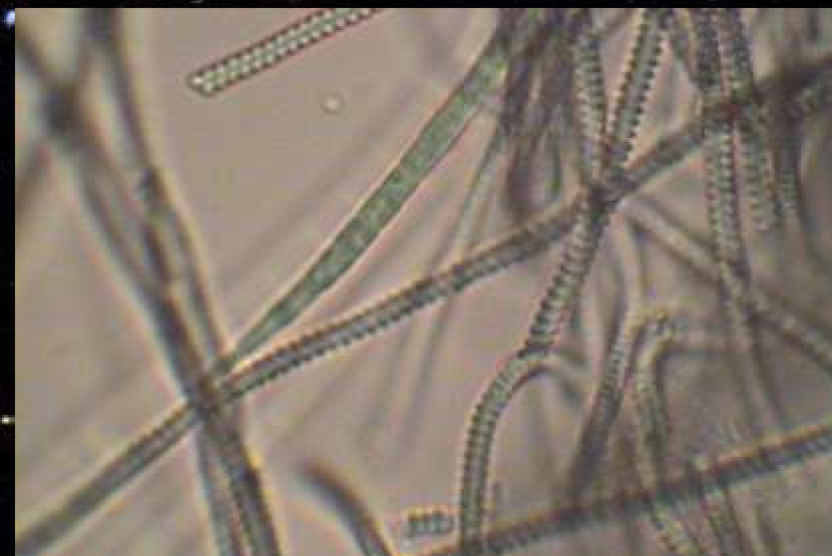
Most Cellular Life is Microbial: Microbes Exchange Genes (HGT); Communicate Between Cells (Quorum Sensing); Translocate Collectively (Swarming Motility); Form Biofilms

Requirements for Life: WATER

2nd most Abundant Molecule in Universe 60%-70% of Cells

Reynolds Number ~ 10^{-5} - Coasting Distance 0.1 Angstrom





Spirulina platensis & Phormidiun tenue

Bent Geometry (H-O-H Bond Angle - 104.5^{o}) - Polarity of Molecule--High Surface Tension/Boiling Point

Water has Maximum Density@ *+3.8 ^{o}C to -2 ^{o}C*

***Deep Oceans of All Planets&Moons Alike:* (No Light; ~0 ^{o}C)**

Water is *"Fine Tuned"* for Life

Water is Essential to Structure, Stability, Dynamics and Function of Biological Macromolecules

- ***Mediates Chain Collapse in Protein Folding & Interactions between Binding Partners to Search Native Topology via Funneled Energy Landscape***

Actively participates in Molecular Recognition and Interactions between Binding Partners-Contributes to Enthalpic or Entropic Stabilization

Water is Not Just and Inert Environment but an Integral and Active Component of Biomolecular Systems with Both Dynamic and Structural Roles

WATER IN THE COSMOS

Water on Planets: Mercury, Venus, Earth, Moon, Mars Jupiter, Saturn, Uranus, Neptune & Pluto

Water Has Been Discovered on Icy Moons of:

Jupiter: (Europa, Io, Ganymede and Callisto);

Saturn : (Titan and Enceladus);

Uranus: (Ariel, Umbriel and Miranda)

Neptune: (Triton- - Water/Ammonia Ocean)

Pluto (Charon-Ocean beneath Water Ice Crust)

Comets: Halley,67P (0.4 g/cc);Temple-1 (0.6 g/cc)

Water-Bearing Asteroids: 24 Themis, Ceres, Vesta

Liquid Water and Ice, Energy, Biogenic Elements and Organics Co-Exist All Across Our Solar System

LIFE ON EARTH

Microbial Extremophiles Inhabit:

Cold Regimes: ***Polar Ice Caps & Glaciers***

Hot Regimes: ***Geysers, Fumaroles, Deep Hot Crustal Rocks & Hydrothermal Vents***

Acidic, Hyperalkaline & Hypersaline Pools: ***Blood Falls, Owens Lake & Lake Untersee***

High Radiation: ***Spent Nuclear Fuel Rods***

High Pressure: ***Lake Vostok, Deep Sea Trench***

Hard Vacuum: ***MIR; International Space Station***

May Inhabit Comets/Ice or Oceans of Planets/Moons

Perspectives in Astrobiology

Evidence for Life

Biomolecules

- ***Molecules produced by Complex Metabolic Pathways in Living Organisms***

Small: Chiral Amino Acids, Nucleobases, Sugars, Lipids, Metabolites, Fatty Acids

Large: DNA, RNA, ATP, Proteins, Enzymes, Kerogen & Pigments (Chlorophyll, Carotenoids)

Large Biomolecules & Chiral Amino Acids Not Formed by any Known Abiotic Mechanisms: Provide Conclusive Evidence for Life

Perspectives in Astrobiology

Evidence for Ancient Life in Meteorites

Chiral Amino Acids

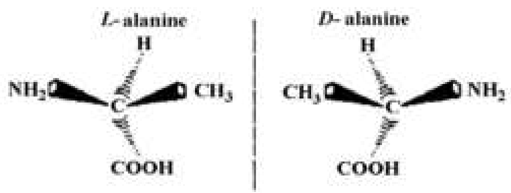


Figure 1. Chirality of levo- (L-) and dextrorotary (D-) mirror-image enantiomers of alanine.

All Protein Amino Acids are L-

After Death Amino Acids Racemize & Then Decompose

Aminos Absent in Meteorites Are Same ss MIssing in Ancient Fossils

Protein amino acids *italics*–not detected (–) in meteorites	Living bacteria[10]				Fossils[11]		Carbonaceous meteorites[12]			
	Micro cystis	*E. coli*	*Salm. pull*	*Salm. senf*	*Fly Amber*	*Hadro saur*	Murchison	Murray	Orgueil	Ivuna
	Wt %	Mol/ ALA	Mol/ ALA	Mol/ ALA	Mol/ GLY	Mol/ GLY	ppb	ppb	ppb	ppb
L-Alanine ALA	10.3	1.00	1.00	1.00	0.37	0.53	956	647	69	157
D-Alanine ALA	–	–	–	–			720	617	69	82
L-Aspartic Acid ASP	12.0	1.01	1.00	1.00	0.23	0.77	342	65	54	146
D-Aspartic Acid ASP	–	–	–	–			100	51	28	30
L-Glutamic Acid GLU	12.3	1.14	1.11	1.14	0.57	0.67	801	261	61	372
D-Glutamic Acid GLU	–	–	–	–			537	135	15	8
Glycine GLY	8.7	0.93	1.02	0.96	1.00	1.00	2919	2110	707	617
Arginine ARG	4.4	0.51	0.48	0.52	–	–	–	–	–	–
Histidine HIS	1.0	0.18	0.21	0.19	–	–	–	–	–	–
Isoleucine ILEU	5.0	0.55	0.51	0.55	–	–	–	–	–	–
Leucine LEU	8.2	0.83	0.78	0.78	–	–	1.9 Nmol/g	–	–	–
Lysine LYS	4.4	0.56	0.59	0.56	–	–	–	–	–	–
Methionine MET	1.9	0.31	0.37	0.23	–	–	–	–	–	–
Phenylalanine PHE	3.8	0.34	0.33	0.33	–	–	–	–	–	–
Proline PRO	4.9	0.25	0.26	0.28	–	–	13 Nmol/g	–	–	–
Serine SER	6.6	0.41	0.48	0.43	0.56	0.91	4.7 Nmol/g	–	–	–
Threonine THR	6.6	0.48	0.50	0.48	–	0.41	–	–	–	–
Tryptophan TRY	0.04	0.05	0.05	0.04	–	–	–	–	–	–
Tyrosine TYR	3.4	0.12	0.15	0.08	–	–	–	–	–	–
Valine VAL	6.5	0.73	0.66	0.75	–	0.24	–	–	–	–
Nonprotein amino acids										
α-Aminoisobutyric AIB	–	–	–	–	–	–	2901	1968	39	46
γ-Aminobutyric γ-ABA	–	–	–	–	–	–	1331	717	~600	628
Isovaline D,L- IVA	–	–	–	–	–	–	3359	2834	<194	<163

Perspectives in Astrobiology
Search for Life on ExoPlanets

Biosignatures in Atmospheres

Spectra of Methane, Nitrous Oxide & Ammonia Produced Mainly by Bacteria on Earth

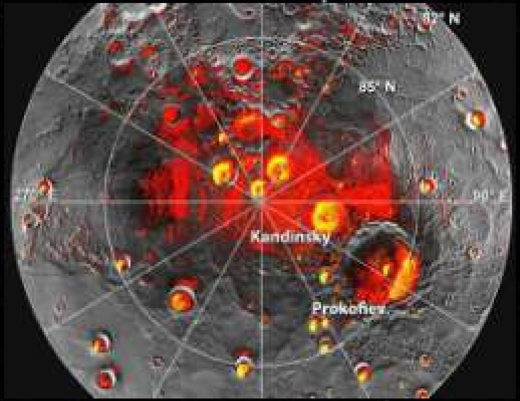
Molecular Oxygen (O_2) is Very Reactive and Released by Photosynthesis:

O_2 Cannot Remain for Long Periods in Equilibrium in Planetary Atmospheres

Molecular O_2 on Earth Produced by Life

Water on Hot Planets
MERCURY and VENUS

2014: NASA Messenger Neutron Spectrometer Confirms Water Ice & Dark Frozen Organics in Kandinsky & Prokofiev Craters at North Pole of Mercury



1961-2011: Russian Venera, ESA Venus Express, & Magellan Probes find Water, H_2SO_4, Oxygen, Ozone

(H_2S - SO_2) & (H_2S -COS) in Layers @58-70 km (0-90 ^{O}C) where Earth' Acidophiles Could Grow in Droplets

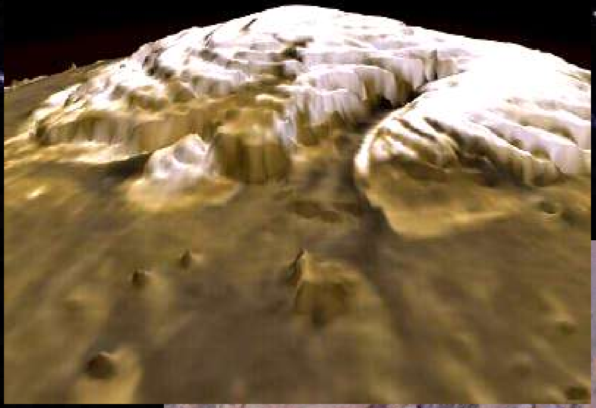
Water, Snow & O_2 on Mars

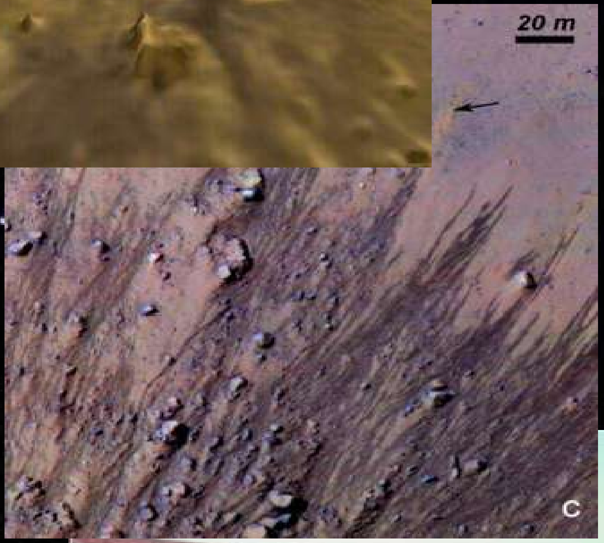
2001 NASA Odyssey γ-ray Spectrometer finds 95% pure Water Ice in Planum Boreum ~3 million km^3 in N. Cap

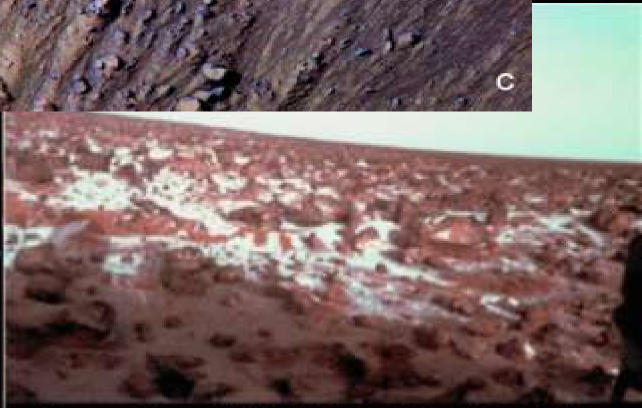
5/18/1979 – Water Snow on Utopia Planitia Viking2 Site

2002-Molecular Oxygen in Mars Atmosphere at levels above photolysis of CO_2

2011- Recurring Slope Lineae Provide Evidence of Present Day Liquid Water on Mars







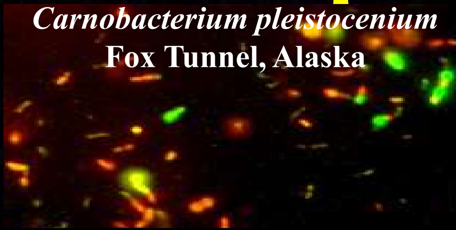
Snow on Mars at Viking 2 Lander Site (48N, 226W)
(211093) May 18, 1979 12:50:43Z
Detector Temperature -18.10 C

Liquid Water Ocean and 125 km Water and Ice Geysers on South Pole of Europa

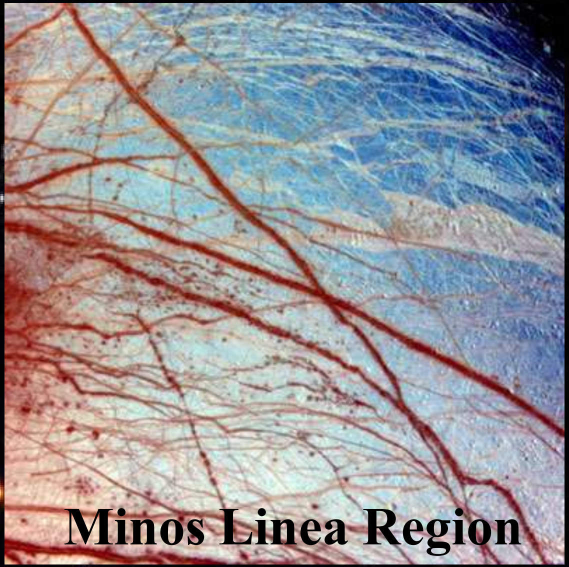
Red Cracks in Crustal Ice: Evidence for Liquid Water Ocean & Life? on Europa

Conamara Chaos (70X30 km)

Herminiimonas glaciei
3042 M Greenland



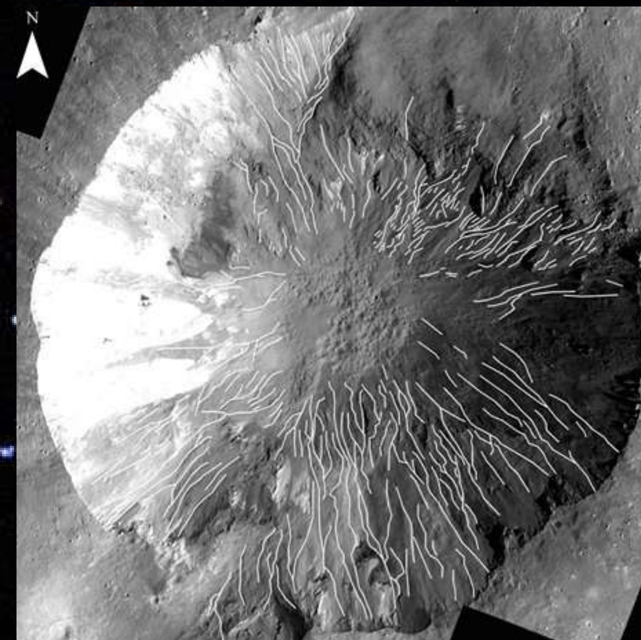
Carnobacterium pleistocenium
Fox Tunnel, Alaska



Minos Linea Region

Red Cyanobacterial Stromatolites Discovered in *2008 International (US/Russia/Austria) Lake Untersee Astrobiology Expedition*

Dawn: Liquid Water & Organics on Asteroids Ceres & 4 Vesta



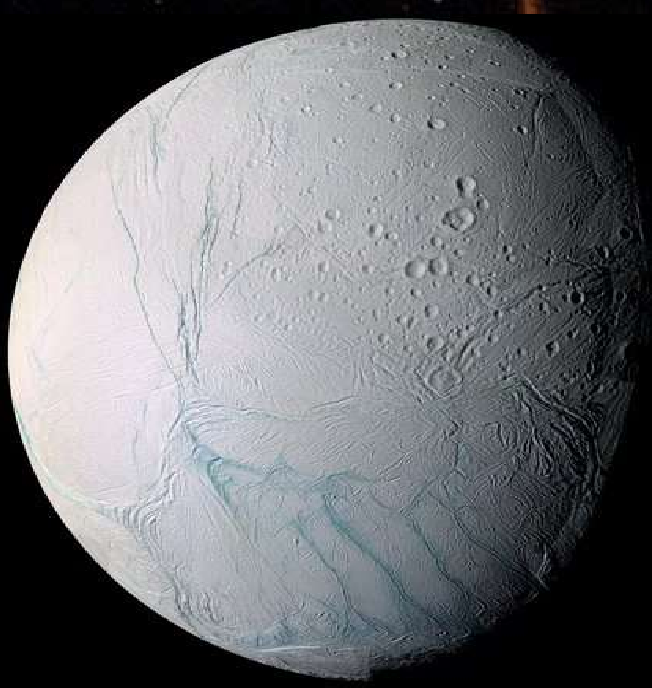
Ceres-Rocky Core with Icy Mantle (~200 million cubic km of water) (G or C Asteroid ~ CI1 meteorites)

4 Vesta-Cornelia Crater with Gullies & RSL Shows Liquid Water Flow ~ HED Meteorites

Thomas, P. C. *et al.* "Differentiation of the asteroid Ceres as revealed by its shape". *Nature* **437,** 224 (2005).

Scully, J. E. C.; et al. "Sub-curvilinear gullies interpreted as evidence for transient water flow on Vesta". *45th Lunar and Planetary Science Conference (2014).*

Geysers & Liquid Water Seas on Saturn's Moon Enceladus



Cassini Mission Finds Water Ice Geysers Tiger Stripes near South Pole of Enceladus

Temperature of Tiger Stripes ~ 273 K

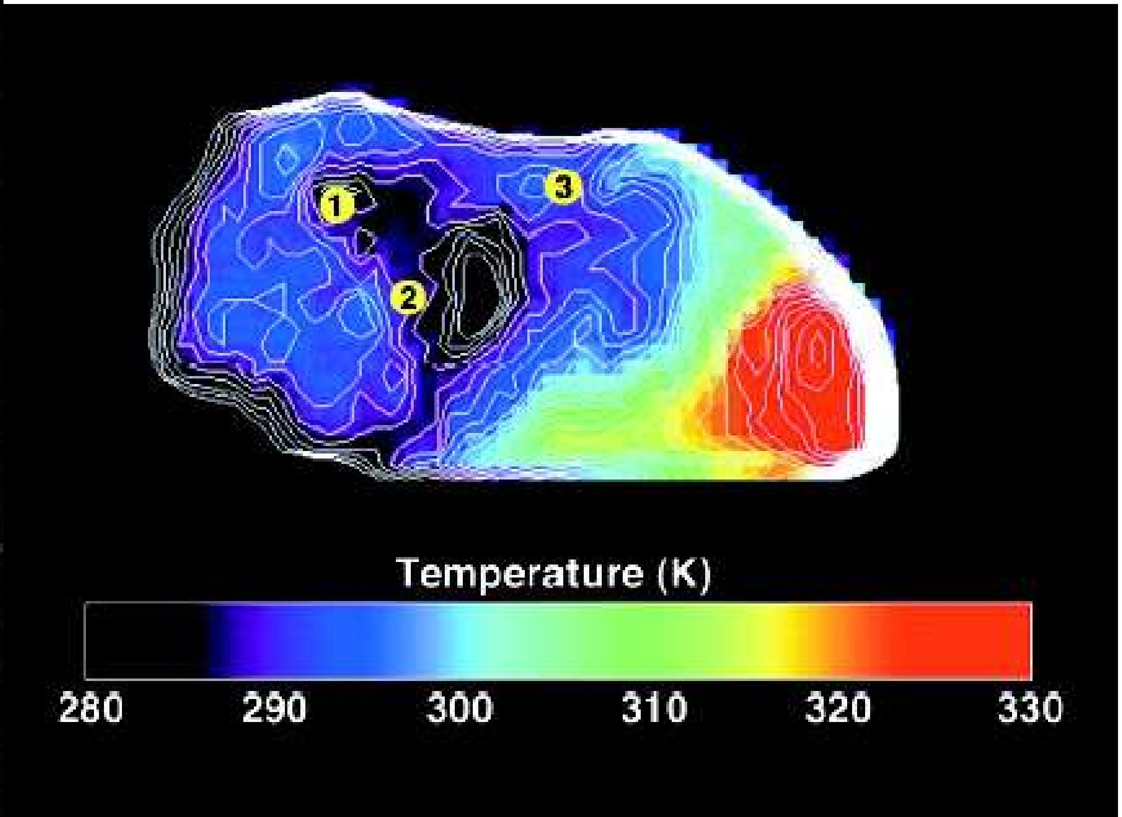
Cassini Gravity Data indicates vast Regional Subsurface Sea of Liquid Water at Depth of 30 to 40 km up to 50^{o} S Latitude

Less at al. "The Gravity Field and Interior Structure of Enceladus" Science 344, 78-80, (2014)

Molecular O_2 in Atmospheres of Europa, Enceladus & Rhea Interpreted as from Ice Decomposition by Magnetospheric Plasma— but could be from Photosynthetic Microbes

Liquid Water, Ice & Jets on Nucleus of Comet 9P/Temple 1

Sunshine et al. *Exposed Water Ice Deposits on the Surface of Comet 9P/Tempel 1 Science 311, 1453 2006*



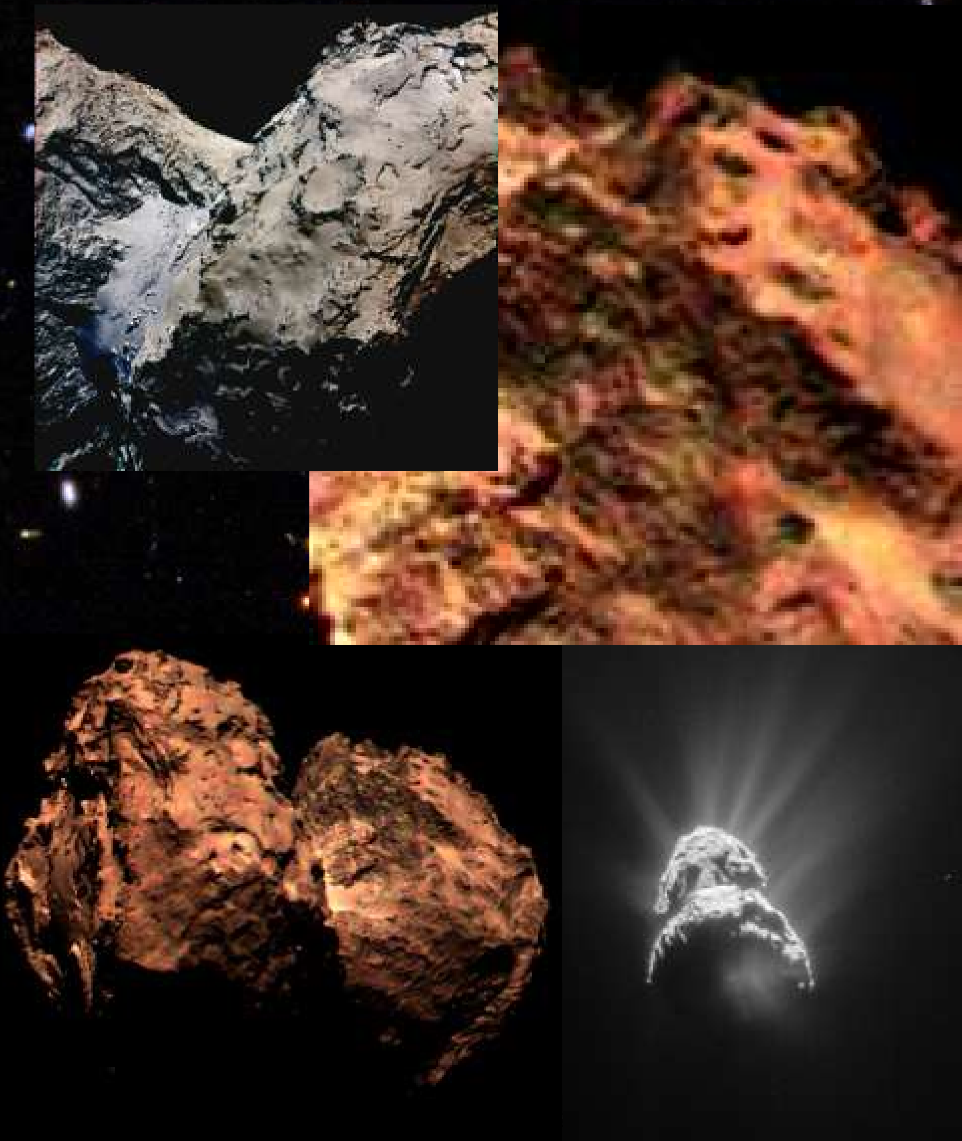
Deep Impact Thermal Map Shows Water on Nucleus of Comet 9P/Temple1 & Flaring at Orbit of Mars – Possibly Ejecting Ice, Cosmic Dust, Diatoms &Cyanobacterial Cells

O_2 & Jets of Water Ice on Comet *67P/Cheryumov-Gerasimenko*

Smooth Blue Ice & Jets on Comet
67P/Cheryumov-Gerasimenko

Molecular Oxygen detected in Comet Coma & Color images showing Red, Pink, Green and Blue-Green areas Support Hypothesis of Active Growth of Cyanobacteria

Photos Credit: ESA OSIRIS Camera Team



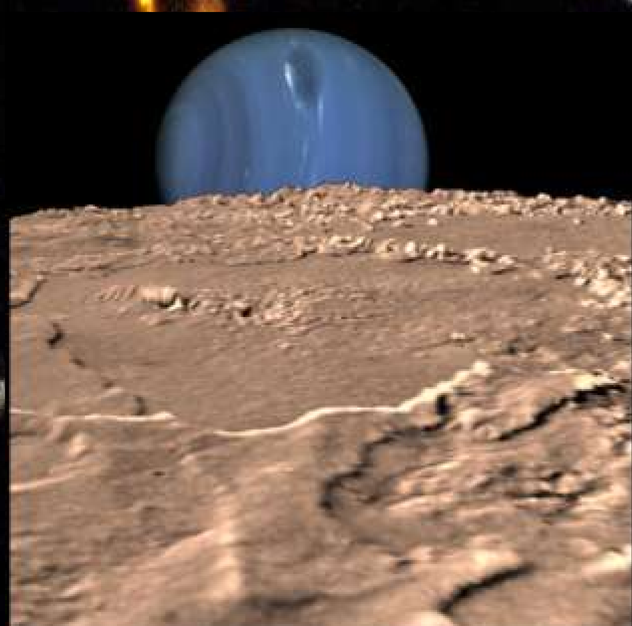
Life in Polar Caps & Ice Caves Suggest Life Possible in Comets

Diatoms from 2827 M Vostok Ice Core & Motile Bacteria from Kverkfjöll Ice Cave, Vatnajökull Ice Cap, Iceland.

Water/Organics on Outer Planets
Uranus and Neptune/Triton

Uranus 20 AU T 40K-4000K
Density 1.27 g/cm^3
Neptune & Triton 30 AU
Credit: NASA/Hubble/Voyager

Neptune 30 AU; Core T < 800K
Pressure < 20 kbar

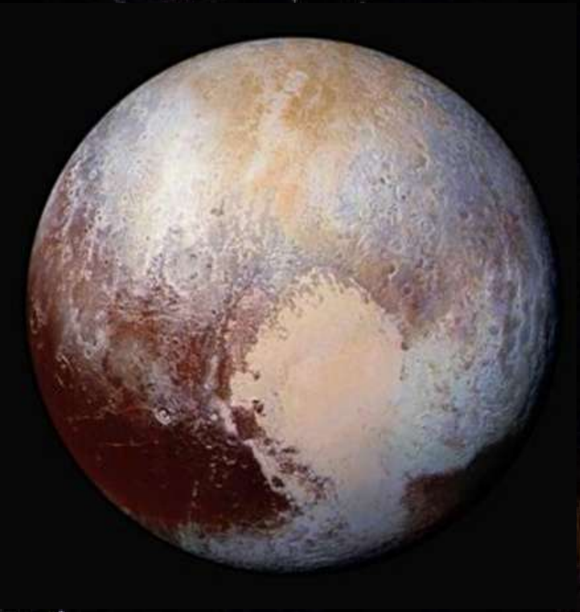


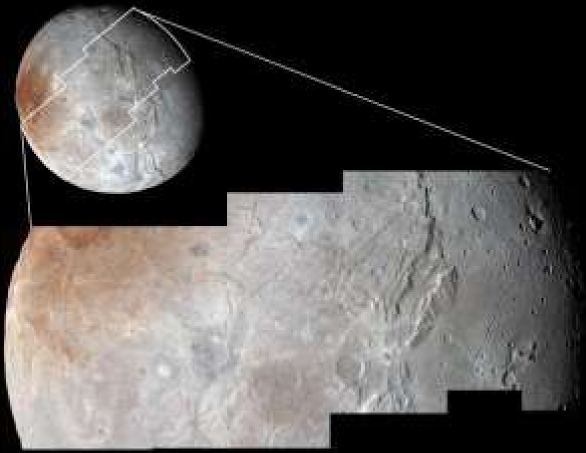
Triton Diameter 2,705 km;
Density ~ 2.066 g/cm^3

Triton Surface Water Ice,
Nitrogen & Methane

Subcrustal Liquid Water Oceans Indicated

DAWN DISCOVERS
Water Ocean/Organics on Pluto/Charon





New Mountains, Polygons & Ice Flows on Pluto indicate Oceans Red&Orange colors from Tholins or Pigments. Sub-Ice Oceans and Cryovolcanism on Charon ***Credit: NASA/GSFC;JHUAPL;SwRI***

CARBONACEOUS METEORITES

Primitive Chondrites (Only 8 Known Groups) with Elemental Abundances ~ Solar Photosphere

CI & CM ~ 3%-22% Deuterium Enriched Water and ~ 4 Wt% Extraterrestrial Carbon

Volatiles & Organics Indicate Heating < 200 C; Organic Grains in Matrix similar to Kerogen or Coal

Have Extraterrestrial Nucleobases & Biomolecules (Murchison: Uracil $\delta^{13}C = +44.5‰$; Xanthine = +37.7‰)

Aqueous Alteration of Minerals & D/H Ratio Prove Liquid Water on CI&CM Meteorites

Parent Body Probable CI-Asteroids or Comets

PHOTOSYNTHETIC PIGMENTS

Chlorophylls, Carotenoids & Phycobilin Pigments of Photosynthetic Organisms Have Never Been Detected in Carbonaceous Meteorites

Porphyrins, Pristane & Phytane (C19 & C20): Diagenetic Breakdown Products of Chlorophyll Phytol Chain Found in CI and CM Meteorites

Isoprenoid Hydrocarbons With No Known Abiotic Production Mechanisms

Biomolecular Evidence for Indigenous Photosynthetic Microbes on Parent Body Long before Arrival on Earth

METEORITE CONTAMINATION

Paradigm Invalidated: All Carbonaceous Meteorites Contaminated by Earth Microbes

Carbonaceous Meteorites Are Missing:

12 of 20 Life-Critical Protein Amino Acids

RNA & DNA Sugars: Ribose & Deoxyribose

2 Unstable Life-Critical Nucleobases Absent:

Cytosine→Uracil: Half-Life 17,000 Years

Thymine→Xanthine: Half-Life 1.3 Ma @ 0 C; pH 7

Contamination by Modern Microorganisms Must Also Introduce These Biomolecules

Microfossils in Carbonaceous Meteorites: Evidence of Life

Yellow: Microfossils Found at MSFC; Red: NOT Found

- **CI1: Alais, Ivuna, Orgueil**
- **C2 Ungrouped: Tagish Lake**
- **CM2: Murchison, Mighei, Murray, Nogoya,Cold Bokkeveld, Bells**
- **CR3: Acfer 324**
- **CK4: *Karoonda***
- **CO3: Rainbow, Dar al Gani (DaG) 749, Kainsaz**
- **CV3: Efremovka, *Allende***
- **C: Carbonaceous UnGrouped: Pollonaruwa, Sutter's Mill**

Stony Chondrites, Achondrites and Iron Meteorites

- **L4: *Nikolskoye, Barratta;* L/LL6: *Holbrook***
- **Diogenite:*Tatahouhine***
- **Iron: *Henbury; Thiel Mountains, Antarctica (TIL 99001-99018)***

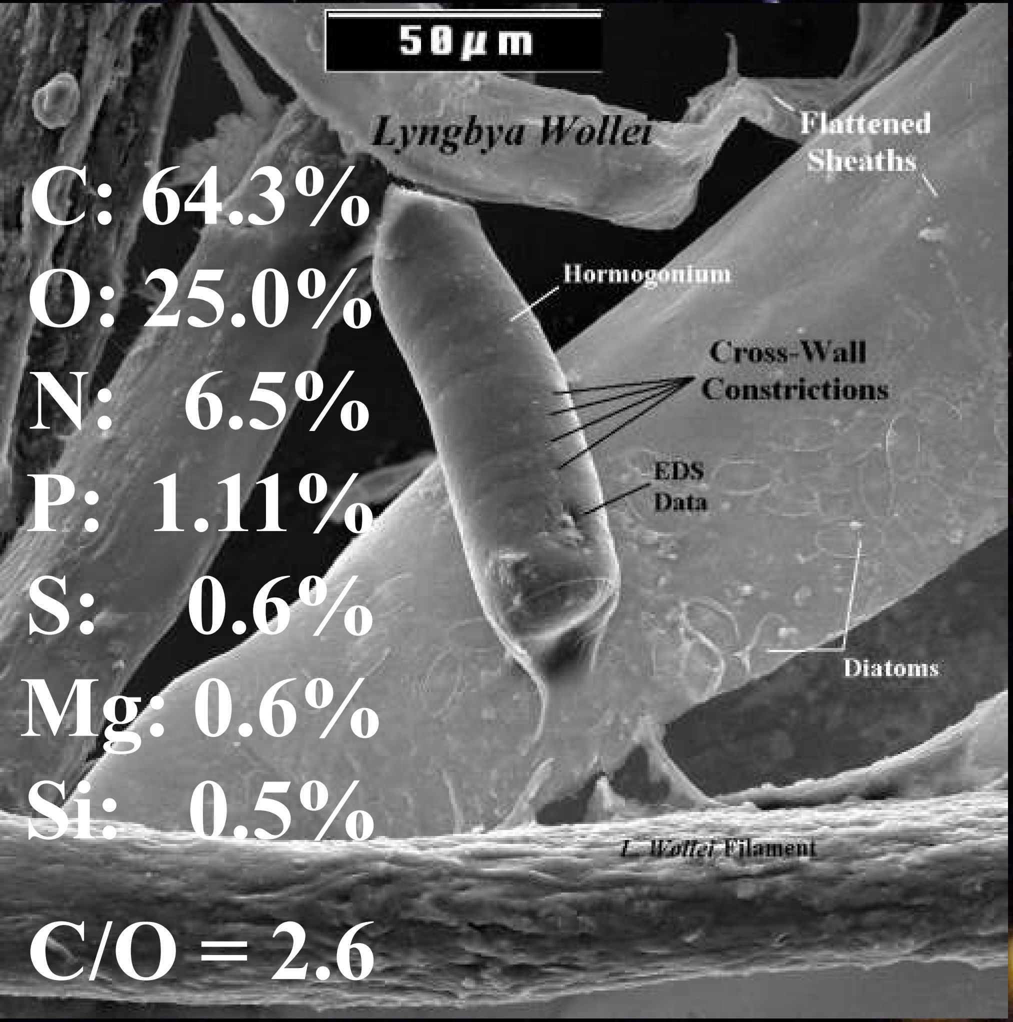
Microfossils in Carbonaceous Meteorites

Contamination Control & Detection

- Study only Uncoated, Freshly Fractured Interior Surfaces; Stones Stored at -80 ºC when not in Use
- Fusion Crust and Old Fractures in Stones Avoided
- All Containers, SEM Mounts & Tools Flame Sterilized
- Null Controls -Silicon Wafers & Apollo Lunar Samples
- NASA FESEM Energy Dispersive X-Ray Spectrometer Calibrated Using Element and Mineral Standards

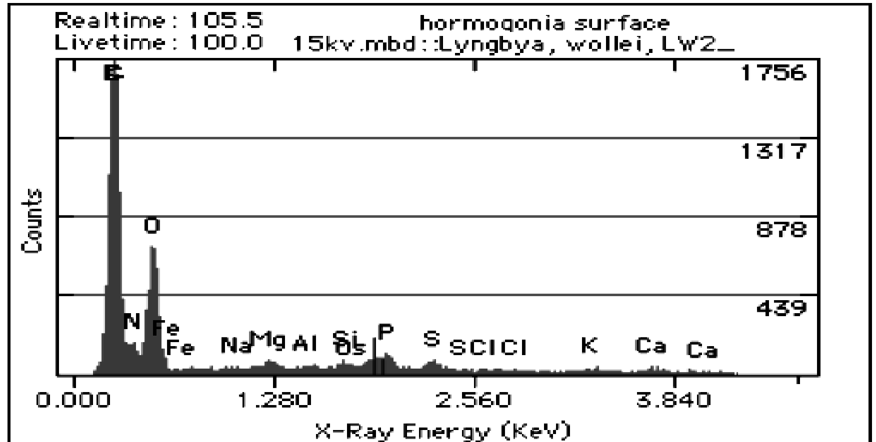
Nitrogen & Beam Damage Used to Detect Contaminants

Nitrogen & Beam Damage Distinguish Living *Lyngbya wollei* Cells from Ancient Fossils



C: 64.3%
O: 25.0%
N: 6.5%
P: 1.11%
S: 0.6%
Mg: 0.6%
Si: 0.5%

C/O = 2.6



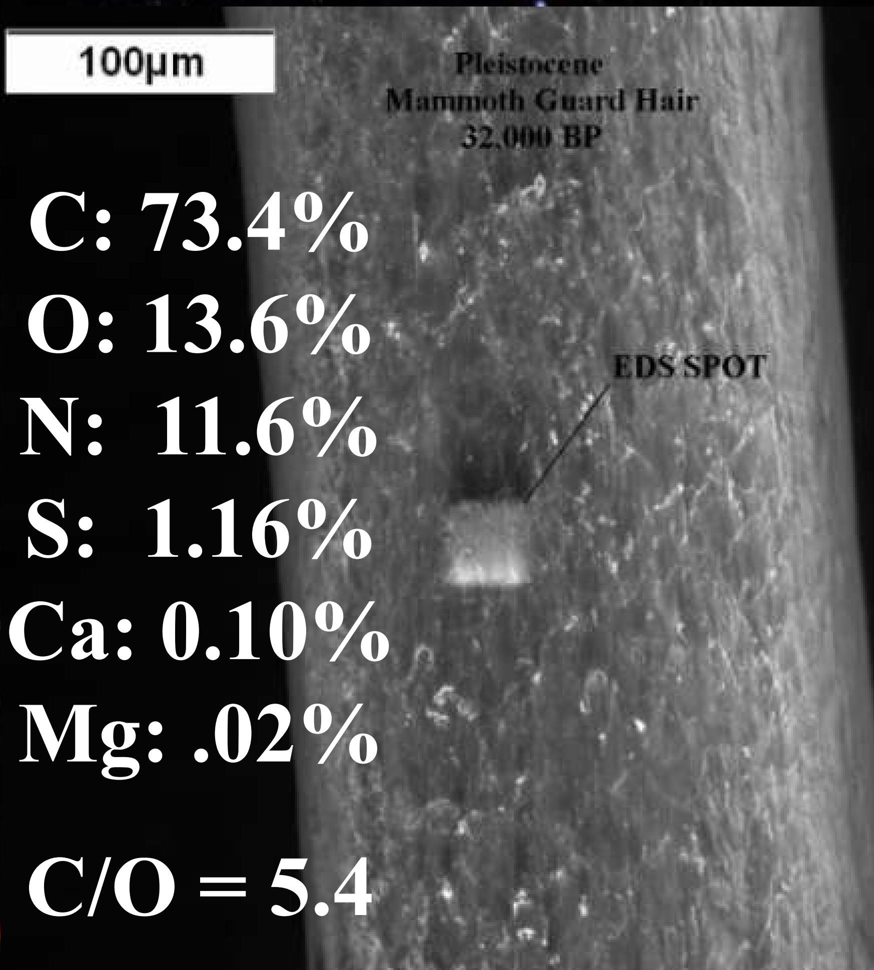
Quantitative Results for Lyngbya, wollei, LW2_h11
Analysis : Bulk Method : Standardless
Acquired 04-Feb-2005, 15.0 KeV @10 eV/channel

Element	Weight %	Std. Dev.	MDL	Atomic %
C	64.25	1.92	0.05	70.98
N	6.87	1.22	0.73	6.51
O	24.98	1.25	0.33	20.72
Na ?	0.42	0.17	2.90	0.24
Mg ?	0.62	0.24	1.77	0.34
Al ?	0.29	0.12	2.30	0.14
Si ?	0.47	0.18	1.50	0.22
P	1.11	0.39	1.05	0.48
S ?	0.60	0.23	1.29	0.25
Cl ?	0.00	0.00	1.39	0.00
K ?	0.00	0.00	1.48	0.00
Ca ?	0.39	0.16	1.81	0.13
Fe ?	0.00	0.00	2.79	0.00
Total	100.00			

? These elements are statistically insignificant.

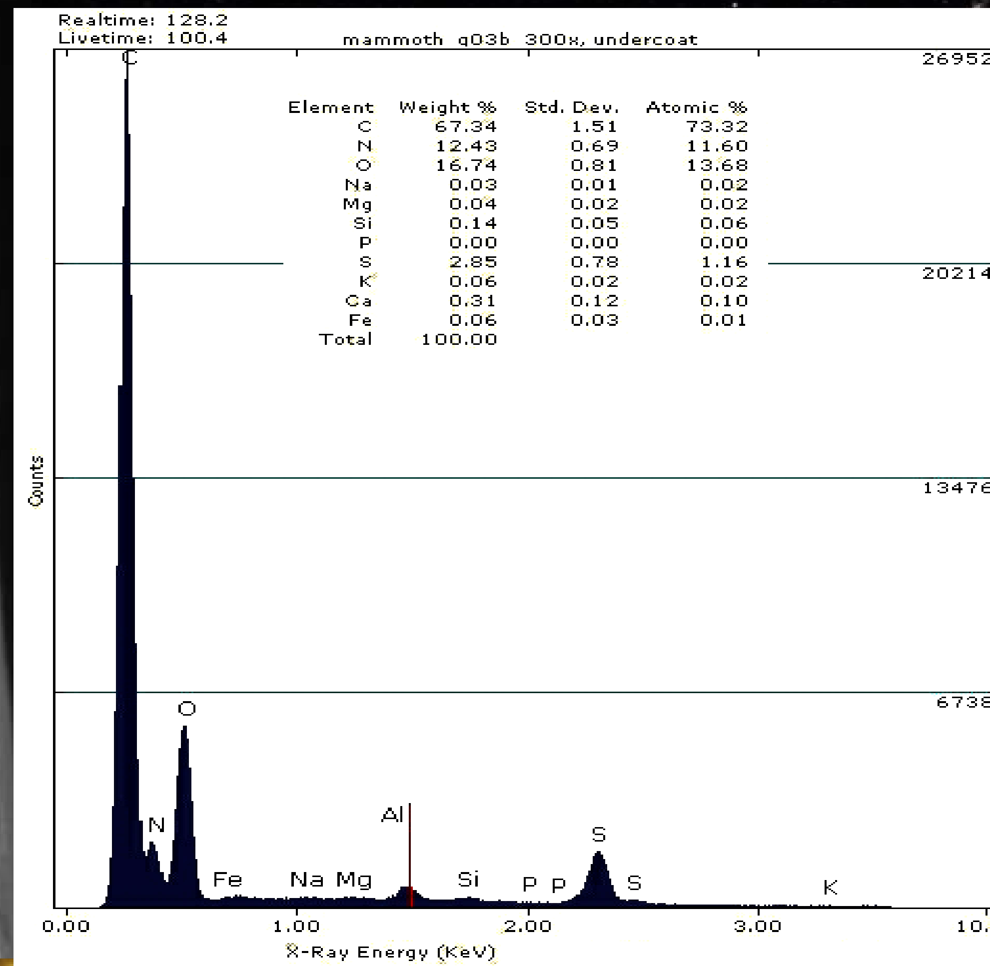
N in Modern Cells~(2-20%);C/O =2.6; Beam Damage

Nitrogen & Beam Damage in Siberian Pleistocene Mammoth Guard Hair



C: 73.4%
O: 13.6%
N: 11.6%
S: 1.16%
Ca: 0.10%
Mg: .02%

C/O = 5.4

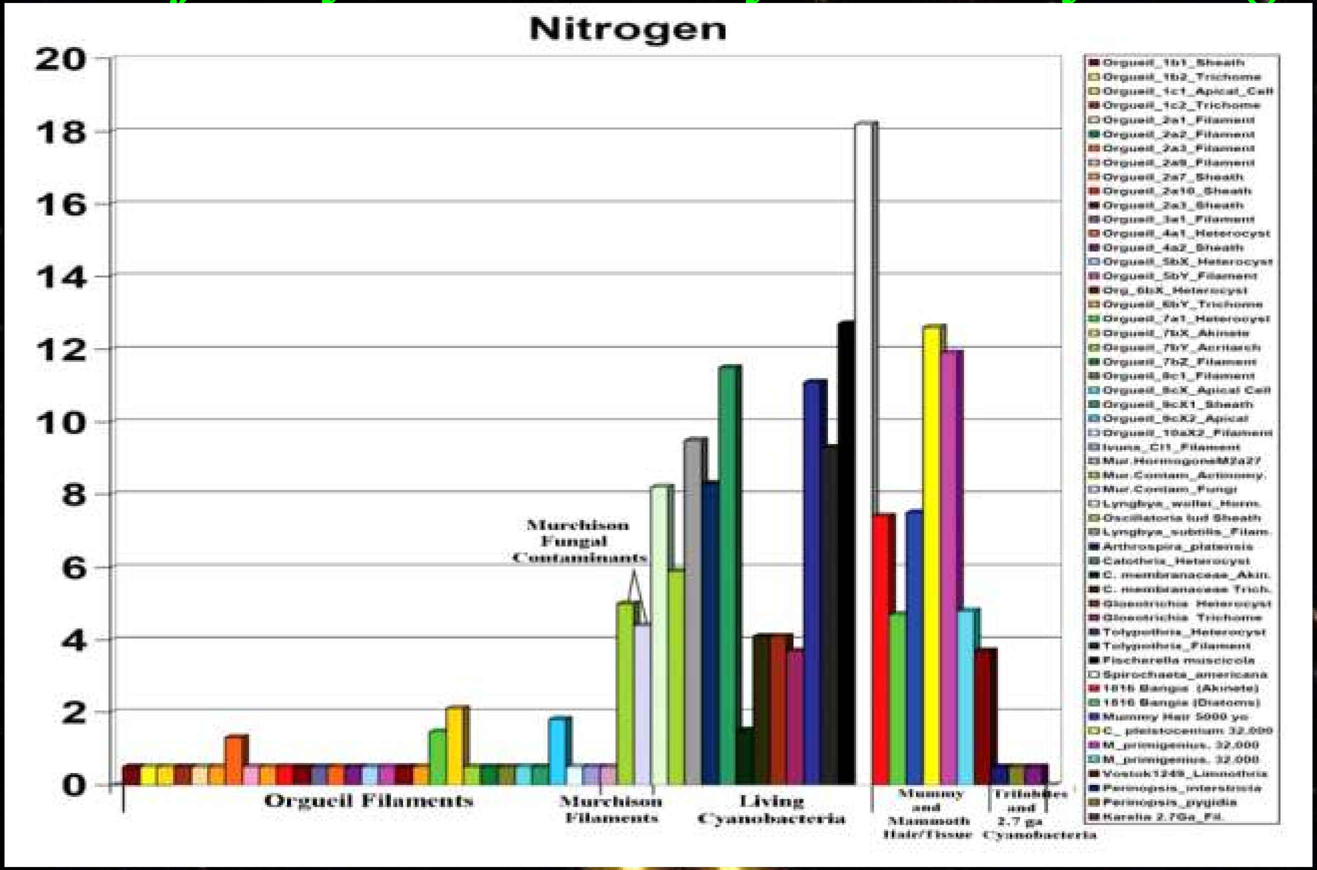


Element	Weight %	Std. Dev.	Atomic %
C	67.34	1.51	73.32
N	12.43	0.69	11.60
O	16.74	0.81	13.68
Na	0.03	0.01	0.02
Mg	0.04	0.02	0.02
Si	0.14	0.05	0.06
P	0.00	0.00	0.00
S	2.85	0.78	1.16
K	0.06	0.02	0.02
Ca	0.31	0.12	0.10
Fe	0.06	0.03	0.01
Total	100.00		

Distinct EDS Nitrogen Peak in 32,000 Yr Old Mammoth Hair N = 11.6% Atomic

Nitrogen for Distinguishing Recent Bio-Contaminants from Indigenous Microfossils

Nitrogen is present in every DNA & RNA Molecule and in All Amino Acids of every Protein & Enzyme in Every Living Cell



Cells of All Living or Pleistocene Microorganisms Typically Contain (~2 to 20%) Nitrogen. NASA EDS Detects N at 0.5% Level or Less

EARLY DISCOVERIES

Organics & Microfossils in Alais & Orgueil

15/03/1806 - Alais; 14/05/1864 - Orgueil (Only 9 CI1)

1834-Berzelius Finds Water & Organic Chemical in Alais & Suggests Extraterrestrial Life

1864-Pisani & Cloëz find Carbon, water & Organics ~ Coal; Orgueil Find Stones Disintegrates in Water

1962 - Nagy Organized Elements

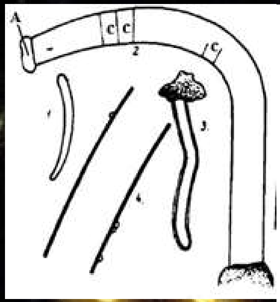
1963- Palik Finds Cyanobacteria

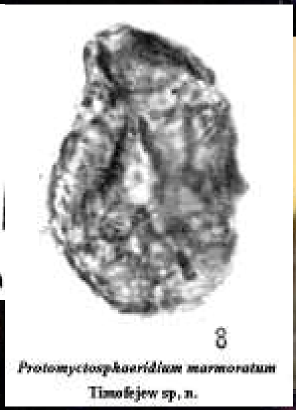
1963-Palynologist Timofejev finds Extinct Acritarchs in Mighei CM2

1997 - Rozanov & Hoover Detect Cyanobacteria & Acritarchs in Orgueil CI1 and Murchison CM2

Alais CI1

Orgueil CI1

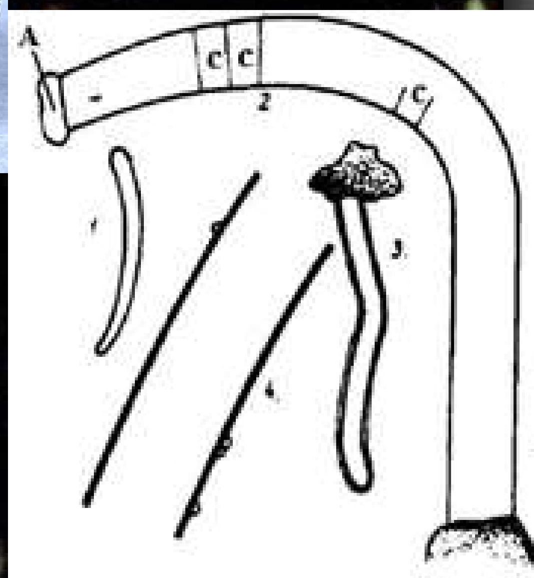


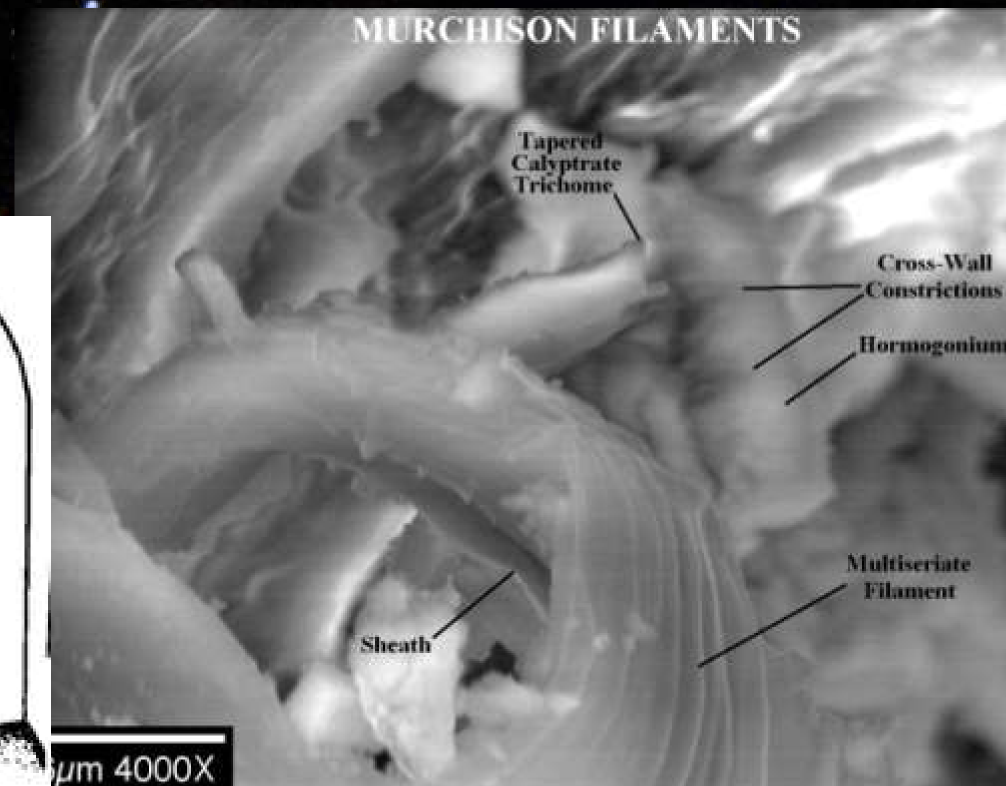


RECENT DISCOVERIES

Microfossils in Carbonaceous Meteorites

- *Sept. 18, 1969, 10:59 A. M.* – **CM2 Carbonaceous Meteorite Falls in Murchison, Australia (>100 kg; Sargeant-Comet 15P/Finlay)**

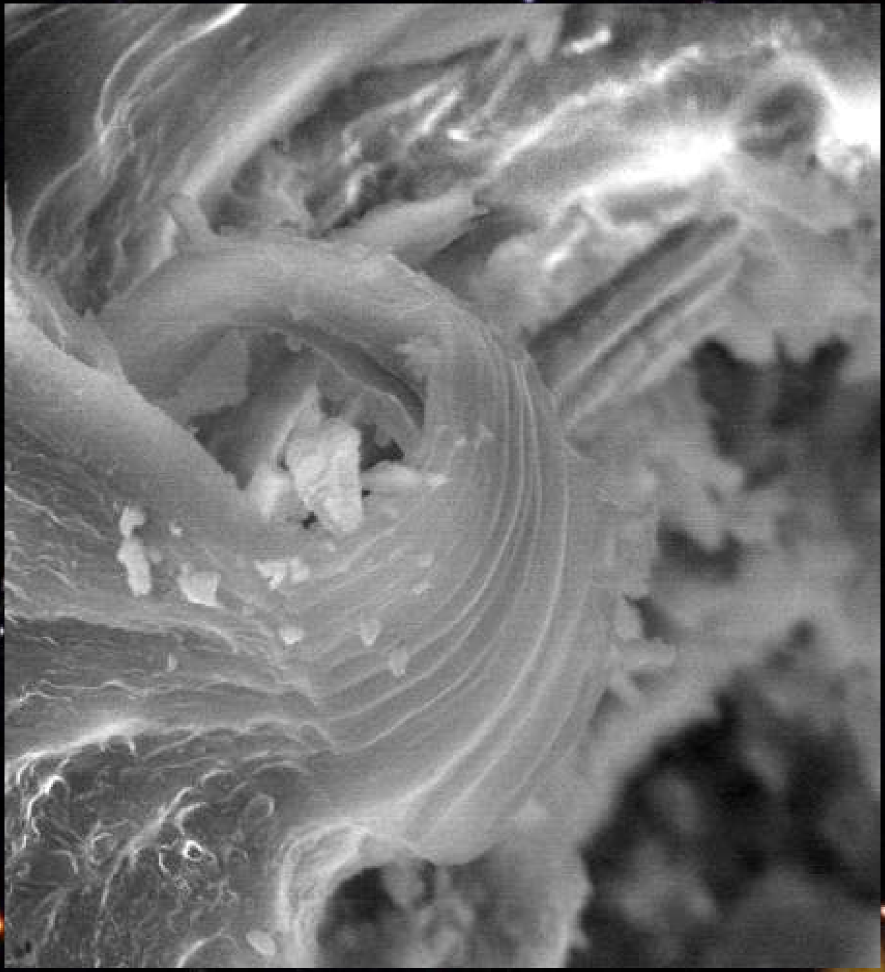




Murchison Contains Large Uniseriate & Multiseriate Trichomic Filaments with Hormogonia, Calyptrate Apical Cells & Sheaths with Cross-Wall Constrictions ~ *Phormidium tenue*, *Nostoc* sp. and *Microcoleus chthonoplastes*

Microfossils in Carbonaceous Meteorites

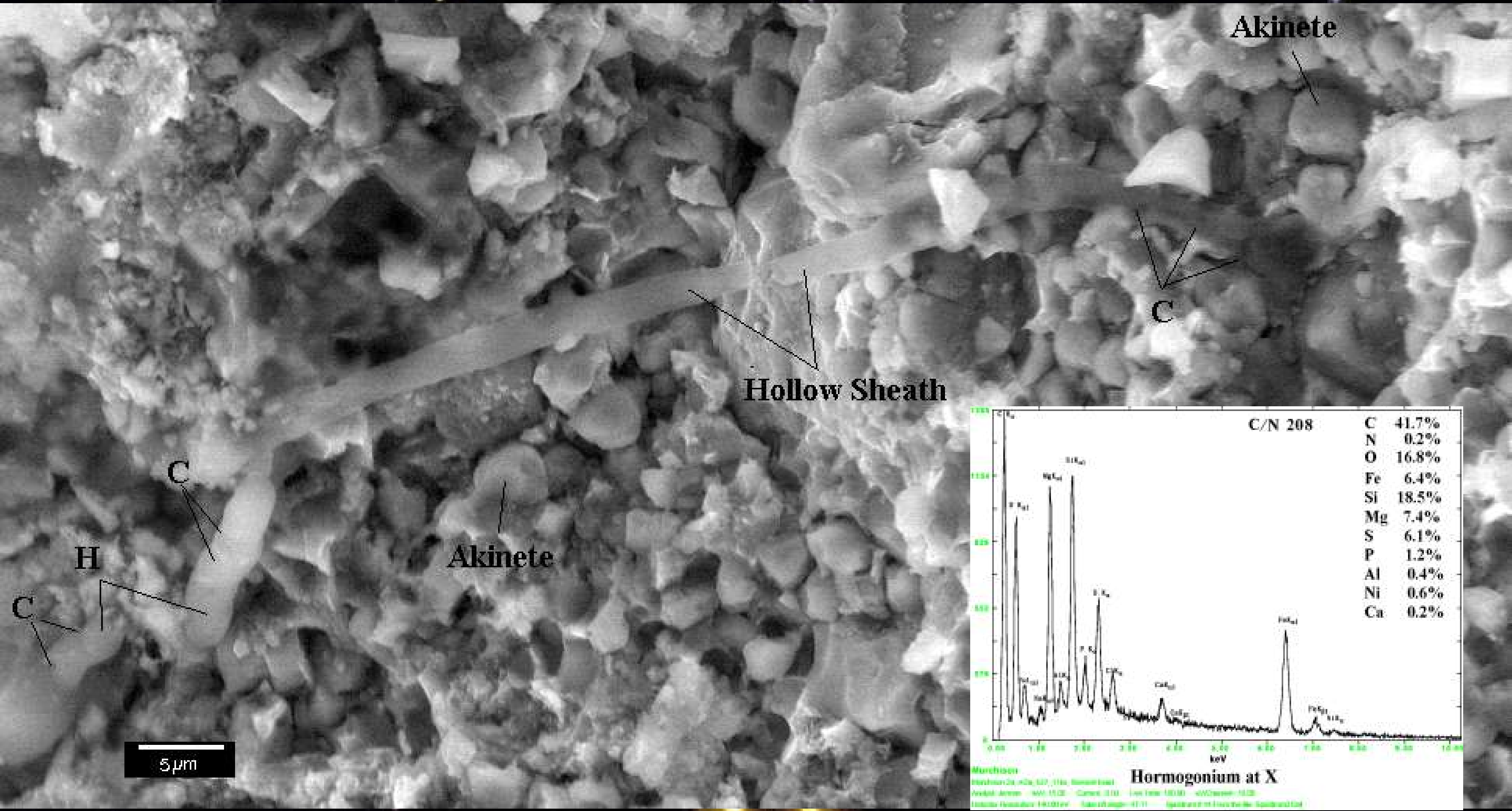
Murchison Meteorite



Cambrian Khubsugul Phosphorite

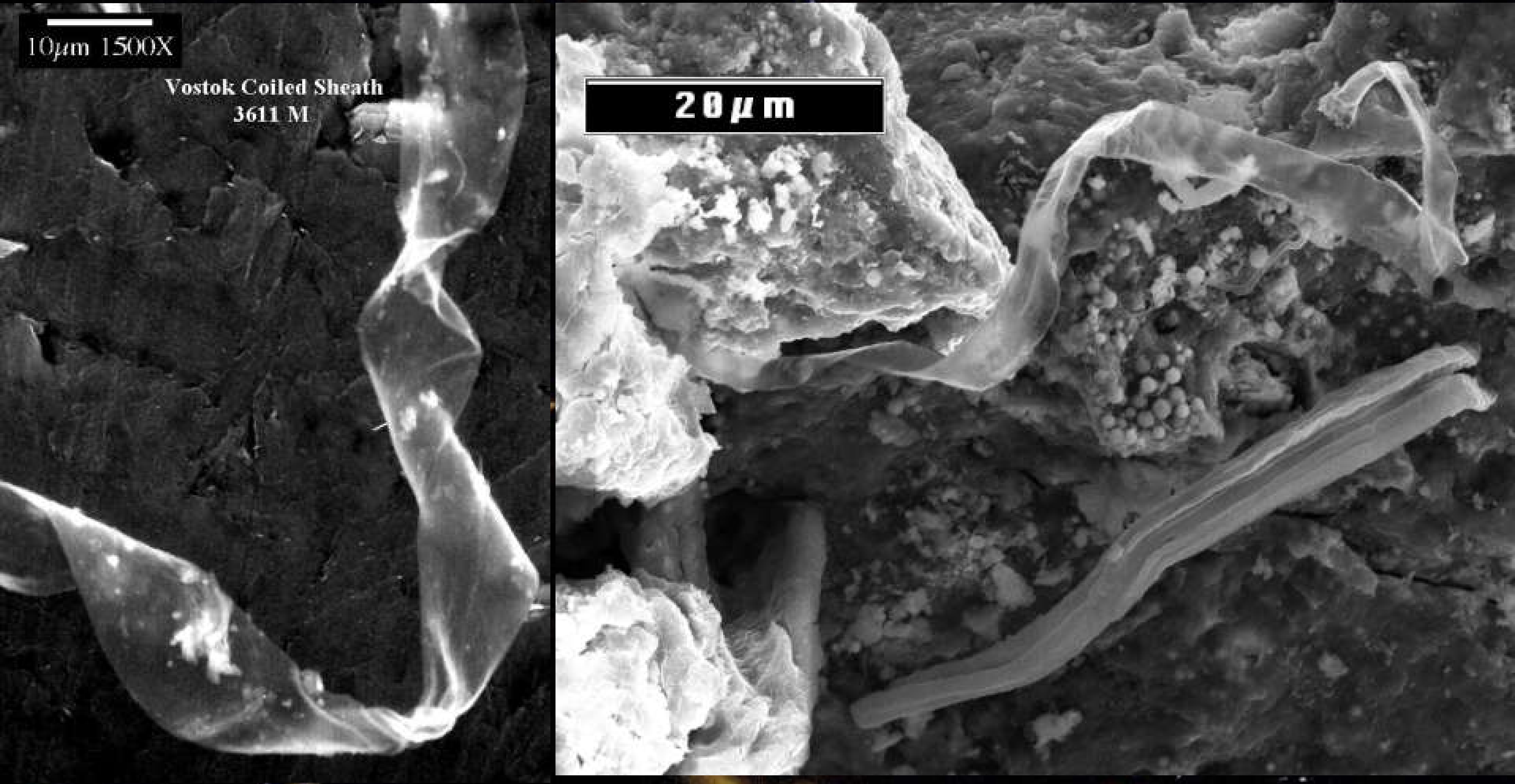
Microcoleus, Phormidium & Nostoc sp. in Murchison ~ *Academican Rozanov' Siphonophycus* in Khubsugul Cambrian Phosphorite

Mineralized *Nostocacean* Cyanobacteria Filament in Murchison CM2 Meteorite



Embedded Filament Hollow Sheath, Emergent Trichomes & Coiling Hormogonia (H) with Cross-Wall Constrictions (C) and Akinetes

EVIDENCE OF *Oscillatoriacean* MOTILITY IN FILAMENT REMAINS IN VOSTOK ICE & ORGUEIL



Hollow Spiral, Flattened, Carbonized Sheath in Deep (3611 M) Vostok Ice and Orgueil CI1 Meteorite

RECENT DISCOVERIES

Specialized Nitrogen Fixation Cells In Orgueil

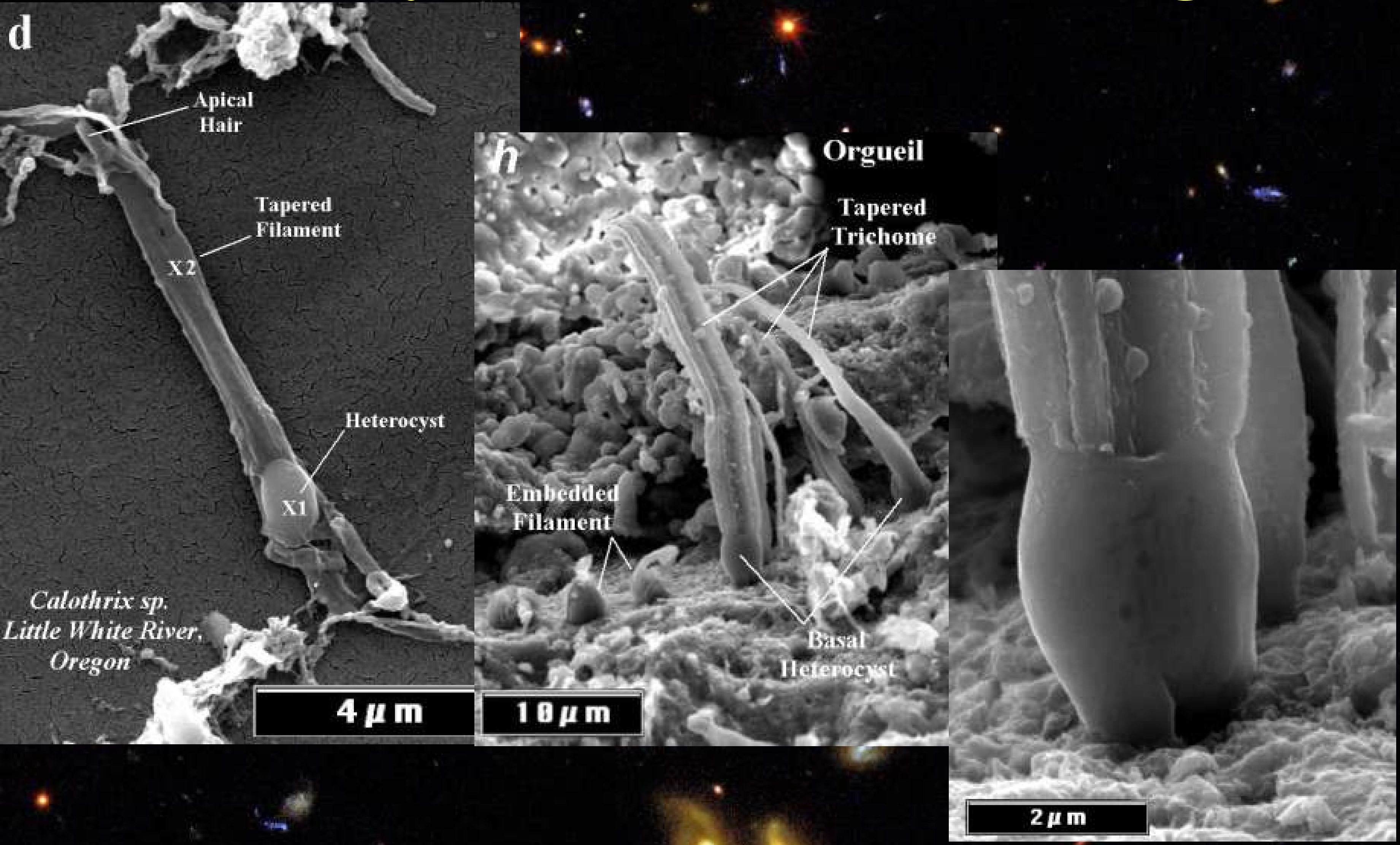
Apical, Intercalary and Basal Heterocysts

Heterocysts Perform Nitrogen Fixation

Conversion of Di-Nitrogen Gas N_2 Molecules from Atmosphere into organic nitrogen (NH_3 or NO_2) molecules usable by cells.

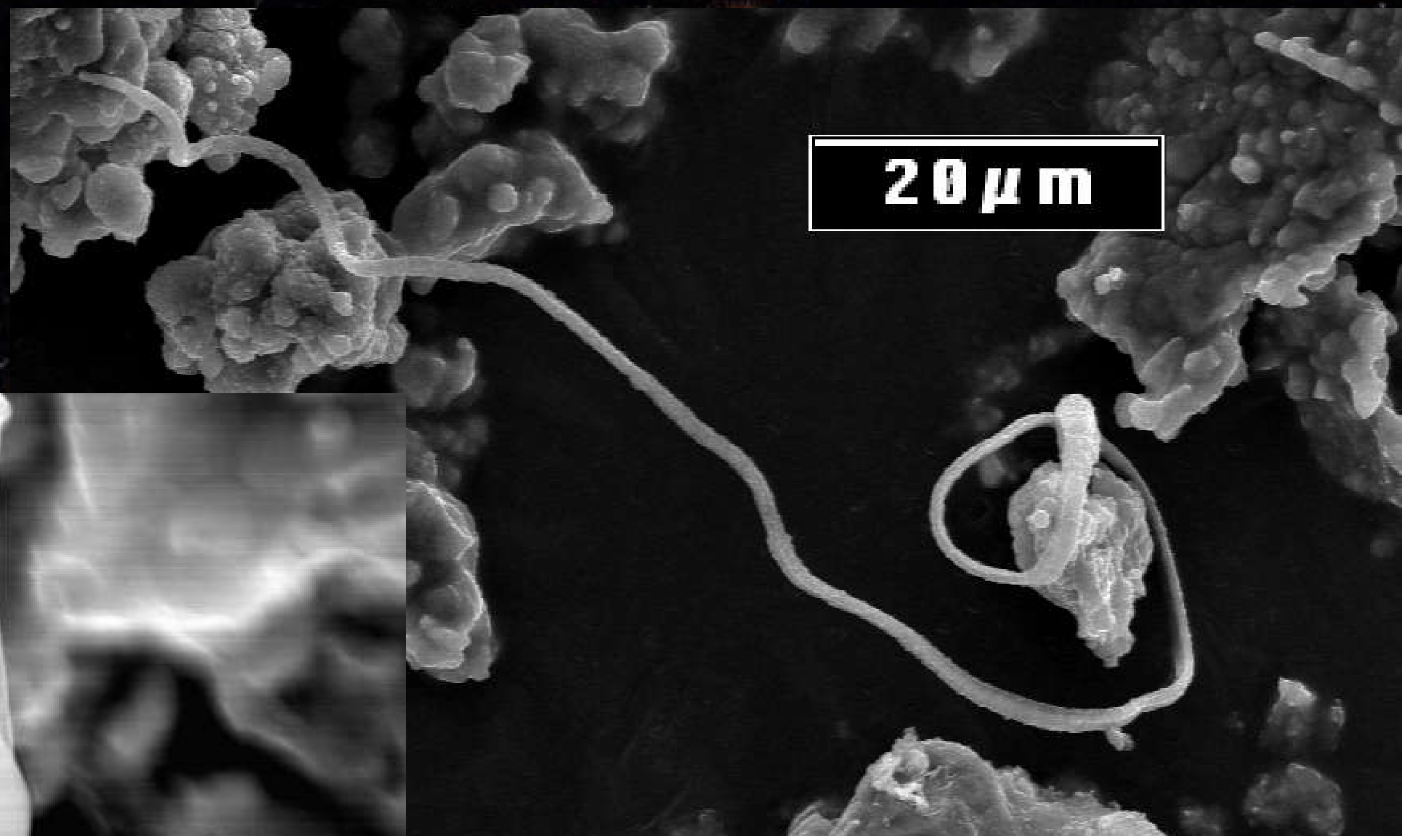
Nitrogen Cycle Essential to all Life on Earth

Heterocystous *Calothrix* in Orgueil

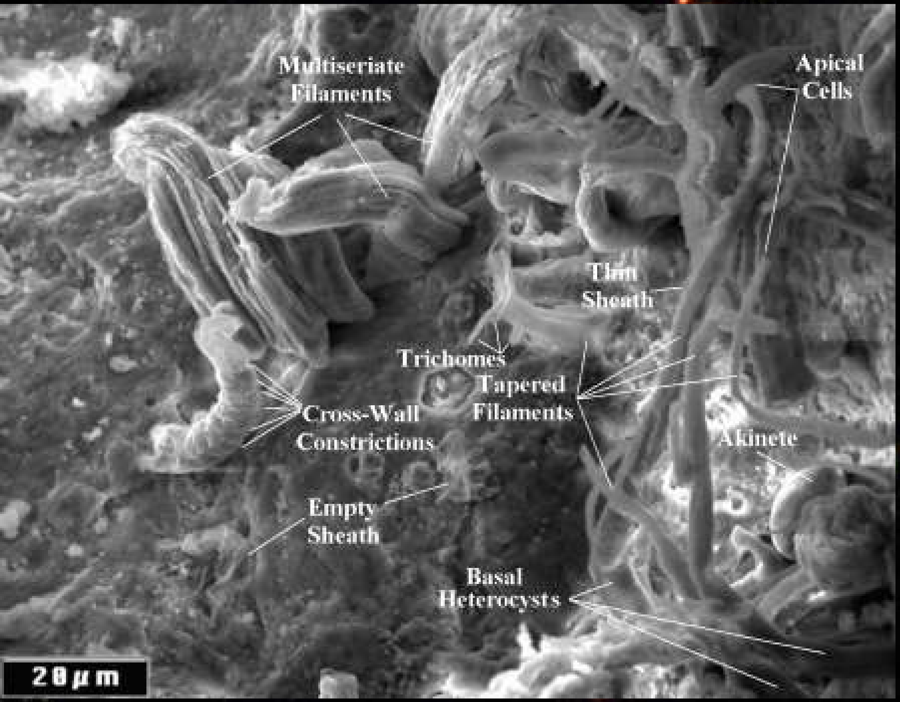


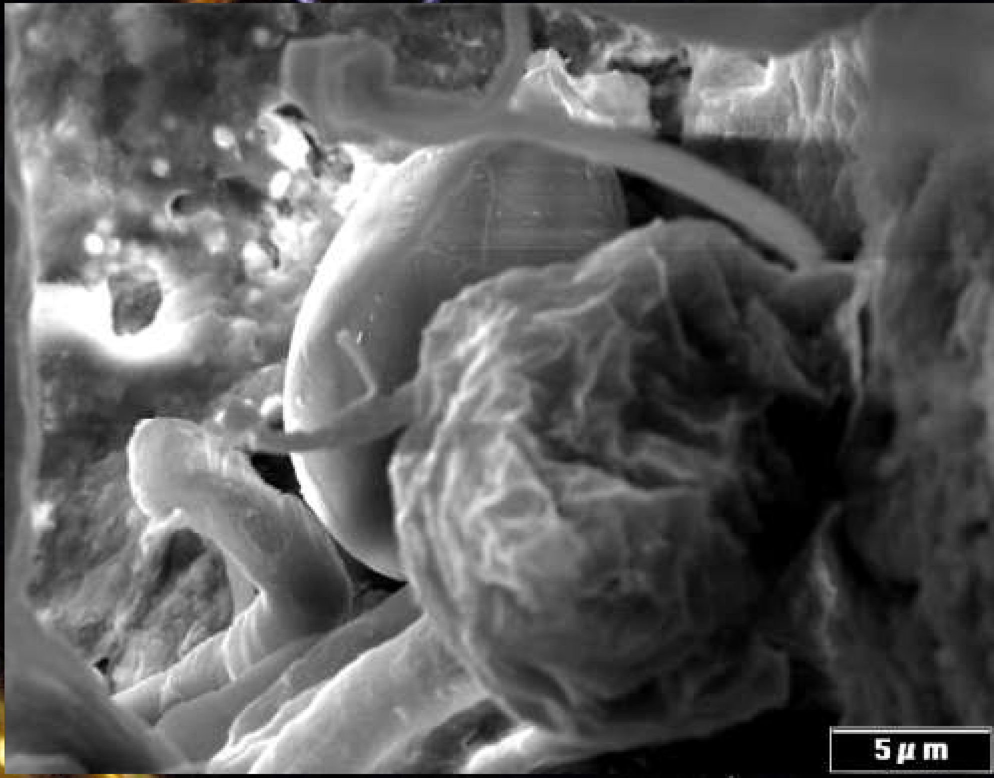
Living *Calothrix sp.* (Little White River) with Heterocyst. & Tapered filaments in Orgueil with Basal Heterocysts

Cyanobacteria w/ Apical & Intercalary Heterocysts in Orgueil (cf. *Nostoc* sp. & *Cylindrospermum* sp.)



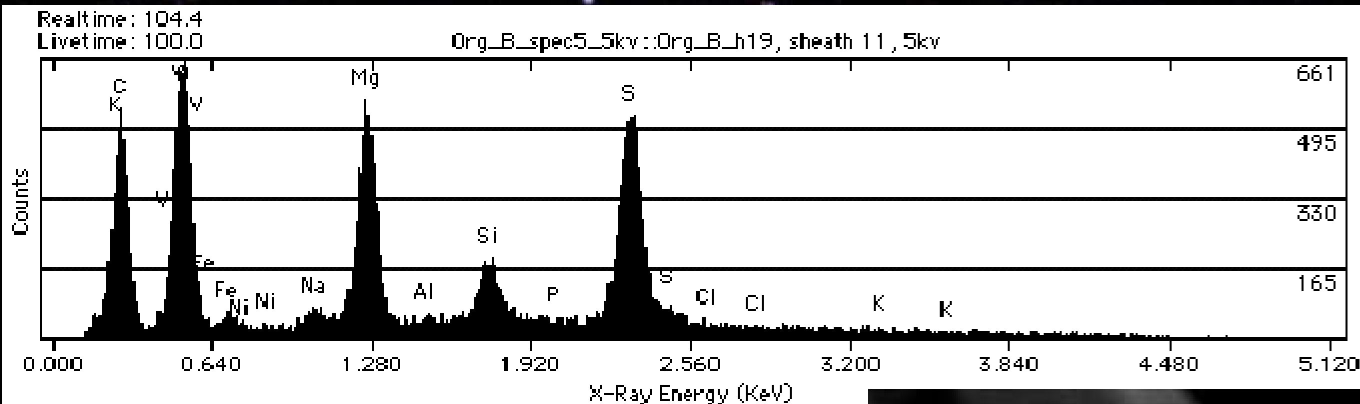
Filaments, Akinetes & Acritarchs in Orgueil





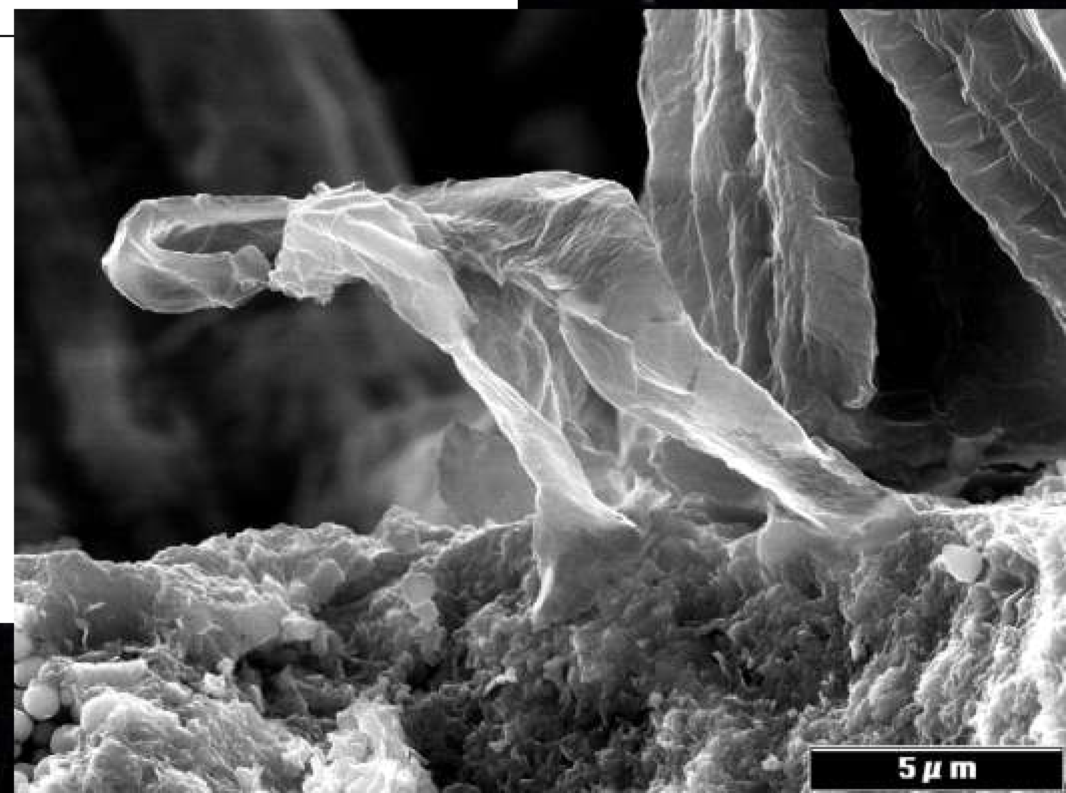
Tapered polarized filaments in Orgueil with funnel shaped apices and bulbous basal heterocysts, akinete and mineralized acritarch *Leiospheridia sp.*

Nitrogen Absent in Embedded Carbonized Filament With Apical Cell in Orgueil

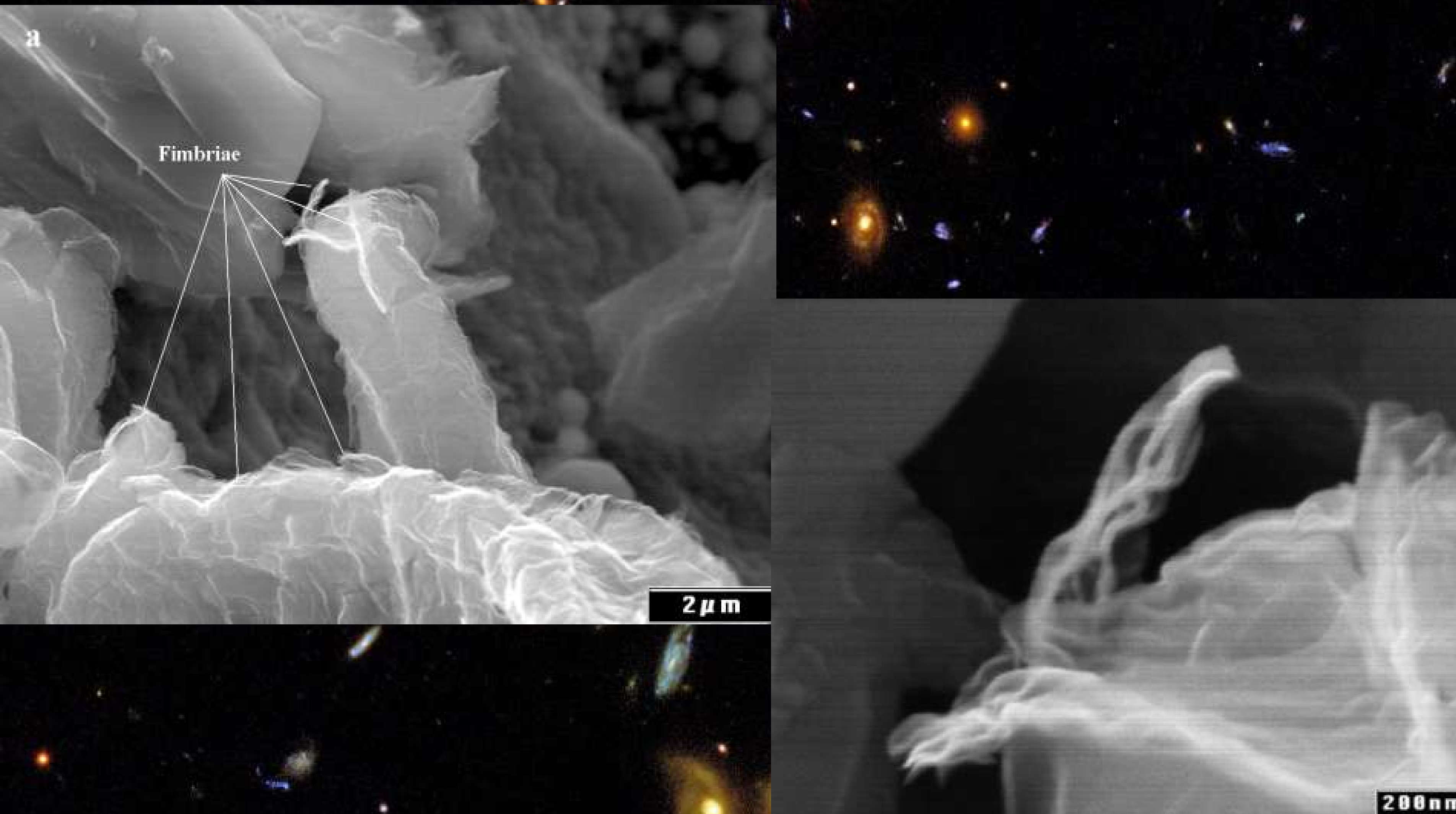


Quantitative Results for Org_B_h19, sheath 11, 5kv
Analysis: Bulk Method: Standardless
Acquired 21-Jul-2004, 5.0 KeV @10 eV/channel

Element	Weight %	Std. Dev.	MDL	Atomic %	k-Ratio	Intensities
C	27.28	1.39	0.34	45.78	0.1036	3010.8
N ?	0.00	0.00	3.39	0.00	0.0000	0.2
O	11.77	0.77	0.43	14.82	0.0871	3347.1
F ?	0.00	0.00	2.40	0.00	0.0000	0.2
Na ?	1.34	0.48	2.67	1.17	0.0117	395.9
Mg	10.27	0.70	0.88	8.52	0.0957	2984.1
Al ?	0.80	0.32	3.55	0.60	0.0073	190.5
Si	5.46	1.18	1.51	3.92	0.0520	1161.0
P ?	0.95	0.38	4.66	0.62	0.0088	151.6
S	34.14	1.41	0.90	21.46	0.3204	4271.7
Cl ?	0.00	0.01	3.94	0.00	0.0000	0.2
K ?	0.01	0.02	6.35	0.00	0.0001	0.2
V	6.44	1.21	1.16	2.55	0.0312	1014.7
Fe ?	1.53	0.55	3.46	0.55	0.0087	312.7
Ni ?	0.00	0.00	2.64	0.00	0.0000	0.2
Total	100.00					

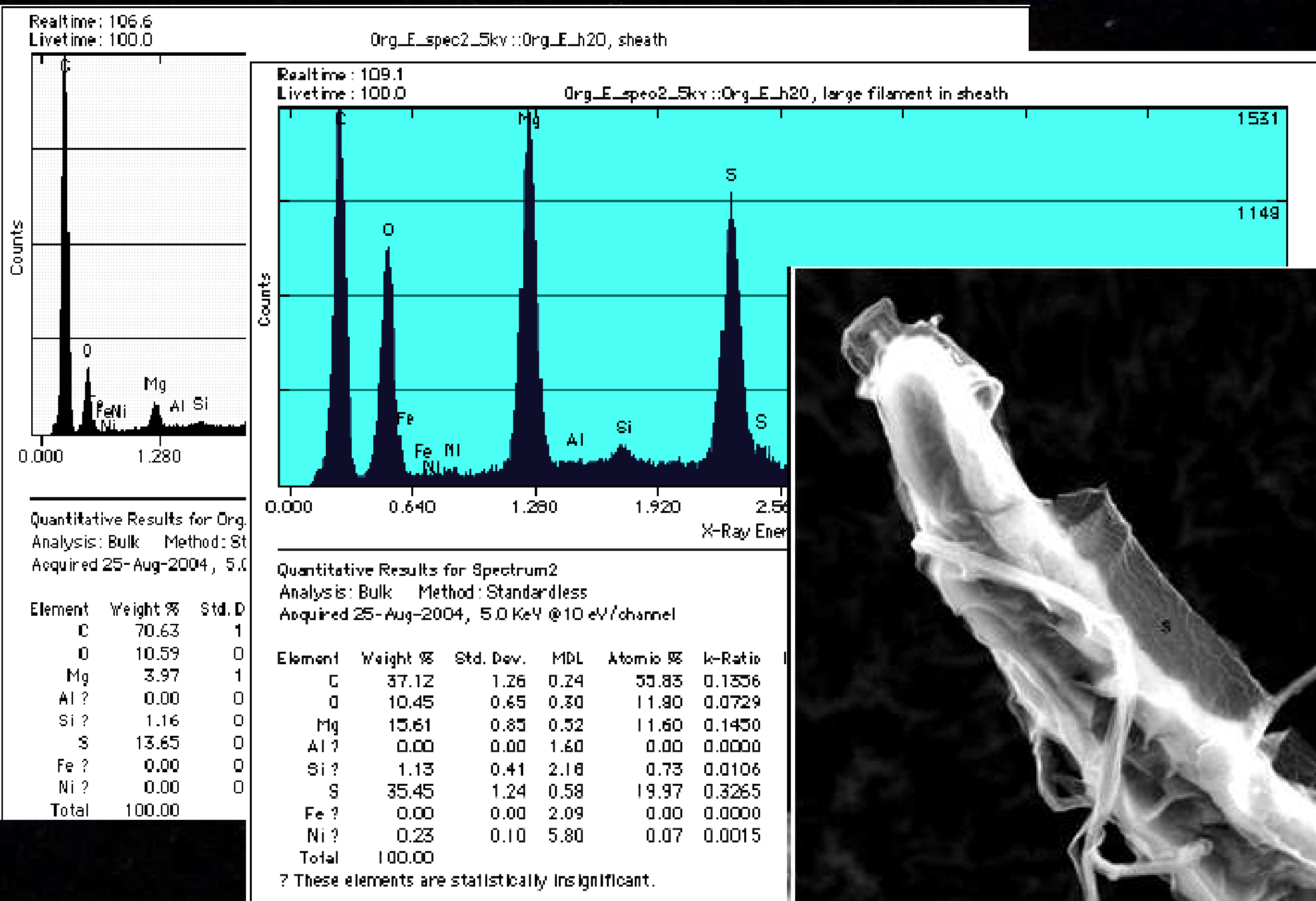


FIMBRIAE OF CYANOBACTERIA IN ORGUEIL CI1 CARBONACEOUS METEORITE



Lophotrichous tufts (20-40 nm) helical fimbriae @ 80kX in Orgueil
-Motility in Many G^{+} Bacteria & *Oscillatoriacean* cyanobacteria

EDS Data of Sheath and Filament in Orgueil



Quantitative Results for Org.
Analysis: Bulk   Method: St
Acquired 25-Aug-2004, 5.0

Element	Weight %	Std. D
C	70.63	1
O	10.59	0
Mg	3.97	1
Al ?	0.00	0
Si ?	1.16	0
S	13.65	0
Fe ?	0.00	0
Ni ?	0.00	0
Total	100.00	

Quantitative Results for Spectrum2
Analysis: Bulk   Method: Standardless
Acquired 25-Aug-2004, 5.0 KeV @10 eV/channel

Element	Weight %	Std. Dev.	MDL	Atomic %	k-Ratio
C	37.12	1.26	0.24	55.83	0.1356
O	10.45	0.65	0.30	11.90	0.0729
Mg	15.61	0.85	0.52	11.60	0.1450
Al ?	0.00	0.00	1.60	0.00	0.0000
Si ?	1.13	0.41	2.18	0.73	0.0106
S	35.45	1.24	0.58	19.97	0.3265
Fe ?	0.00	0.00	2.09	0.00	0.0000
Ni ?	0.23	0.10	5.80	0.07	0.0015
Total	100.00				

? These elements are statistically insignificant.

Epsomite infilled Cyanobacterial Filament (O/C=0.2) with Emergent Trichomes and Kerogenous Sheath (N< 0.3%; O/C=0.1)

Polonnaruwa Meteorite

Yellow Green Fireball Seen: NE - SW Trajectory Polonnaruwa, Sri Lanka: 29/12/2012 at 6:30 P.M. (13:00 GMT). Low Density (0.6 g/cc) Black Stones Enhanced in Iridium & Deuterium Fell in Rice Fields, Aralaganwila (N 7^{o} 52’ 59.5”; E 81^{o} 9’ 15.7”)

Left Fig 1a Map of Sri Lanka showing location of meteorite

Right Fig 1b Piece of meteorite

Polonnaruwa Stones Unlike Earth Rocks & Known Meteorites - May Represent New Group of Carbonaceous Meteorites

Polonnaruwa Meteorite: Mineralogy & Petrology

- Highly porous poikilitic textures of isotropic Silica-rich Plagioclase-like hosts with Shock Fractured Inclusions of: Ilmenite $Fe^{2+}TiO_3$, Fayalitic Olivine $Fe_2^{2+}SiO_4$, Quartz SiO_2, and Zircon $ZrSio_4$

- Bulk minerals include accessory Cristobalite, Hercynite, Anorthite, Wuestite, Albite, and Anorthoclase.
- High pressure Olivine polymorph Wadsleyite (Mg,Fe_2^{2+}) $2(SiO_4)$ Implies Extraterrestrial Shock Pressure of ~20 GPa – Stable in Earth Upper Mantle @ 425 km

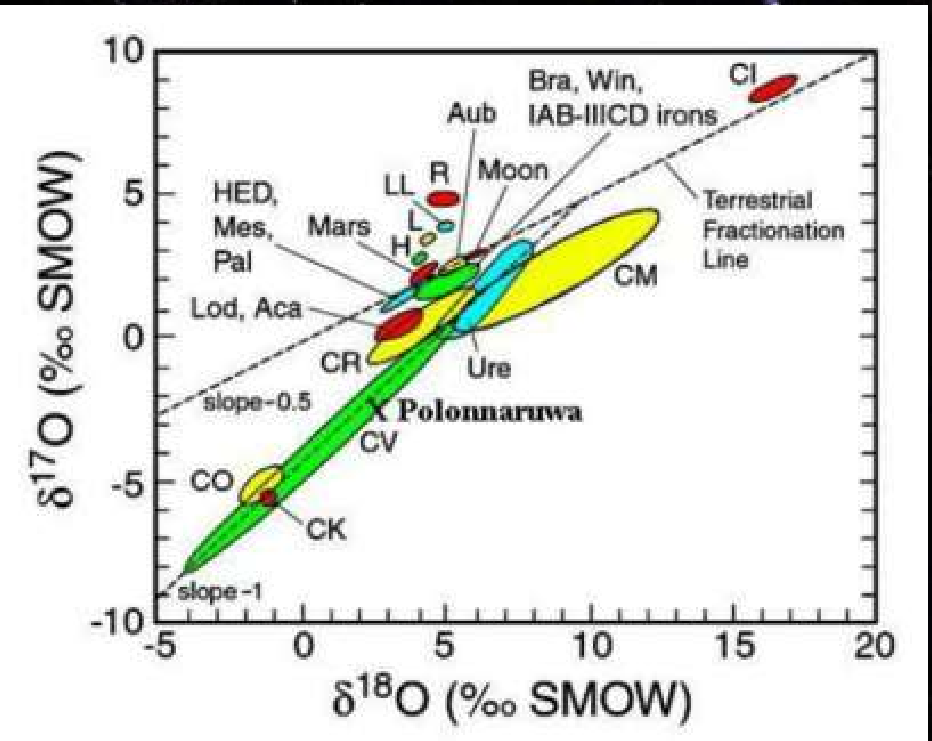
Oxygen Isotopes of Polonnaruwa Stones

Independent Laser Fluorination Measurements of Triple Oxygen Isotopes by Prof. Dr. Andreas Pack University of Göttingen and Prof. Eizo Nakamura Okayama University Produced Consistent Results with $\Delta^{17}O$ Far Away from Terrestrial Fractionation Line

TABLE I
TRIPLE OXYGEN ISOTOPE DATA

Measurement	$\delta^{18}O$	$\delta^{17}O$	$\Delta^{17}O$
Prof. Dr. Andreas Pack	17.816	8.978	-0.335
Prof. Eizo Nakamura - Run 1	20.84	10.60	-0.328
Prof. Eizo Nakamura-Run 2	20.75	10.59	-0.296

Oxygen Isotopes of Polonnaruwa Stones



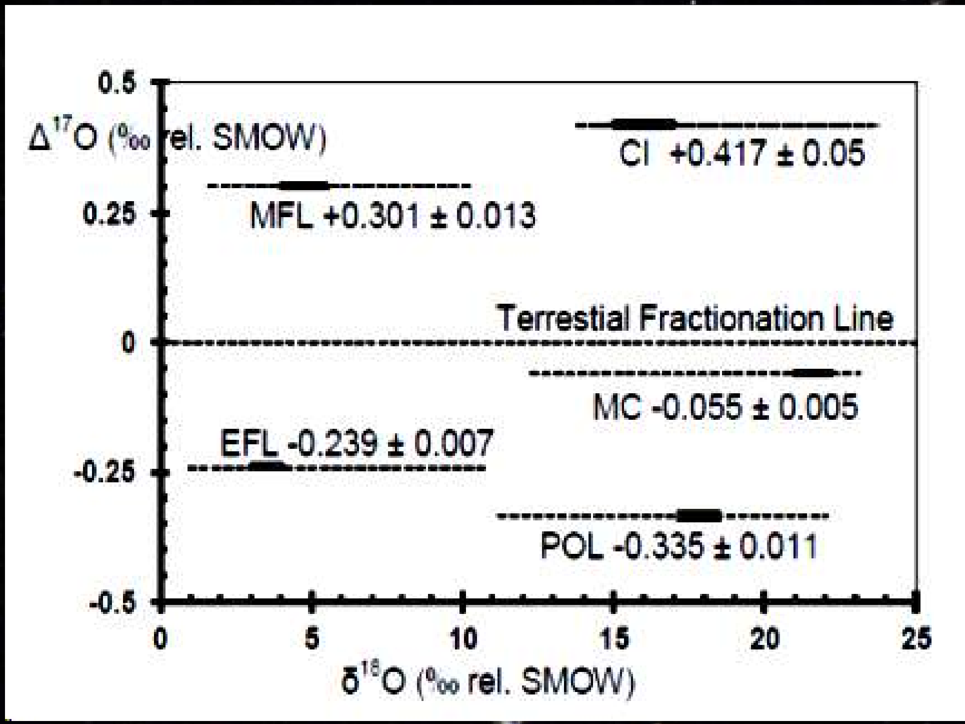
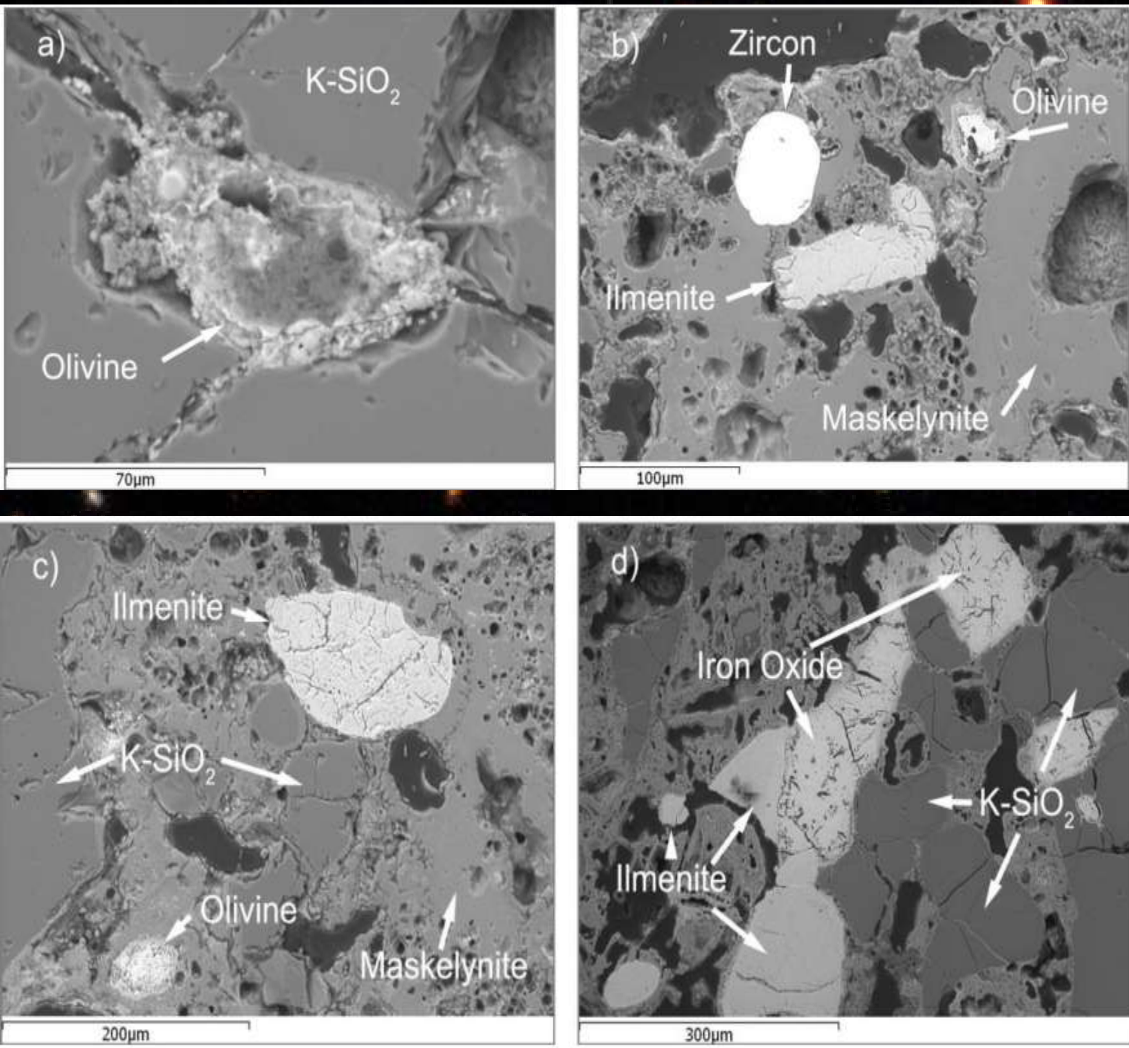
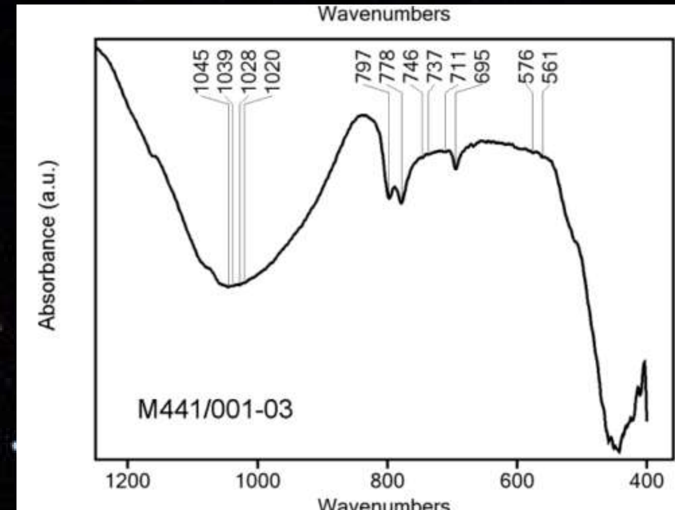
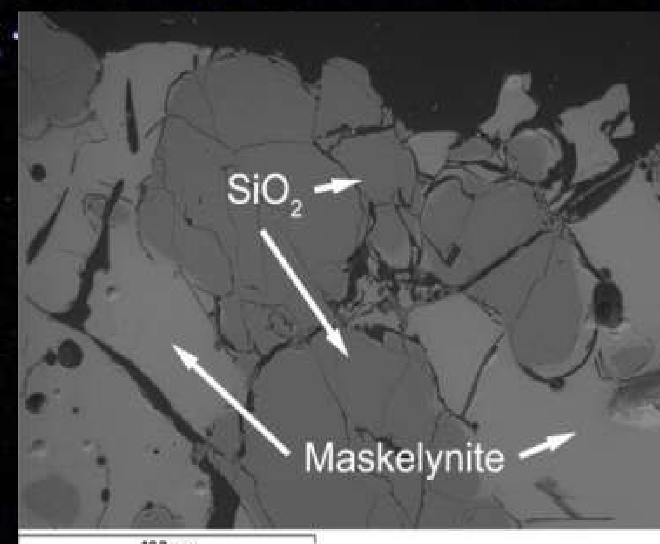


Fig. 1. Triple Oxygen Isotope measurements by laser fluorination at the Stable Isotope Laboratory of the University of Göttingen in Germany by Prof. Dr. Andreas Pack revealed the Polonnaruwa samples were far away from the Terrestrial Fractionation Line and could not be logically considered typical Earth rocks.

Shocked Grains & High Pressure Minerals

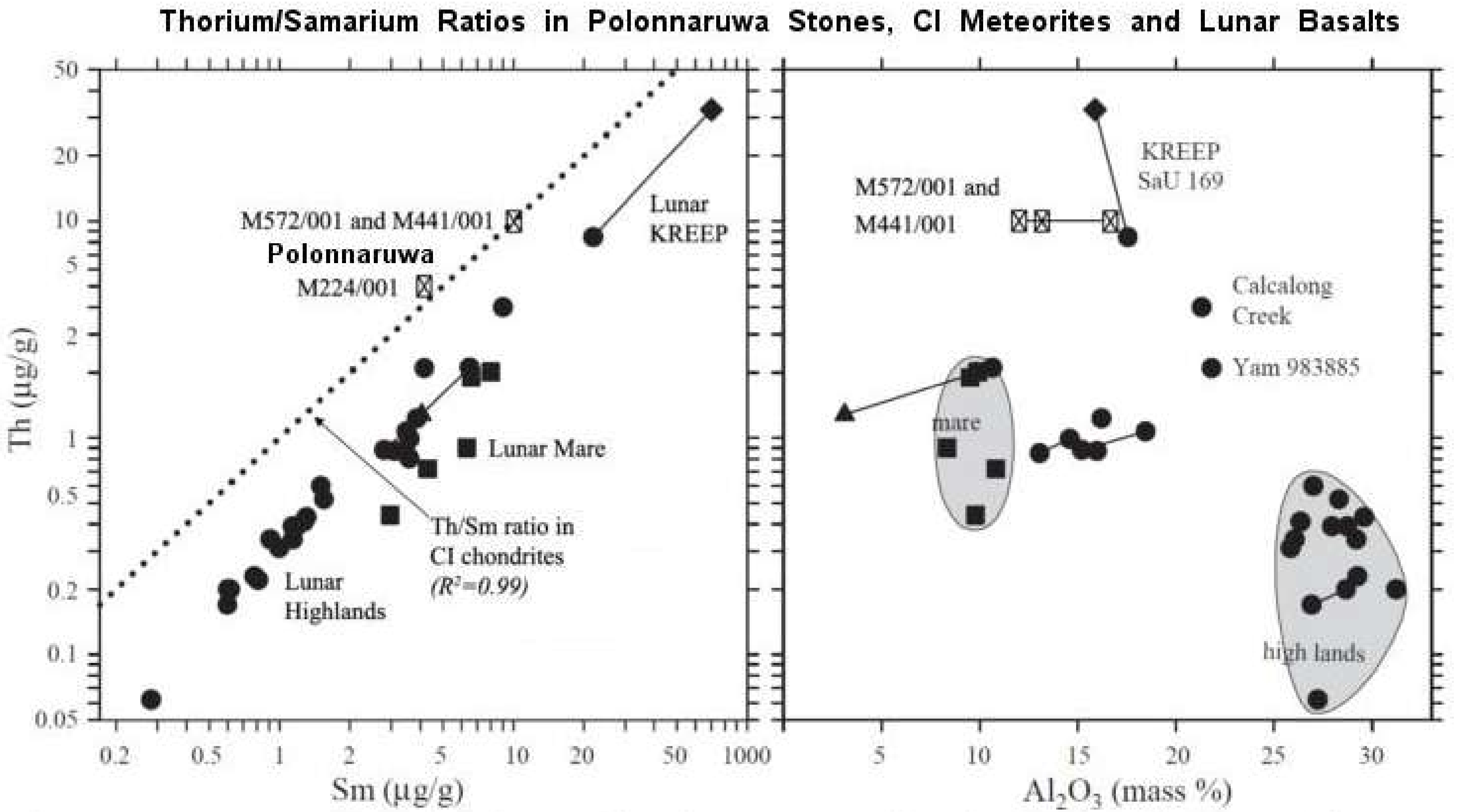






Shock Fractured Zircon & Quartz Grains. FTIR Absorption at 778 cm^{-1} & 797 cm^{-1} of Maskelynite

Polonnaruwa Th/Sm & Th/Al_2O_3 Data



Anders, E., Grevesse, N., 1989. Abundances of the elements: Meteoritic and solar. Geochim. Cosmochim.Acta 53.
Korotev, R. L. Lunar geochemistry as told by lunar meteorites. Chemie der Erde 65 (2005) 297–346

ICP-OES Ratios ~ CI Meteorites & KREEP

Bulk Chemistry at Cardiff by Inductively Coupled Plasma - Optical Emission Spectroscopy

Table 3

Average bulk compositions of samples P159/001, M224/001, M572/001 (two samples) and M441/001 together with comparative compositions taken from the literature

	S1 – M572/001-05, S2 – M572/001-08, S3 – M441/001, S4 –P159/001, S5 – M224/001					S6 – Fusion Crust MIL 05035, S7 Bulk Recon, S8 – Bulk Rock			S9, S10 – Core and rim of Mafic glass (NWA 1664), S11, S12 – High K/Low K Felsic Glass			
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12
SiO_2	49.74	49.42	51.34	60.65	65.46	45.50	47.0	48.4	51.10	49.82	66.41	65.36
Al_2O_3	11.90	16.82	13.23	0.00	0.19	9.61	9.26	8.85	13.38	13.17	17.87	18.96
Na_2O	1.62	1.62	3.91	0.54	0.54	0.32	0.26	0.21	0.20	1.21	0.56	0.61
MgO	1.39	0.60	0.99	4.97	3.98	5.83	7.44	7.79	8.34	7.72	0.21	0.19
K_2O	7.41	1.61	6.44	22.69	22.69	0.05	0.03	0.01	1.41	0.06	5.80	3.95
CaO	4.34	1.68	2.38	4.90	5.18	11.9	11.8	12.1	10.91	10.82	4.99	7.04
FeO	12.68	12.16	5.56	0.35	0.17	22.5	22.0	20.7	13.17	15.52	1.97	1.96
TiO_2	0.83	1.00	0.67	0.00	0.00	1.99	1.44	0.90	0.73	0.72	1.04	1.11
MnO	1.03	0.13	0.00	1.29	1.16	0.36	0.32	0.33	0.47	0.54	0.08	0.05
Cr_2O_3	na	na	na	na	na	0.30	0.33	0.30	0.45	0.43	0.26	0.49
P_2O_5	na	na	na	na	na	0.05	0.05	0.02	0.01	0.07	0.01	0.00
SO_2	na	na	na	na	na	0.05	0.11	na	na	na	na	na
Total	92.09	85.26	84.52	97.45	101.44	98.5	100	99.3	100.17	100.08	99.20	99.72
Mg#	16.38	8.05	24.19	96.23	97.61	31.6	37.8	40.2	28.02	28.74	24.63	39.20

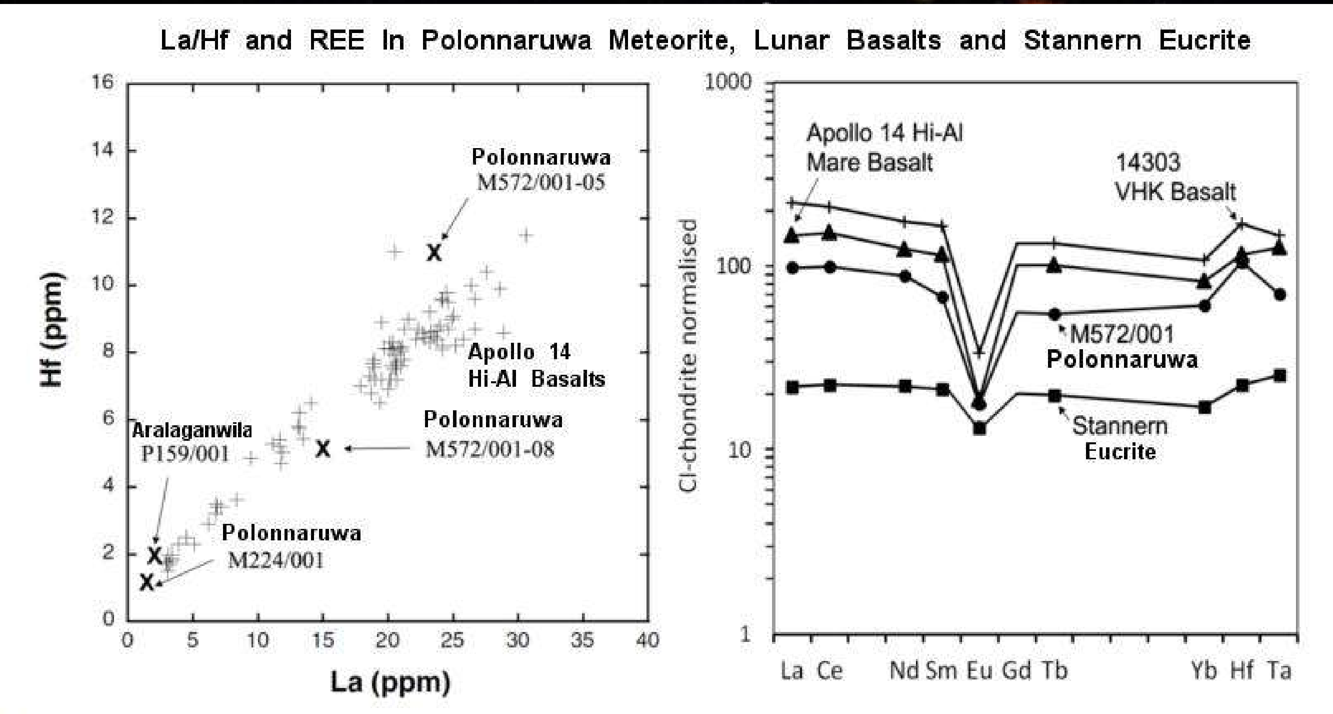
Na - not analysed. S1 – M572/001-06, S2 – M572/001-08, S3 – M441/001-03, S4 –P159/001-05, S5 – M224/001-03, S6 – Fusion Crust (MIL 05035) (Thaisen and Lawrence[47], 2009), S7 – Bulk rock composition of MIL 05035 (Liu et al.[48], 2009), S8 – Bulk rock composition of MIL 05035 (Joy et al.[49], 2009), S9/S10 – NWA 1664 Core and Rim mafic glass (Barrat et al.[43], 2009) S11/S12 – NWA 1664 High K/low K felsic glass (Barrat et al.[43], 2009).

REE Patterns ~ High K & High Al Glasses in Lunar and 4 Vesta -

Europium – 0.7 to 0.9 ppm (~Europium Anomaly Lunar Highlands)

Iridium ~ 1-7 ppm (~ 10^4 times that of Terrestrial Crustal Rocks)

Polonnaruwa Cardiff & JINR Data

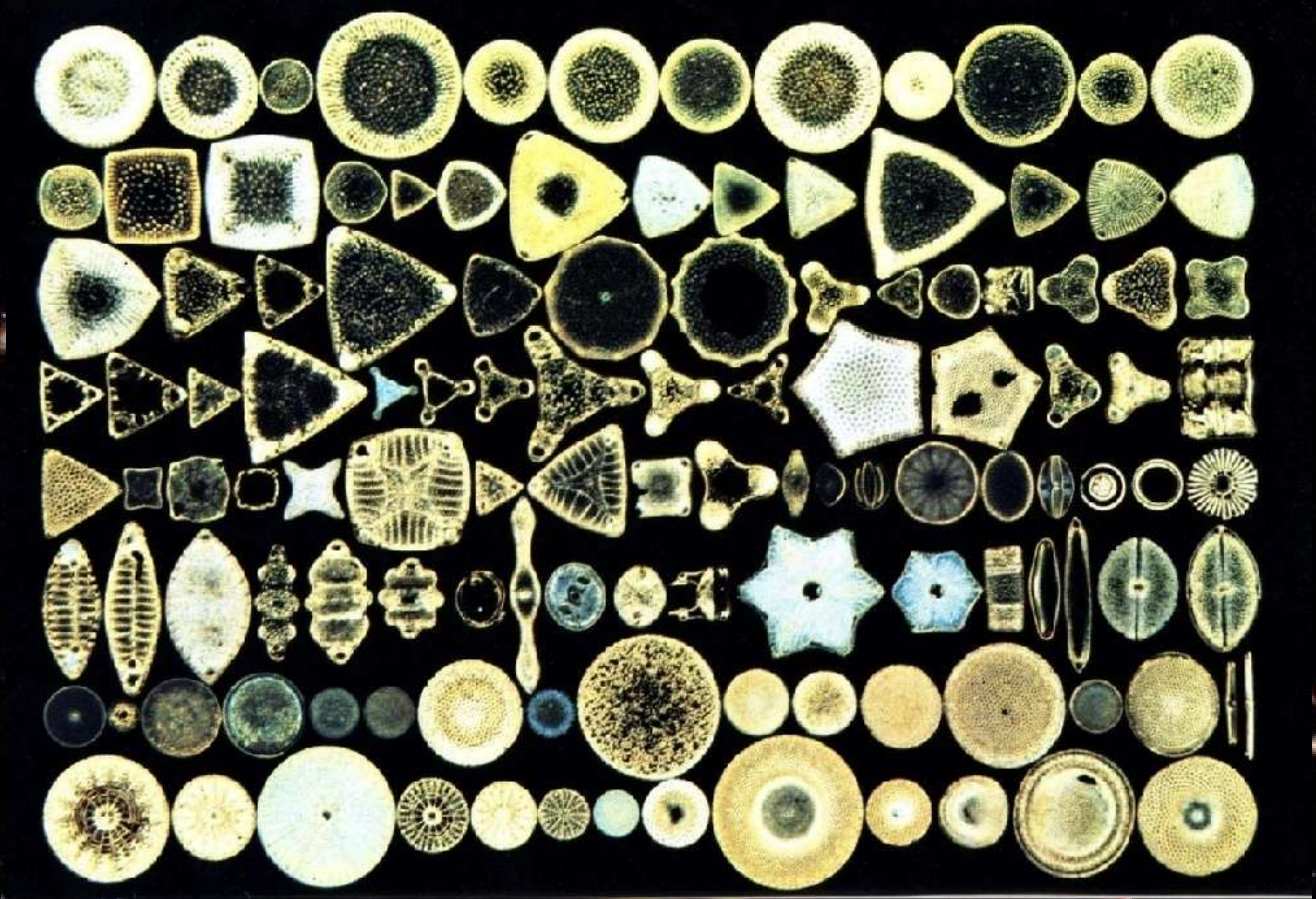


Meteorite	Rb	Re	U
Orgueil CI1	3.14	-	-
Murchison CM2	3.57	-	-
Polonnaruwa 141	439	3.47	-
Polonnaruwa 162	158	1.55	1.06
Polonnaruwa 162	378	4.02	0.39
Polonnaruwa Crust	323	4.44	0.043

Hf/La & REE Plots for Aralaganwila/Polonnaruwa, Lunar Basalts and Stannern Eucrite from Vesta

Fossil Diatoms

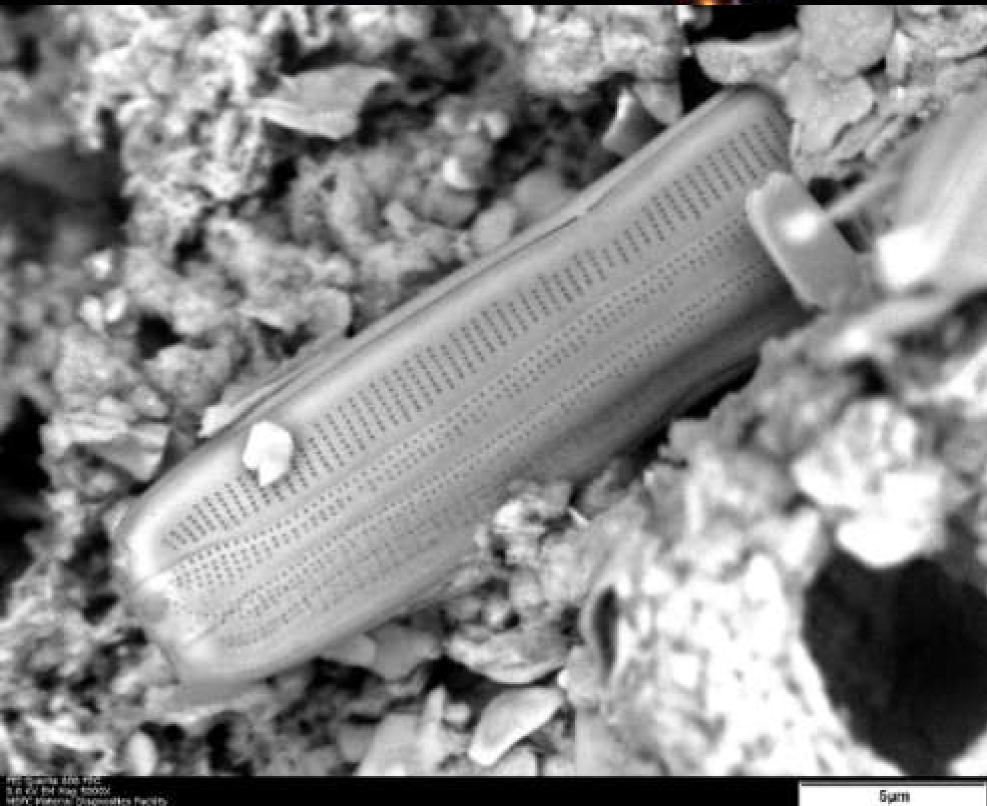
Richard B. Hoover – Those Marvelous Myriad Diatoms, *National Geographic,* June, 1979

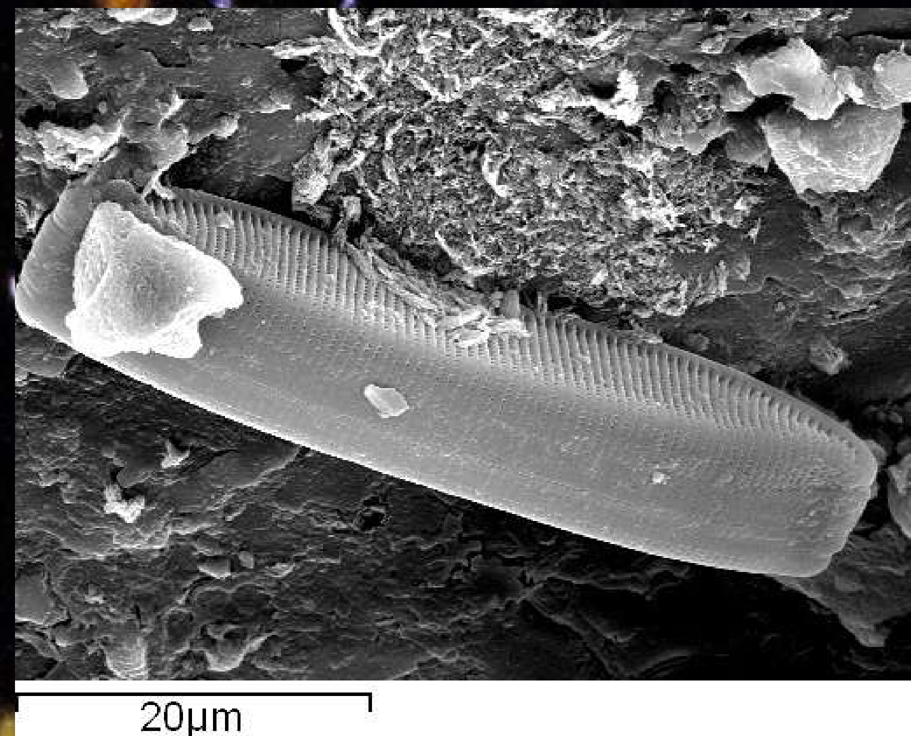


Taxonomy of Diatoms based entirely on Shell Morphology

Centrics: Radial Symmetry - Pennates: Bilateral Symmetry

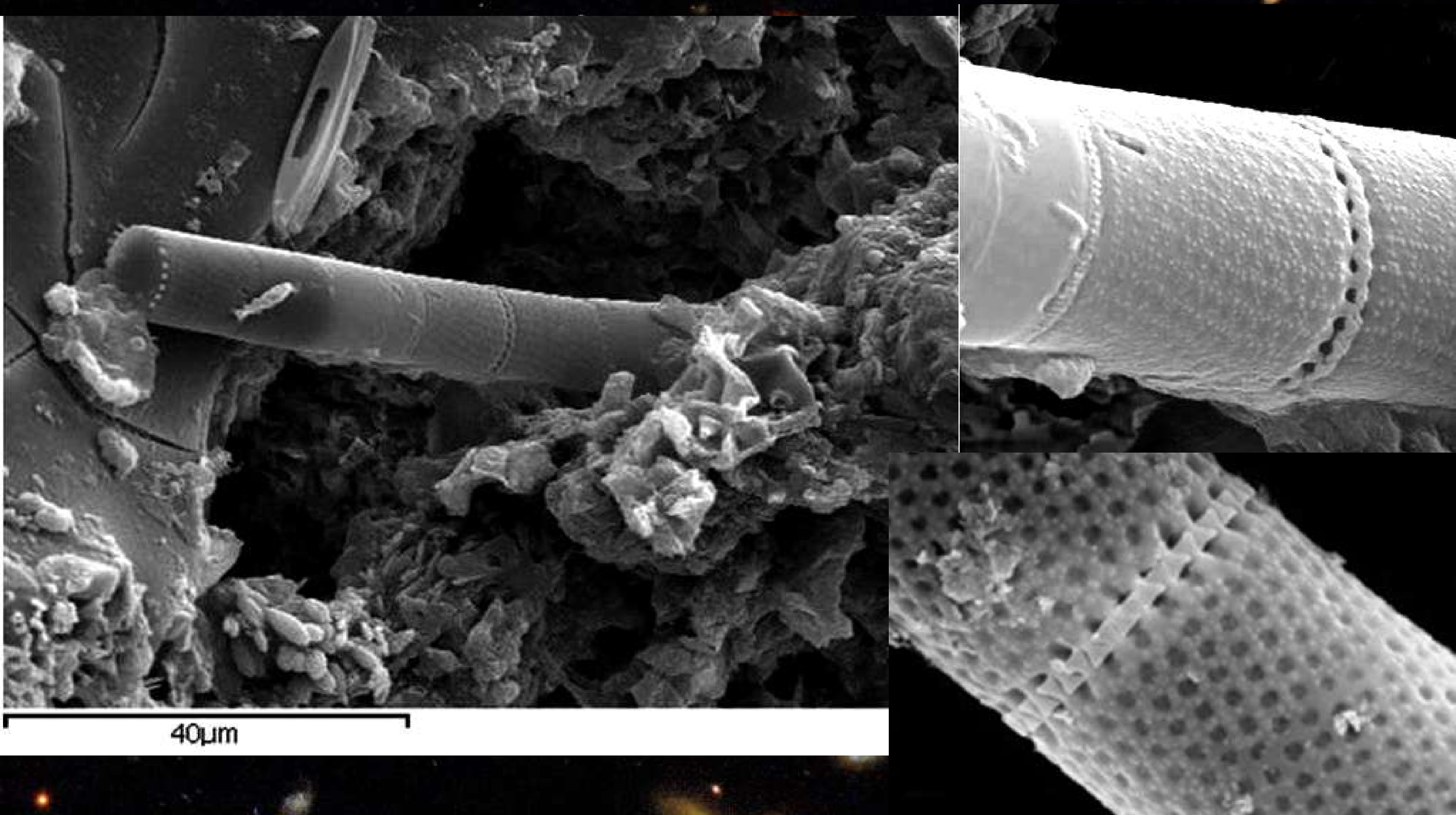
Marine Diatoms in Polonnaruwa Meteorite





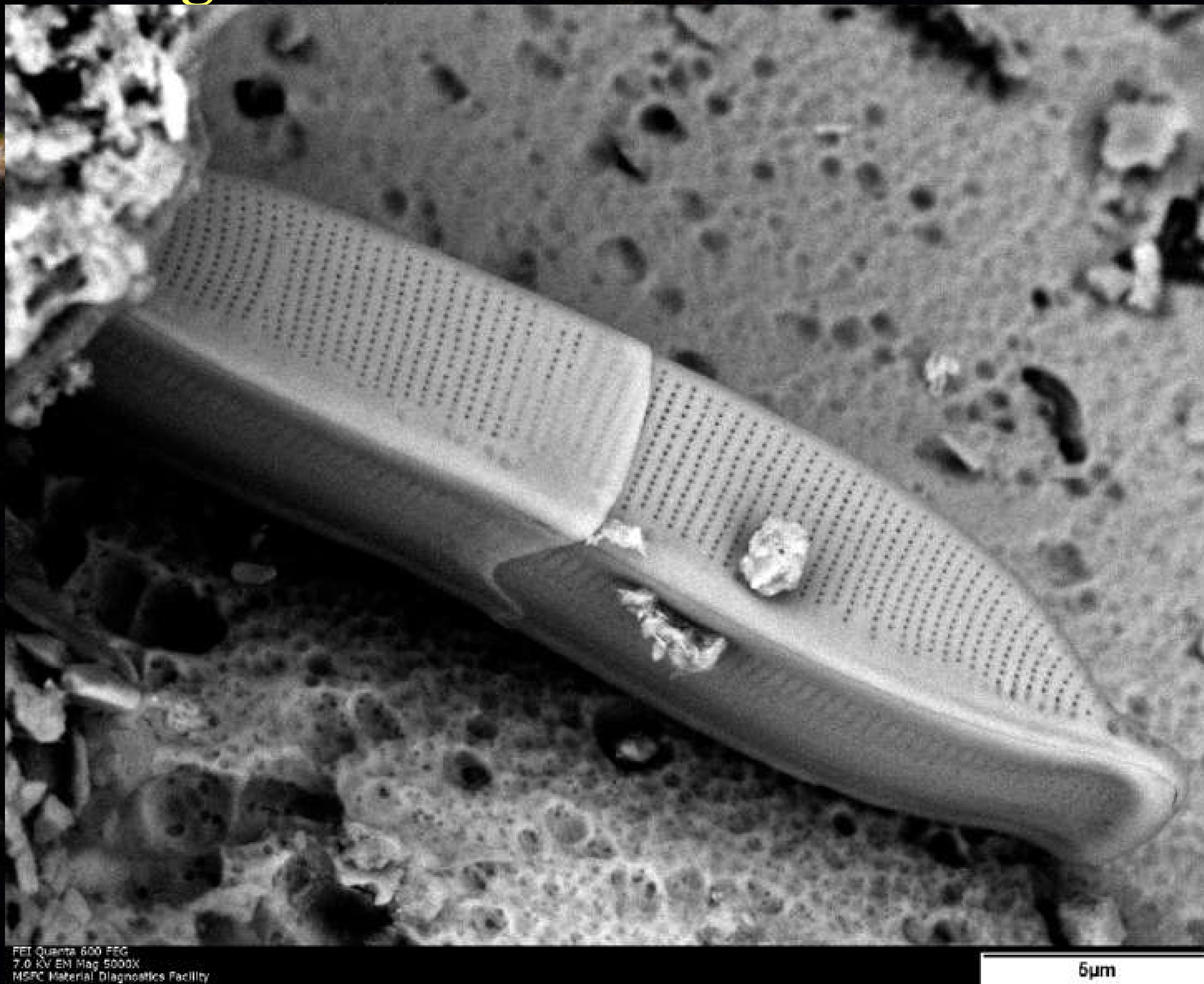
Complete Frustules of *Hantzschia amphioxys* and Araphid Marine Pennate - *Ardissonea robusta*

Marine Planktonic Diatoms in Polonnaruwa



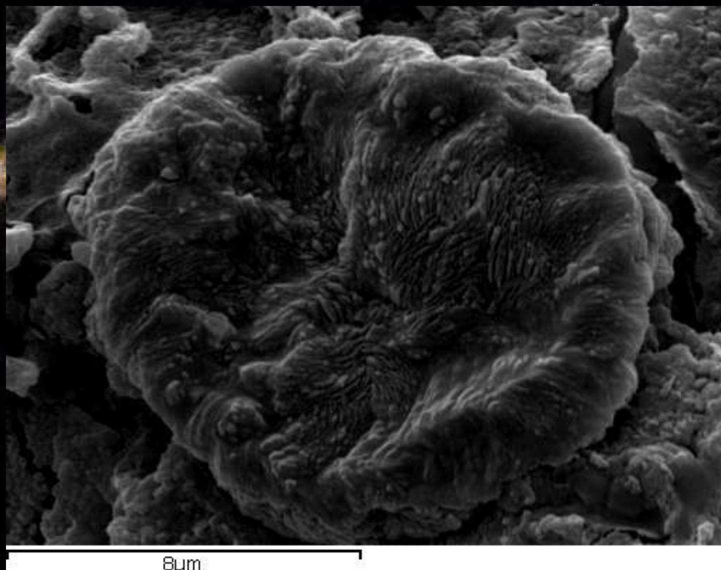
Embedded *Aulacoseira ambigua* Filament in Polonnaruwa & Cells from Polar Ocean

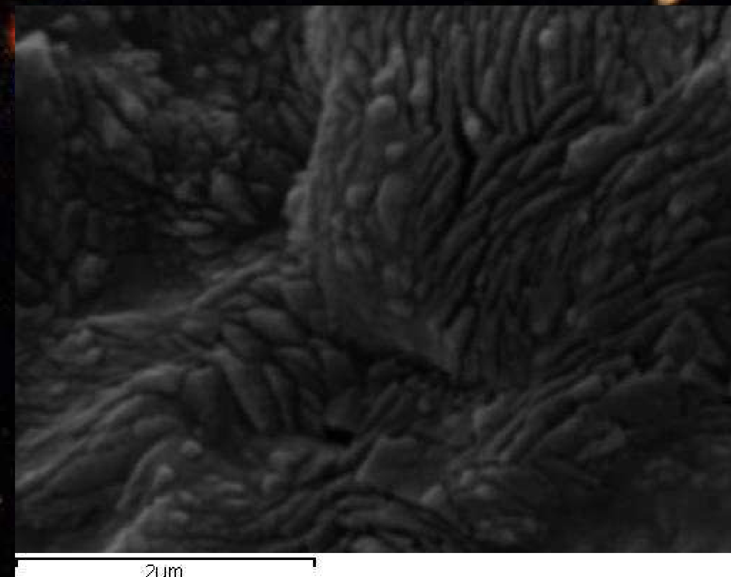
Strange Diatom in Polonnaruwa Meteorite

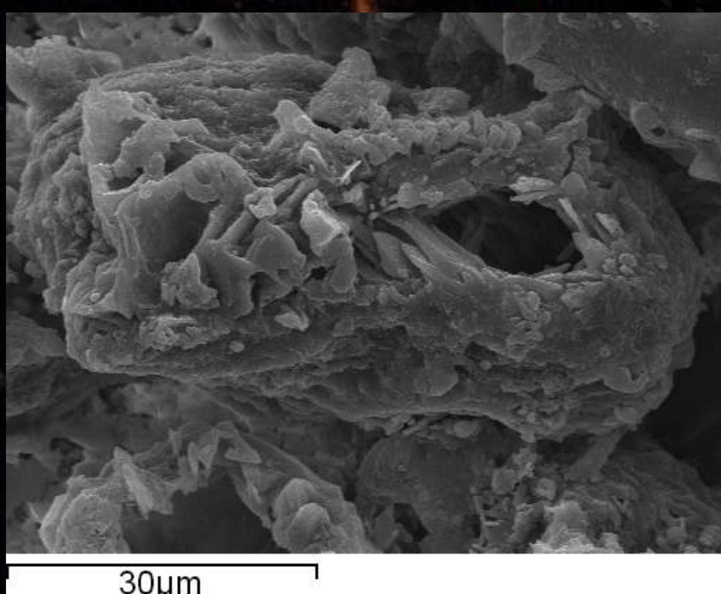


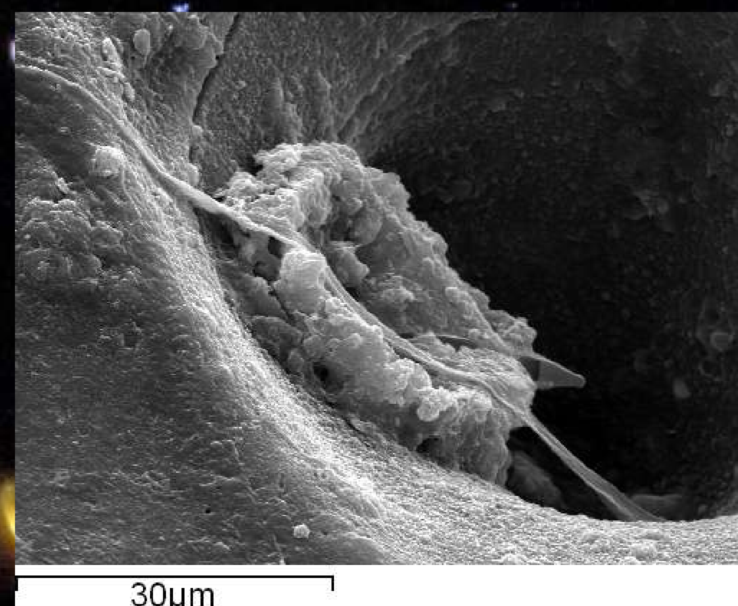
UNKNOWN-Possible New Family of Diatoms

Acritarchs in Polonnaruwa Meteorite



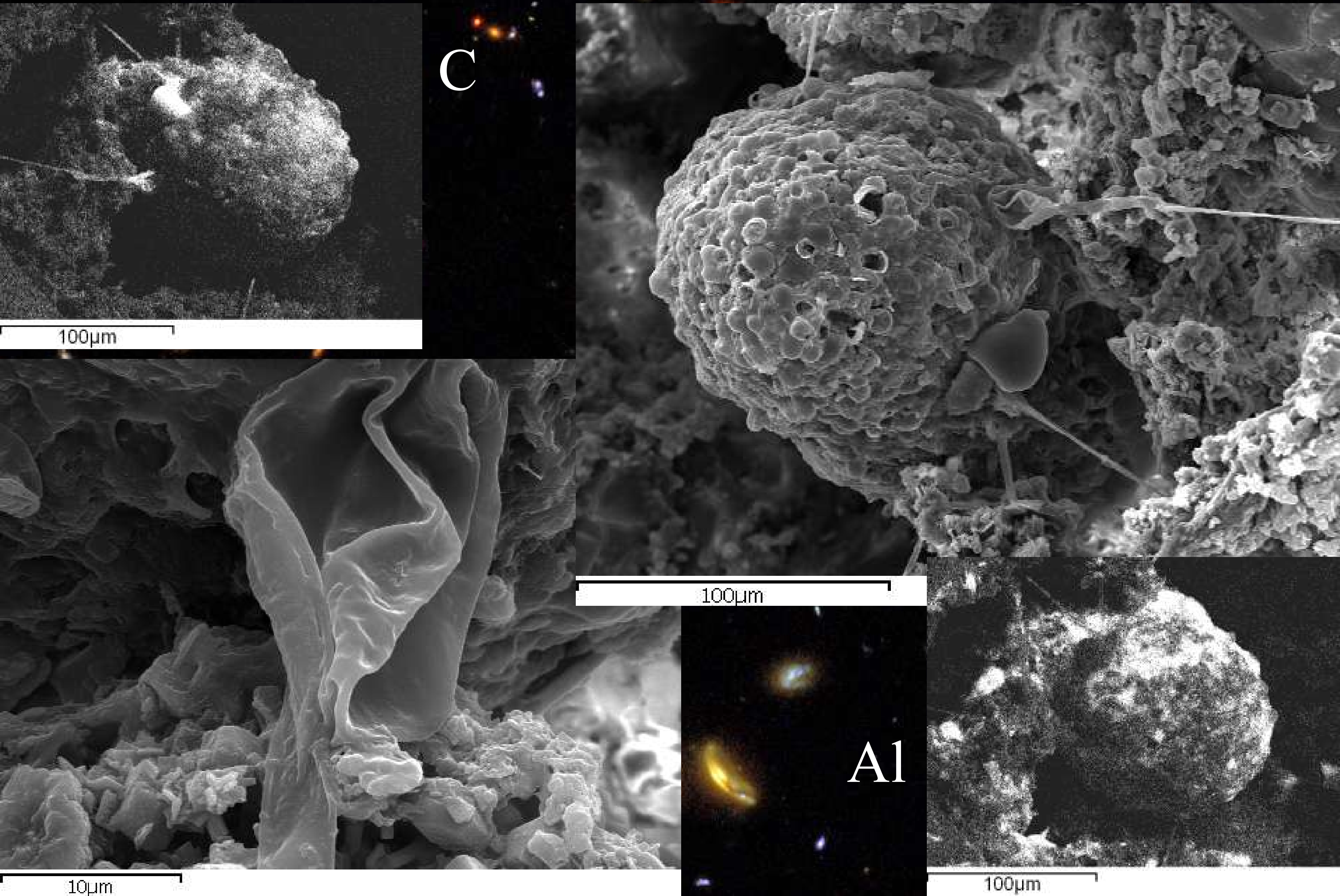




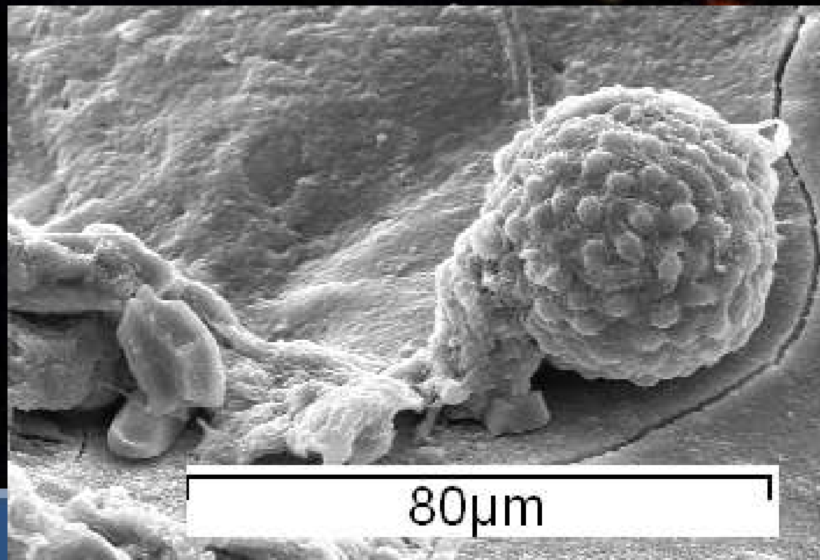


Kerogen - *cf. Leiospheridia sp.* C 84%; O 14%

Extinct Hystrichosphere in Polannaruwa Meteorite

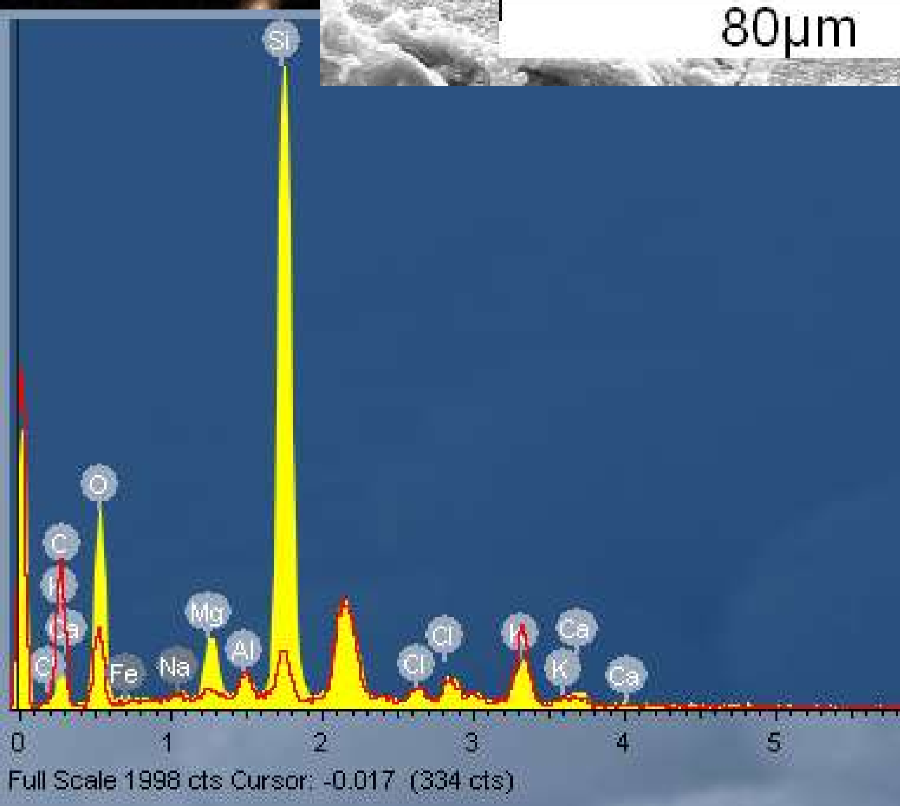


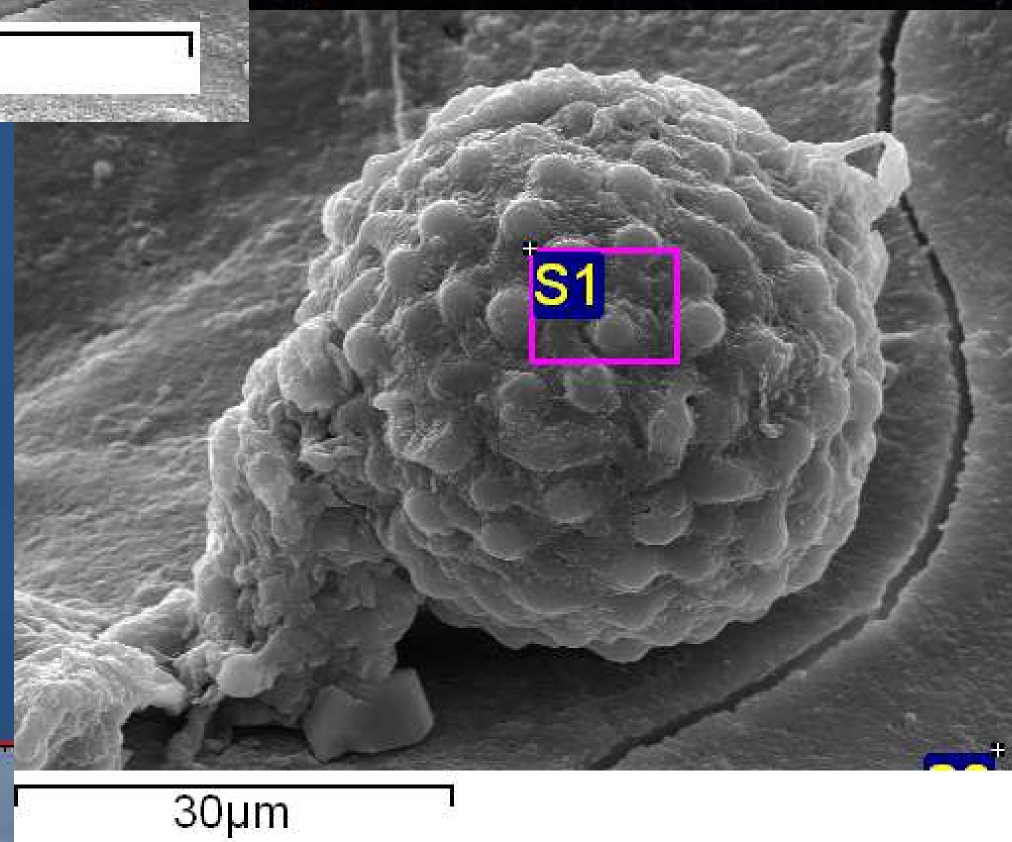
Silica Scaled Chrysophyte algae or Testate Amoeba



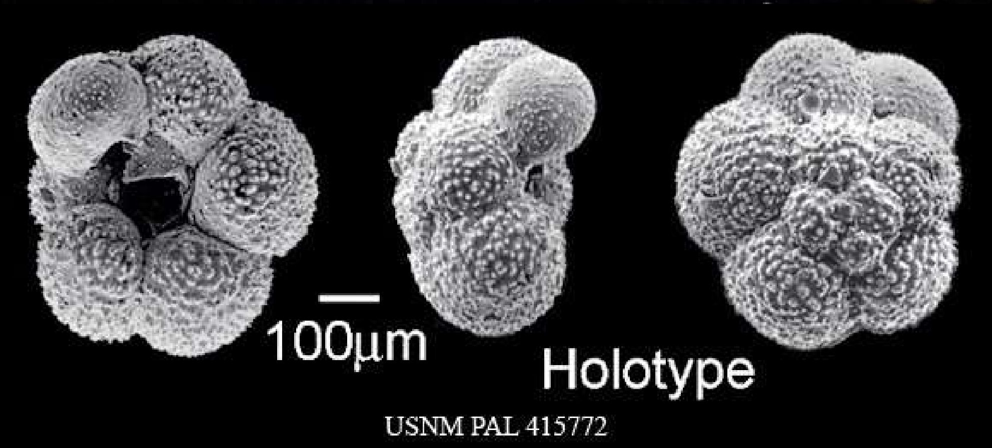
Synurid

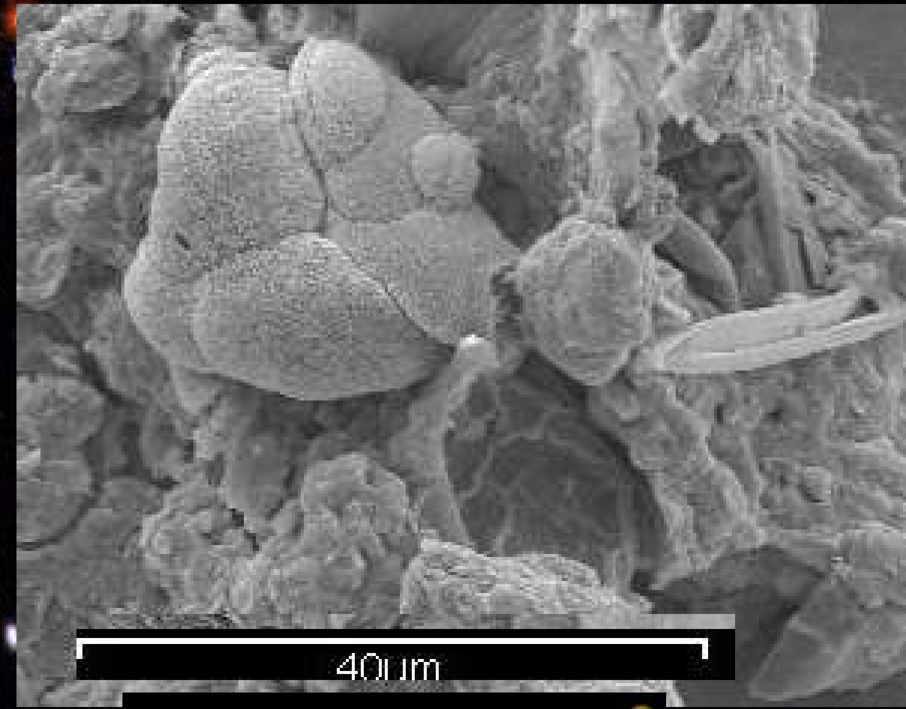
Difflugia corona

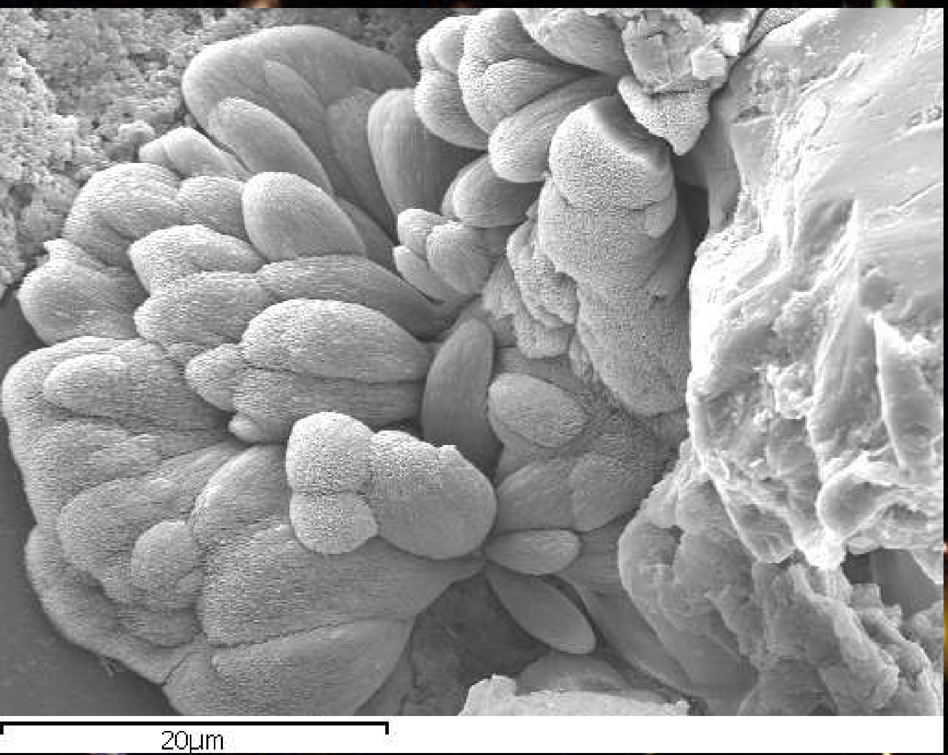


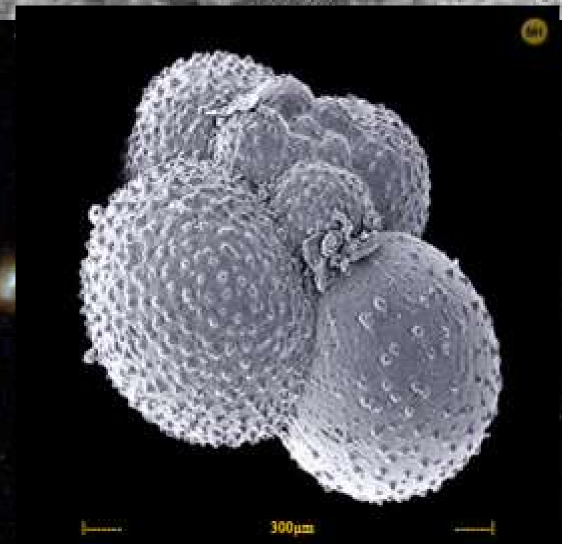


Globigerina sp. Foraminifera in Polonnaruwa

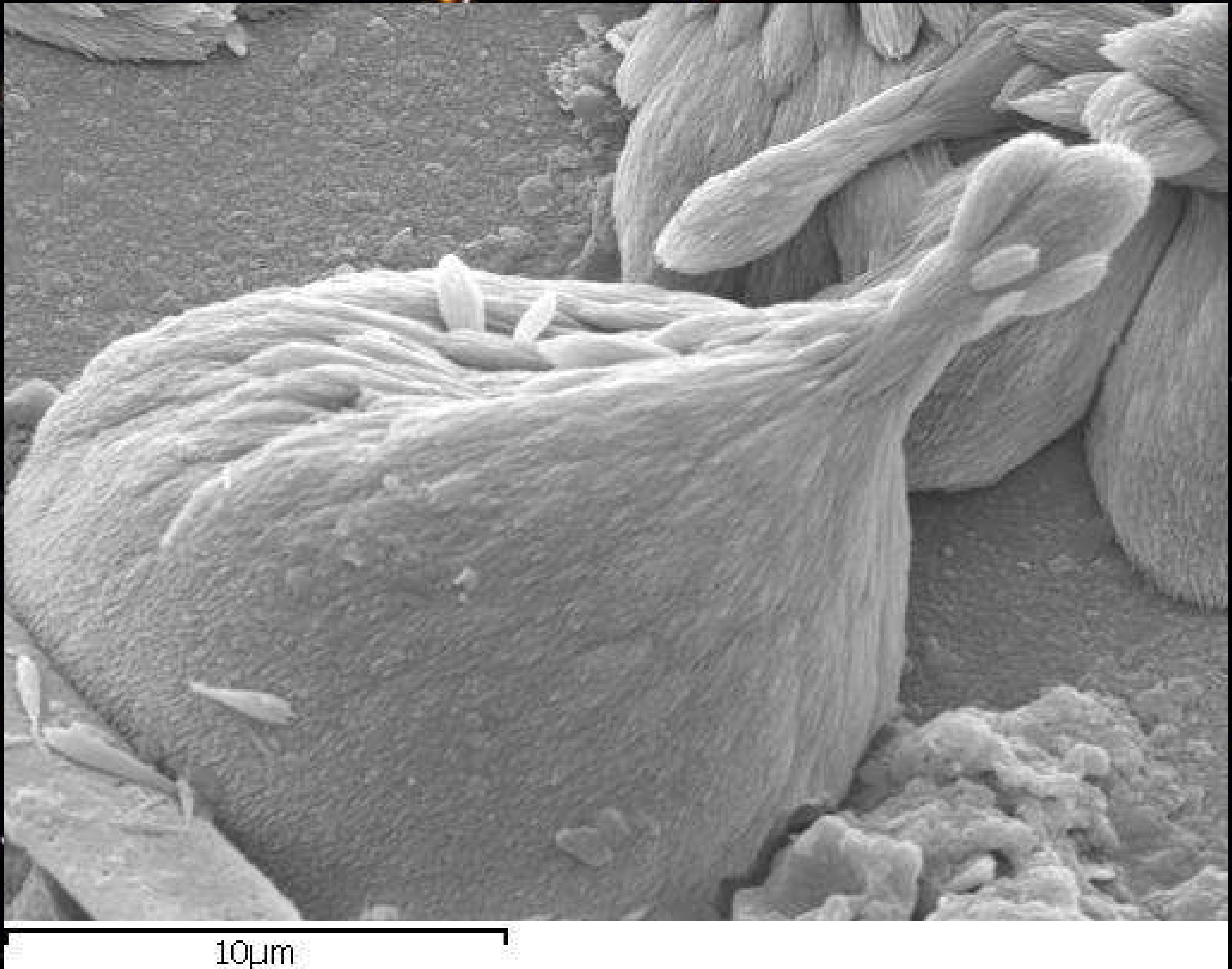




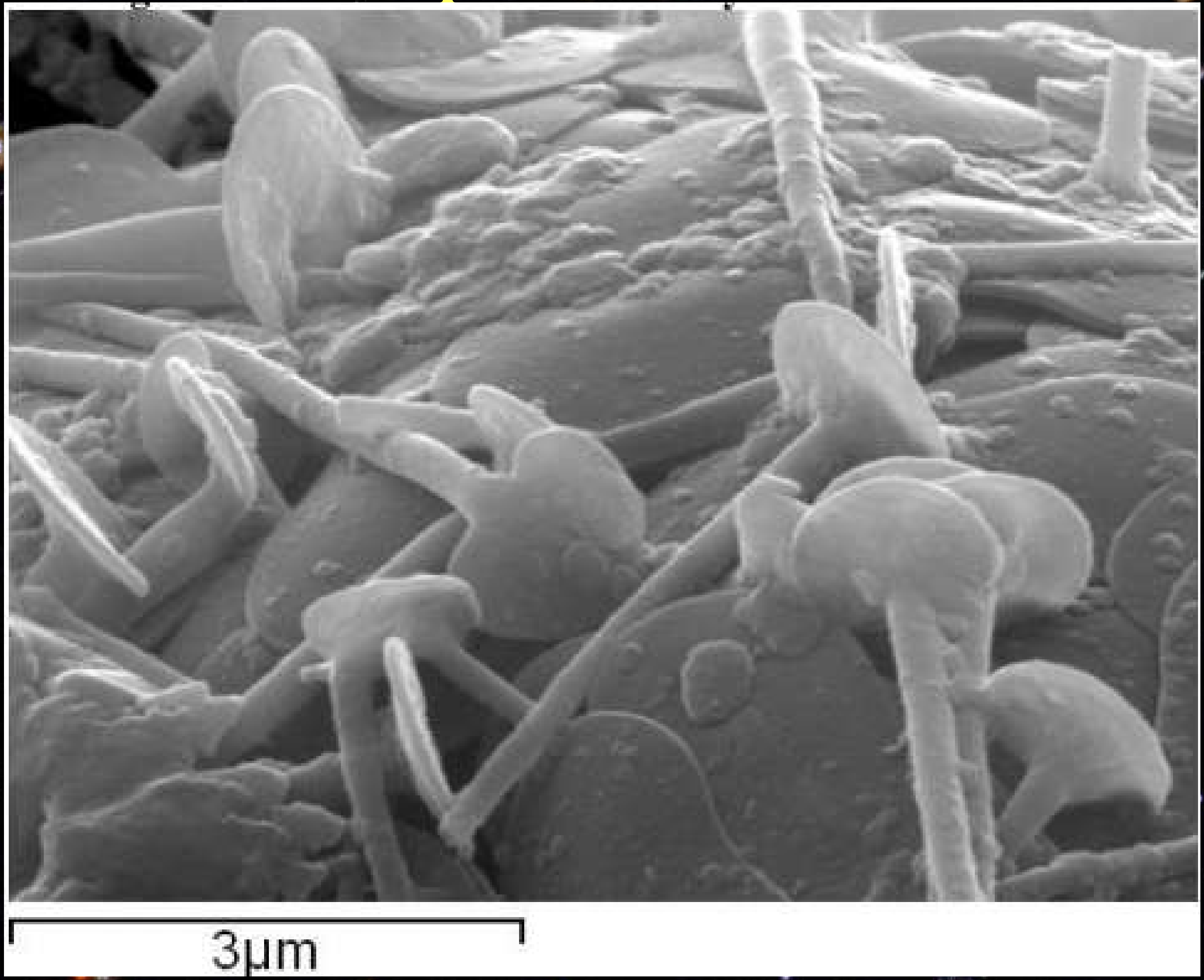




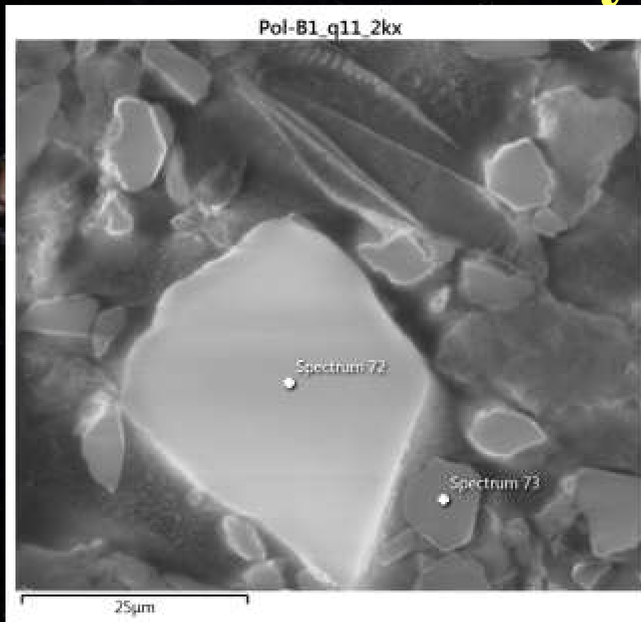
Testate Amoebae cf. *Difflugia sp.*



Testate Amoeba Spines & Plates in Polonnaruwa

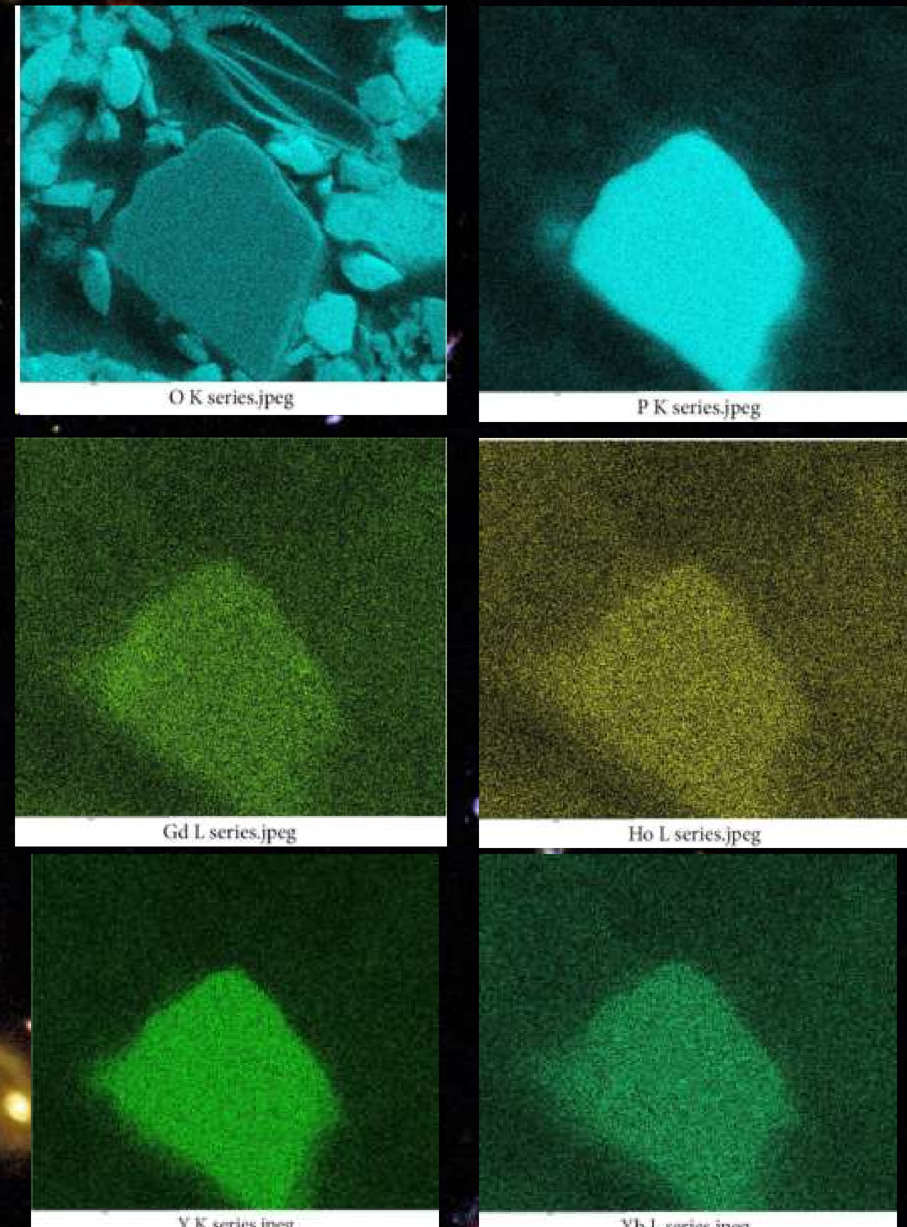


REE & Heavy Metals in Polonnaruwa



Spectrum Label	Spectrum 72	Spectrum 73
C		30.89
O	32.16	43.82
Na	0	
Mg	0.16	
Al	0.13	0.87
Si	1.26	21.81
P	17.45	
K	0.2	0.47
Ca	0.06	0.06
Ti	0.03	0.03
Mn	0	
Fe	0.03	0.24
Ni	0	
Y	31.06	0.87
Gd	1.54	0.09
Dy	5.74	0.32
Ho	1.32	0.09
Er	4.23	0.21
Yb	3.98	0.24
U	0.65	
Total	100	100

Percentages are in weight%



Perspectives in Astrobiology:
Microfossils in Carbonaceous Meteorites

CONCLUSIONS

Requirements for Life (Water, Energy & Biogenic Elements) Co-Exist on all Planets, Moons & Comets

Carbonaceous Meteorites Contain 8 of 20 Protein Amino Acids and 3 of 5 DNA Nucleobases & Indigenous Microfossils

Absence of Biomolecules in Stones and Nitrogen in Filaments proves these Microfossils are Ancient and Indigenous - NOT MODERN BIO-CONTAMINANTS

Conclusive Evidence for Extraterrestrial Life

Perspectives in Astrobiology:
Microfossils in Carbonaceous Meteorites

Future Research on Polonnaruwa Meteorite

Radiochemical Neutron Activation Analysis for Precise Determination of Elements for Comparison with Other Meteorites and Classification

Study Fractionation of Isotopes of Lithophiles Lanthanides and Heavy Metals

Measure Radionuclides and Noble Gas to Determine Cosmic Ray Exposure Age of Polonnaruwa Stones

Measure Age of Zircons, SiC and Graphite Grains in Stones & Isotopes of C, Si & O in Fossils

Unravel the Mysteries of the Polonnaruwa Stones

Perspectives in Astrobiology: Microfossils in Carbonaceous Meteorites

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Meteorite Samples Courtesy: **Claude Perron & M. Rossignol-Strick-** *Musee d'Histoire Naturelle de Paris*; **Emile Ladier-***Montauban Museum*; **P. Sipiera** *Planetary Studies Foundation & Field Museum, Chicago*; **William Birch,** *Victoria Museum, Melbourne*

Discussions of Meteoritics, Bacterial Paleontology and Cyanobacteria -

Academician Alexei Yu. Rozanov, Astrobiology Institute, JINR

Academician Eric Galimov, Director, *Vernadsky Institute (RAS)*

Academician Georgi Zavarzin & Ludmilla Gerassimenko- *Institute of Microbiology (RAS);* **Rosemarie Rippka -** *Institut Pasteur, Paris*