Adventist Agricultural Association
4th Annual Convention
2018
Session 1

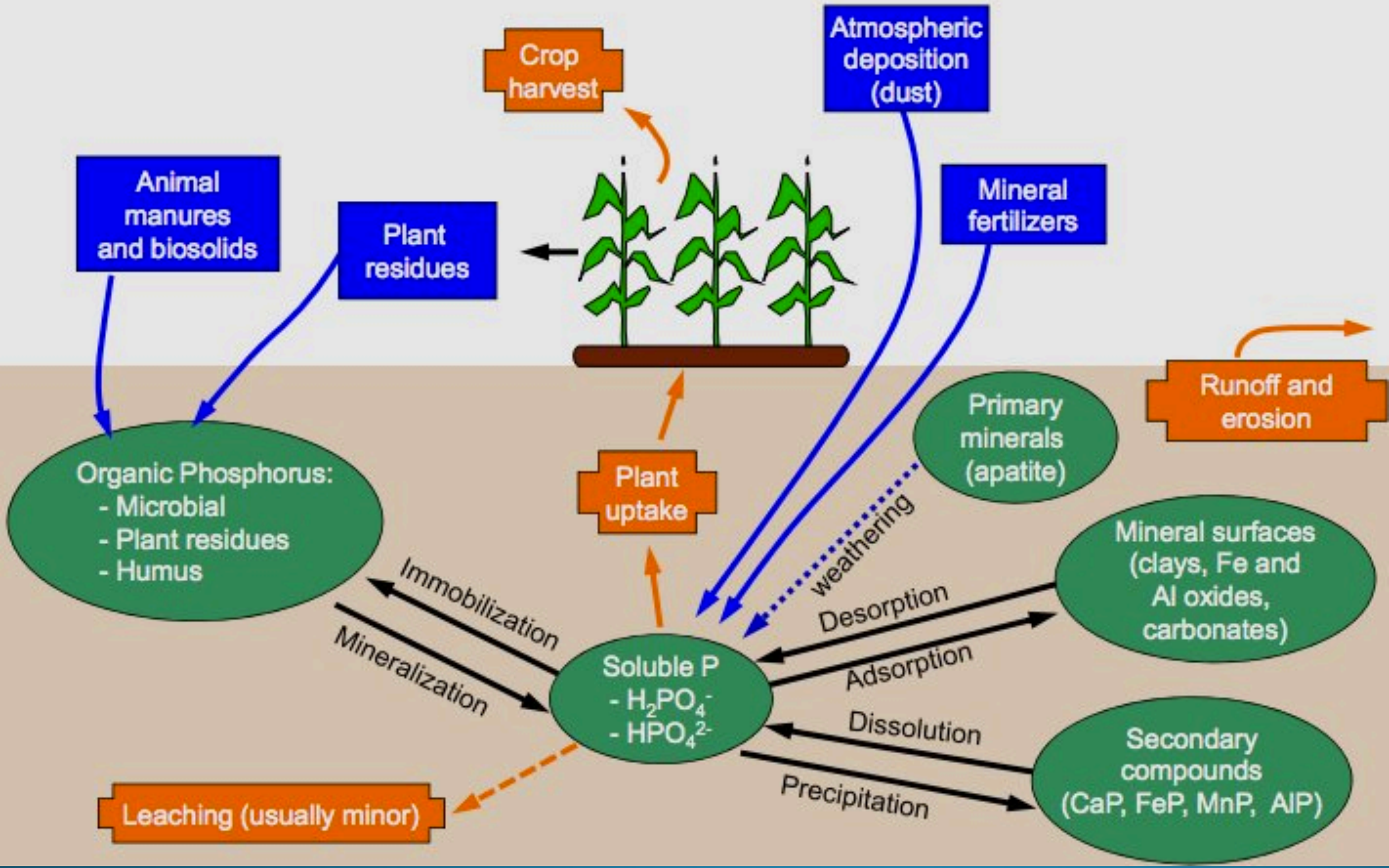
Phosphorus and Sulfur Cycle

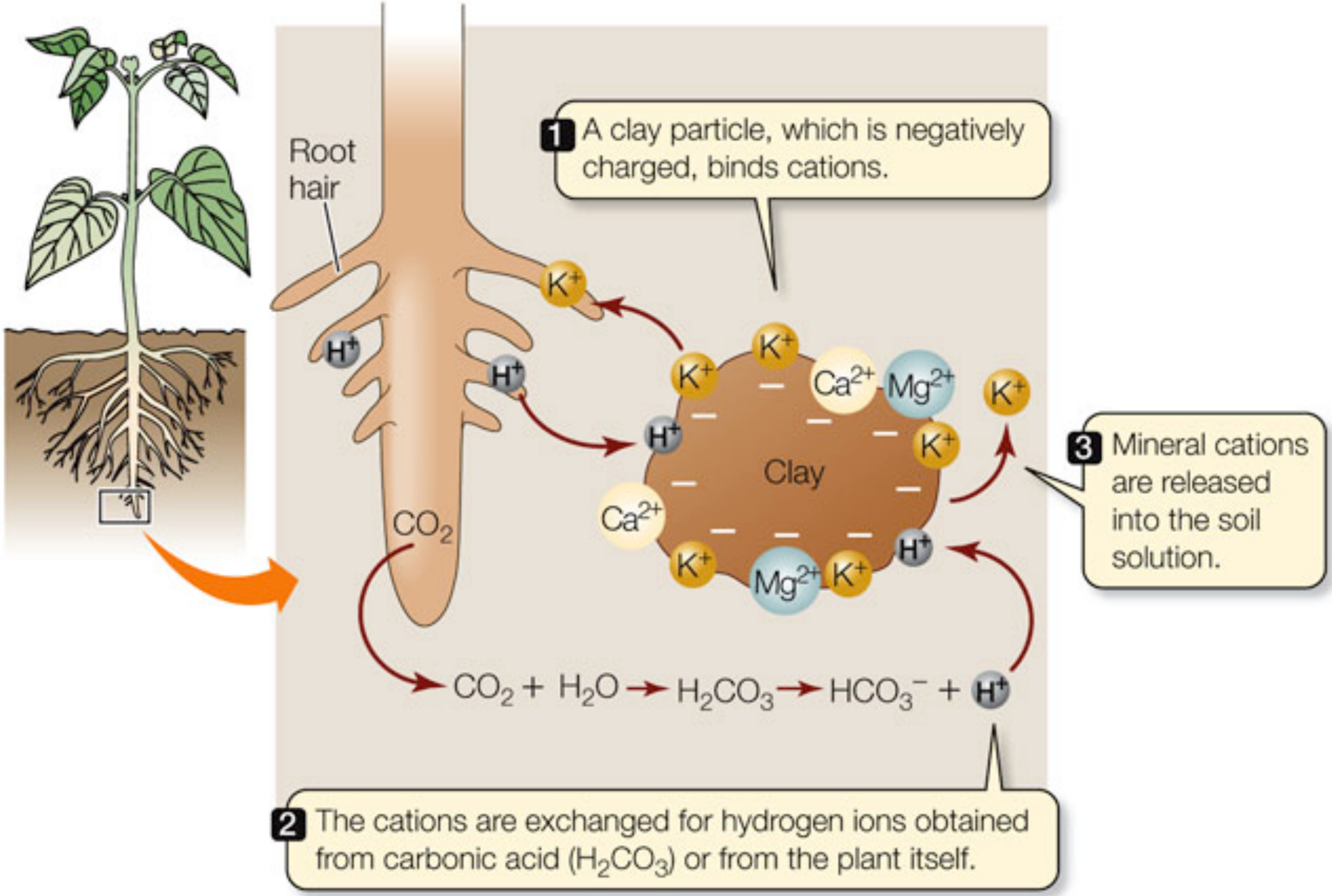
PRESENTED BY:

MICHAEL ROCKY TREVIZO

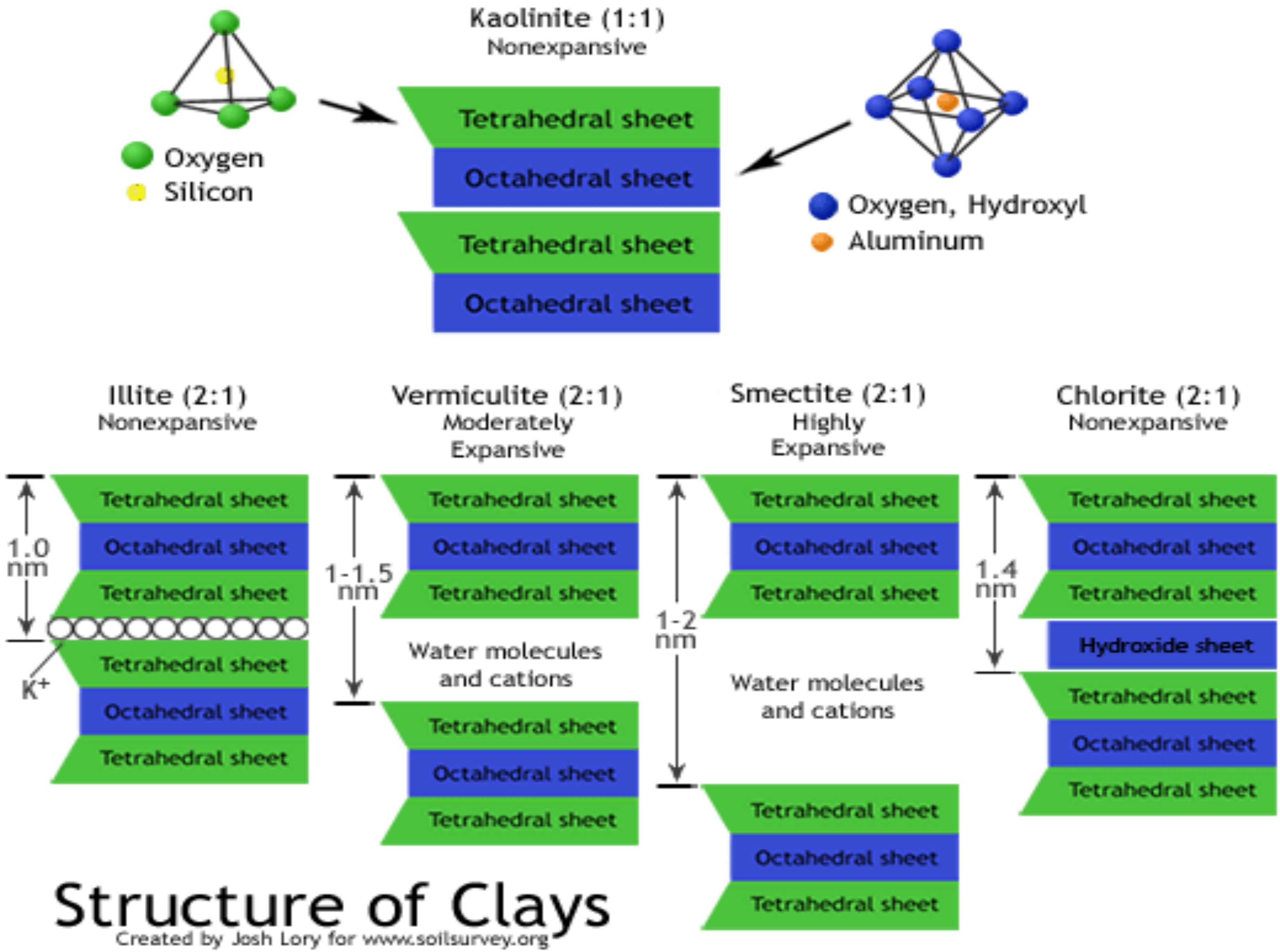
The Phosphorus cycle

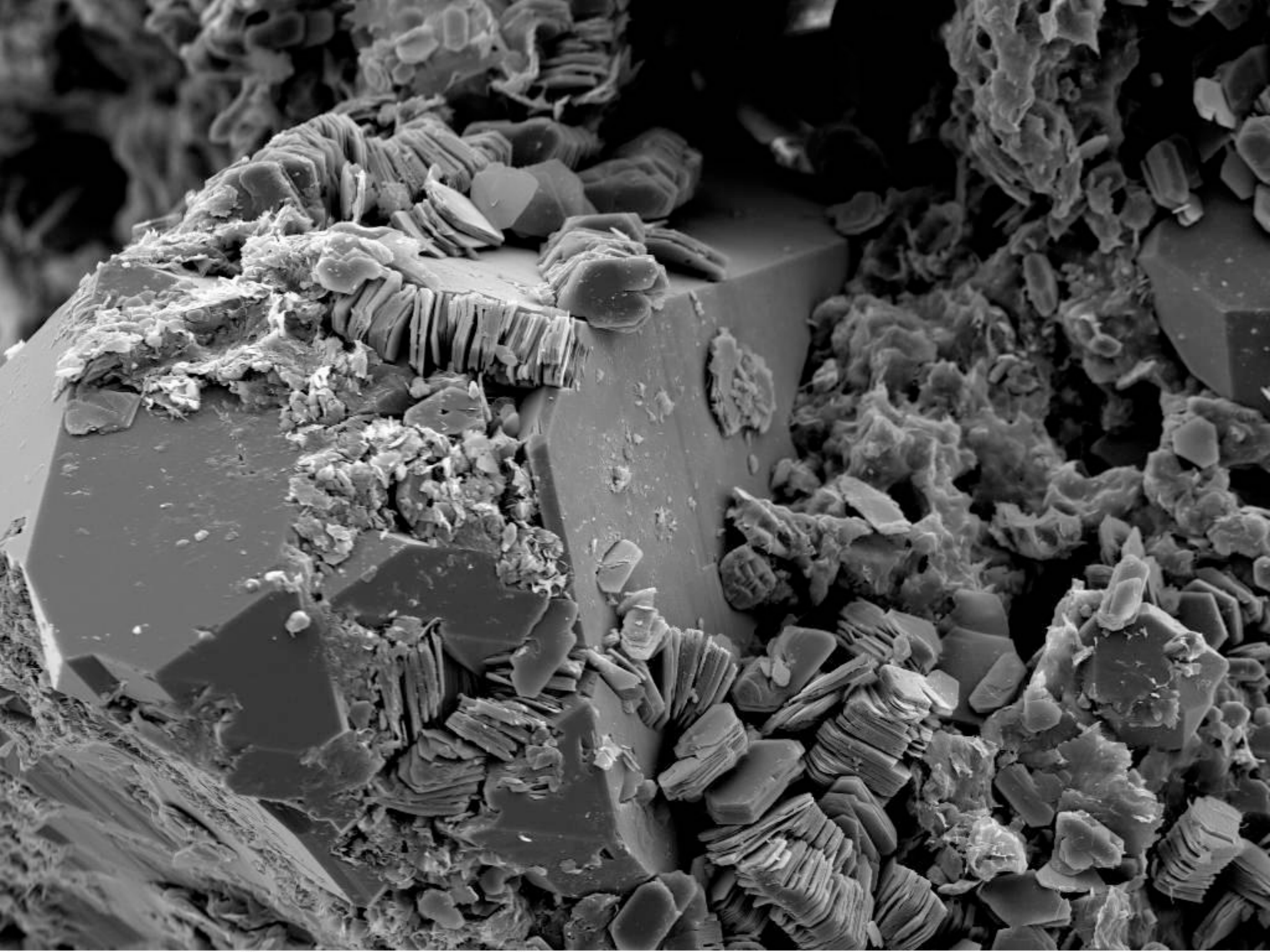
Component | Input to soil | Loss from soil





***LIFE* 8e, Figure 36.6**

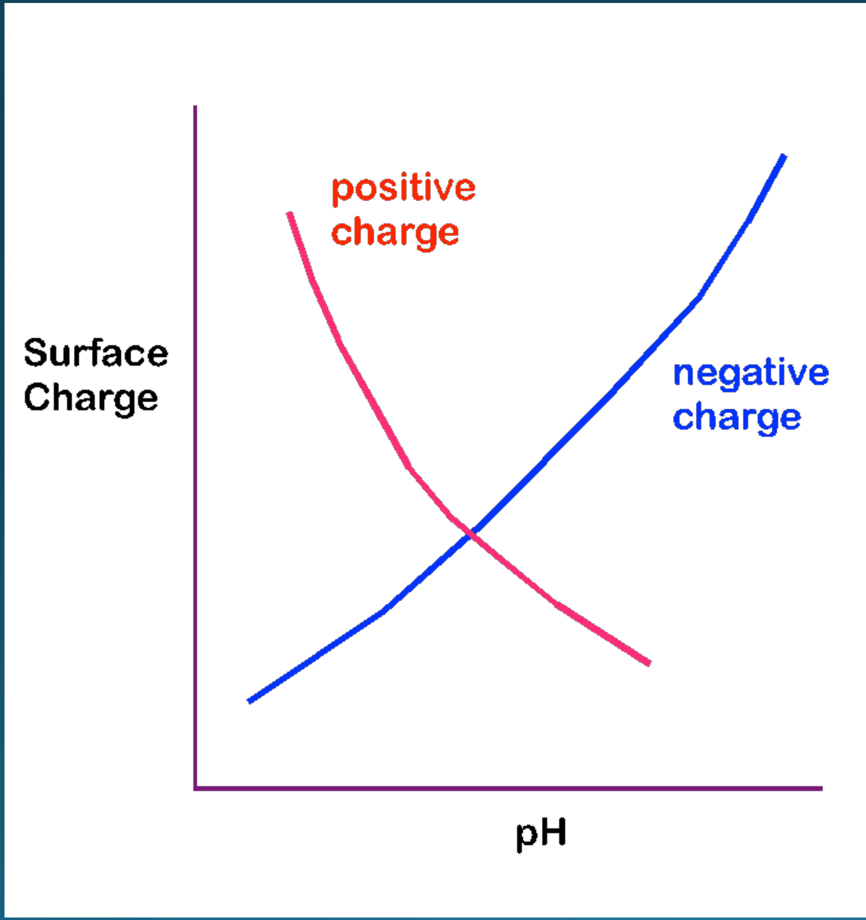

Kaolinite (1:1)
Nonexpansive
Tetrahedral sheet
Octahedral sheet
Tetrahedral sheet
Octahedral sheet
Oxygen
Silicon
Oxygen, Hydroxyl
Aluminum
Illite (2:1)
Nonexpansive
1.0 nm
Tetrahedral sheet
Octahedral sheet
Tetrahedral sheet
K+
Tetrahedral sheet
Octahedral sheet
Tetrahedral sheet
Vermiculite (2:1)
Moderately Expansive
1-1.5 nm
Tetrahedral sheet
Octahedral sheet
Tetrahedral sheet
Water molecules and cations
Tetrahedral sheet
Octahedral sheet
Tetrahedral sheet
Smectite (2:1)
Highly Expansive
1-2 nm
Tetrahedral sheet
Octahedral sheet
Tetrahedral sheet
Water molecules and cations
Tetrahedral sheet
Octahedral sheet
Tetrahedral sheet
Chlorite (2:1)
Nonexpansive
1.4 nm
Tetrahedral sheet
Octahedral sheet
Tetrahedral sheet
Hydroxide sheet
Tetrahedral sheet
Octahedral sheet
Tetrahedral sheet
Structure of Clays
Created by Josh Lory for www.soilsurvey.org



Anion Exchange Capacity (AEC)

- Quantity of anions that can be reversibly adsorbed on soil particles due to their negative charge
- Expressed as moles or equivalents of negative charge per unit weight of mineral or soil
- In most soils, there is WAY MORE negative charge than positive charge, so it is less common to hear about AEC
- (can be important in some tropical soils, however)

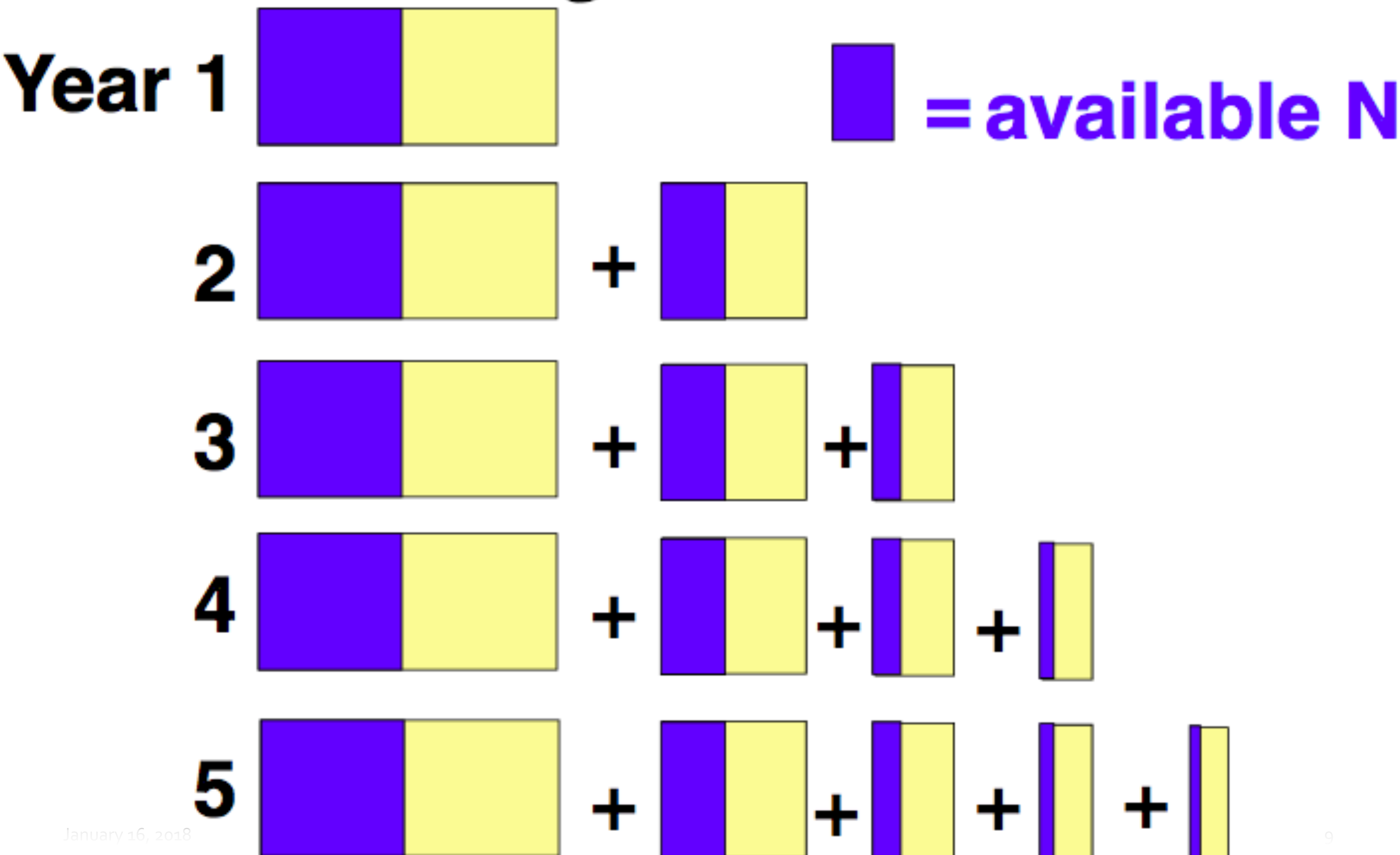
Variable or pH-dependent charge



EXODUS 20:5 & 6

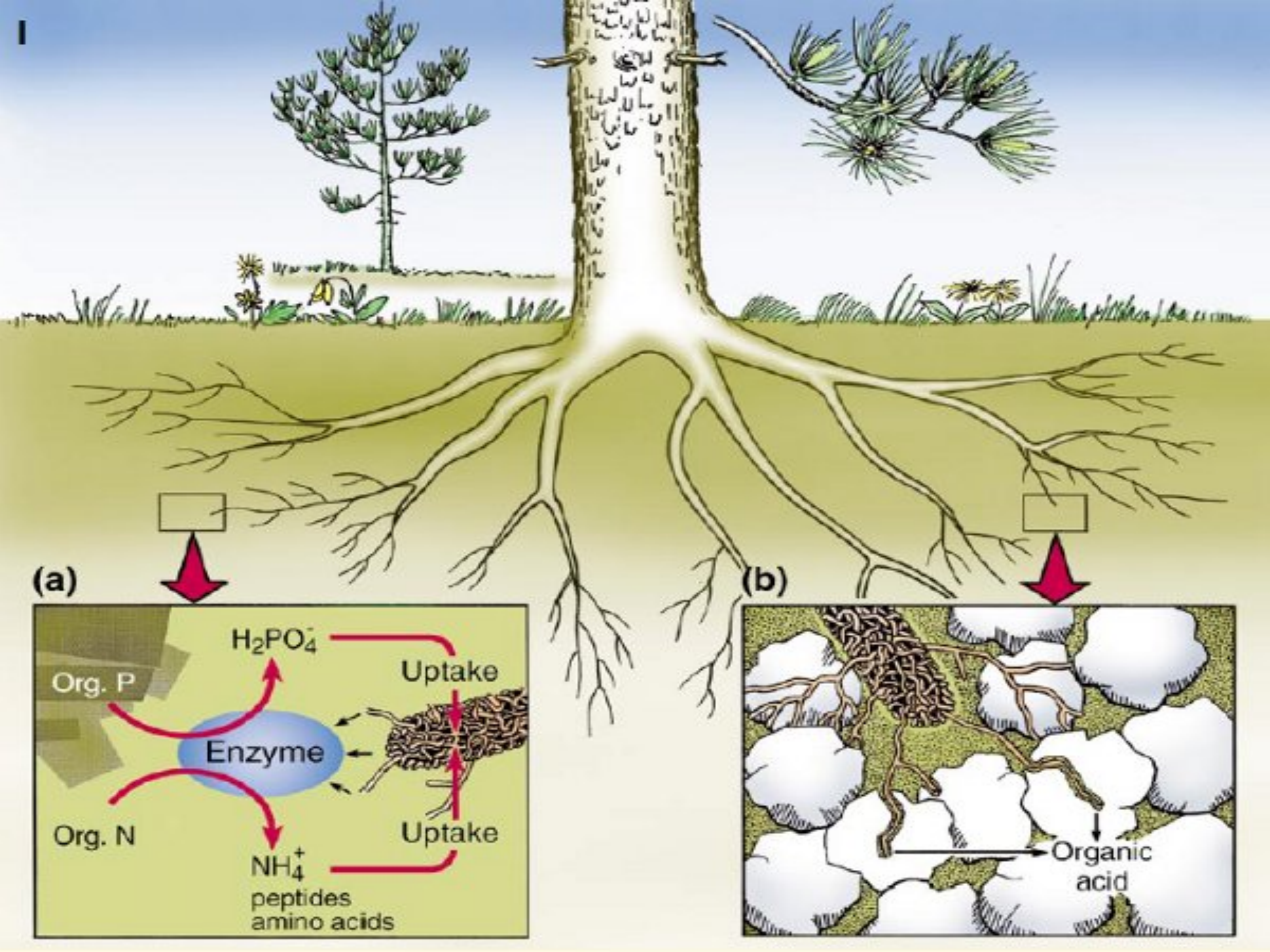
- 5 Thou shalt not bow down thyself to them, nor serve them: for I the LORD thy God am a jealous God, visiting the iniquity of the fathers upon the children unto the third and fourth generation of them that hate me; and shewing mercy unto thousands of them that love me, and keep my commandments.

Cumulative available N from an organic source



Psalms 11:3

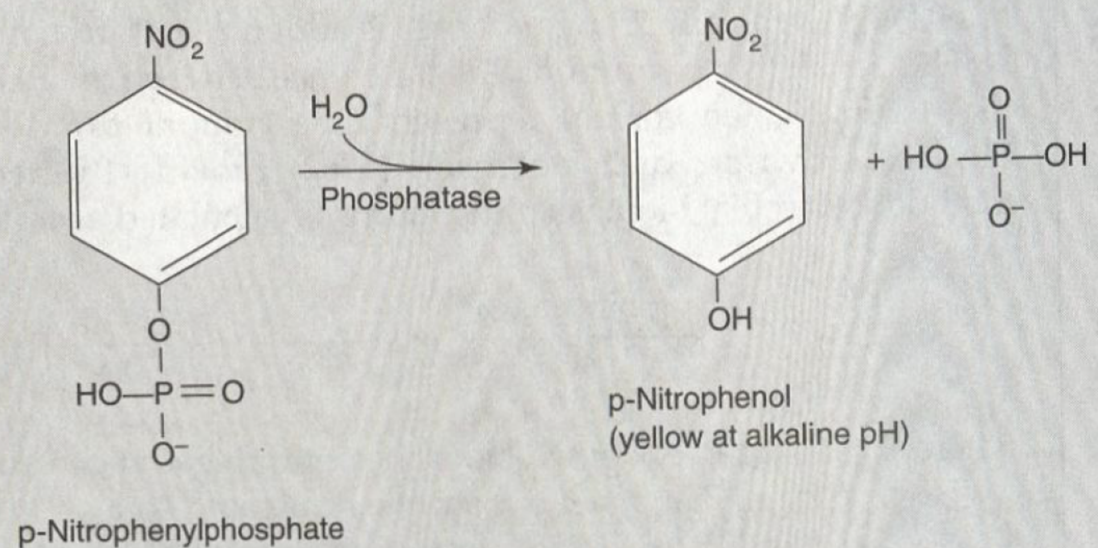
- If the foundations be destroyed, what can the righteous do?


I
(a)
H$_2$PO$_4^-$
Org. P
Uptake
Enzyme
Org. N
Uptake
NH$_4^+$
peptides
amino acids
(b)
Organic
acid

BOX 18–2

The Phosphomonoesterase Assay

This assay measures the potential of a soil to mineralize orthophosphate by hydrolysis of phosphomonoester bonds in organic phosphorus sources. The assay includes an organic phosphate analog, p-nitrophenylphosphate, as a substrate (Tabatabai, 1994). The soil is treated with toluene to inhibit microbial activity and a buffer solution to maintain the reaction pH. As the phosphate-ester bond is hydrolyzed, p-nitrophenol is formed. After incubation, NaOH is added to the soil to stop the reaction and adjust the soil to an alkaline pH where p-nitrophenol forms a yellow color. Colorimetric determination of the p-nitrophenol concentration permits calculation of the rate of enzyme activity. The reaction is:



$$\text{and phosphatase activity} = \frac{\mu\text{g p} - \text{nitrophenol released}}{\text{g soil hour}}$$

Sulfur and Phosphorus

- Sulfur in the form of Hydrogen Sulfide can chelate orthophosphate mineralizing phosphorus.
- Produced in water logged soil conditions, by sulfur reducing bacteria
- Possible reason for the importance of balancing P with S in soil solution; suggested ratios of 3:1 P/S ratio

Bacillus megaterium

- Know group of species that can weather Apatite
- Also know to produce Vitamin B-12

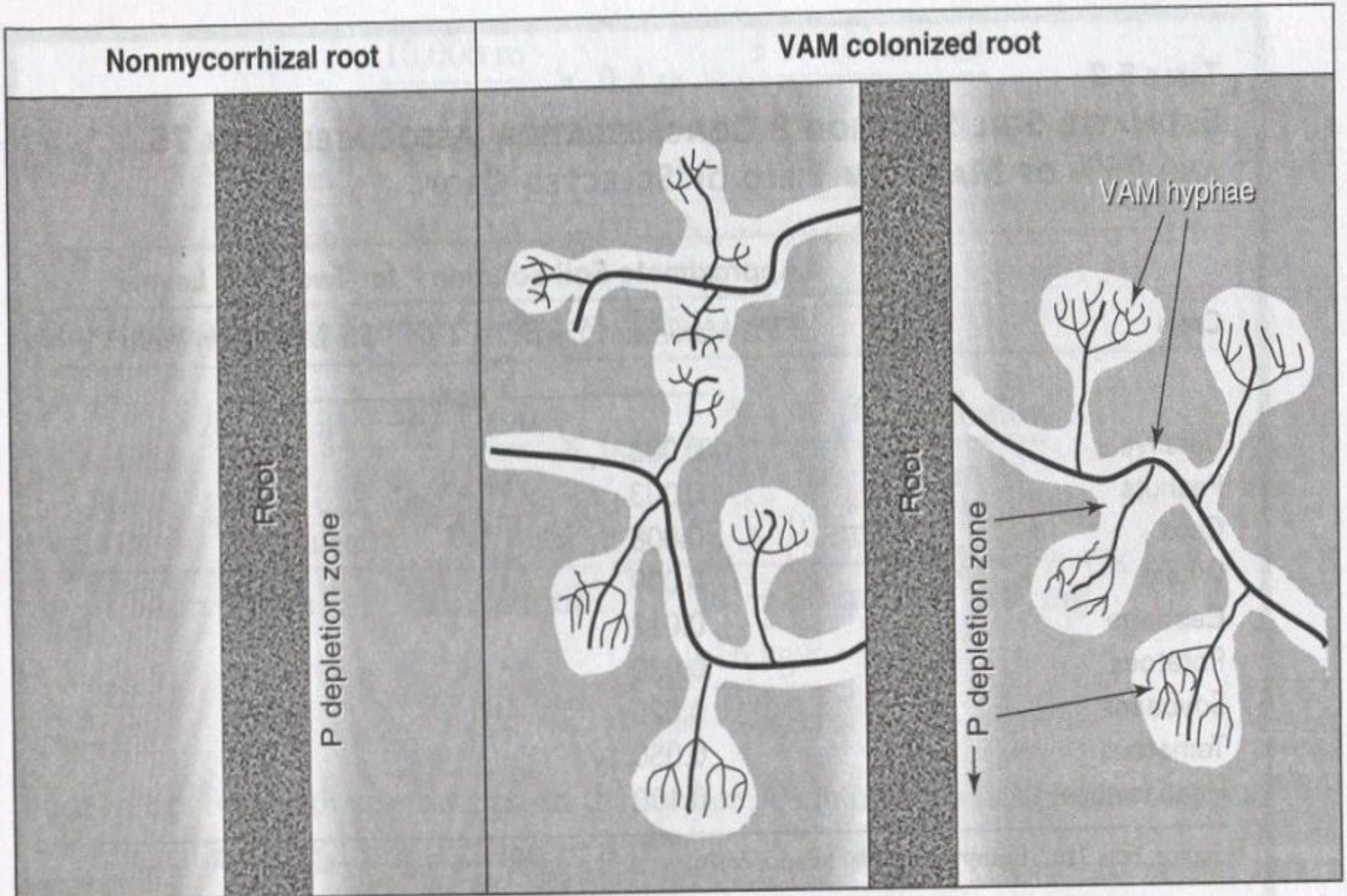


Figure 5-7
Influence of VAM-colonized roots on soil volume accessed for P uptake.

TABLE 18–2 Examples of Inorganic Phosphorus Minerals in Soil and Their Solubilities with Respect to Dissolution of the Cation and PO_4^{3-}

Name	Formula	Solubility Product (Log)
Fluorapatite	$Ca_5(PO_4)_3F$	−59
Hydroxyapatite	$Ca_5(PO_4)_3OH$	−57
Tricalcium phosphate	$Ca_3(PO_4)_2$	−29
Variscite	$AlPO_4 \cdot 2H_2O$	−21
Strengite	$FePO_4 \cdot 2H_2O$	−26

Calculated from equilibrium data in Lindsay (1979).

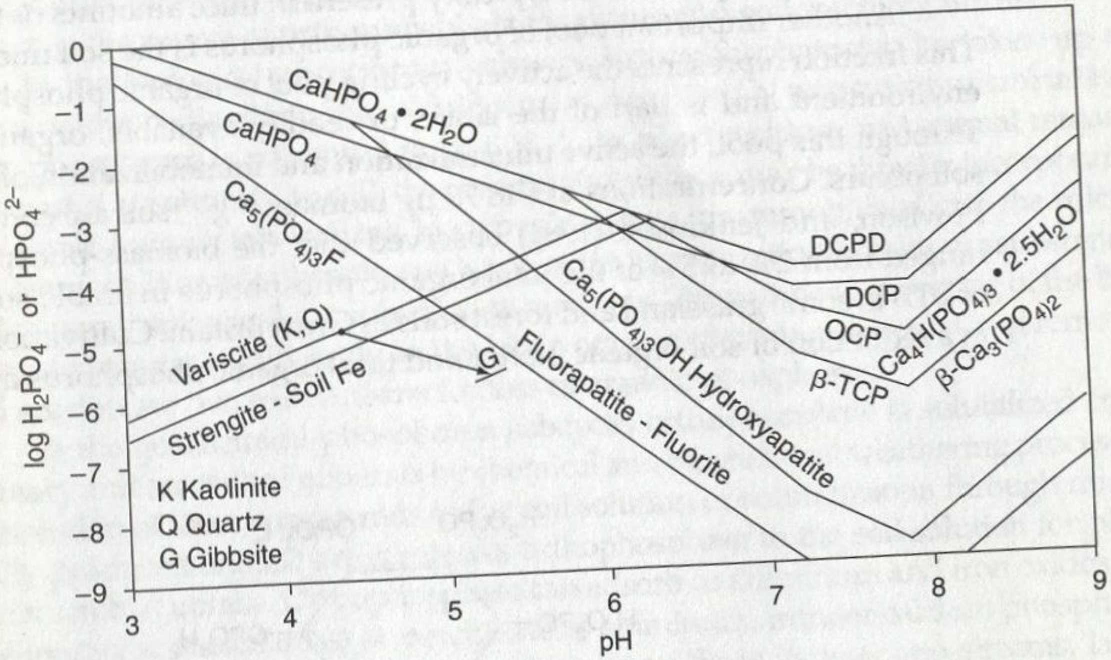
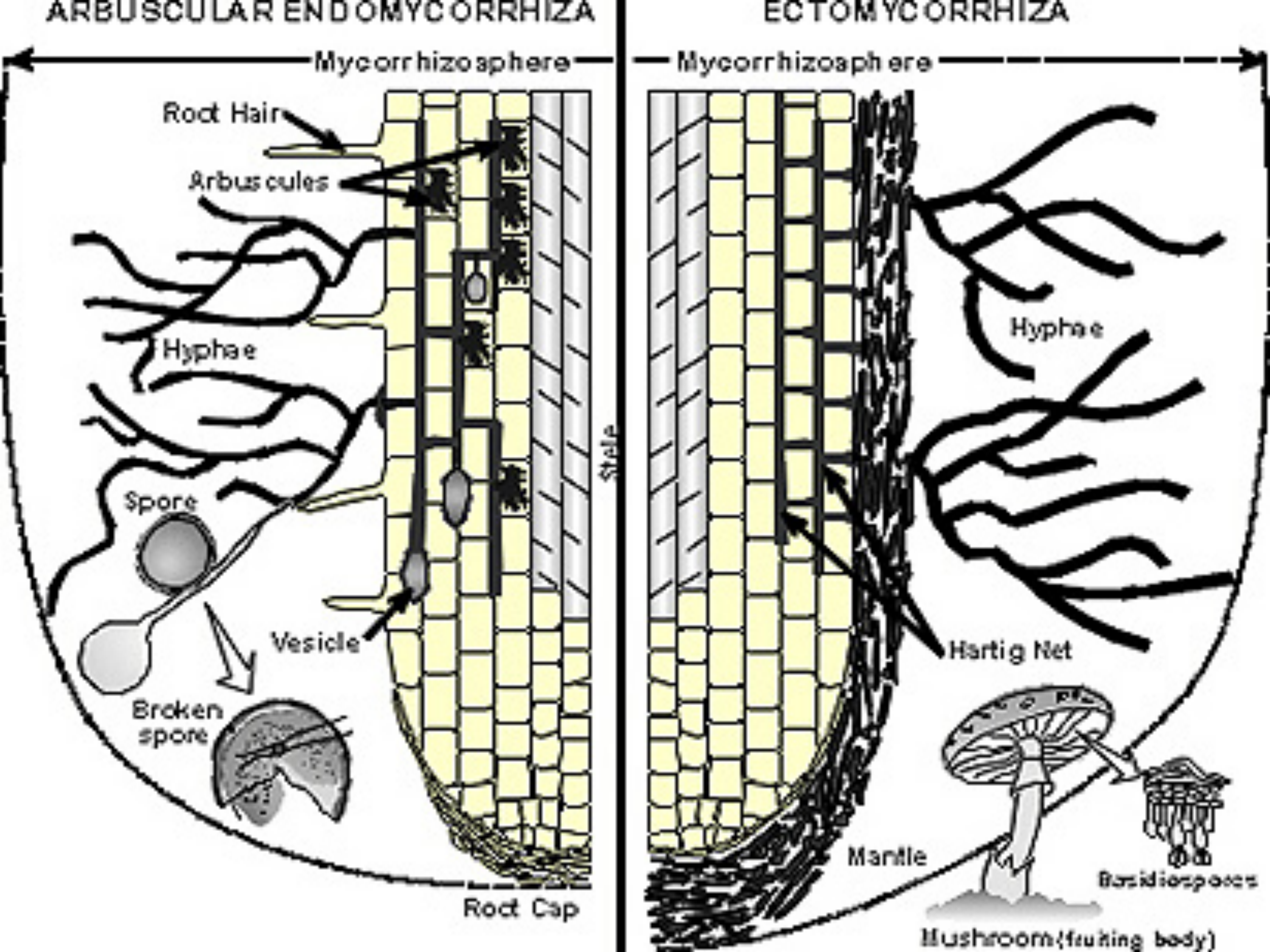
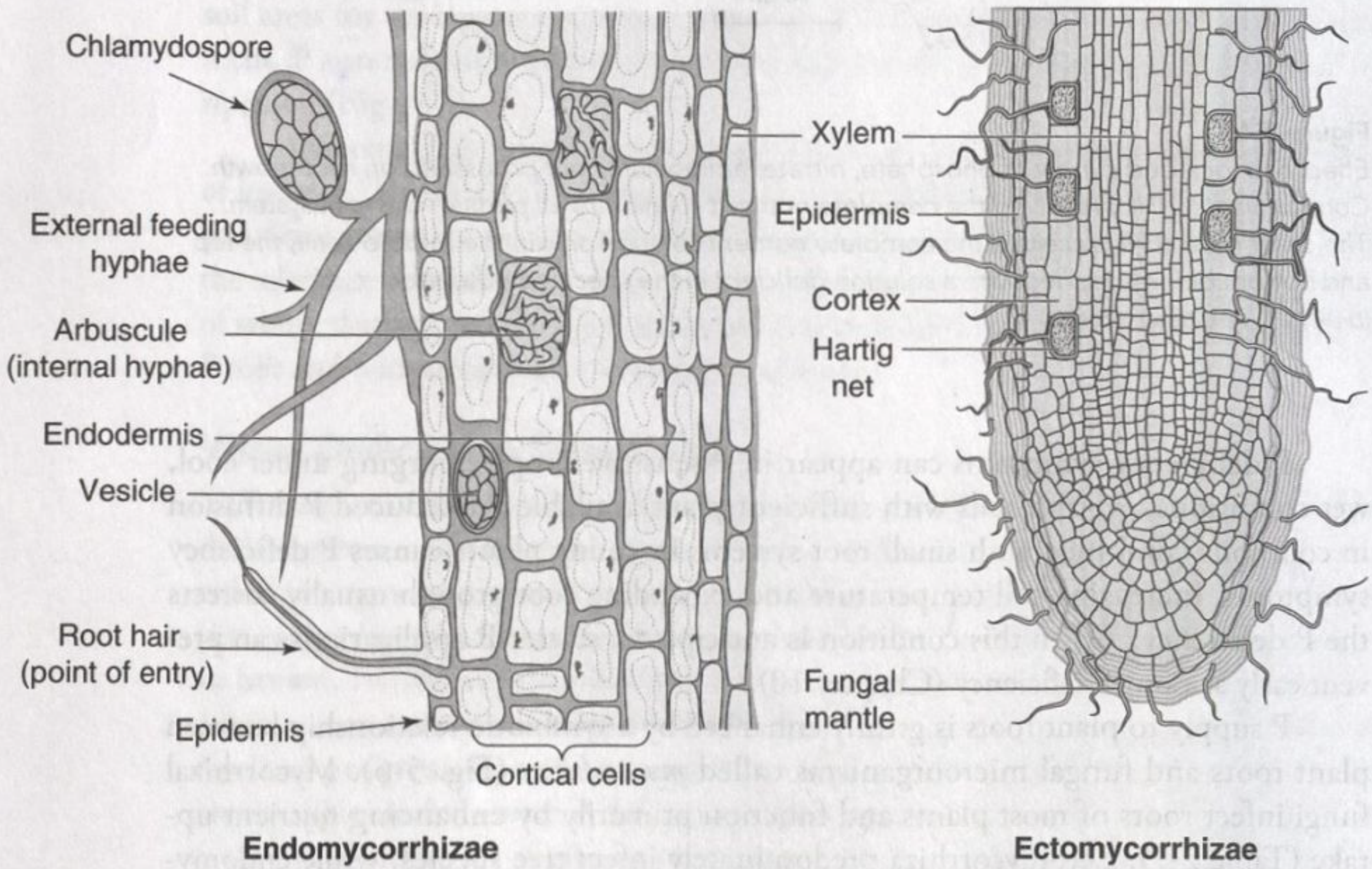


FIGURE 18–1
Solubility of orthophosphate from various calcium phosphates compared with variscite ($AlPO_4 \cdot 2H_2O$) and strengite ($FePO_4 \cdot 2H_2O$) and as a function of solution pH. These equilibria assume a Ca^{2+} activity of $10^{-2.5}$ M or equilibrium with $CaCO_3$ and CO_2 at 0.03 k Pa at high pH. *From Lindsay (1979), Used with permission.*


ARBUSCULAR ENDOMYCORRHIZA
ECTOMYCORRHIZA
Mycorrhizosphere
Mycorrhizoaphere
Root Hair
Arbuscules
Hyphae
Spore
Broken spore
Vesicle
Root Cap
Stele
Hyphae
Hartig Net
Mantle
Basidiospores
Mushroom (fruiting body)


Chlamydospore
External feeding hyphae
Arbuscule (internal hyphae)
Endodermis
Vesicle
Root hair (point of entry)
Epidermis
Cortical cells
Endomycorrhizae
Xylem
Epidermis
Cortex
Hartig net
Fungal mantle
Ectomycorrhizae

TIME-LINE OF INFECTION

Outside of host ⟷ Inside of host

Fungal pathogen:

Preinfection:
- Germination
- Germ tube search
- Appressorium formation
- Penetration peg

Postinfection
- Haustorium formation (biotroph)
- Toxin formation (necrotroph)
- Suppression of host defenses
- Reproduction

Host:

General induced defenses:
- Papillae formation
- Basal defense
- Cork & lignin layers
- Systemic acquired resistance

Specific recognition:
- Hypersensitivity
- Phytoalexins

structural ⟷ CONSTITUATIVE DEFENSES ⟷ chemical

Step 1: Getting inside the plant

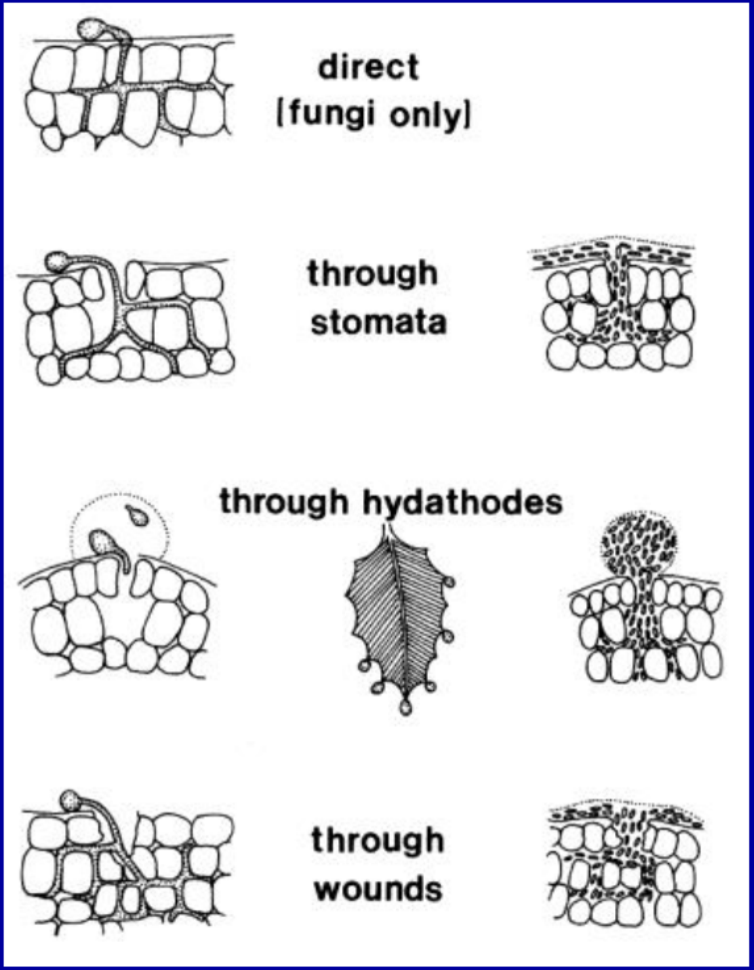
Pathogen group:

Fungi: Host entry is active
forceful penetration (or wound or natural openings)

Bacteria: Entry active but not forceful
requires wound or natural opening

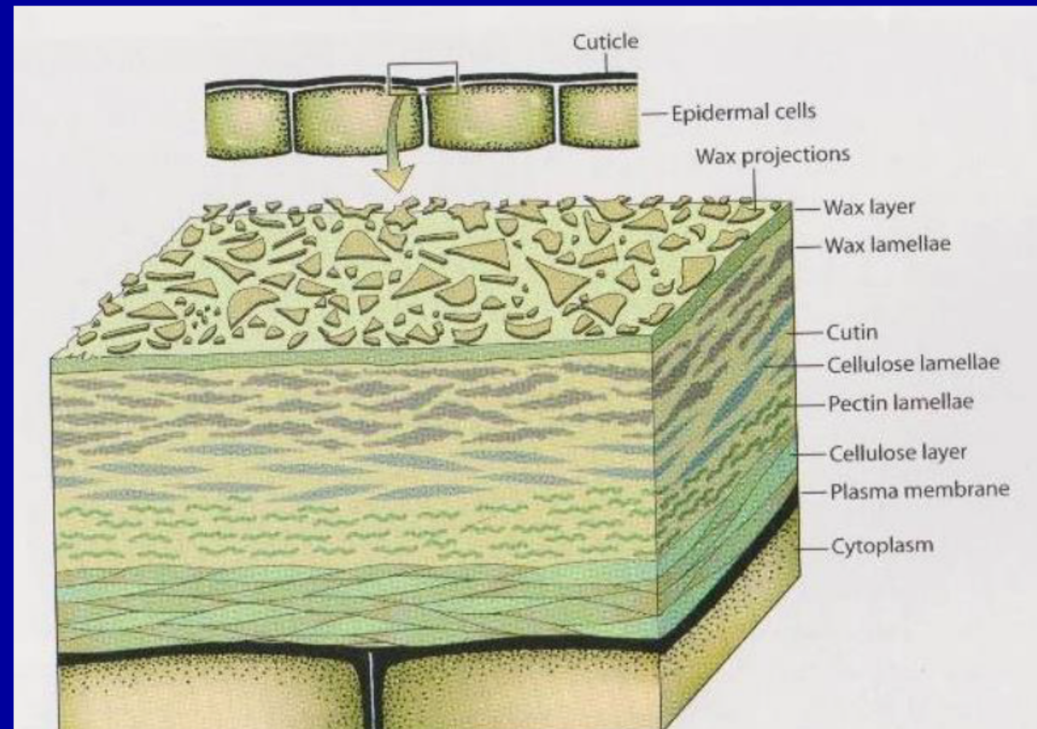
Viruses: Entry is passive
requires wound or vector

Nematodes: Entry active
forceful penetration

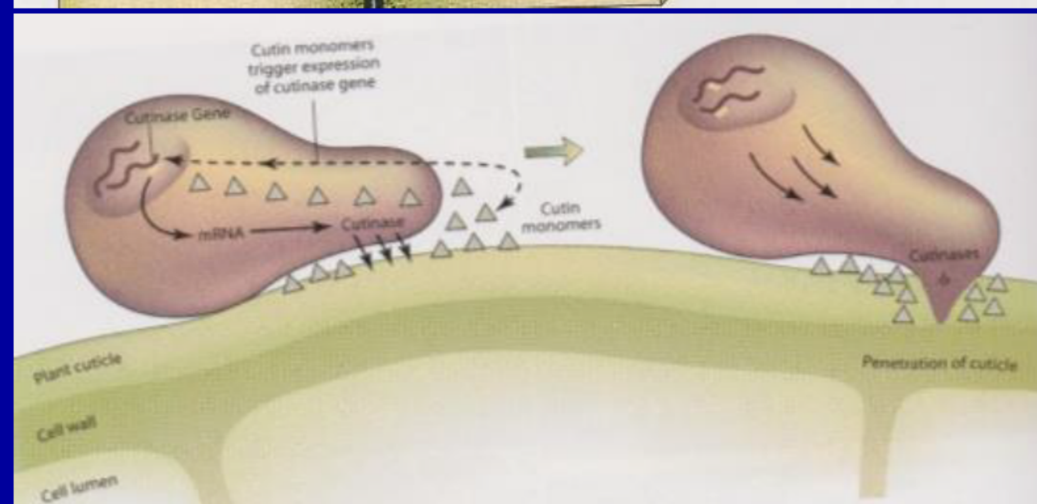


Direct attack by fungal pathogens

Structure and composition of the cuticle and cell wall of foliar epidermal cells

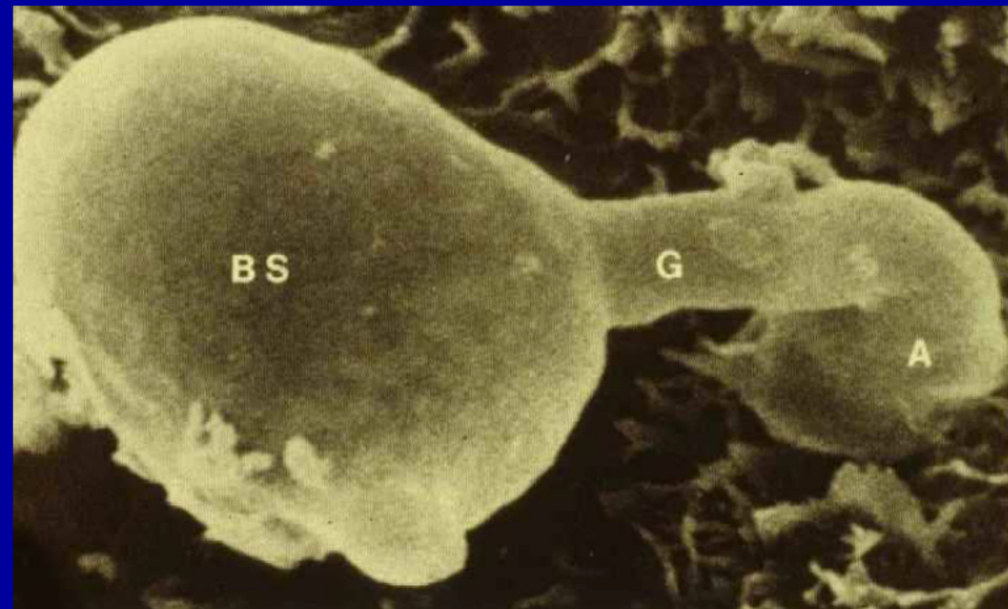


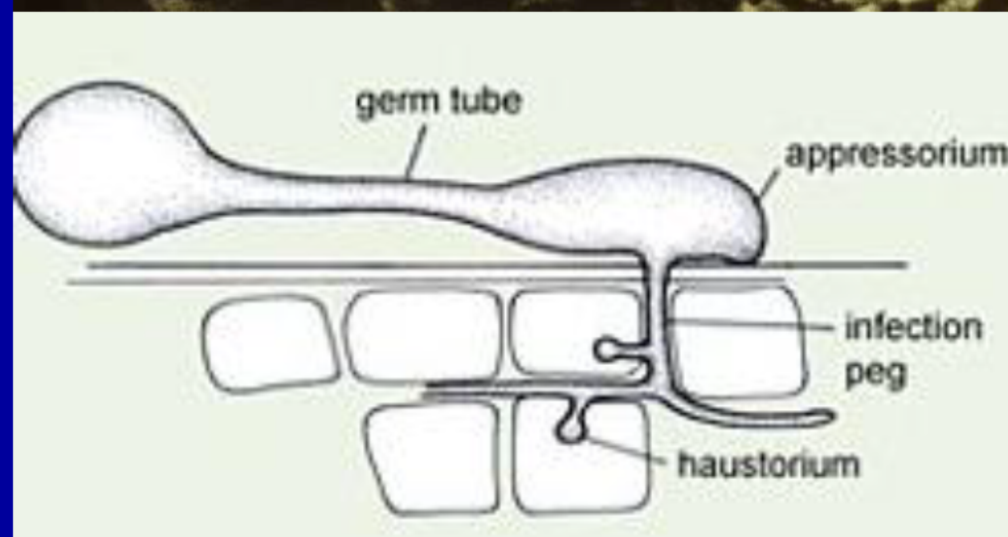
Pathogens must possess enzymes to dissolve specific structural components of the external wall



Fungal Infection: Appressoria

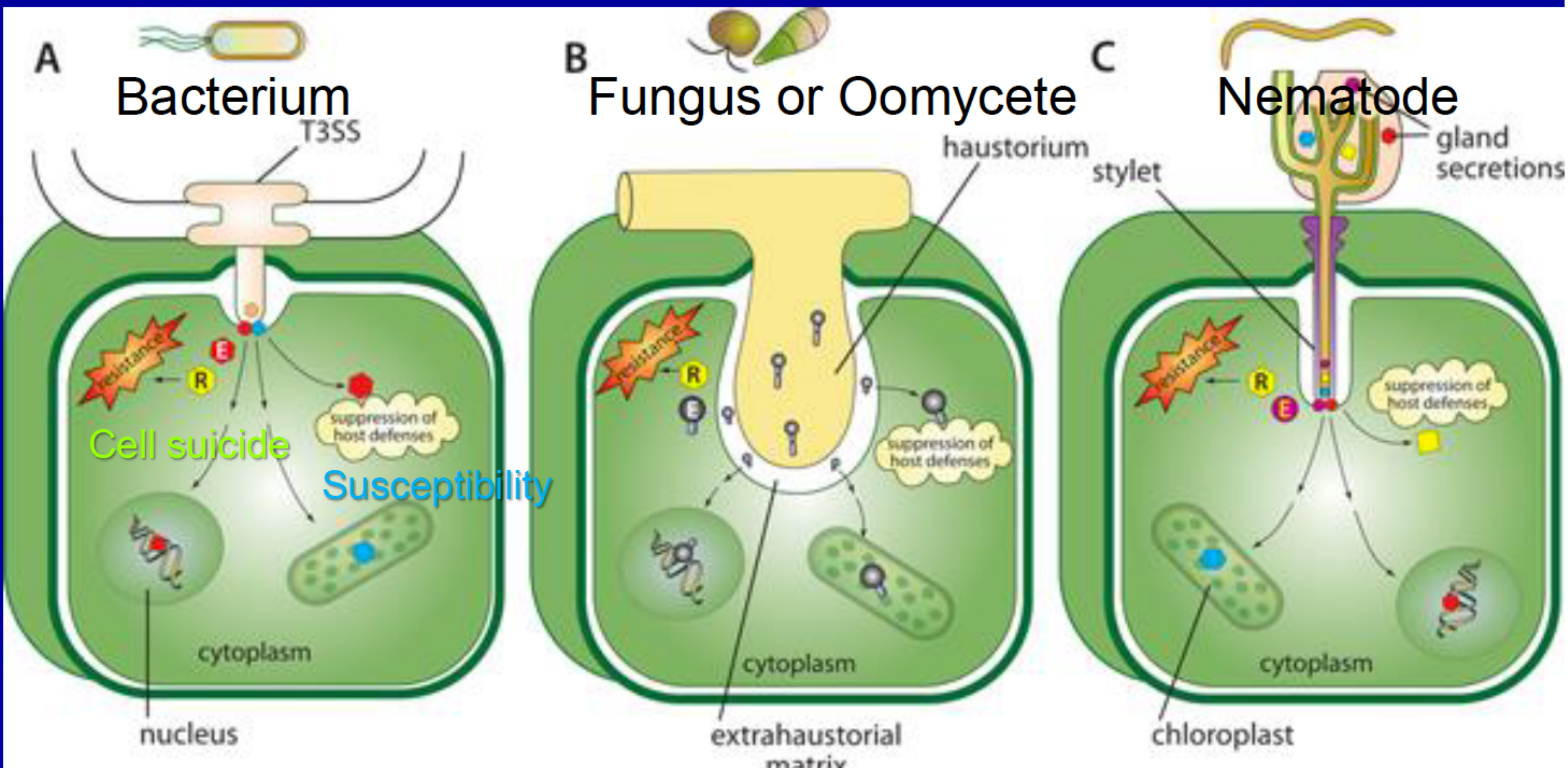
Hyphal ends swell to produce a structure termed an appressorium (infection cushion). A penetration peg emerges from the side of the appressorium in contact with the host surface

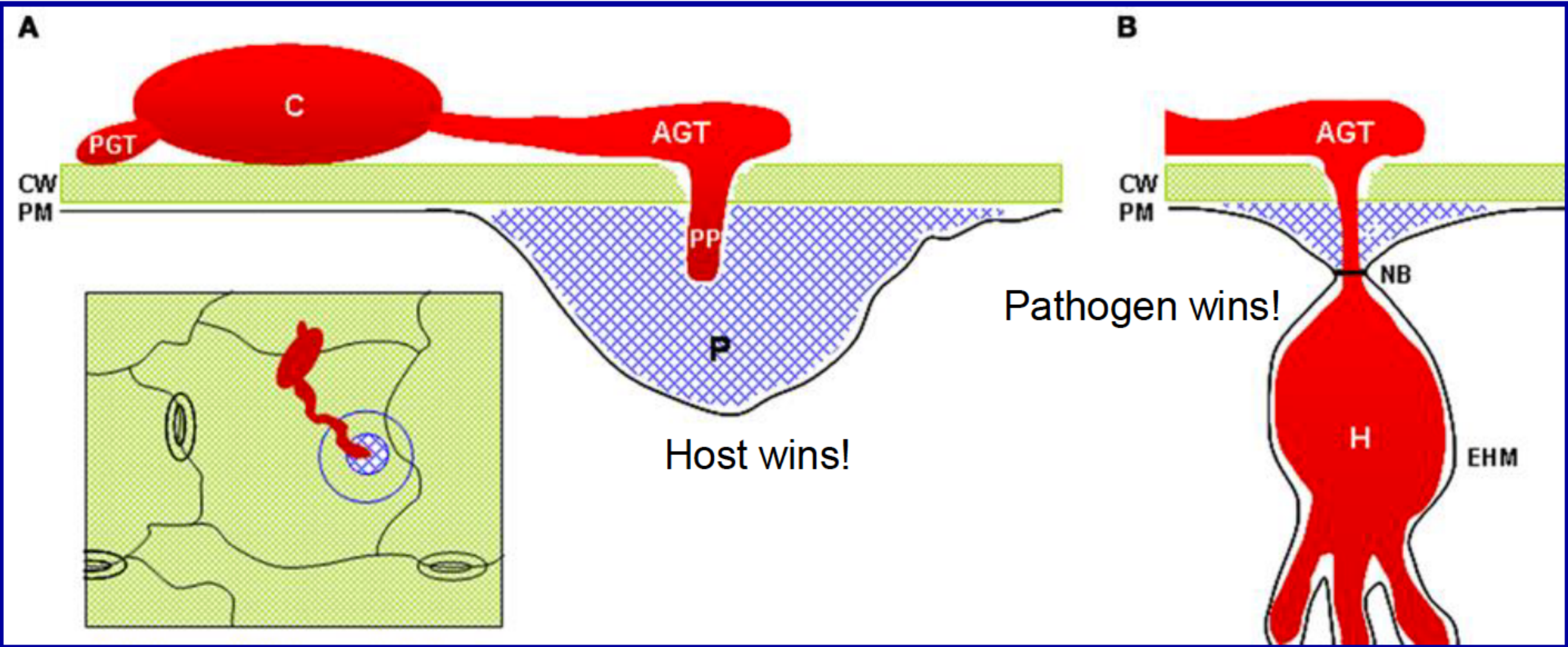


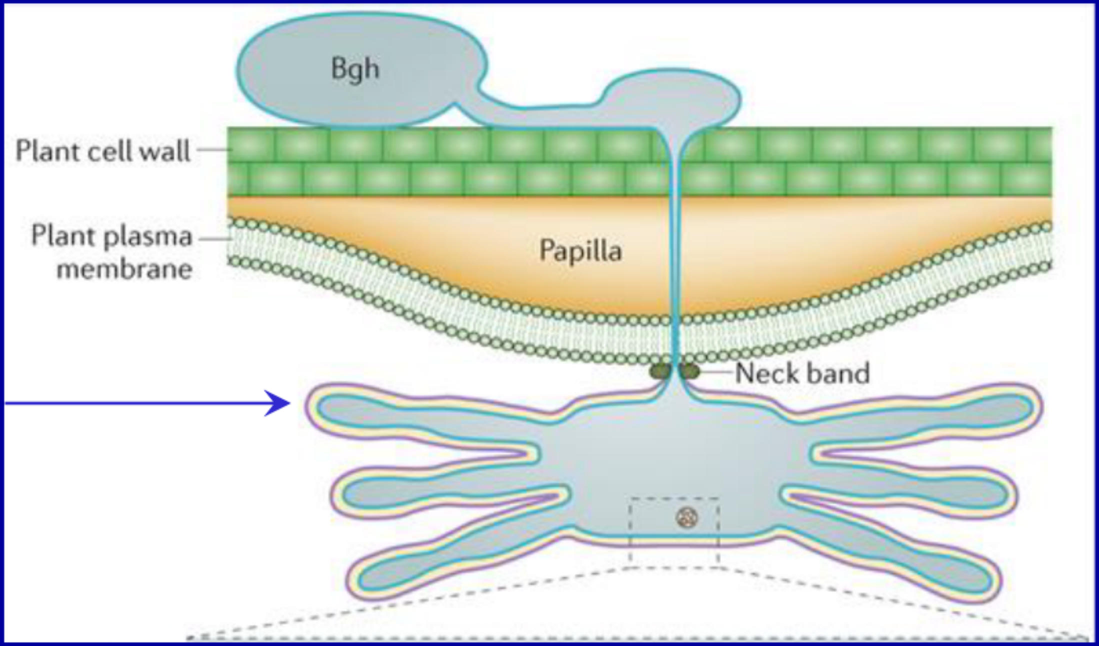


All pathogen groups make effectors

Effectors are molecules secreted by the bacterial, fungal, oomycete and nematode pathogens. They target and disable host defense. But, sometimes effectors can be recognized by host receptors leading to the ultimate defense, cell suicide!.





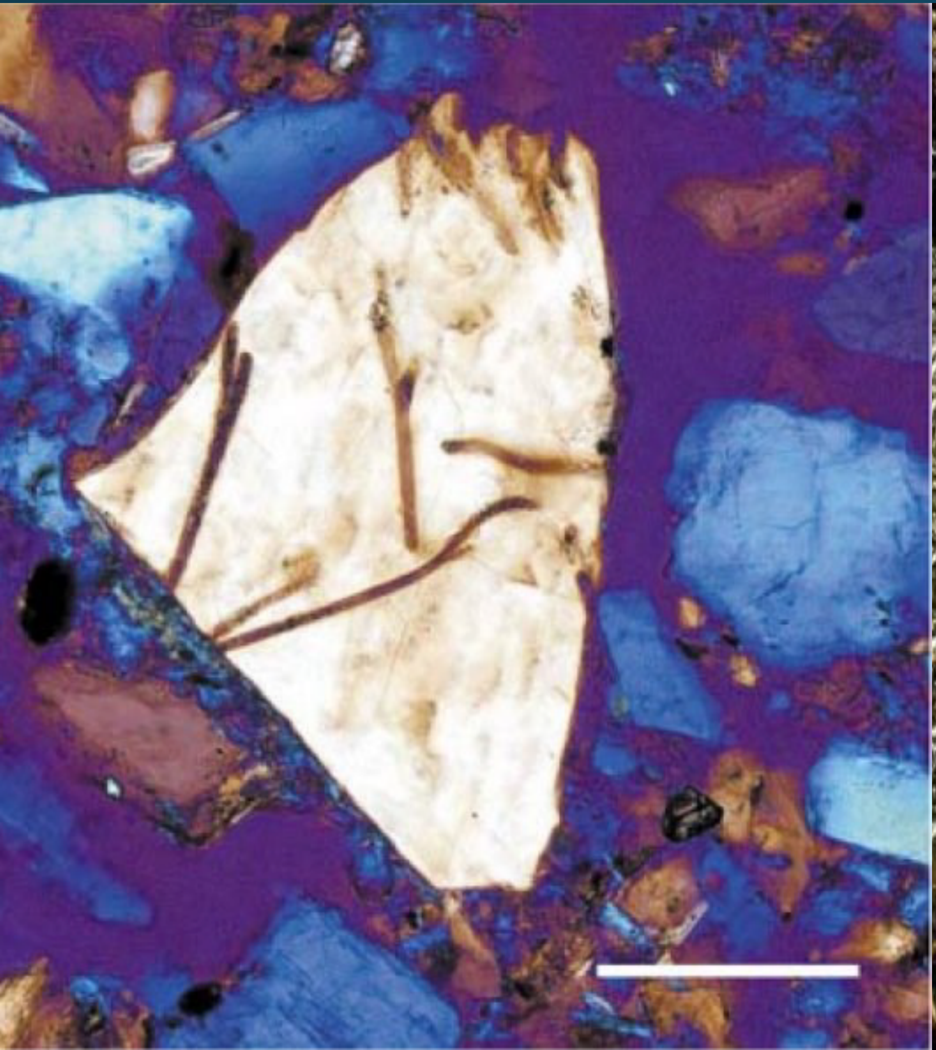


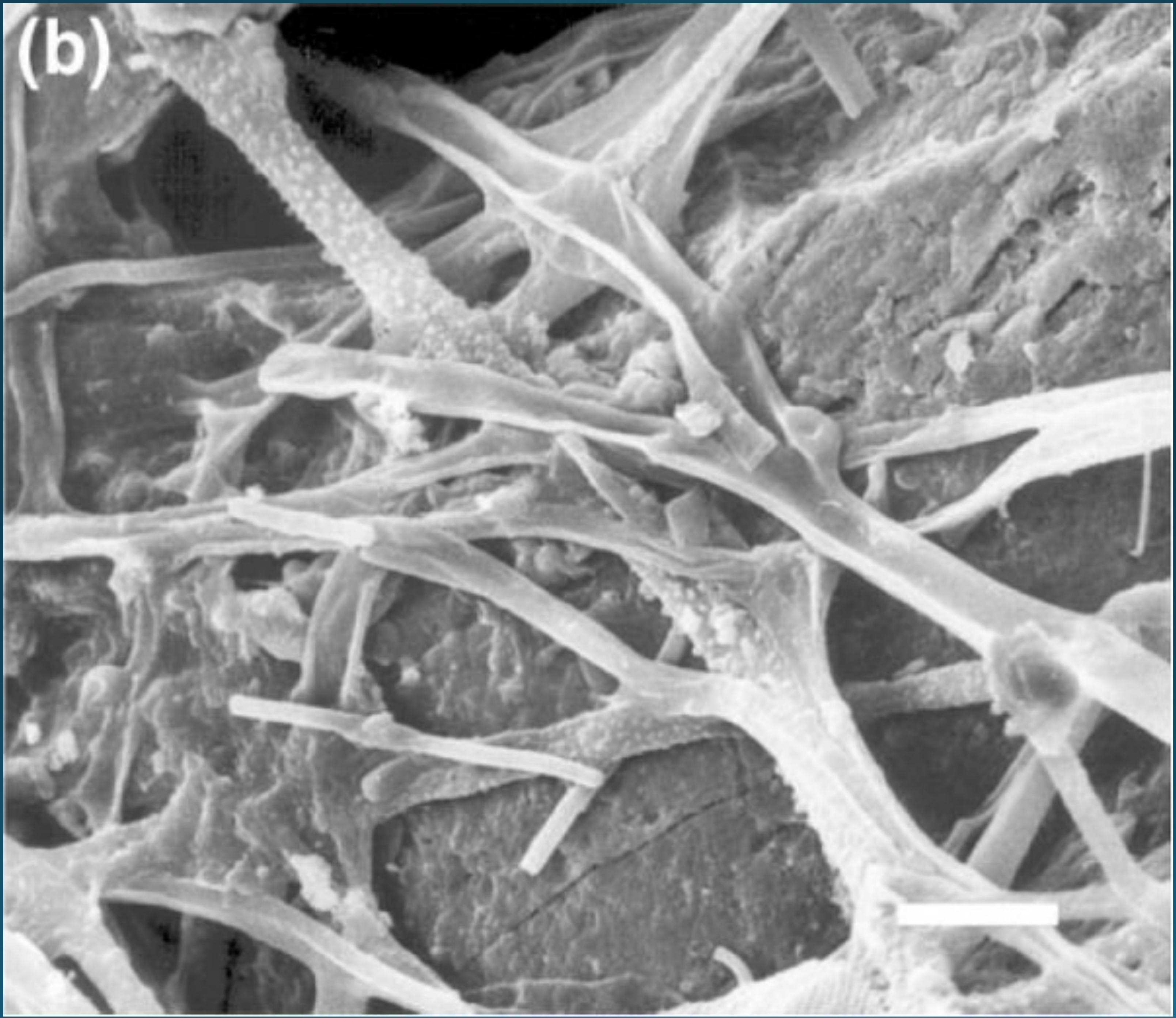
Extrahaustorial membrane

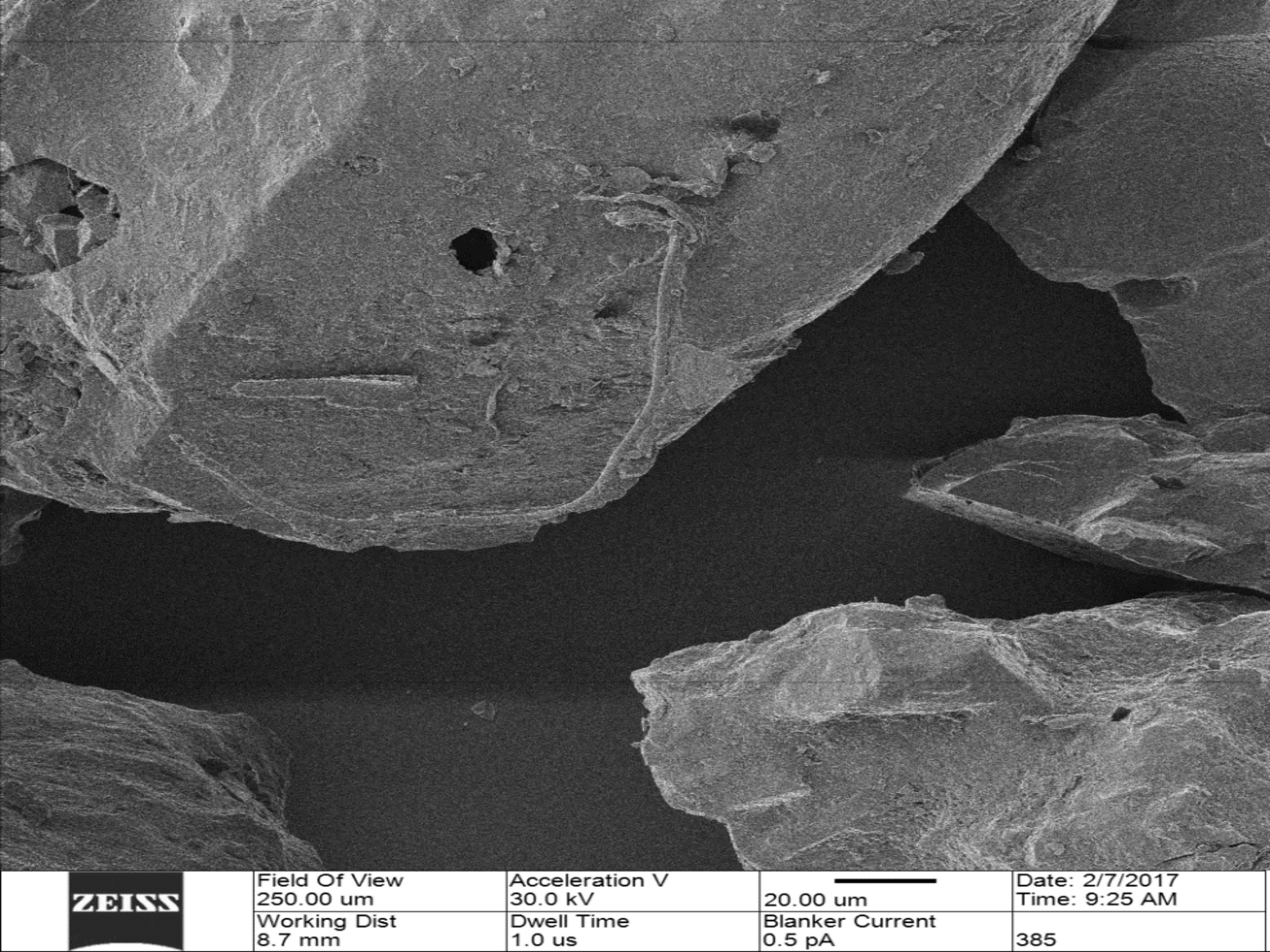
Part 6

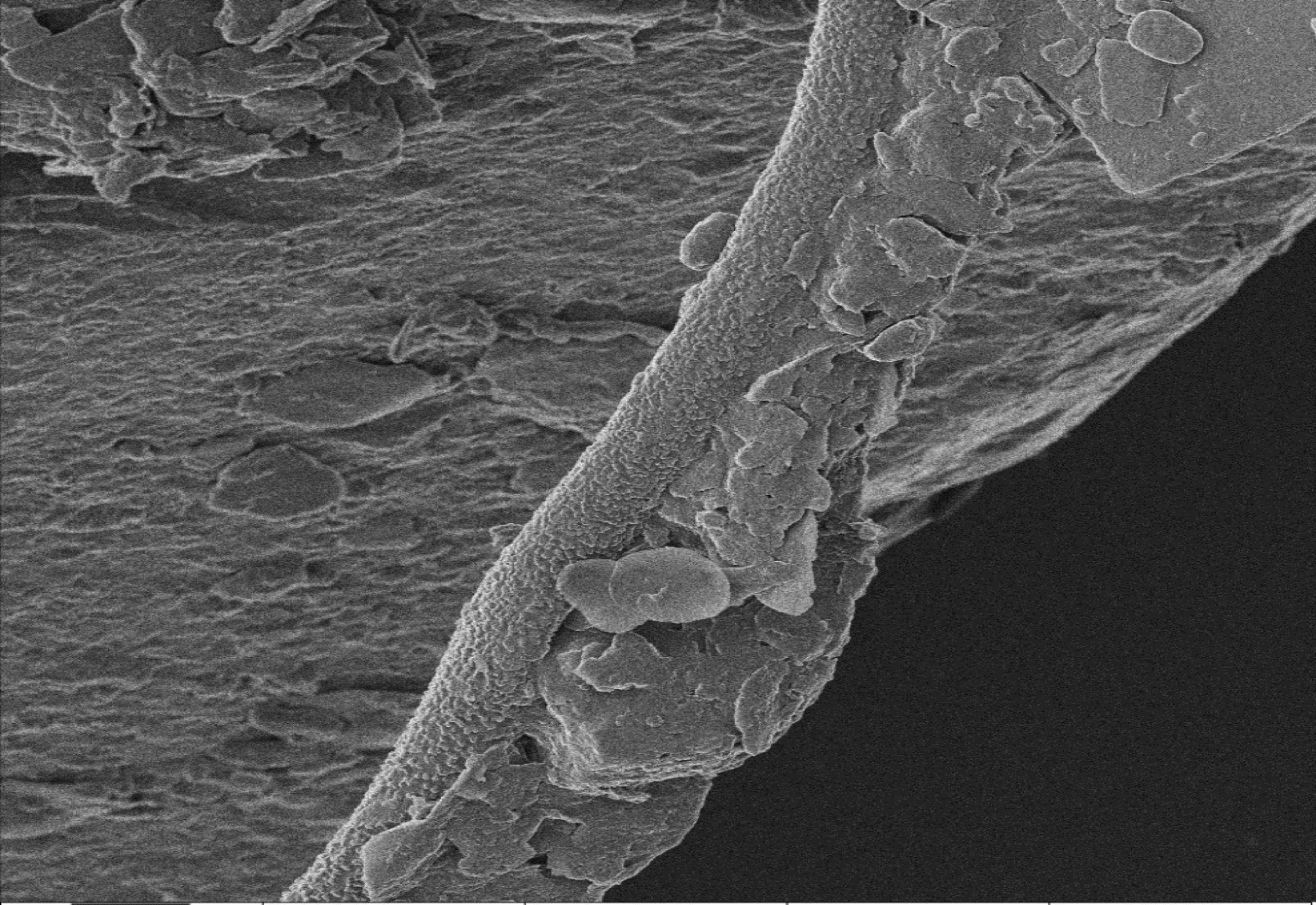
- Sulfur Cycle

The world's largest mining operation is run by fungi.



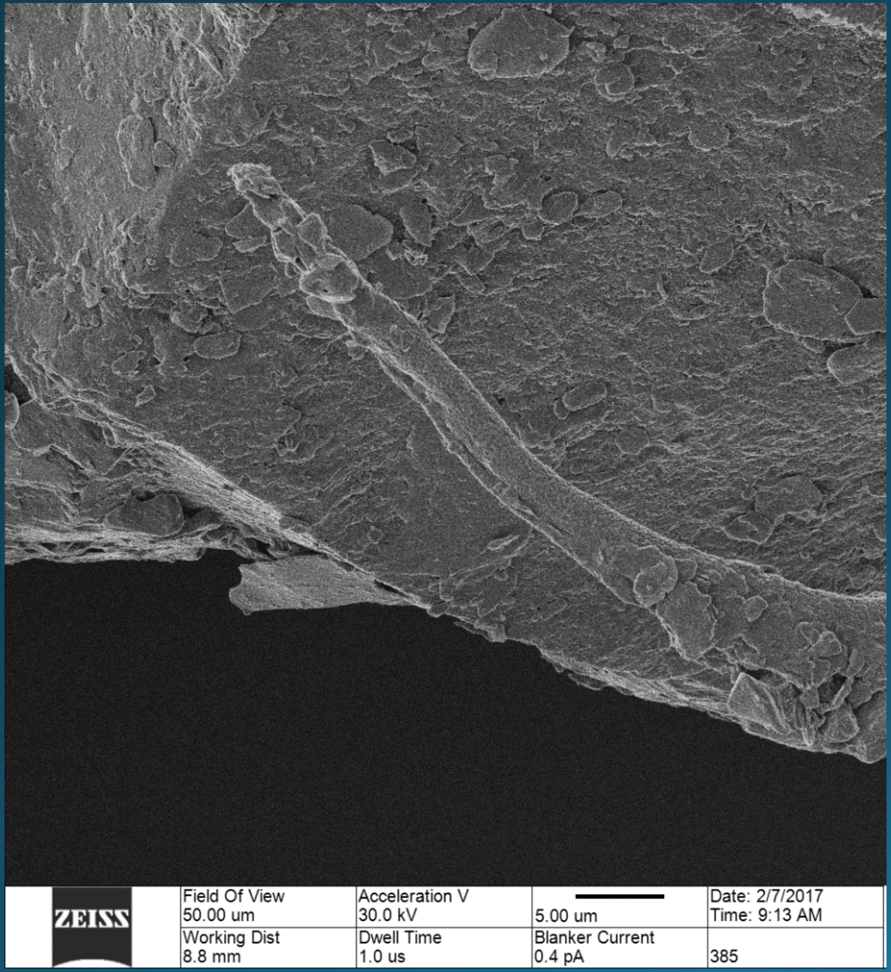

(b)

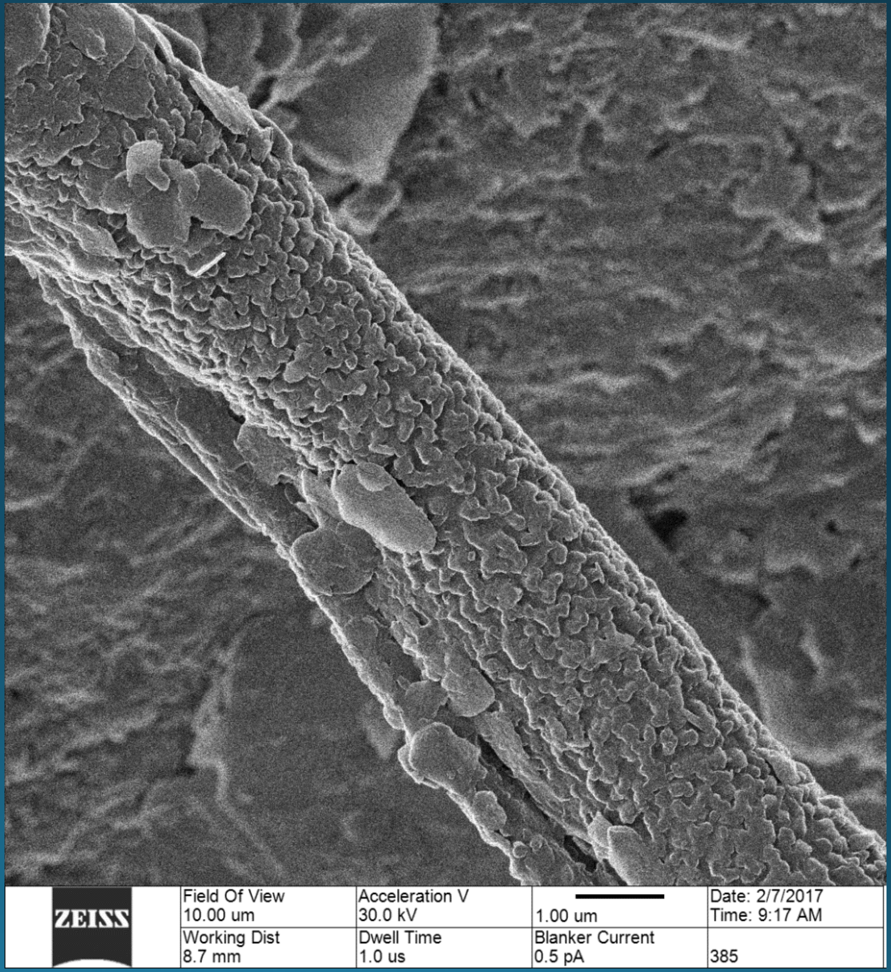

ZEISS
Field Of View
250.00 um
Acceleration V
30.0 kV
20.00 um
Date: 2/7/2017
Time: 9:25 AM
Working Dist
8.7 mm
Dwell Time
1.0 us
Blanker Current
0.5 pA
385

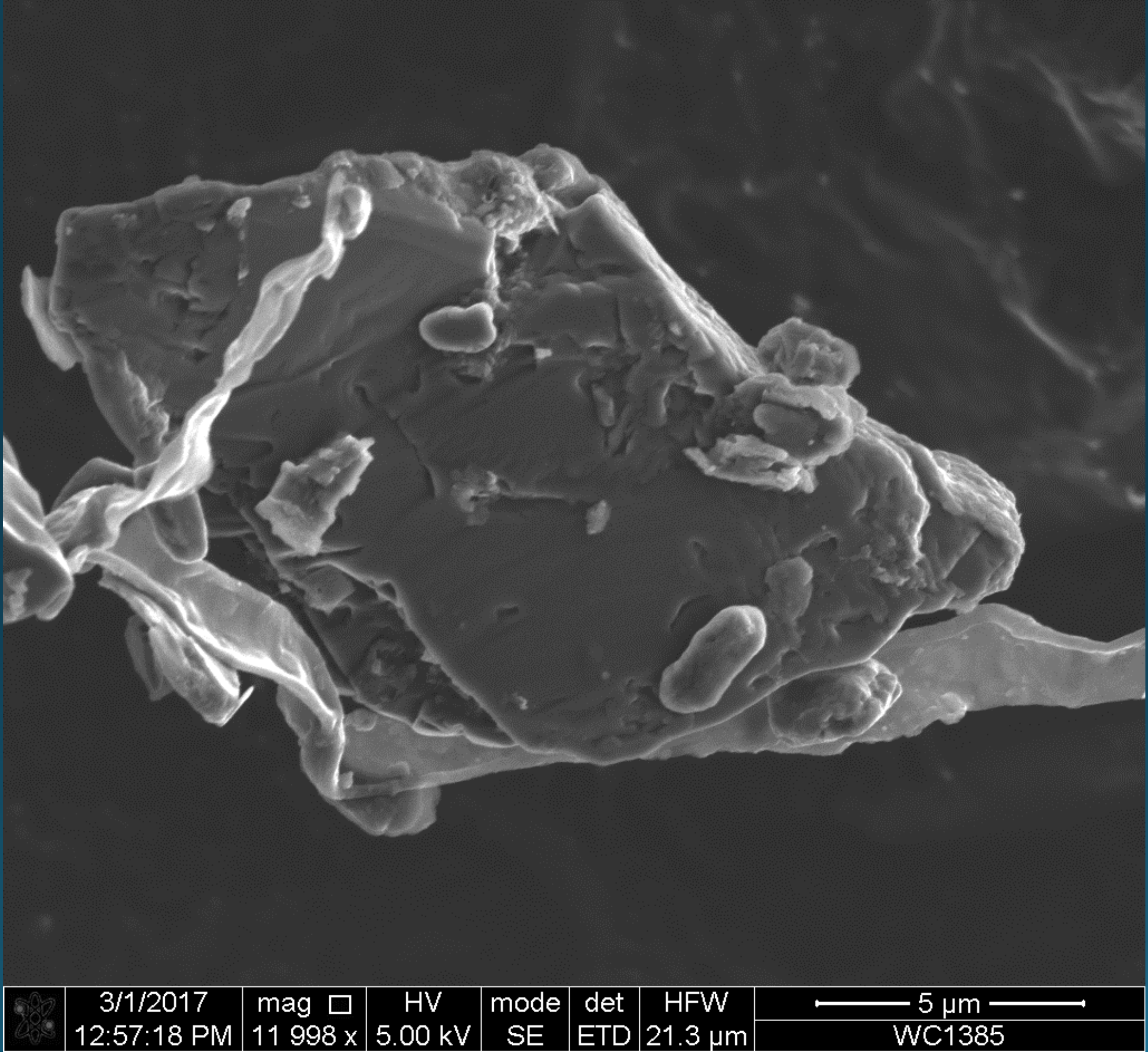


ZEISS	Field Of View 30.00 um	Acceleration V 30.0 kV	2.00 um	Date: 2/7/2017 Time: 9:24 AM
	Working Dist 8.7 mm	Dwell Time 1.0 us	Blanker Current 0.4 pA	385

Basalt weathering



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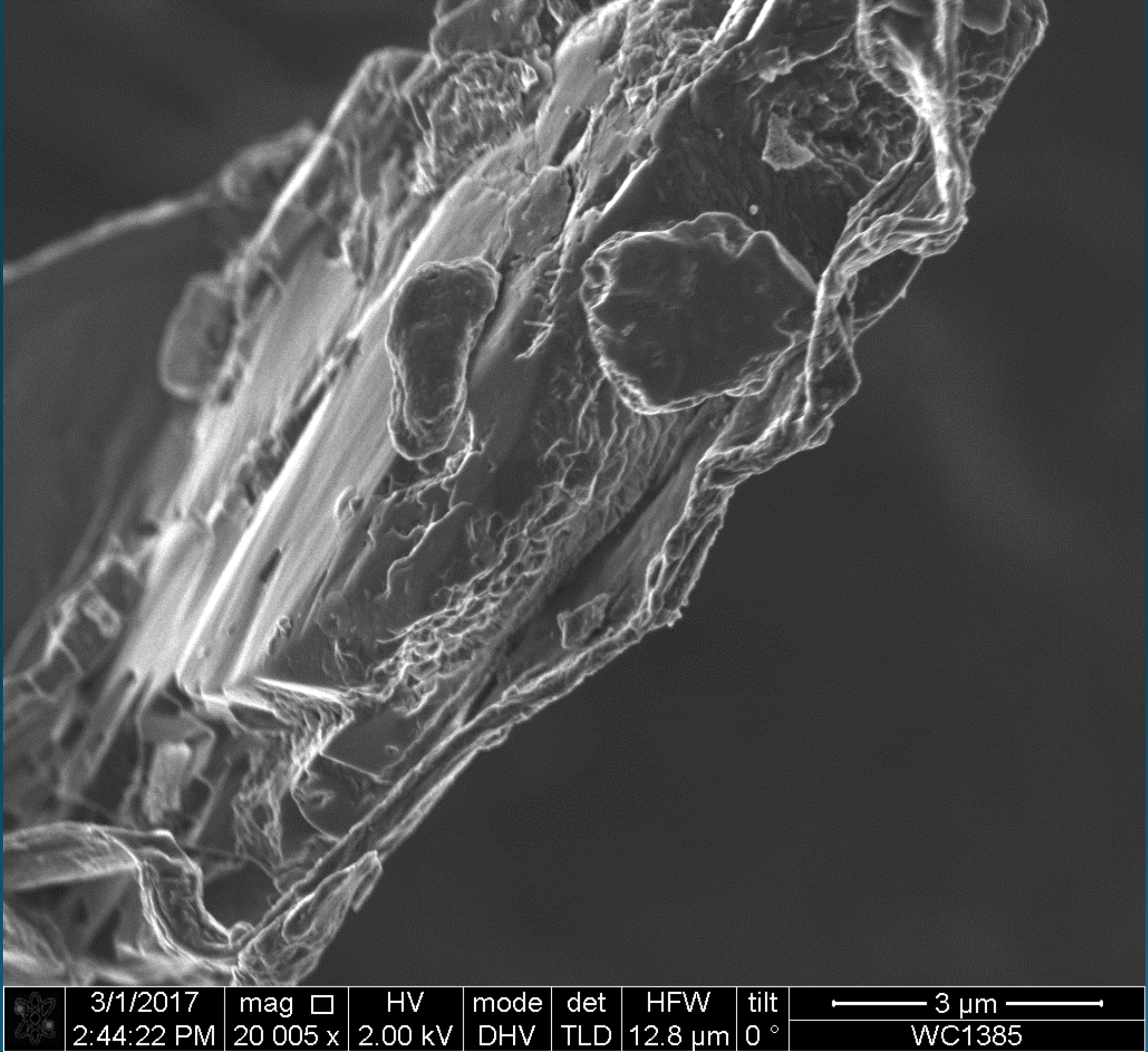
HV
5.00 kV
mode
SE
det
ETD
HFW
21.3 µm
5 µm
WC1385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2:44:22 PM
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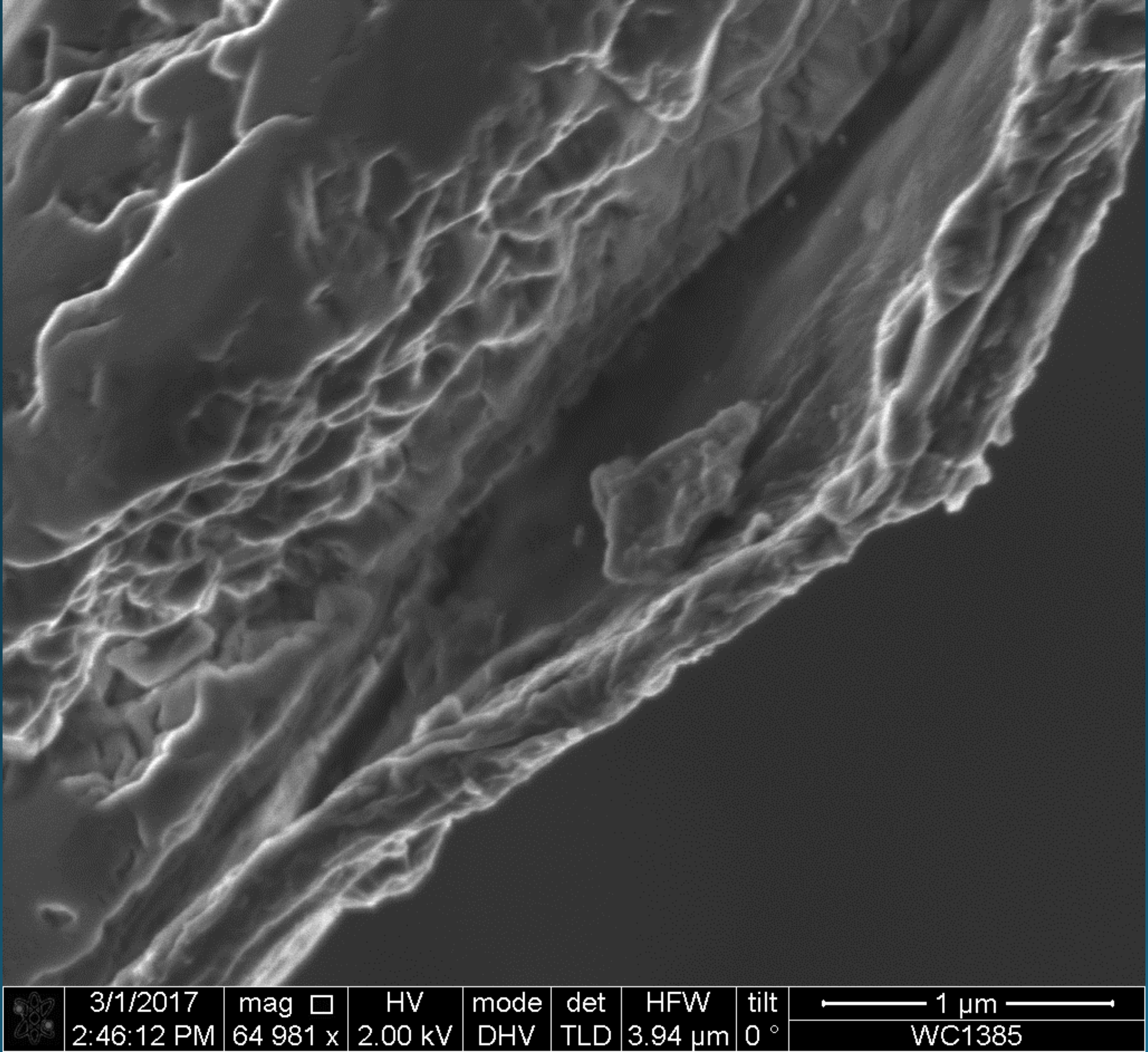
3 μm
WC1385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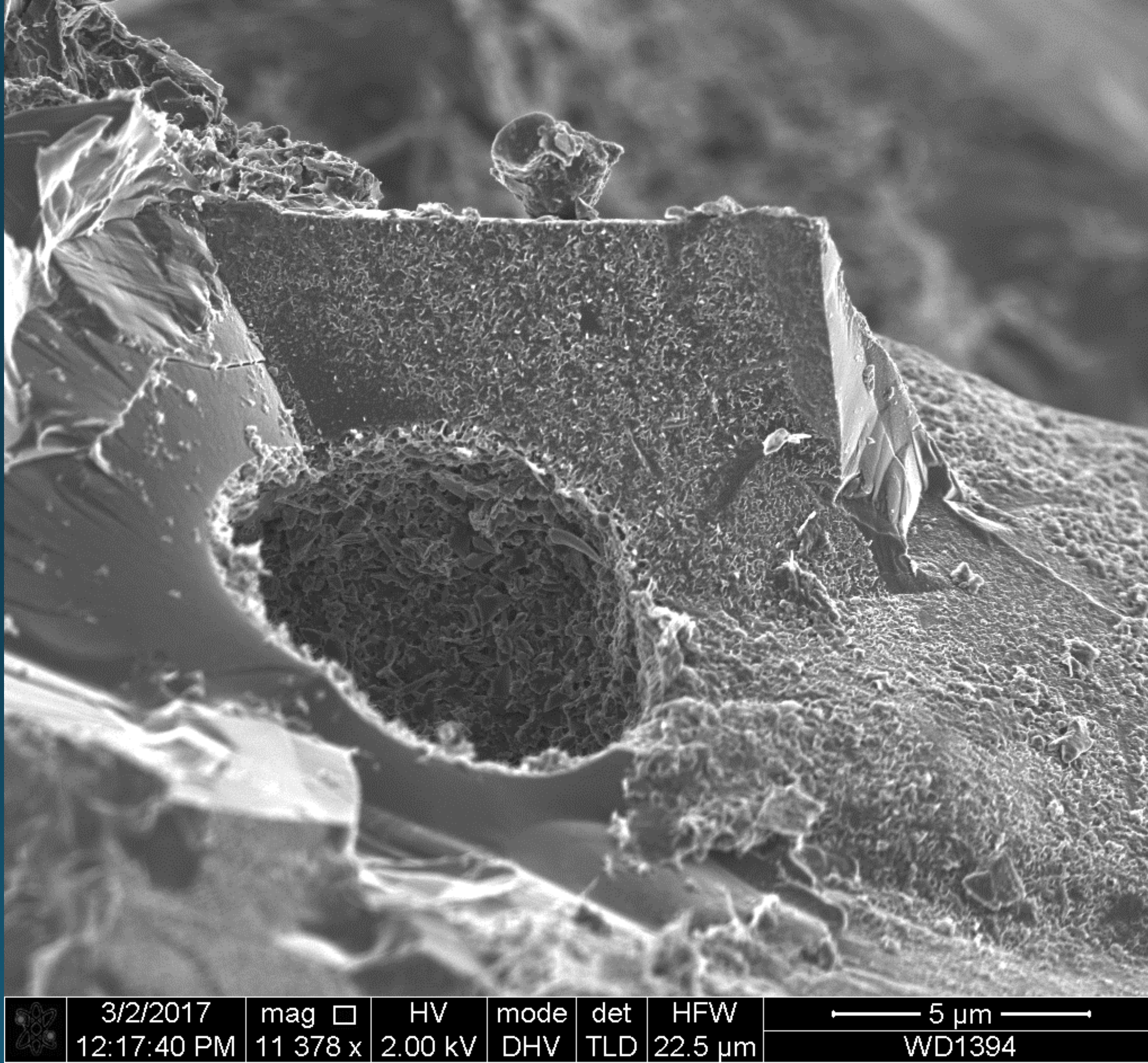
HV
2.00 kV
mode
DHV
det
TLD
HFW
3.94 µm
tilt
0 °
1 µm
WC1385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mag
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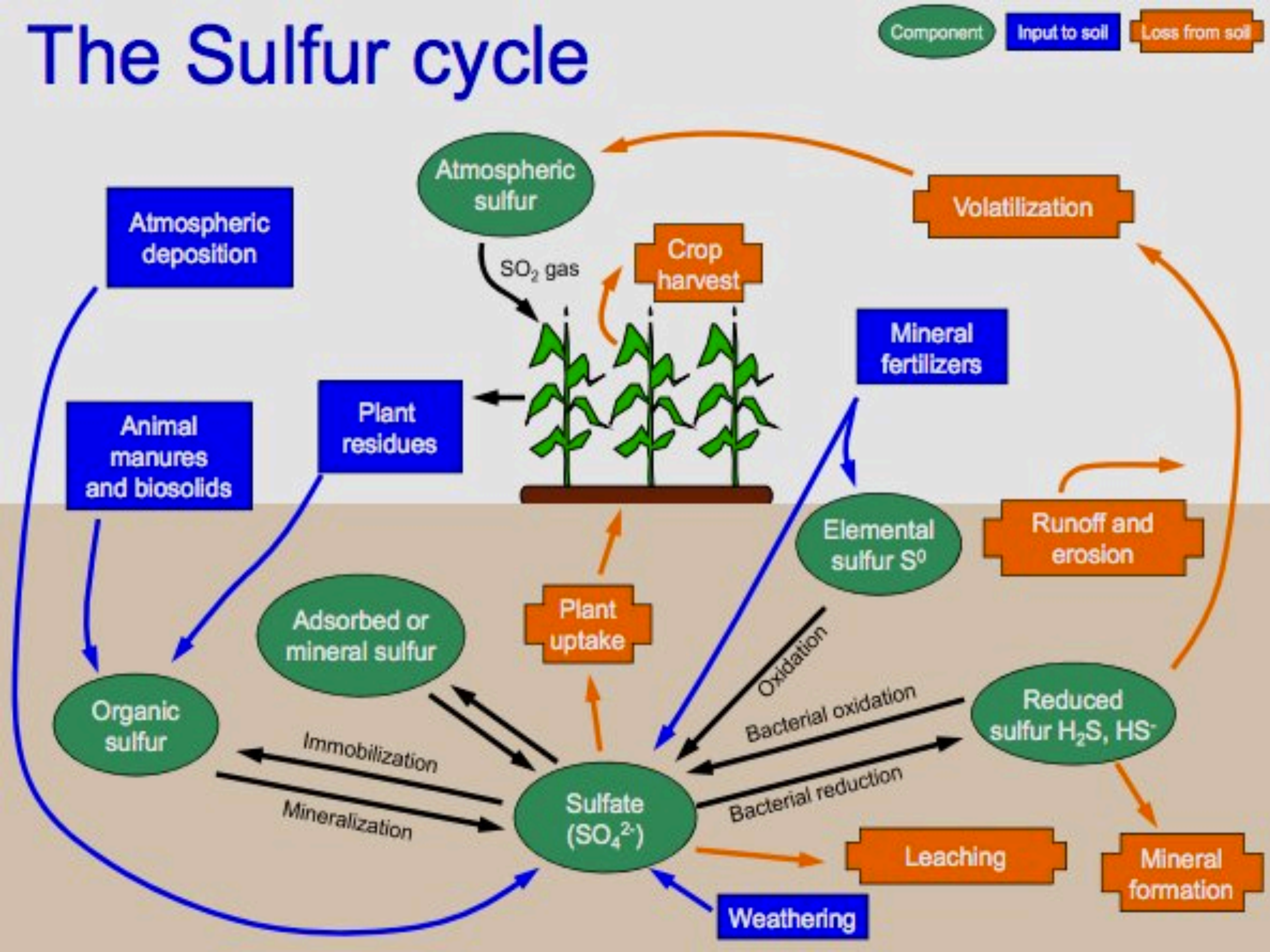
HV
2.00 kV
mode
DHV
det
TLD
HFW
22.5 µm
5 µm
WD1394

The Sulfur cycle



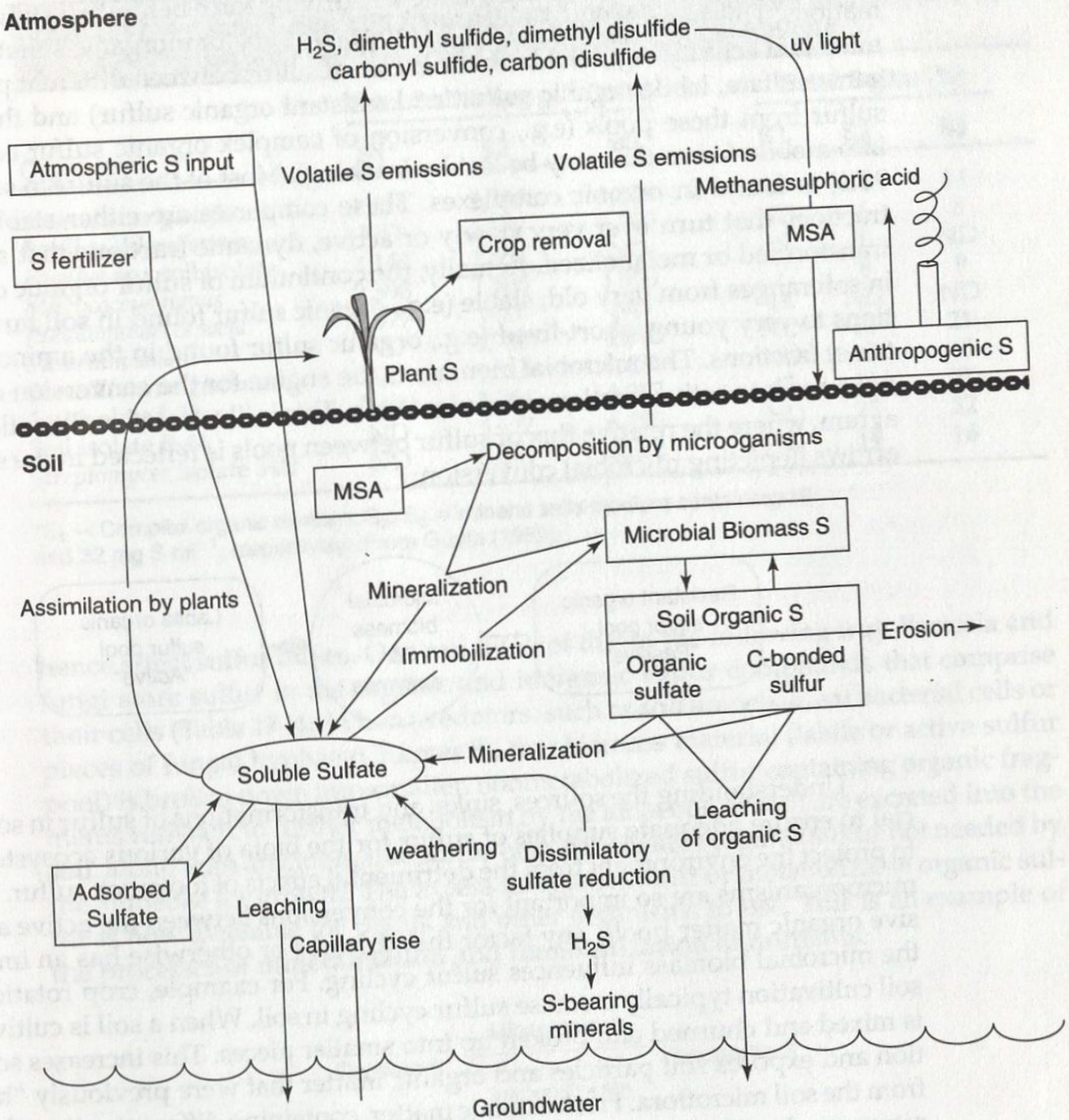


FIGURE 17–2
Conceptual sulfur cycle in agroecosystems. Numbers represent flux estimates (kg ha^{-1} yr^{-1}) for sulfur transformations in western Canadian soils. *From Schoenau and Germida (1992). Used with permission.*

Sulfur and Phosphorus

- Sulfur in the form of Hydrogen Sulfide can chelate orthophosphate mineralizing phosphorus.
- Produced in water logged soil conditions, by sulfur reducing bacteria
- Possible reason for the importance of balancing P with S in soil solution; suggested ratios of 3:1 P/S ratio

TABLE 17–3 Important Forms of Sulfur and Their Oxidation States

Compound	Formula	Oxidation State(s) of Sulfur
Sulfide	S^{2-}	−2
Polysulfide	$S_n^{\ 2-}$	−2, 0
Sulfur*	$S_8^{\ o}$	0
Hyposulfite (dithionite)	$S_2O_4^{\ 2-}$	+2
Sulfite	$SO_3^{\ 2-}$	+4
Thiosulfate**	$S_2O_3^{\ 2-}$	−1, +5
Dithionate	$S_2O_6^{\ 2-}$	+6
Trithionate	$S_3O_6^{\ 2-}$	−2, +6
Tetrathionate	$S_4O_6^{\ 2-}$	−2, +6
Pentathionate	$S_5O_6^{\ 2-}$	−2, +6
Sulfate	$SO_4^{\ 2-}$	+6

From Vairavamurthy et al. (1993).
*Occurs in an octagonal ring in crystalline form.
**Outer S has a valence of −1; inner S has a valance of +5.

Soil microorganisms drive the sulfur cycle. Hence, sulfur undergoes many microbially mediated transformations in soil, including:

- Oxidation and reduction reactions
- Mineralization and immobilization
- Volatilization reactions

TABLE 17–4 Total Sulfur and Ester Sulfate Content of Selected Microorganisms Grown in Culture with Varying Sulfur Concentrations

Organism	Total Sulfur (μg g⁻¹ Cells)			Ester Sulfur (%)		
	S1*	S2	S3	S1	S2	S3
Arthrobacter globiformis	1,626	1,706	1,850	23	10	14
Bacillus licheniformis	ND	1,667	1,700	ND	6	8
Bacillus sp., soil isolate	1,142	1,054	ND	19	10	ND
Micrococcus flavus	2,398	1,500	1,950	7	8	9
Pseudomonas cepacia	2,477	ND	ND	16	ND	ND
Fusarium solani	ND	4,750	4,900	ND	13	21
Penicillium nalgiovensis	ND	1,815	2,450	ND	45	45
Soil isolate J-20	2,800	3,764	4,017	45	14	27
Soil isolate P-44	ND	5,527	6,400	ND	25	32
Streptomyces isolate 34L	ND	3,043	3,072	ND	14	16

*S_1 = Complex organic medium; S_2, S_3 = mineral salts medium containing 16 and 32 mg S ml^{-1}, respectively. From Gupta (1989).

TABLE 17–5 Sulfur-Using Bacteria Occurring in Soil and Aquatic Habitats

Group	Sulfur Conversion	Habitat Requirements	Habitat Example	Examples of Genera
Heterotrophs that use oxidized S species as electron acceptors	$SO_4^{2-} \rightarrow HS^-$ $S_2O_3^{2-} \rightarrow HS^-$ or S^o $S^o \rightarrow HS^-$ $SO^2{}_3{}^- \rightarrow HS^-$	anaerobic; organic substrates available; light not required	anoxic sediments and soils	*Desulfomonas* *Desulfovibrio* *Desulfotomaculum* *Desulfuromonas* *Campylobacter*
Obligate and faculative autotrophs that use reduced S as an energy source	$HS^- \rightarrow S^o$ $S^o \rightarrow SO_4^{2-}$ $S_2O_3^{2-} \rightarrow SO_4^{2-}$	$H_2S - O_2$ interface; light not required	mud; hot springs; mine drainage; soils	*Acidithiobacillus* *Thiobacillus* *Thiomicrospira* *Achromatium* *Beggiatoa*
Phototrophs that use reduced S as an electron donor	$HS^- \rightarrow S^o$ $S^o \rightarrow SO_4^{2-}$	anoxic; H_2S; light	shallow water; anoxic sediments; metalimnion or hypolimnion; anoxic water	*Chlorobium* *Chromatium* *Ectothiorhodospira* *Thiopedia* *Rhodopseudomonas*
Heterotrophs that use organic S compounds as energy sources or that hydrolyze esters	org S → HS^- org S → volatile org S ester $SO_4 \rightarrow SO_4^{2-}$	source of organic S compounds	sediments; soils; water column	Many
Microorganisms that use SO_4^{2-} or H_2S in biosynthesis	SO_4^{2-} → protein HS^- → protein SO_4^{2-} → DMSP*	nonspecific	sediments; soils; water column	Many

*dimethylsulfoniumpropionate

From Cook and Kelly (1992). Used with permission.

TABLE 17–6 Characteristics of Species of Sulfur Chemolithotrophs

Species	Electron Donor	Electron Acceptor	Facultative Heterotroph	Facultative Anaerobe	pH Optimum
Acidithiobacillus thiooxidans	$H_2S, S^o, S_2O_3^{2-}$	O_2	−	−	2.2
Acidithiobacillus ferrooxidans	$S^o, S_2O_3^{2-}, Fe^{2+}$	O_2	+	−	3.0
Halothiobacillus neapolitanus	$S^o, S_2O_3^{2-}$	O_2	−	−	6.6
Thiobacillus kabobis	S^o	O_2	−	−	ND
Thermithiobacillus tepidarius	$S_2O_3^{2-}$,	O_2	−	−	7.0
Thiobacillus thioparus	$S^o, S_2O_3^{2-}, NCS^-$	O_2, NO_2^-	−	+	6.9
Thiobacillus denitrificans	$S^o, S_2O_3^{2-}, S_4O_6^{2-}$	O_2, NO_3^-	−	+	7.0
Thiomonas intermedius	$S_2O_3^{2-}$	O_2	+	−	ND
Thiobacillus novellas	$S_2O_3^{2-}$	O_2	+	−	8.4
Acidiphilium acidophilus	ND	O_2	+	−	3.0
Thiobacillus organoparus	ND	O_2	+	−	ND
Paracoccus versutus	$S_2O_3^{2-}$	O_2, organic-C	+	+	8.2
Thiomonas perometabolis	$S_2O_3^{2-}, S^o$	O_2	+	−	ND

Adapted from Germida and Janzen (1993), Konopka et al. (1986), Kuenen and Beudeker (1982), and Kelly and Wood (2000).
ND = no data