Exploration07

Exploration In The New Millenium

Exploration Geochemistry

Basic Principles and Concepts

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Exploration Geochemistry - Basic Principles and Concepts

- *Introduction*
- *Exploration Geochemistry - Definition*
- *Basic Principles*
- *Secondary Geochemical Environment*
- *Trace Element Mobilities*

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Exploration Geochemistry

Relies on the fact that the chemical characteristics of certain constituents (rock, soil, stream sediments) of the natural environment in the vicinity of a mineral deposit differ from those of similar constituents elsewhere.

Detect these differences by systematic measurement of the concentration of individual or, more commonly, suites of elements and/or compounds and/or chemically influenced properties of a naturally occurring material.

Exploration Geochemistry - Basic Principles and Concepts

Basic Principles

Exploration Geochemistry relies very heavily on certain basic concepts:

Elements

Associate with certain phases:

Siderophile (Fe) Chalcophile (S) Lithophile (Si)

Atmophile (gas) Biophile (organic)

Distributions in the natural environment are influenced by an element's fundamental chemical characteristics.

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Geochemical Cycle

Geologically and geochemically the Earth constitutes a dynamic system consisting of two major environments:

Deep seated (Primary)

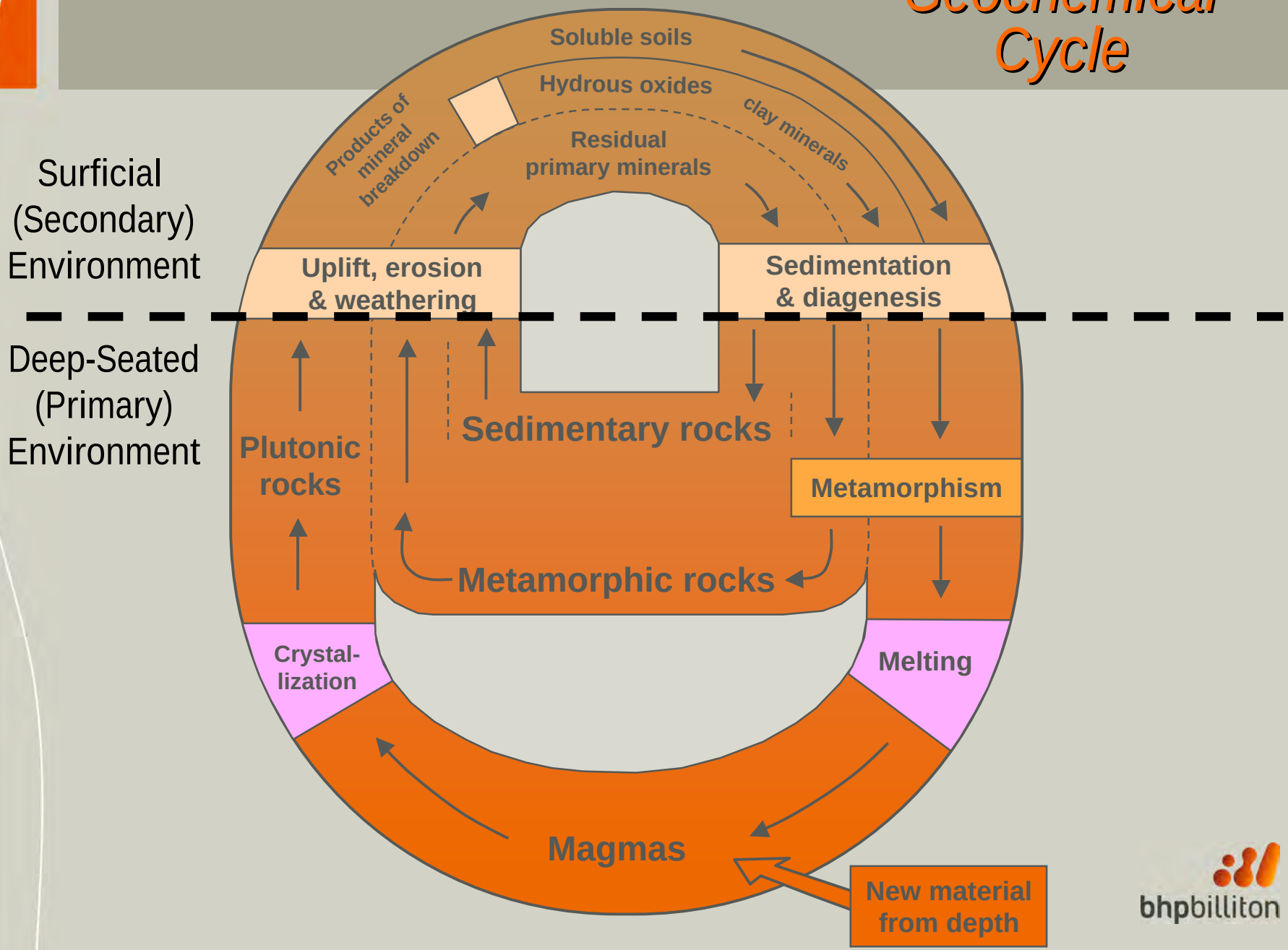
&

Surficial (Secondary)

They have gross differences in pressure, temperature and chemistry, which can be represented by the:

Geochemical Cycle

Geochemical Cycle



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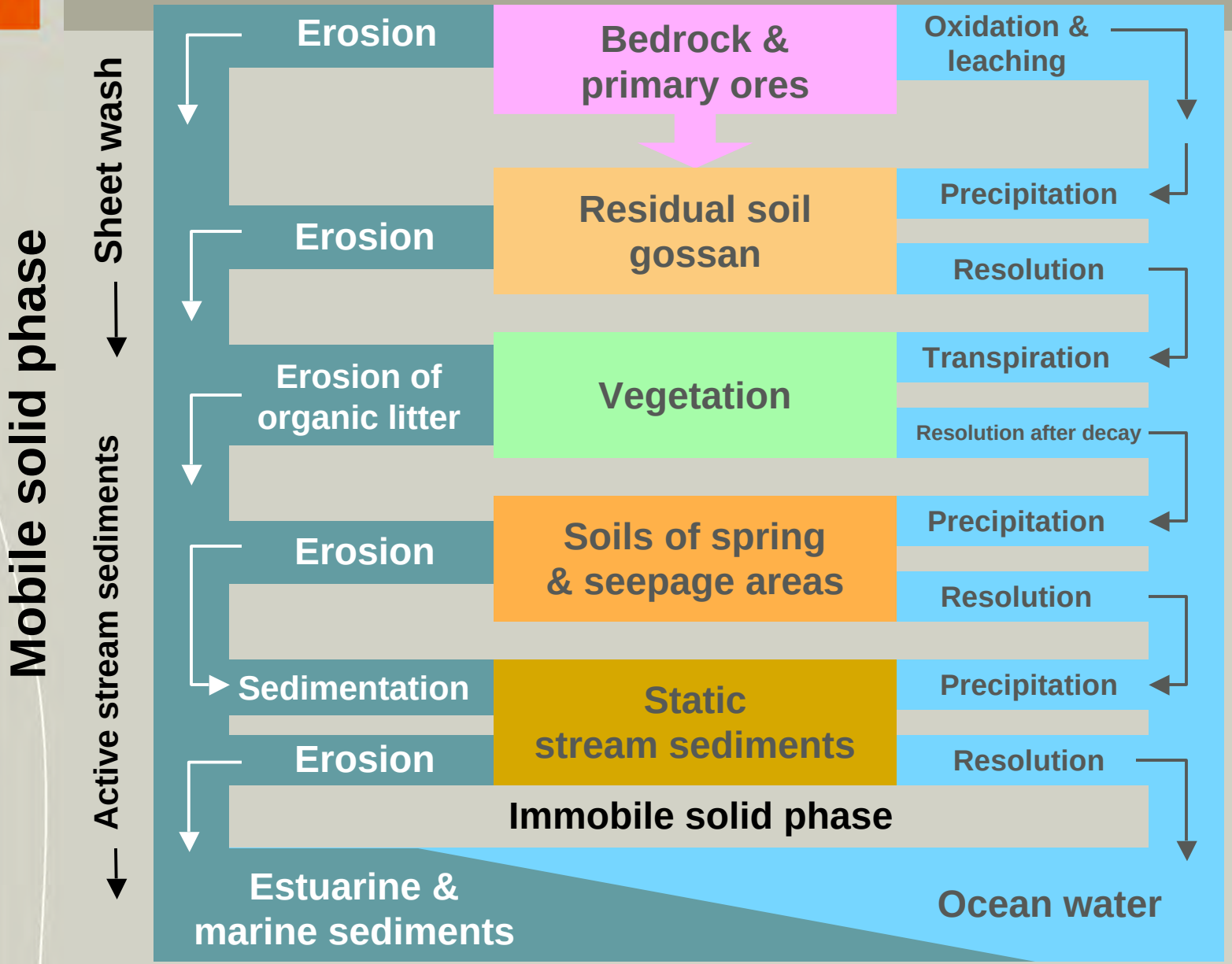
Surficial (Secondary) Environment

Zone of weathering, erosion and sedimentation at (or near) the surface of the earth.

Characterized by low temperature, nearly constant low pressure and abundant free oxygen, water and carbon dioxide which:

- breakdown - minerals / bedrock
- replace - more stable mineral or other phases
- redistribute - immobile elements lag behind with the clastic weathering component
  - mobile elements disperse

Dispersion of Weathering Products



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Geochemical Background

Normal element abundance level in unmineralized earth material which usually is a range rather then an absolute value.

Any departure from the normal range, positive or negative, is viewed as anomalous.

The upper and lower limits, above or below which, respectively, values are considered anomalous are defined as thresholds

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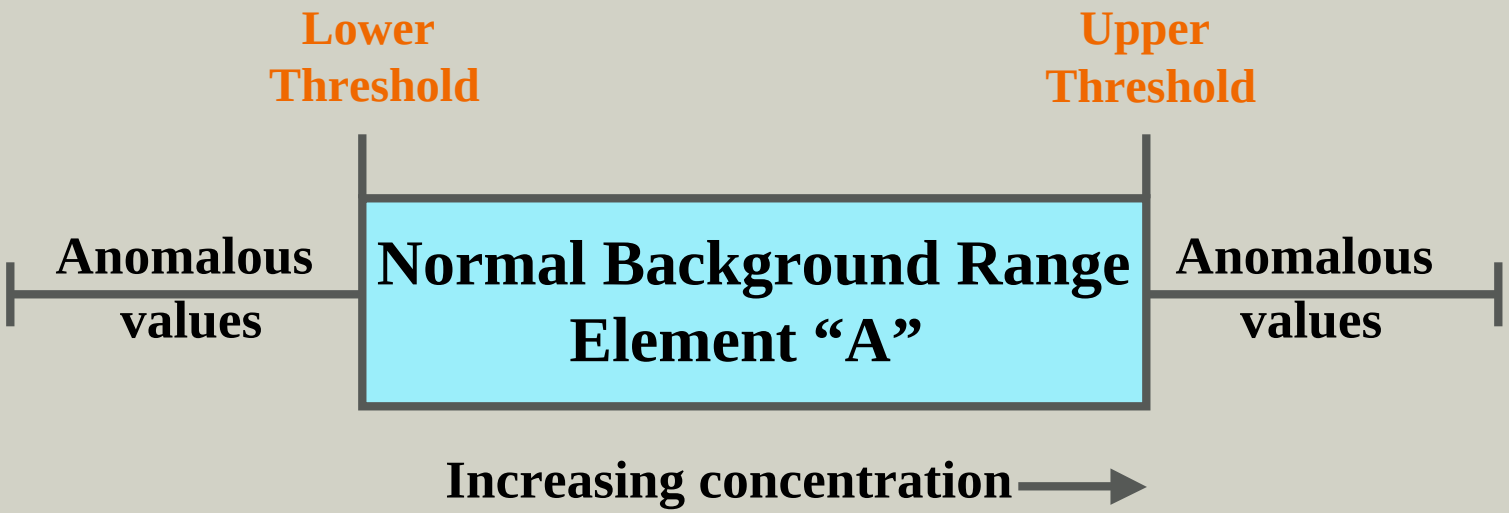

Geochemical Background

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Target and Pathfinder Elements

Use is frequently made of target elements (i.e. Au). However, in some instances these elements may not be particularly effective.

In these cases attention is directed to pathfinder elements (As, Hg, Sb) which may not be the target metal but have geochemically useful features (immobility, mobility, easier or cheaper analysis, better detection limits, etc.

Geochemical Haloes

Many mineral deposits have distinct patterns of geochemical anomalism surrounding them.

This could be at sub-economic to trace levels.

It could be in target, associated or pathfinder elements.

It could be enrichment, depletion or a combination of both.

It could be syngenetic, epigenetic or a combination of both.

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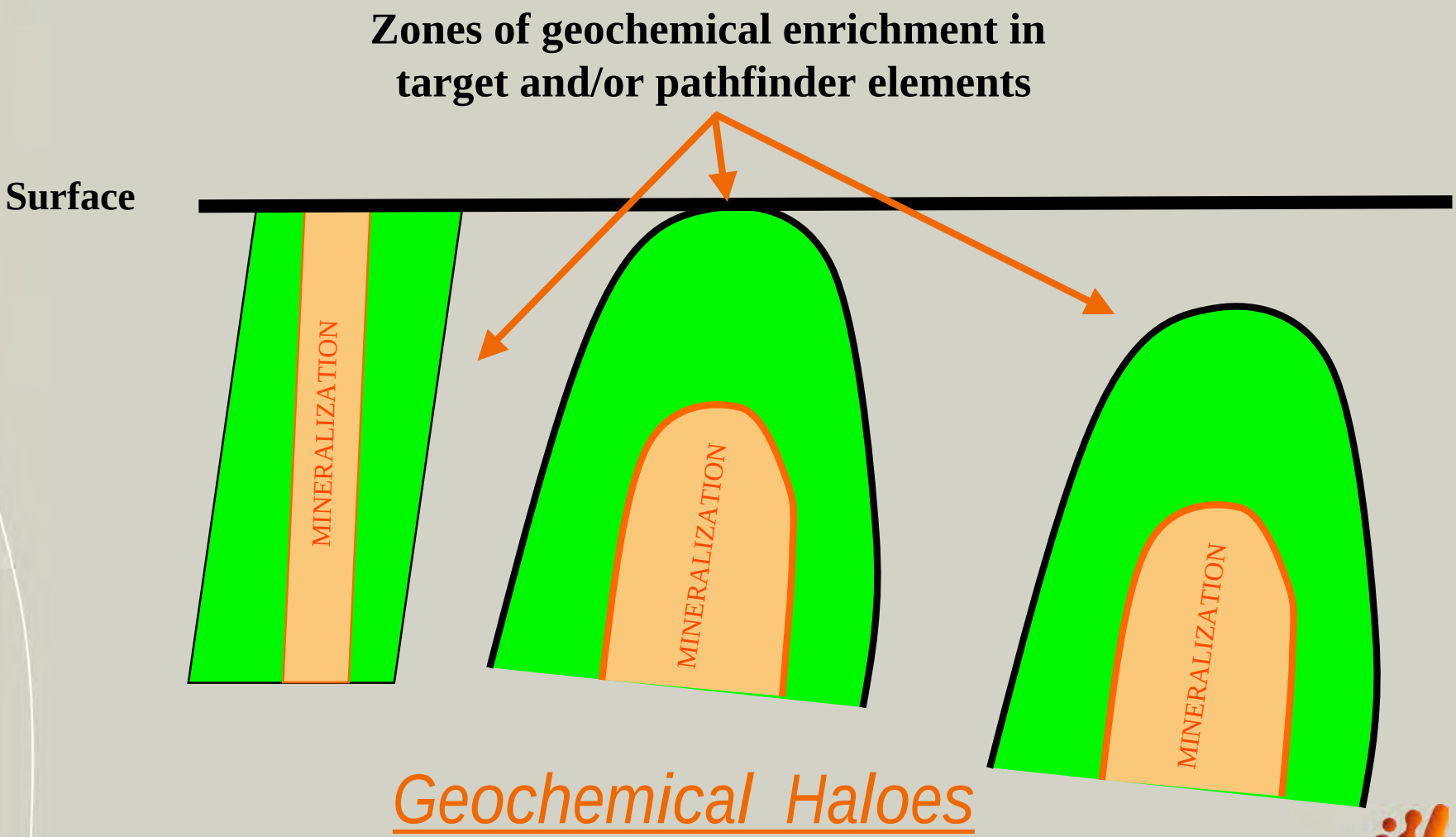

Geochemical Haloes

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Secondary Geochemical Environment

This is the zone of weathering in which rocks are transformed from the massive to the particulate clastic state.

It is dependent on local surficial conditions.

It involves: - Physical and mechanical disaggregation;

- Chemical weathering.

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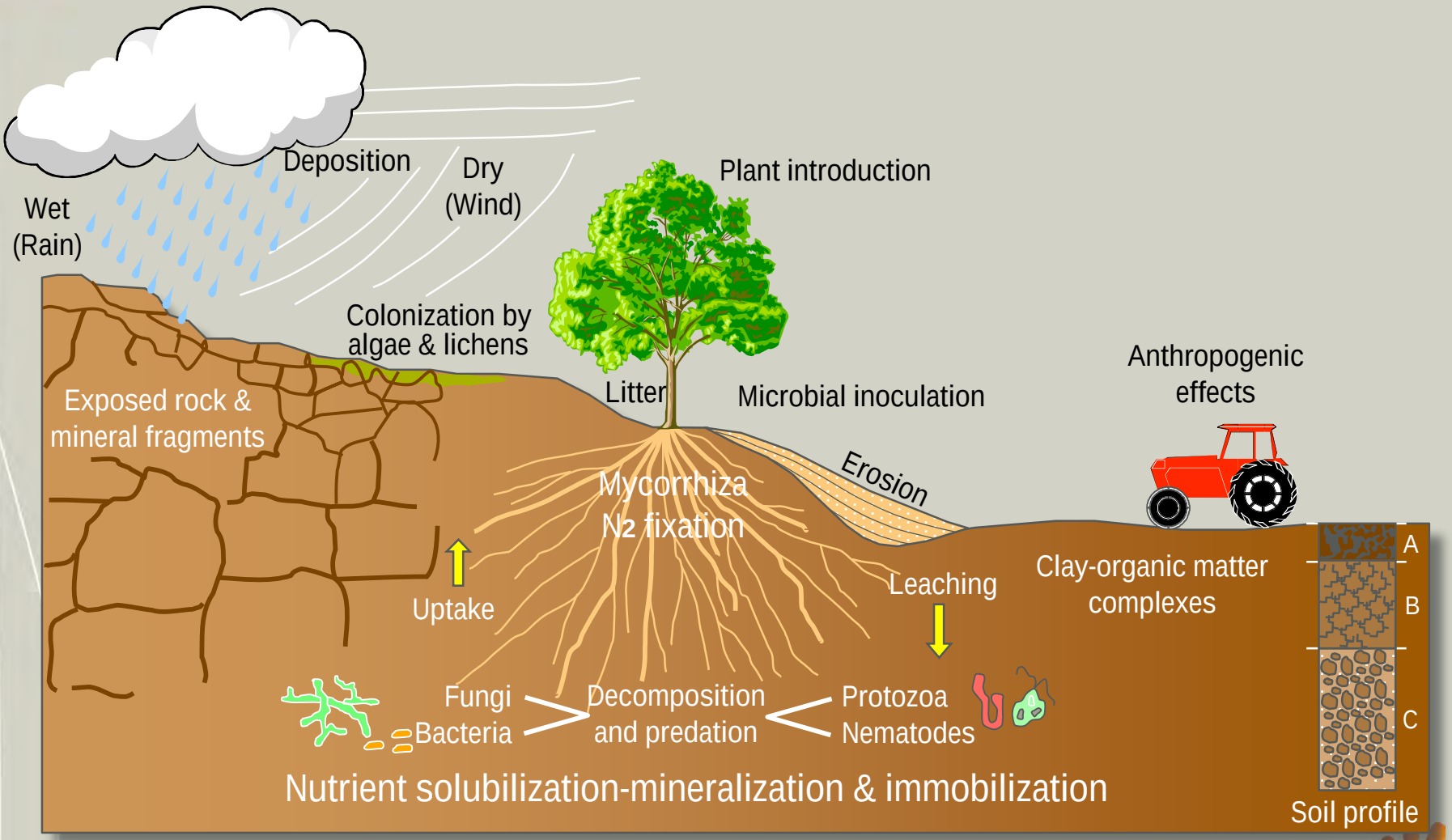
Interrelationships of organisms, organic matter, & parent materials weathering and soil development



Time ⟶ Weathering ⟶ Humus Formation ⟶ Profile Development

Physical Weathering

Processes of physical weathering are generally related to uplift and erosion - cracks and joints.

Get further development of cracks and joints due to rapid temperature change in hot and arid as well as cold and wet regions.

Plant roots.

Secondary mineral growth.

Chemical Weathering

Results from percolating water carrying active agents.

Controlling factors include: climate, vegetation, Eh-pH, and micro-organisms.

Also effected by relief, drainage, bedrock geology and mineralogy – control nature, rate and intensity of chemical weathering.

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Climate: temperature and rainfall – high temperature with large volumes of water are optimum conditions for chemical weathering.

Vegetation: protects weathered rocks versus erosion and limits water evaporation. Soluble organic compounds have potent weathering properties – important in soil formation.

Eh – pH: solution chemistry dominated by Eh – pH relationships.

Eh - oxidizing or reducing (Redox) potential of a system.

pH – relative acidity or alkalinity of an aqueous system.

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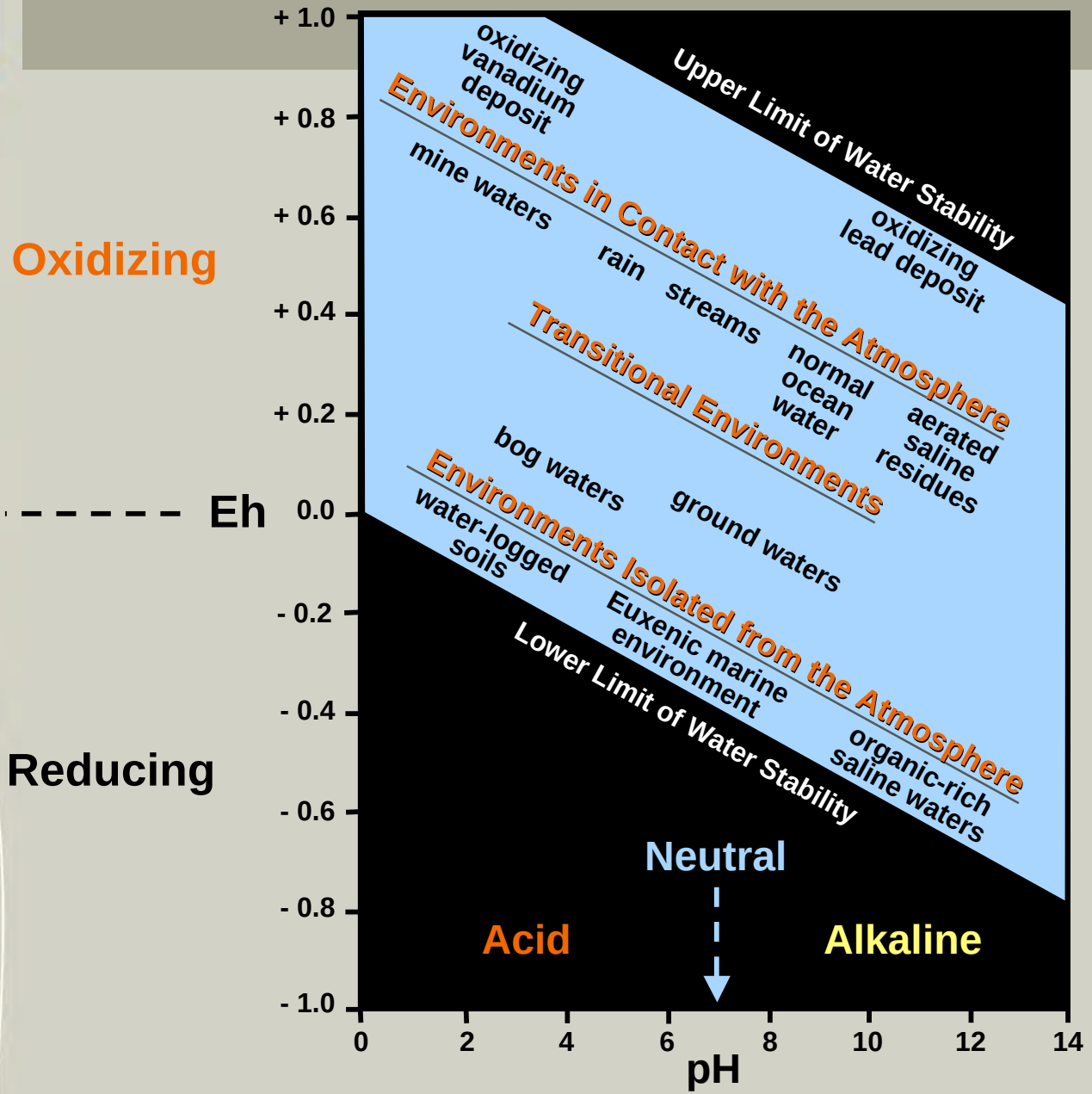
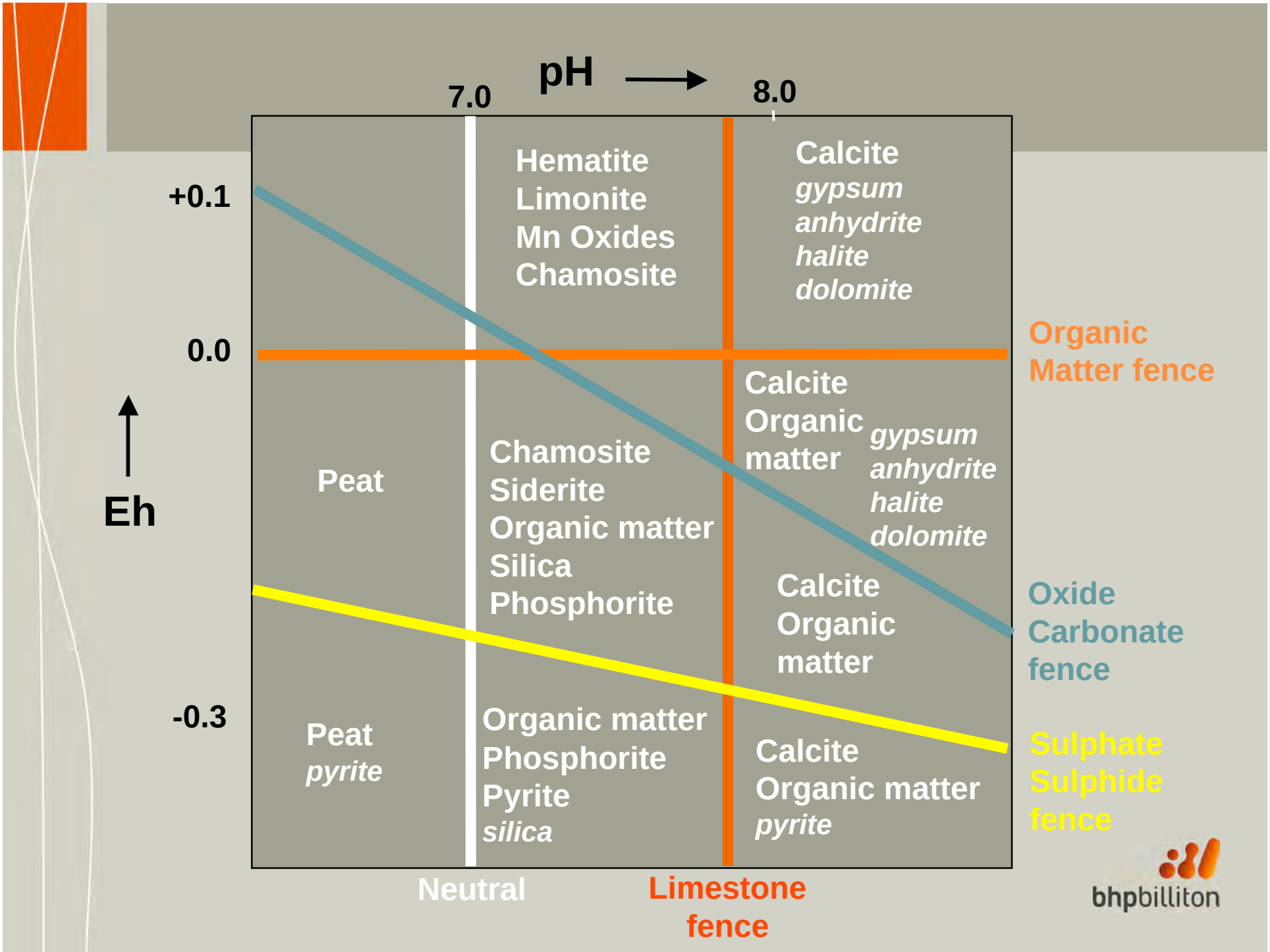

Oxidizing
Eh
Reducing
+ 1.0
+ 0.8
+ 0.6
+ 0.4
+ 0.2
0.0
- 0.2
- 0.4
- 0.6
- 0.8
- 1.0
0
2
4
6
8
10
12
14
pH
Upper Limit of Water Stability
Lower Limit of Water Stability
oxidizing vanadium deposit
Environments in Contact with the Atmosphere
mine waters
rain
streams
normal ocean water
oxidizing lead deposit
aerated saline residues
Transitional Environments
bog waters
ground waters
Environments Isolated from the Atmosphere
water-logged soils
Euxenic marine environment
organic-rich saline waters
Neutral
Acid
Alkaline


pH
7.0
8.0
+0.1
0.0
-0.3
Eh
Hematite
Limonite
Mn Oxides
Chamosite
Calcite
gypsum
anhydrite
halite
dolomite
Organic
Matter fence
Calcite
Organic
matter
gypsum
anhydrite
halite
dolomite
Peat
Chamosite
Siderite
Organic matter
Silica
Phosphorite
Calcite
Organic
matter
Oxide
Carbonate
fence
Peat
pyrite
Organic matter
Phosphorite
Pyrite
silica
Calcite
Organic matter
pyrite
Sulphate
Sulphide
fence
Neutral
Limestone
fence
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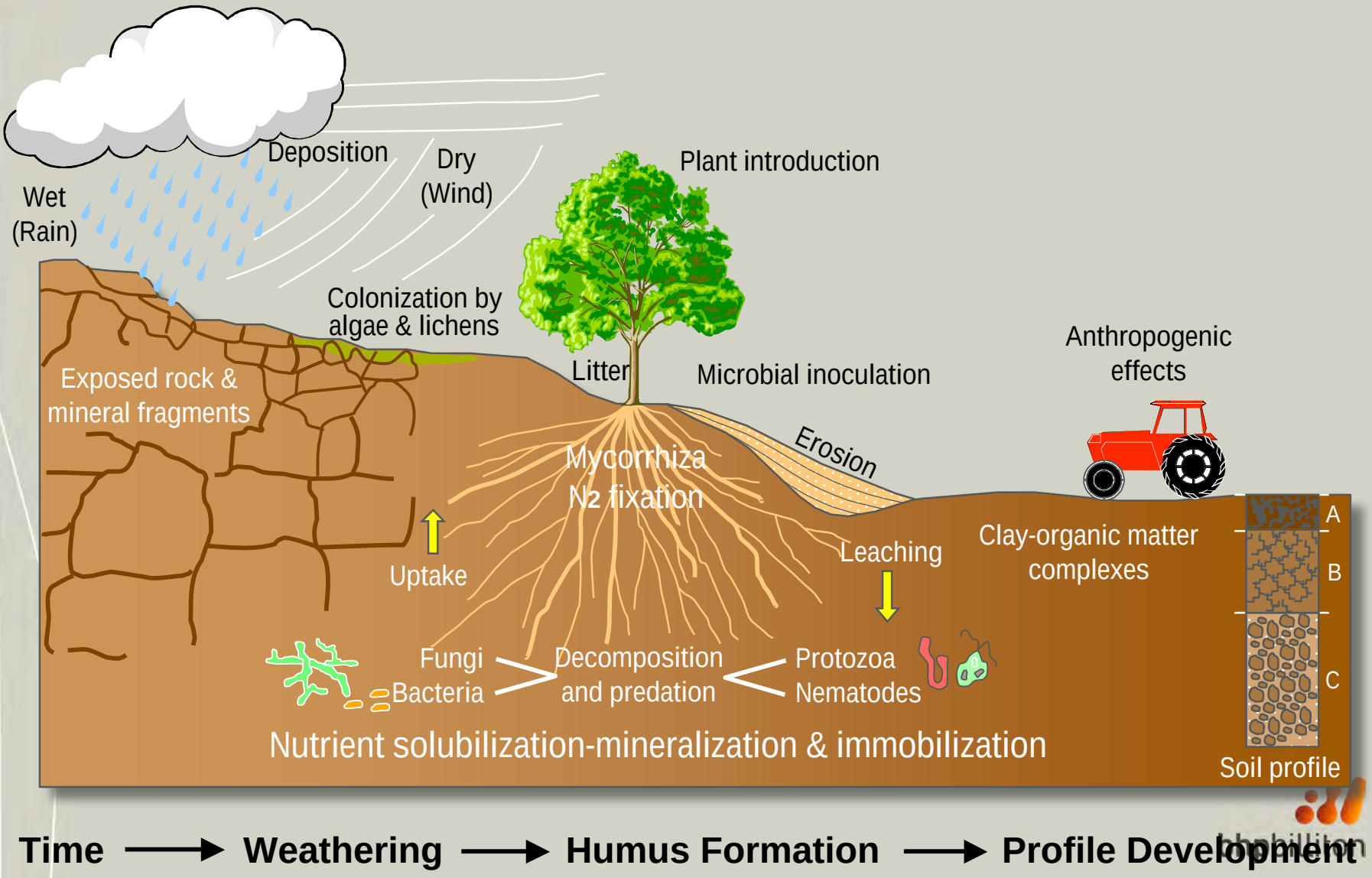
Interrelationships of organisms, organic matter, & parent materials in soil development



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Micro-organisms: occur extensively in association with organic matter- role in weathering is significant but poorly understood.

Relief and Drainage: Bedrock Mineralogy:

Dissolution Processes

Solution, Hydration, Hydrolysis, Chelation, Bio-leaching, Oxidation-Reduction (rock forming minerals and sulphides)

Products

Residual minerals, soluble components, clays, gases, organic compounds, metal oxides, silica, secondary ore minerals.

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Trace Element Mobility

Trace element mobilities determine the nature and size of the surface geochemical patterns related to outcropping, sub-outcropping and buried mineralization.

Attention must be given to local chemical, physical and biochemical processes which might effect element mobility.

One must also consider the physical and chemical characteristics of the elements of interest.

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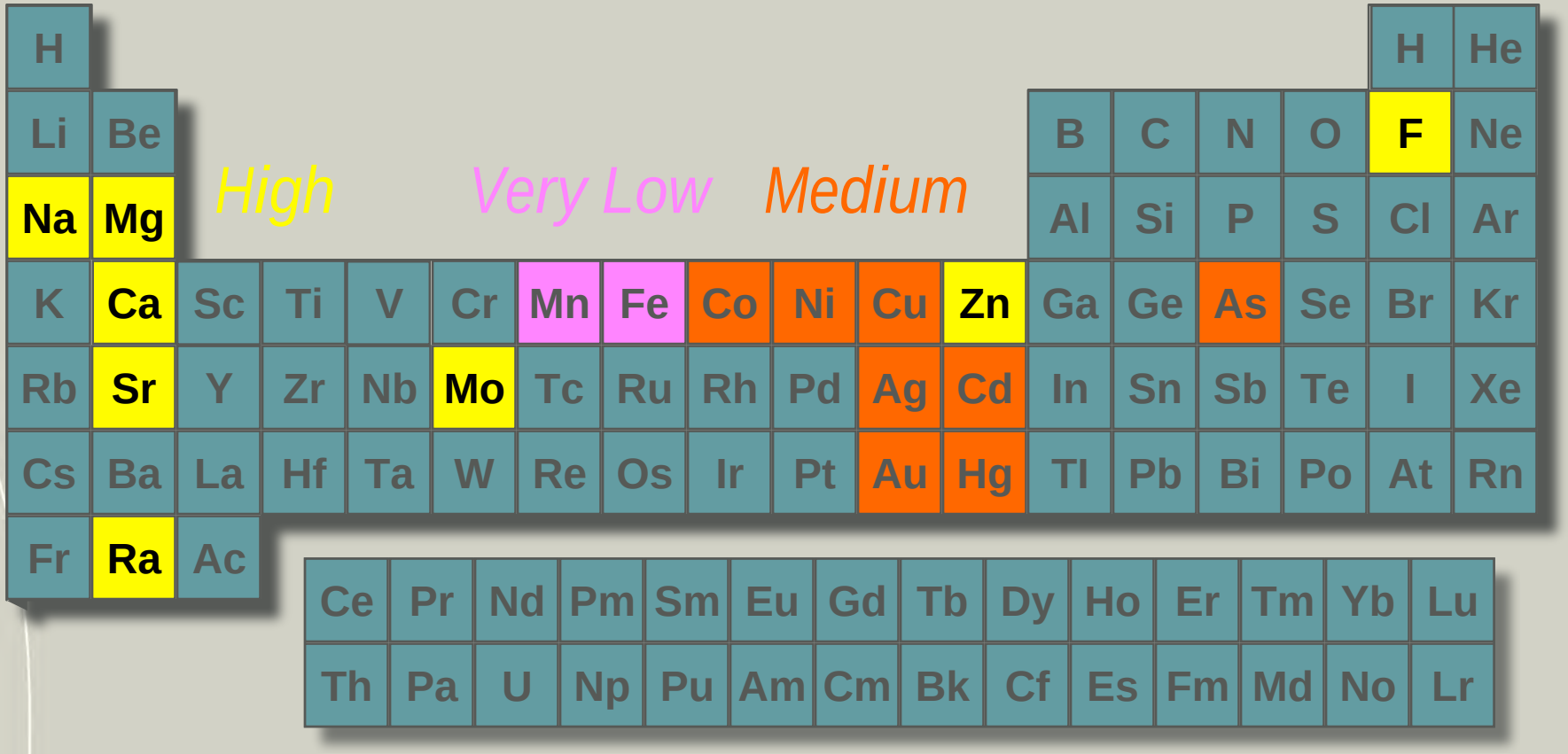
Aqueous Media

Chemical mobility in the surficial environment is generally dominated by aqueous transport.

Solution chemistry is dominated by Eh (oxidation-reduction (redox)) and pH (acid-alkalinity) conditions

One can use Eh-pH diagrams to predict mobility, but natural systems and resulting conditions are usually far more complex.

Relative mobilities of the elements in an oxidizing environment



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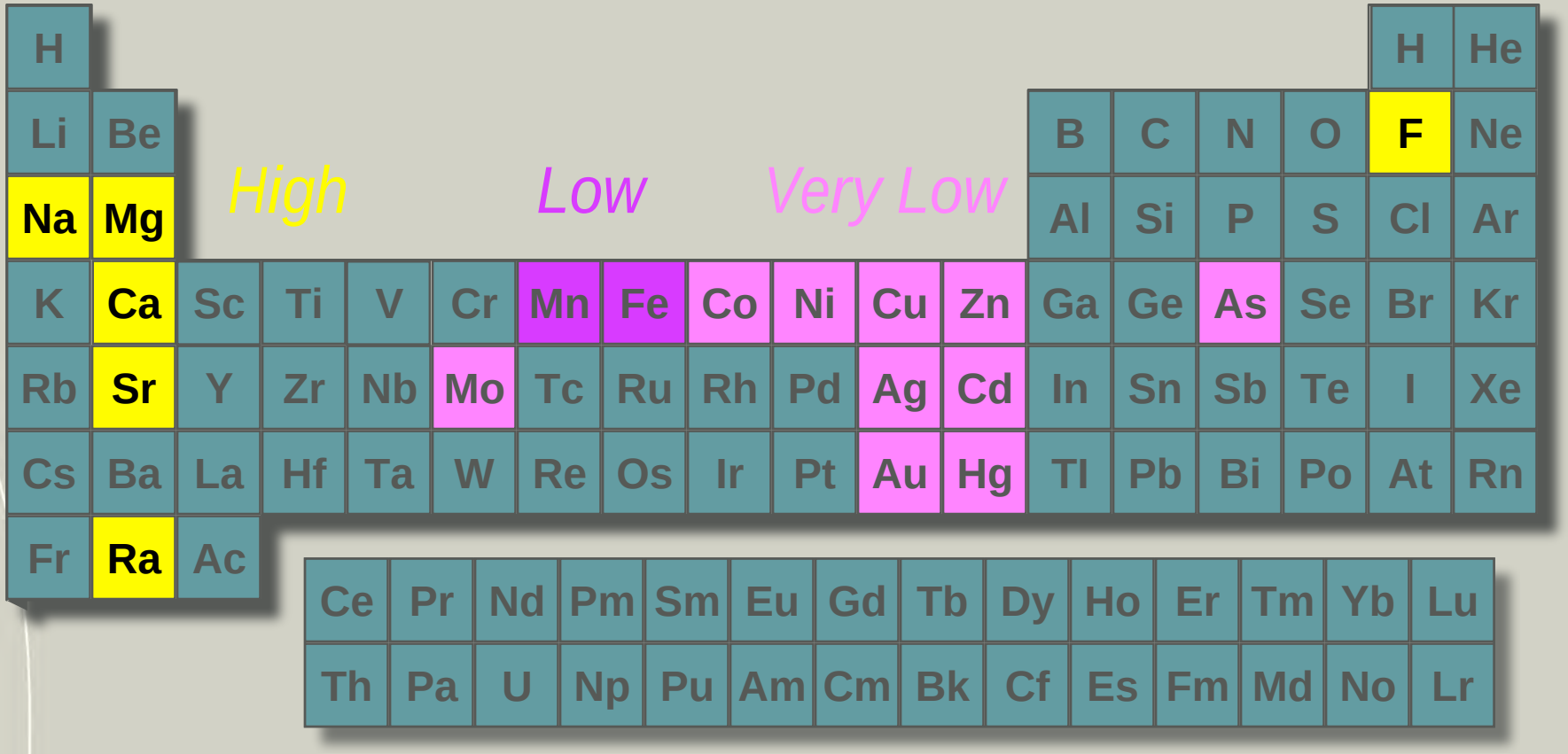
Relative mobilities of the elements in a reducing environment



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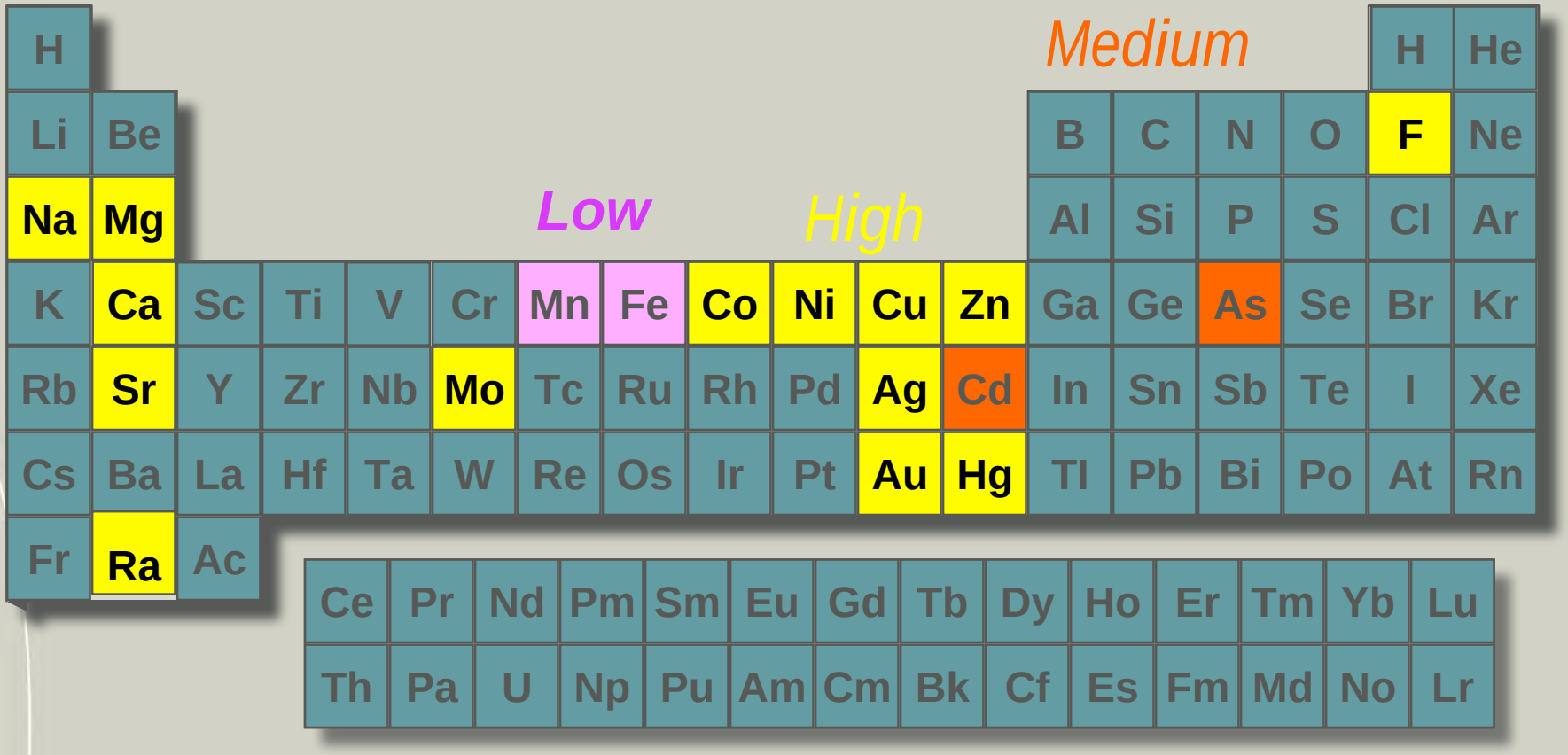
Relative mobilities of the elements in an acid environment



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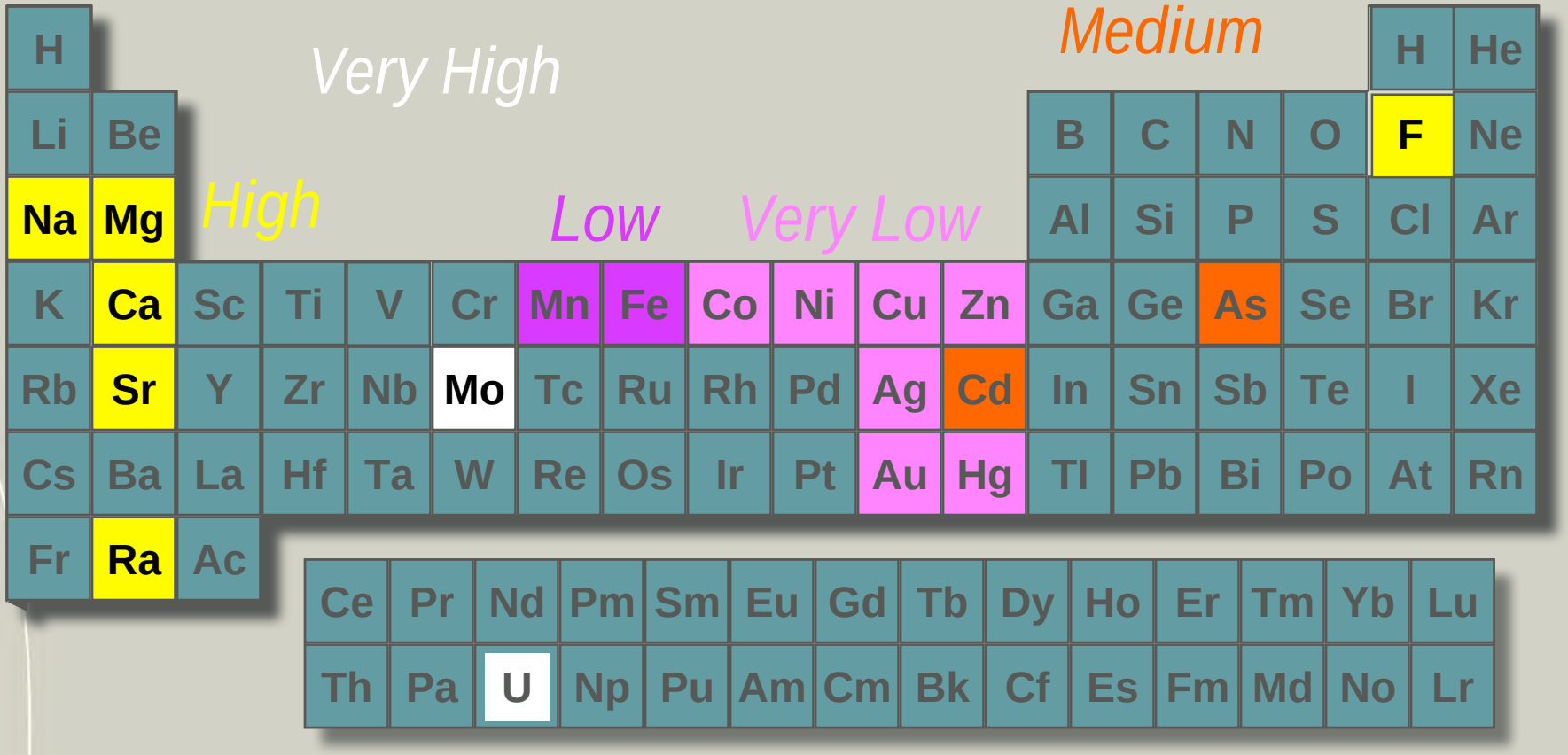
Relative mobilities of the elements in a neutral to alkaline environment



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Relative Mobilities of Some Common Trace Elements in the Surficial Environment
(Modified after Andrews-Jones, 1968)

Relative Mobilities	Environmental Conditions			
	Oxidizing	Acid	Neutral to Alkaline	Reducing
Very High	Cl, I, Br	Cl, I, Br	Cl, I, Br	Cl, I, Br
	S, B	S, B	S, B	
			Mo, V, U, Se, Re	
High	Mo, V, U, Se, Re	Mo, V, U, Se, Re		
	Ca, Na, Mg, F, Sr, Ra	Ca, Na, Mg, F, Sr, Ra	Ca, Na, Mg, F, Sr, Ra	Ca, Na, Mg, F, Sr, Ra
	Zn	Zn		
		Cu, Co, Ni, Hg, Ag, Au		
Medium	Cu, Co, Ni, Hg, Ag, Au			
	As, Cd	As, Cd	As, Cd	
Low	Si, P, K	Si, P, K	Si, P, K	Si, P, K
	Pb, Li, Rb, Ba, Be, Bi, Sb, Ge, Cs, Tl	Pb, Li, Rb, Ba, Be, Bi, Sb, Ge, Cs, Tl	Pb, Li, Rb, Ba, Be, Bi, Sb, Ge, Cs, Tl	
		Fe, Mn	Fe, Mn	Fe, Mn
Very Low to Immobile	Fe, Mn			
	Al, Ti, Sn, Te, W, Nb, Ta, Pt, Cr, Zr, Th, Rare Earths	Al, Ti, Sn, Te, W, Nb, Ta, Pt, Cr, Zr, Th, Rare Earths	Al, Ti, Sn, Te, W, Nb, Ta, Pt, Cr, Zr, Th, Rare Earths	Al, Ti, Sn, Te, W, Nb, Ta, Pt, Cr, Zr, Th, Rare Earths
				S,B
				Mo, V, U, Se, Re
			Zn	Zn
			Cu, Co, Ni, Hg, Ag, Au	Cu, Co, Ni, Hg, Ag, Au
				As, Cd
				Pb, Li, Rb, Ba, Be, Bi, Sb, Ge, Cs, Tl

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Thus, some examples of relative mobilities in the surficial aqueous environment are:

Zn: high - acid/oxidizing; very low-immobile - neutral-alkaline/reducing.

Cu, Co, Ni, Hg, Ag, Au: medium-high - acid/oxidizing; very low-immobile - neutral-alkaline/reducing

Mo: very high - neutral-alkaline; high - acid/oxidizing; but, very low to immobile in reducing.

Fe, Mn: very low to immobile - oxidizing; low - reducing and acid or neutral-alkaline.

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Coprecipitation

Coprecipitation occurs when a dissolved species is incorporated as a minor component in a solid phase.

Co, Ni, Pb, Zn and Cu to varing degrees will coprecipitate with Fe and Mn hydroxides/oxides.

This can give rise to false anomalies.

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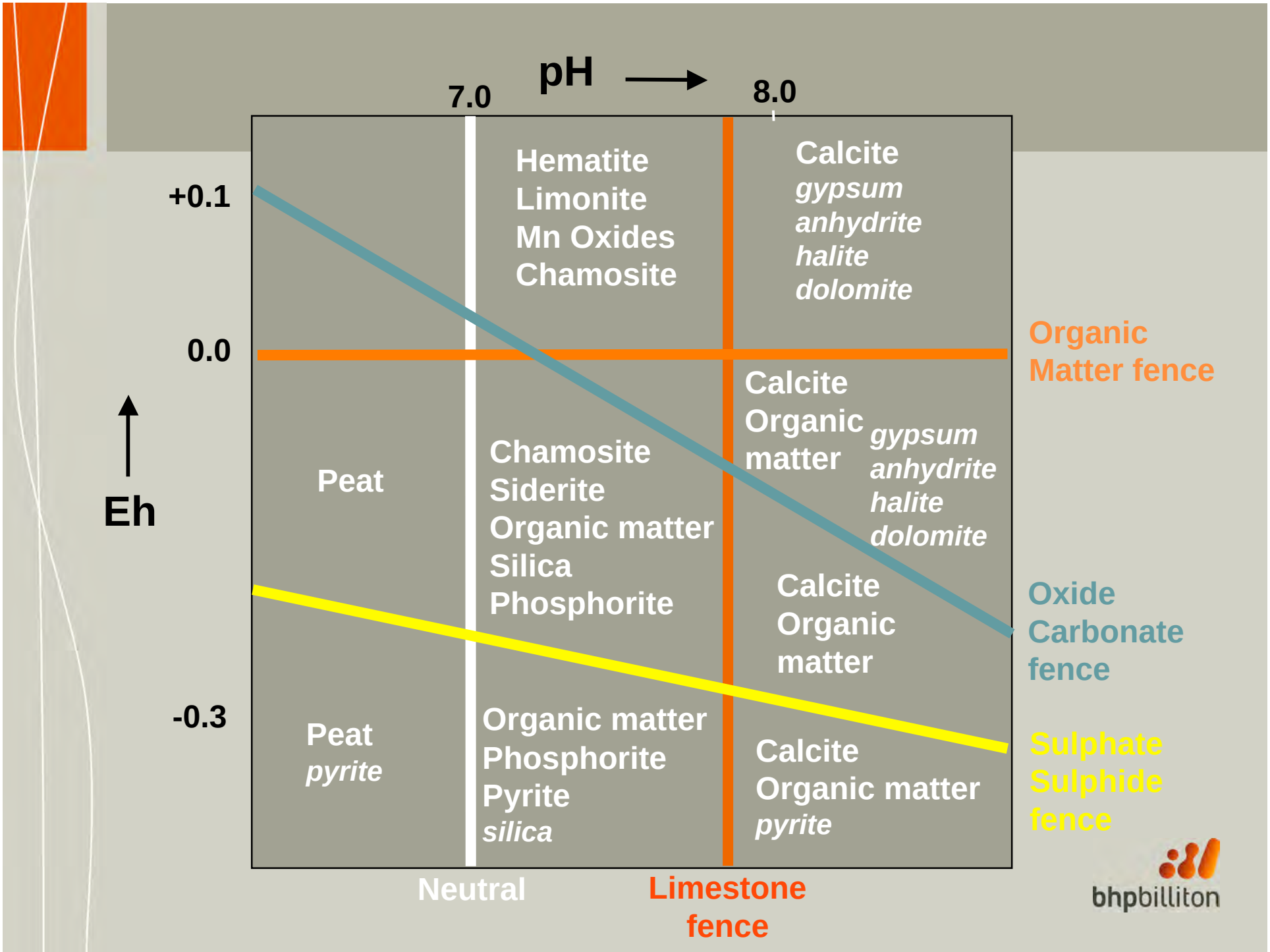
pH
7.0
8.0
+0.1
0.0
-0.3
Eh
Hematite
Limonite
Mn Oxides
Chamosite
Calcite
gypsum
anhydrite
halite
dolomite
Organic
Matter fence
Calcite
Organic
matter
gypsum
anhydrite
halite
dolomite
Peat
Chamosite
Siderite
Organic matter
Silica
Phosphorite
Calcite
Organic
matter
Oxide
Carbonate
fence
Peat
pyrite
Organic matter
Phosphorite
Pyrite
silica
Calcite
Organic matter
pyrite
Sulphate
Sulphide
fence
Neutral
Limestone
fence
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Colloidal Chemistry

The mobility and dispersion of many trace metals in surficial aqueous environments are strongly influenced by ion (cation) exchange, and the adsorption properties of colloids:

-commonly consist of Fe, Al, & Mn oxides and hydroxides, organic matter, clays and silica;

-particle charges - fixed negative charges in the silicate layers of clays and fixed surface charges on the oxides of Si, Al, Fe, & Mn, organic matter and edges of clays;

Colloidal Chemistry (cont'd)

-many chalcophile elements are adsorbed onto colloids (i.e. Co, Cu, Zn in presence of Mn hydroxides/oxides).

-ion exchange (exchange ions among different colloids)

Reactions with Organic Matter

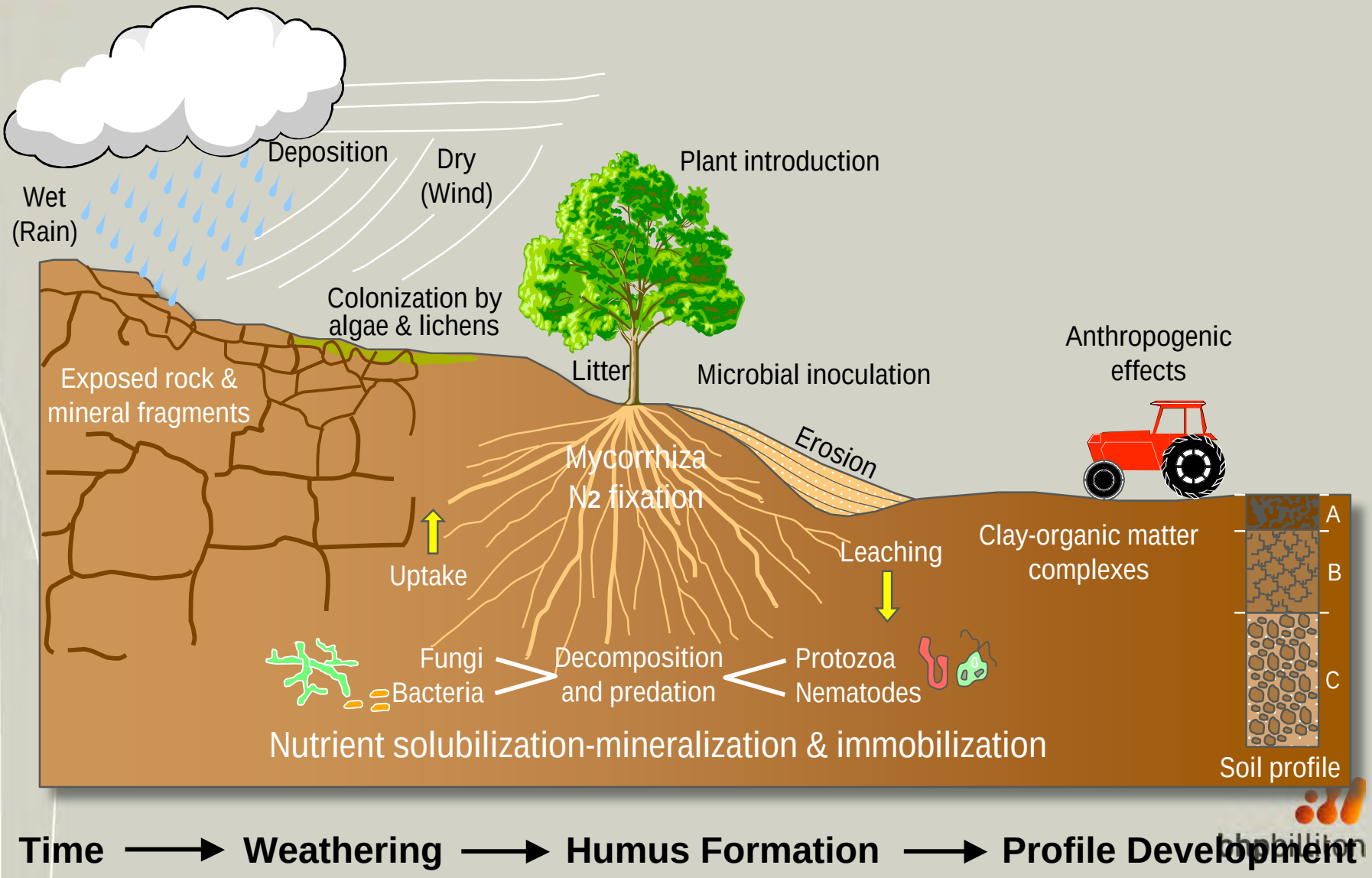
Metals may be bound to organic compounds in many ways:

-strongly to C or N, O, P, S atoms or compounds;

-moderately to strongly by replacement of ionizable H in organic acids;

-complex organic compounds, such as humic and fulvic acids, can adsorb and chelate metal ions (chelation by humics Cu>Ni>Co>Pb=Ca>Zn>Mn>Mg).

Interrelationships of organisms, organic matter, & parent materials in soil development



Chemical Mobility of Trace Elements in the Surficial Environment

	pH conditions			Immobilization factors			
Element	Acid <5.5	Neutral pH 5.5–7.0	Alkaline pH >7.0	Fe/Mn oxides	Organic matter	Other	Heavy minerals
Antimony	Low	Low	Low	Yes		Sulfide; reducing conditions	
Arsenic	Medium	Medium	Medium	Yes		Sulfide; clay conditions	
Barium	Low	Low	Low			Sulfate; reducing conditions; carbonate; clay	
Beryllium	Low	Low	Low	Yes	Yes	Clay	
Bismuth	Low	Low	Low	Very		Reducing conditions	
Boron	V. High	V. High	V. High				Tourmaline
Cadmium	Medium	Medium	Medium			Reducing conditions	
Cerium	Insoluble	Insoluble	Insoluble				Rare earth minerals
Chromium	V. Low	V. Low	V. Low				Chromite
Cobalt	High	Medium to Low	V. Low			Sulfide; adsorption	
Copper	High	Medium to Low	V. Low	Yes	Yes	Sulfide; adsorption	
Fluorine	High	High	High			CaF_2, adsorption	
Gold	Immobile	Immobile	Immobile				Native gold
Iron-Fe^{+++}	High to V. Low	V. Low	V. Low	Yes			Magnetite
Iron-Fe^{++}	High	Medium to Low	V. Low	Yes		Oxidizing condition	
Lead	Low	Low	Low			Insoluble carbonate, sulfate, phosphate; reducing conditions	
Lithium	Low	Low	Low	Yes		Clays	
Manganese	High	High	High to V. Low	Yes		Clays	
Mercury (aq)	Medium	Low	Low	Yes		Sulfide	Cinnabar
Mercury (vap)	High	High	High				
Molybdenum	Low	Medium	High	Yes		Adsorption; in presence of Pb, Fe, Ca, carbonate; sulfide; reducing conditions	

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Chemical Mobility of Trace Elements in the Surficial Environment

	pH conditions			Immobilization factors			
Element	Acid <5.5	Neutral pH 5.5–7.0	Alkaline pH >7.0	Fe/Mn oxides	Organic matter	Other	Heavy minerals
Nickel	High	Medium to Low	V. Low			Sulfide, adsorption, silicate minerals	
Niobium/ Tantalum	Insoluble	Insoluble	Insoluble				Yes
Platinum	Insoluble	Insoluble	Insoluble				Native platinum
Radium	High	High	High	Yes	Yes	Coprecipitation with Ba, Ca, Fe, Mn	
Radon	High	High	High			Limited by half life	
Selenium	High	High	V. High	Yes		Reducing conditions, adsorption	
Silver	High	Medium to Low	V. Low	Yes	Yes	Reducing conditions; sulfide; precipitated by Pb, Cl, chromate, arsenate	
Tellurium	V. Low	V. Low	V. Low				Yes
Thorium	V. Low	V. Low	V. Low			Adsorption by clay, aluminum hydroxides	Yes
Tin	Insoluble	Insoluble	Insoluble				Cassiterite
Tungsten	Insoluble	Insoluble	Insoluble	Yes			Wolframite Sheelite
Uranium	Low to Medium	High	V. High	Yes	Yes	Reducing conditions; special ion precipitates; adsorption	
Vanadium	High	High	V. High			Silicate minerals; reducing conditions, adsorption	V-magnetites
Zinc	High	High to Medium	Low to V. Low	Yes	Yes	Sulfide, precipitated by high carbonate, phosphate	

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Biological Media

Plants take up metals through their roots and distribute them to their various organs (biogeochemistry).

As plants decay the insoluble components are concentrated in the upper parts of the soil profile (humus).

Soluble products are removed by surface waters but also move down through the mineral soil leaching and carrying these materials, including trace metals, to the zone of accumulation (B horizon).

Exploration Geochemistry – Basic Principles and Concepts

Clastic Media

Mechanical processes play a major role in the dispersal of clastic weathering products.

Gravity, water, glaciers, wind, animals, insects, etc.

Gaseous Media

Vertical migration of gases, particularly up faults and fractures, can play a role in metal movement.

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Exploration Geochemistry

An understanding of the aforementioned basic principles and concepts of exploration geochemistry is absolutely critical to the successful application of geochemistry within mineral exploration.

You will see these basic principles and concepts of exploration geochemistry coming through in the more method specific presentations that will follow throughout today's workshop.

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