



Fundamentals of Mine-Drainage Formation and Chemistry

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U.S. Geological Survey**

Colorado School of Mines

Acidity

pH is a function of:

- **Balance between acid-generating and acid-consuming reactions**
- **Relative rates of these reactions**
- **Accessibility of minerals that contribute to these reactions**

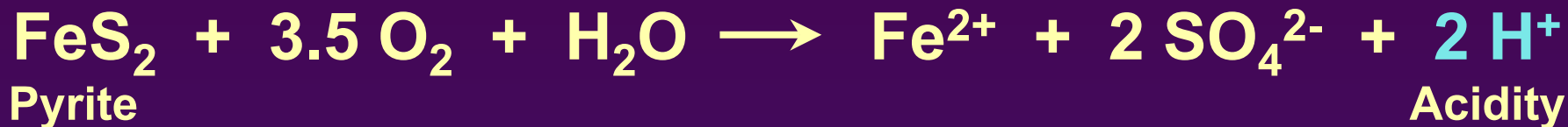
Acid-Generating Reactions

- **Oxidation of pyrite and some other sulfide minerals**
- **Hydrolysis of metal cations**
 - especially Fe and Al
- **Precipitation of hydrous metal-oxide minerals**
 - such as iron and aluminum oxides

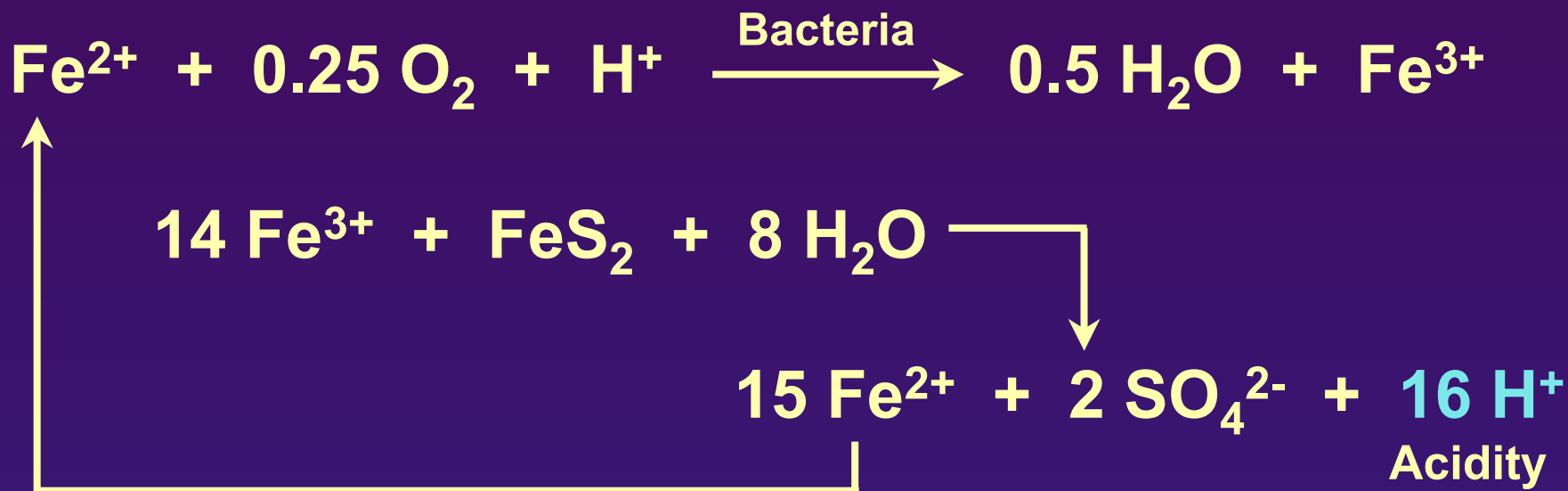
Oxidation Reactions

(from Singer and Stumm, 1970; Forstner and Wittmann, 1979)

Initiator Reaction:



Propagation Cycle:



Oxidation Reactions

Pyrite (FeS₂)



Pyrite oxidation by oxygen:



Pyrite oxidation by ferric iron (Fe³⁺):

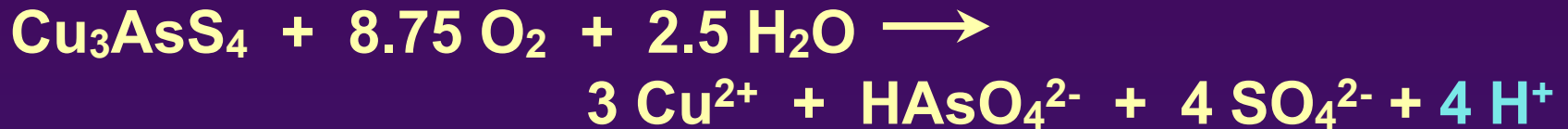


Oxidation Reactions

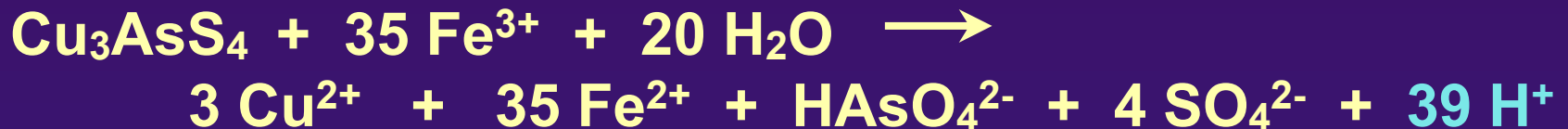
Enargite (Cu_3AsS_4)



Enargite oxidation by oxygen:



Enargite oxidation by ferric iron (Fe^{3+}):



Sources of Fe³⁺

- **Microbially catalyzed oxidation of Fe(II)**
 - 10⁶ times faster than abiotic (Singer and Stumm, 1970)
 - See Schrenk et al., 1998
- **Secondary iron-sulfate soluble salts**
 - e.g., Coquimbite [Fe₂(SO₄)₃ · 9H₂O]
 - Form from acid mine drainage

Soluble Salts

- Soluble salts may form upon evaporation of acidic waters
- These salts store acid and metals until released by rainfall or snowmelt



Acid-Generating Reactions

Hydrolysis of metal cations



Acid-Generating Reactions

Precipitation of
hydrous
metal-oxide
minerals



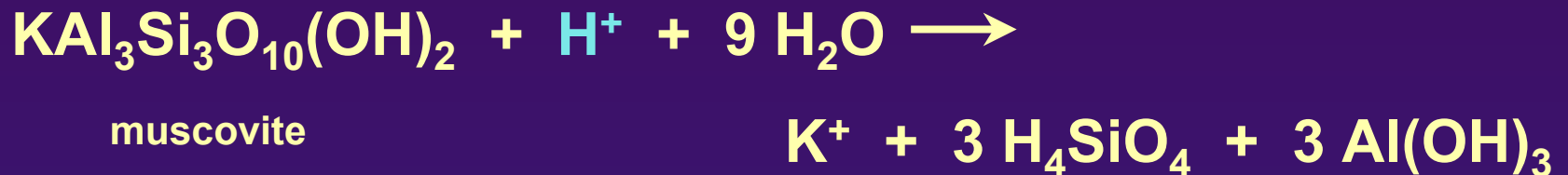
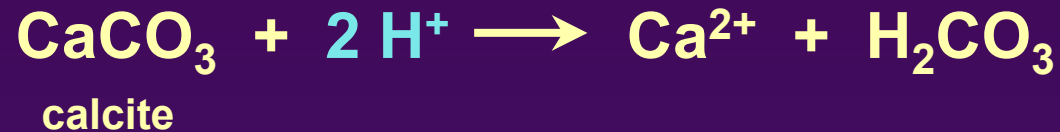
Acid-Consuming Reactions

- **Dissolution of carbonate minerals releases Ca, Mg, H_2CO_3^0 or HCO_3^- or CO_3^{2-}**
- **Dissolution of aluminosilicate minerals releases Al, Ca, Fe, K, Mg, Mn, Na, Si**
- **Dissolution of hydrous Fe and Al oxide minerals releases Fe, Al, sorbed elements**
- **Sorption of H^+ onto mineral surfaces releases sorbed elements**



Acid-Consuming Reactions

Most weathering reactions consume acid

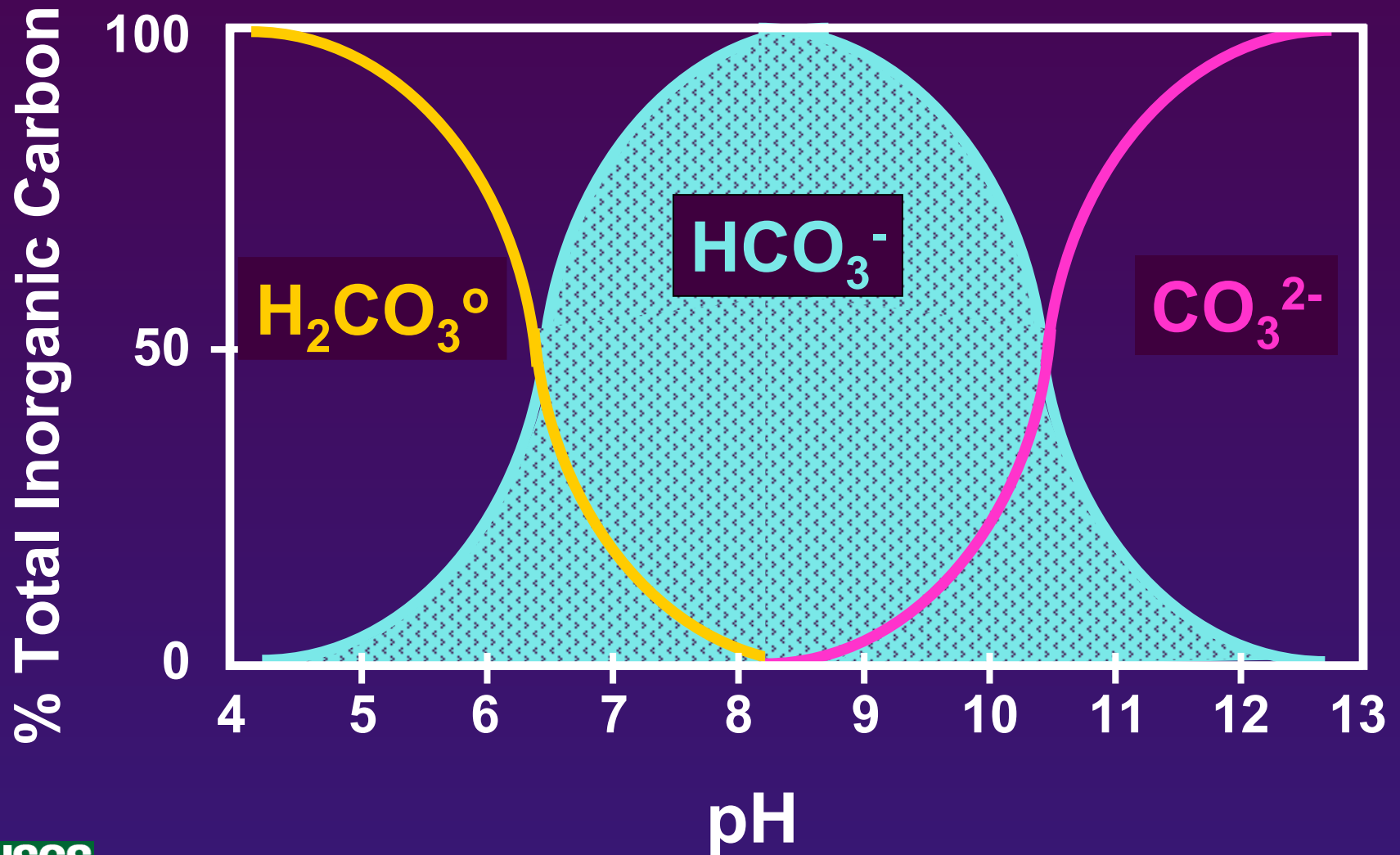


The Carbonate System



- Important pH buffering system
- Usually responsible for alkalinity

Carbonate Buffering



Alkalinity

- **Capability of water to neutralize acid**
- **Important to aquatic life**
 - **Buffers against rapid pH change**
- **Often related to hardness**
 - **Hardness is the concentration of divalent cations (e.g., Ca^{2+} , Mg^{2+})**
 - **Water-quality criteria for some metals are hardness-dependent**
 - **In mining impacted systems, Ca^{2+} , Mg^{2+} , etc. can originate from the weathering of a variety of minerals**



Chemical Constituents

**Concentration of a chemical element
is a function of:**

- **Presence and concentration of that element in the ore or host-rock minerals**
- **Accessibility of these minerals (mining method, porosity, grain size, climatic conditions, etc.)**
- **Susceptibility of these minerals to weathering**
- **Mobility of the element**

Geoavailability

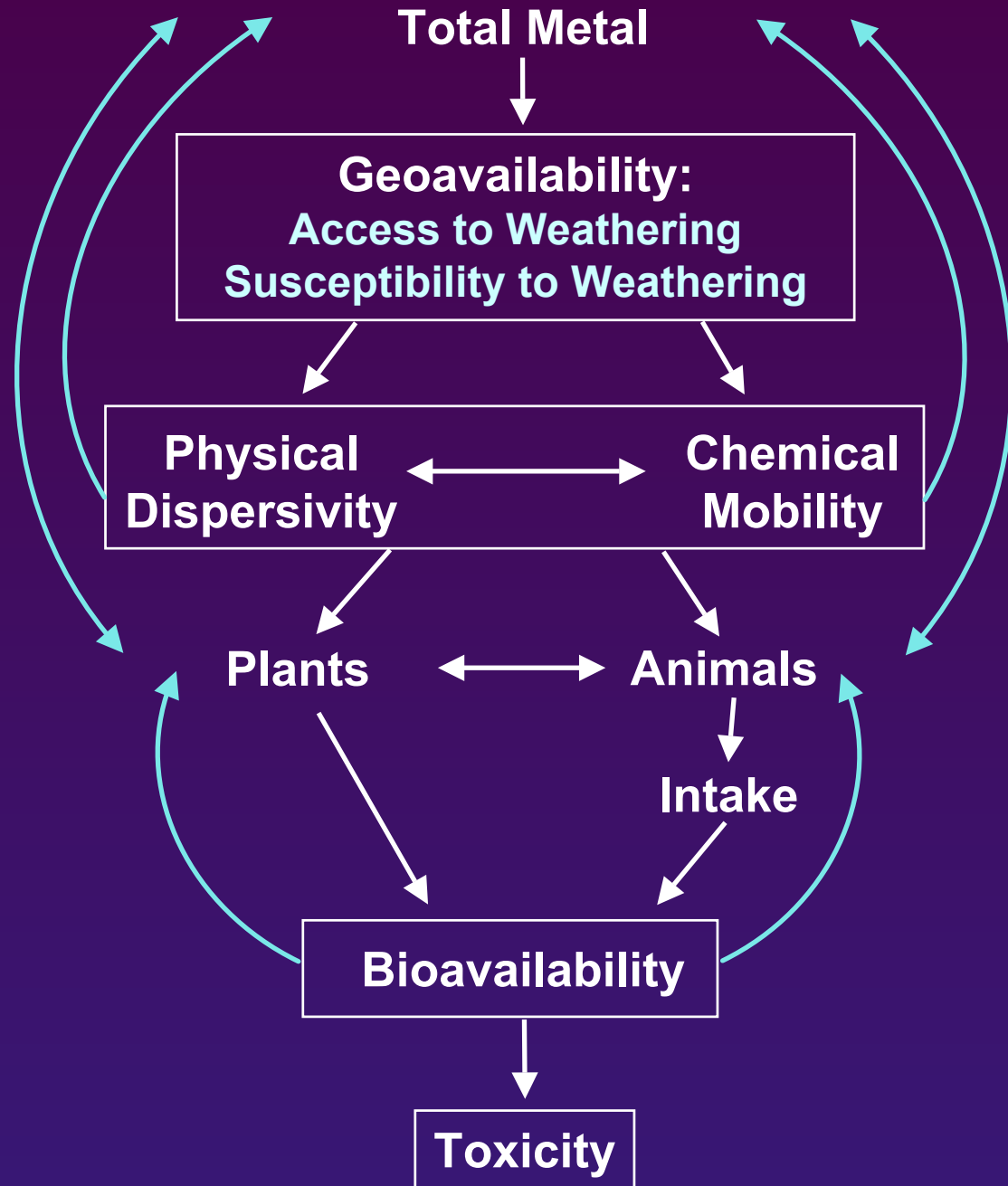
“...that portion of a chemical element’s or a compound’s total content in an earth material that can be liberated to the surficial or near-surface environment (or biosphere) through mechanical, chemical, or biological processes”

Smith and Huyck (1999)

More

Metal Concentration

Less



Trace Elements in Natural Waters

Regardless of their source, high concentrations of dissolved trace elements often do not persist as they are transported through aqueous systems due to:

- **Precipitation reactions**
- **Sorption reactions**
- **Biological uptake and transformation**
- **Dilution**
- **Some exceptions include Mn and Zn**

