WHAT CAN CLAY MINERALOGY TELL US ABOUT ALTERATION ENVIRONMENTS ON MARS?

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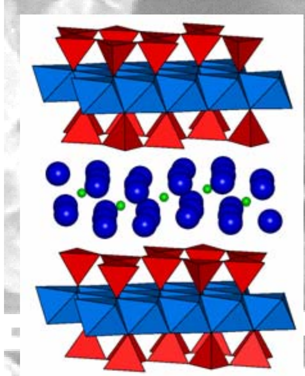
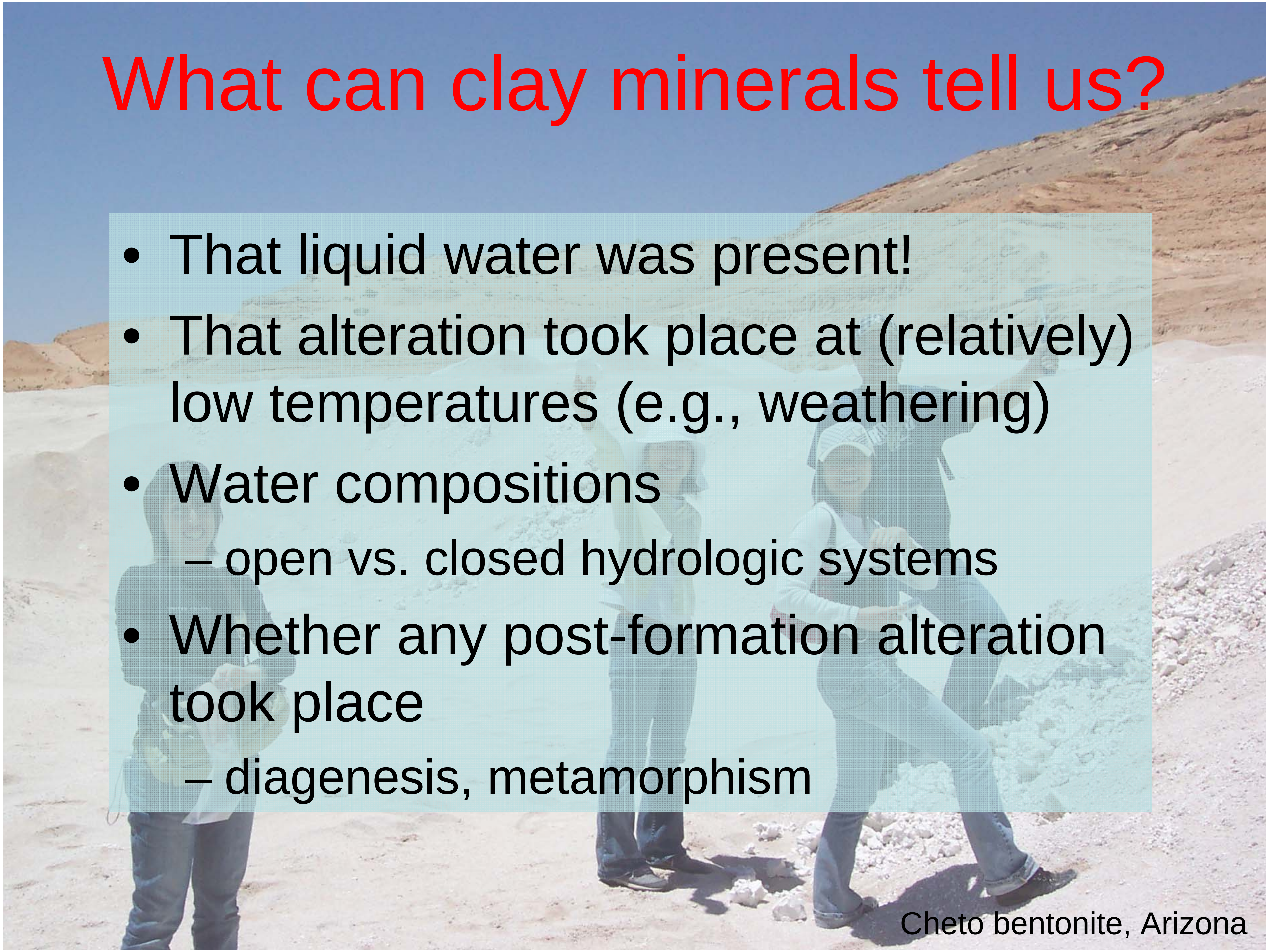


Products of Mineralogical Studies

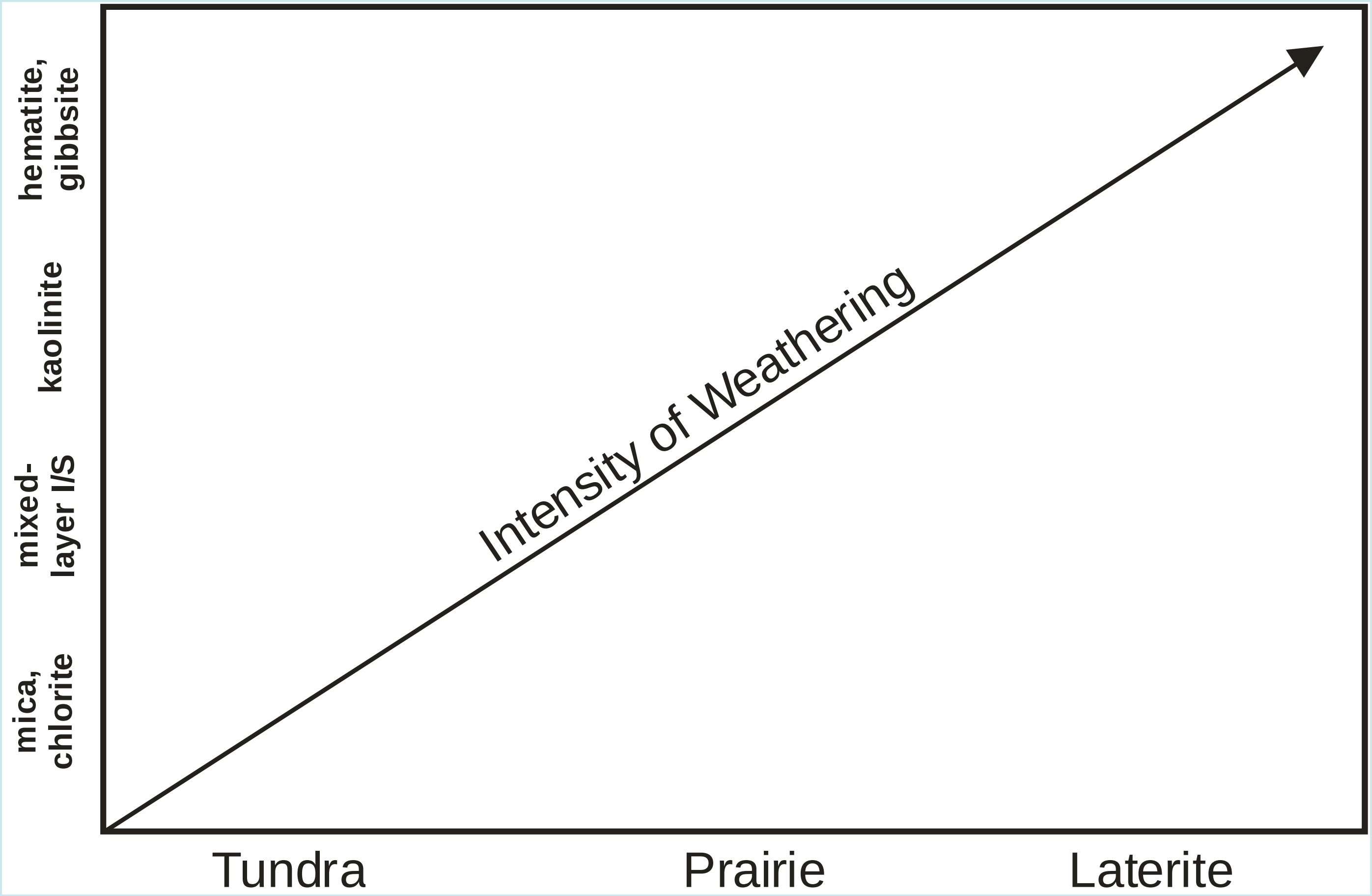
- Mars' surface mineralogy can provide:
  - clues to its hydrologic, atmospheric, and geochemical histories
  - constraints on past alteration processes, both surface and subsurface
- Distribution of clay minerals over time and with depth $\Rightarrow$ time-resolved information on alteration
- *Presumably*, organics/biology did not participate in the low-T formation of clay minerals.

What can clay minerals tell us?

- That liquid water was present!
- That alteration took place at (relatively) low temperatures (e.g., weathering)
- Water compositions
  – open vs. closed hydrologic systems
- Whether any post-formation alteration took place
  – diagenesis, metamorphism



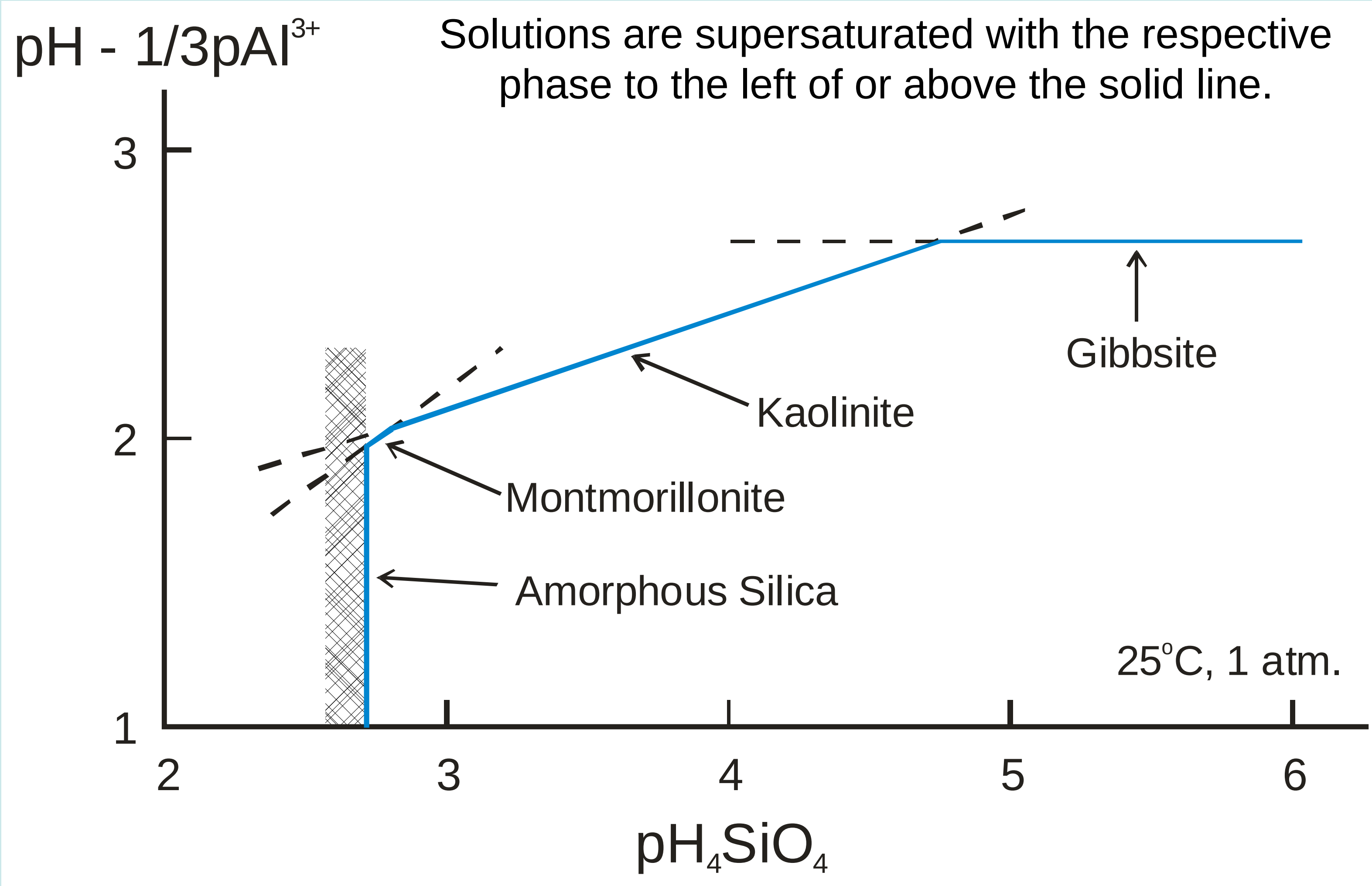
Cheto bentonite, Arizona



Mineralogy vs. intensity of weathering (modified from Velde, 1985).

Importance of Silica Activity

- Silica activity often controls the formation of both clay minerals and zeolites
  - zeolites and smectites are stable at elevated silica activities
  - depend on open- vs. closed-system hydrology
- Numerous recent suggestions of amorphous-silica deposits on Mars
  - hydrothermal alteration or from acidic vapors with small amounts of liquid water.
- Stability diagrams can shed light on alteration conditions.



Stability diagram for minerals in the Al_2O_3-SiO_2-H_2O system. "p" in axis labels refers to –log[] (Kittrick, 1969).

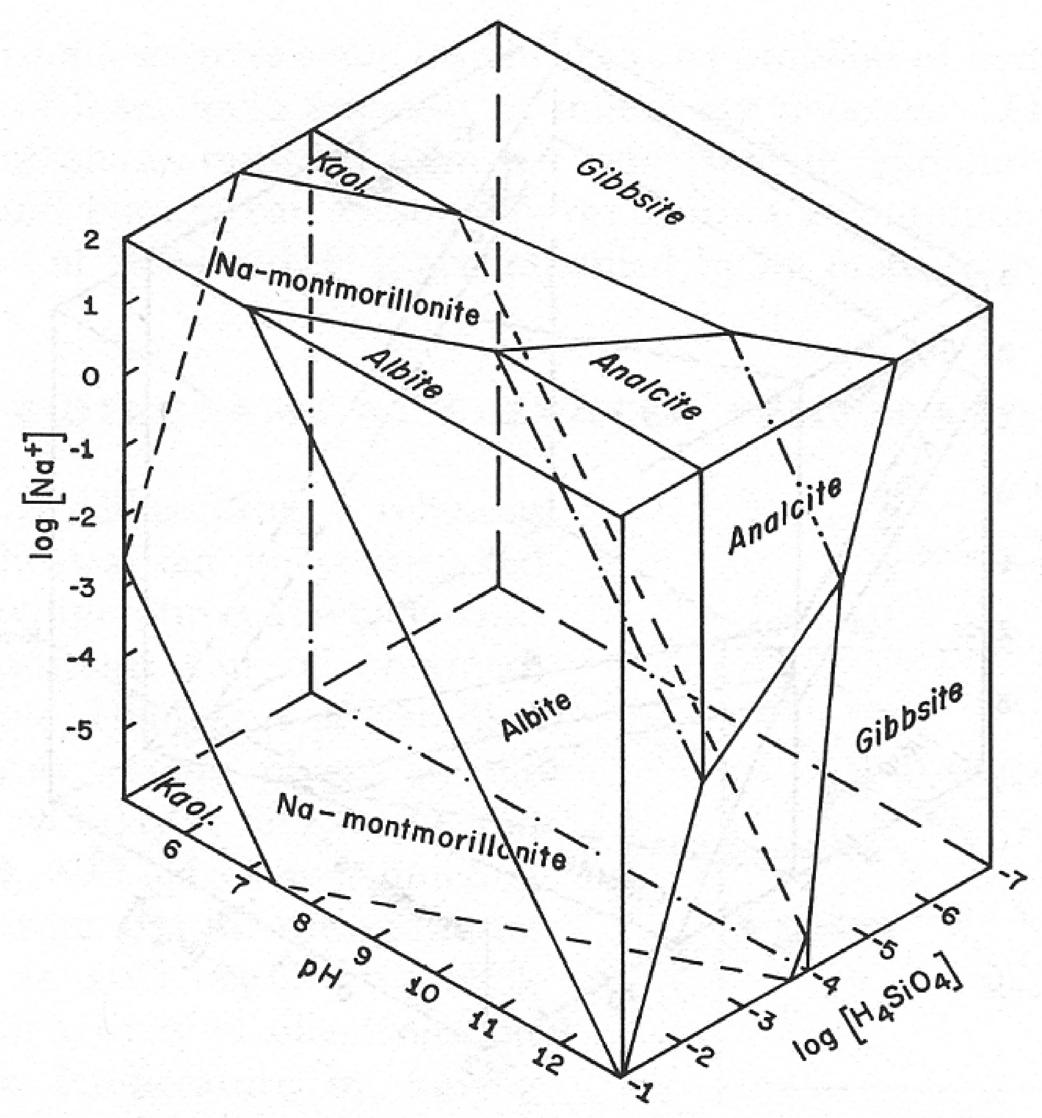
Alteration of Volcanic Glass to Clinoptilolite

St. Cloud Mining, Buckhorn, NM

Smectites vs. Zeolites

- Smectites or zeolites can form from volcanic ash, depending on conditions
  - basaltic ash does not *always* alter to phyllosilicates
  - smectite—near- or below-neutral pH conditions
  - zeolites—alkaline conditions
  - smectites and zeolites *together* would indicate a more persistent and evolved hydrogeologic system

- Kaolinite stable at low pH, low Na, and high silica
- Smectite stable at high silica, medium pH, and medium to high Na
- Note the analcime stability field at high pH's and high Na

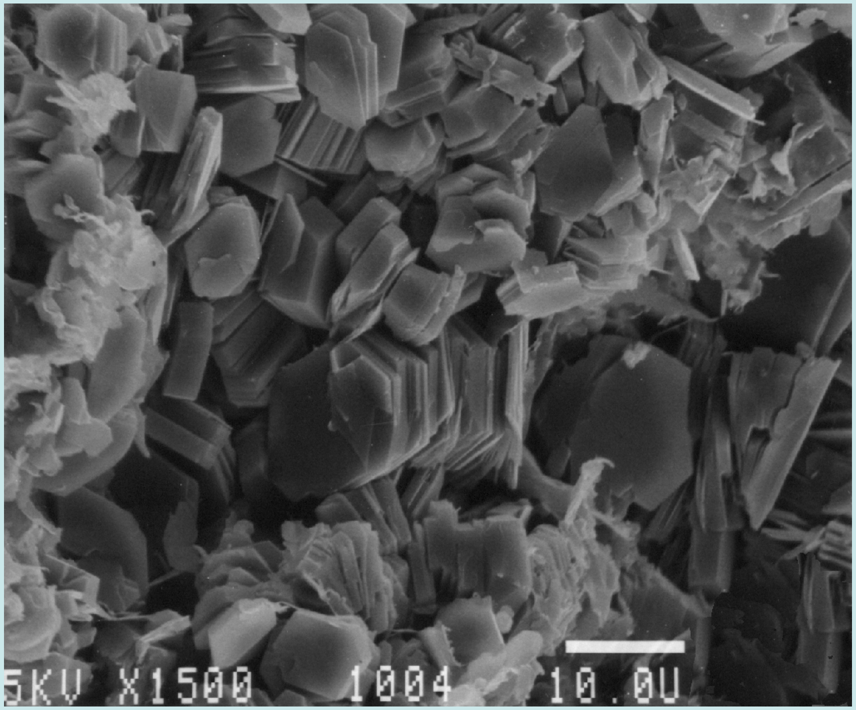


Stability relations of phases in the Na_2O-Al_2O_3-SiO_2-H_2O system at 25ºC and 1 atm.

From Garrels and Christ (1965)

Smectites vs. Kaolin Minerals

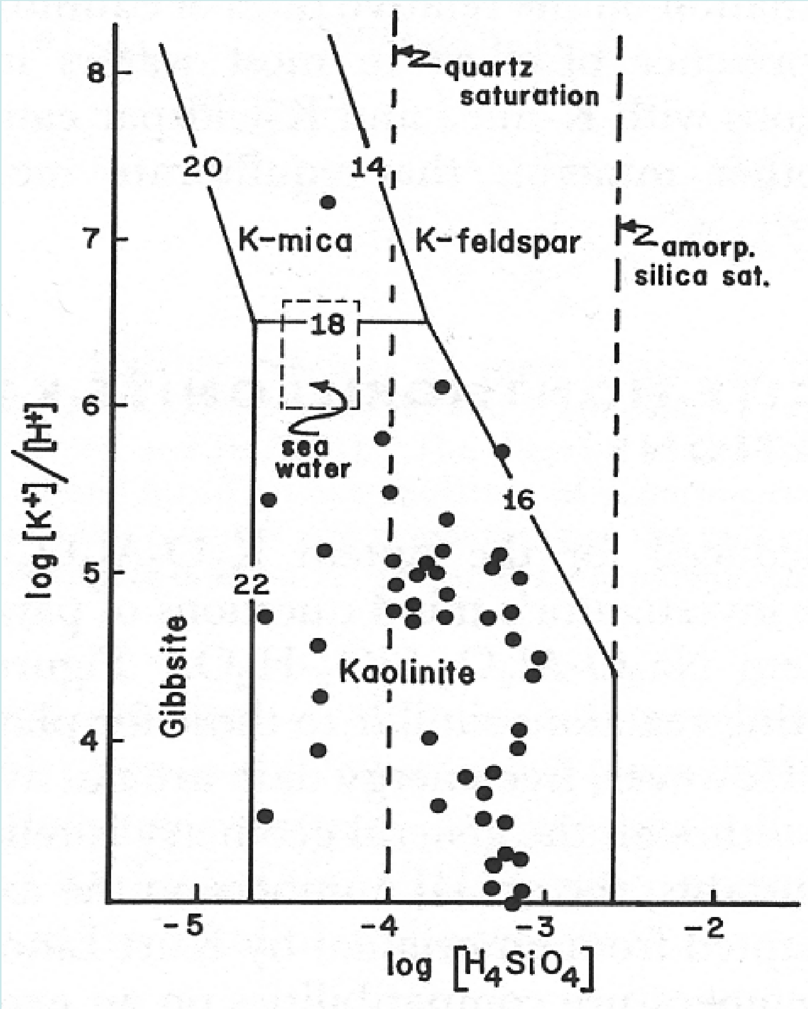
- Kaolin minerals form on Earth most commonly in tropical climates, usually under more-acidic conditions and with high water:rock ratios (i.e., well drained).



- But, they can form hydrothermally, accompanied by amorphous silica and TiO_2 minerals such as anatase.
- On Mars, a Ti-Si association has been considered to support acid-vapor alteration (Yen et al., 2007)—not a unique solution.

- Kaolinite stable at low pH, low K, and a(SiO_2) > qtz

- Mica stable at low a(SiO_2), med pH, and med-high K



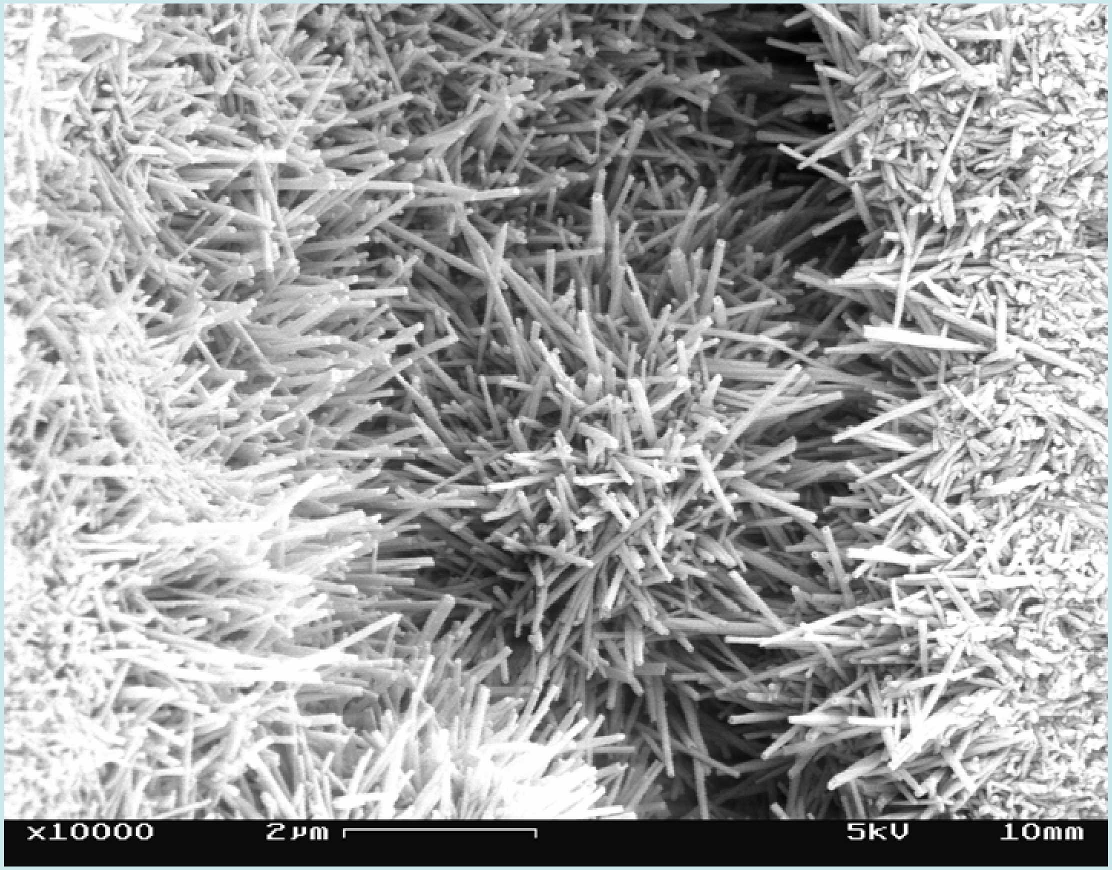
Stability phases in the K_2O-Al_2O_3-SiO_2-H_2O system at 25ºC/1 atm.

Solid circles represent of waters from arkosic sediments.

From Garrels and Christ (1965)

Halloysite vs. Kaolinite

Detection of 10Å hydrated halloysite, a more hydrated kaolin mineral, on Mars would imply that the mineral had never experienced dehydration after formation.

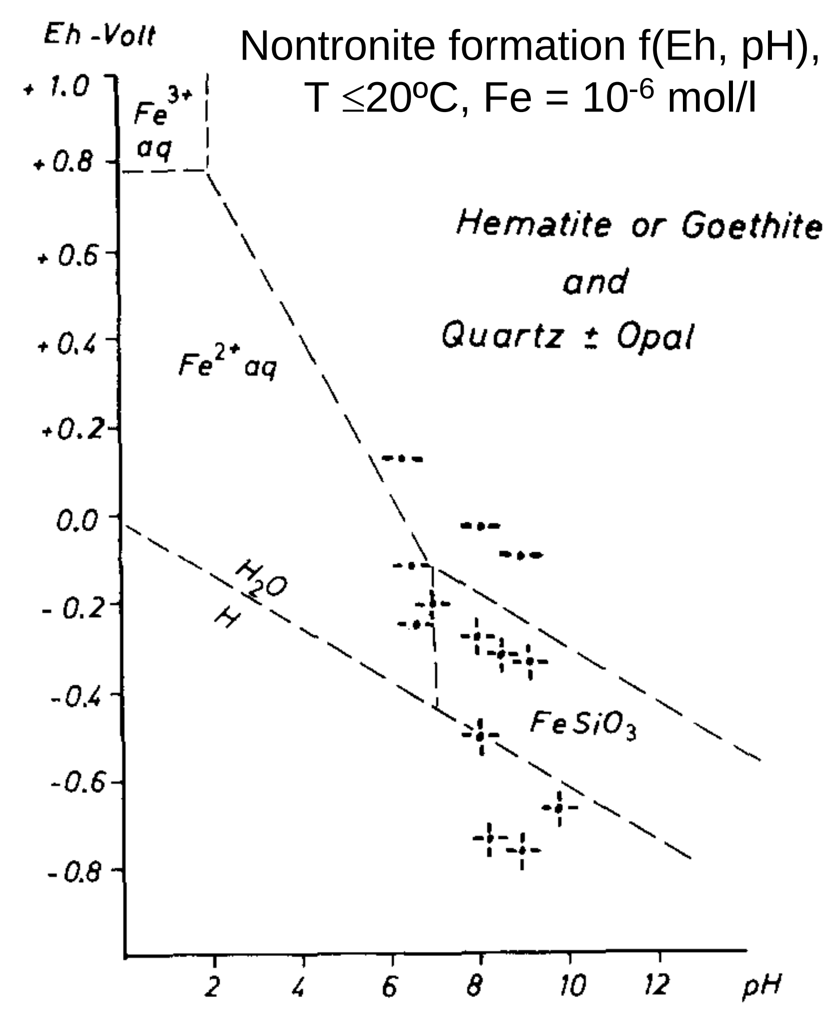


Halloysite implies very different formation processes than kaolinite.

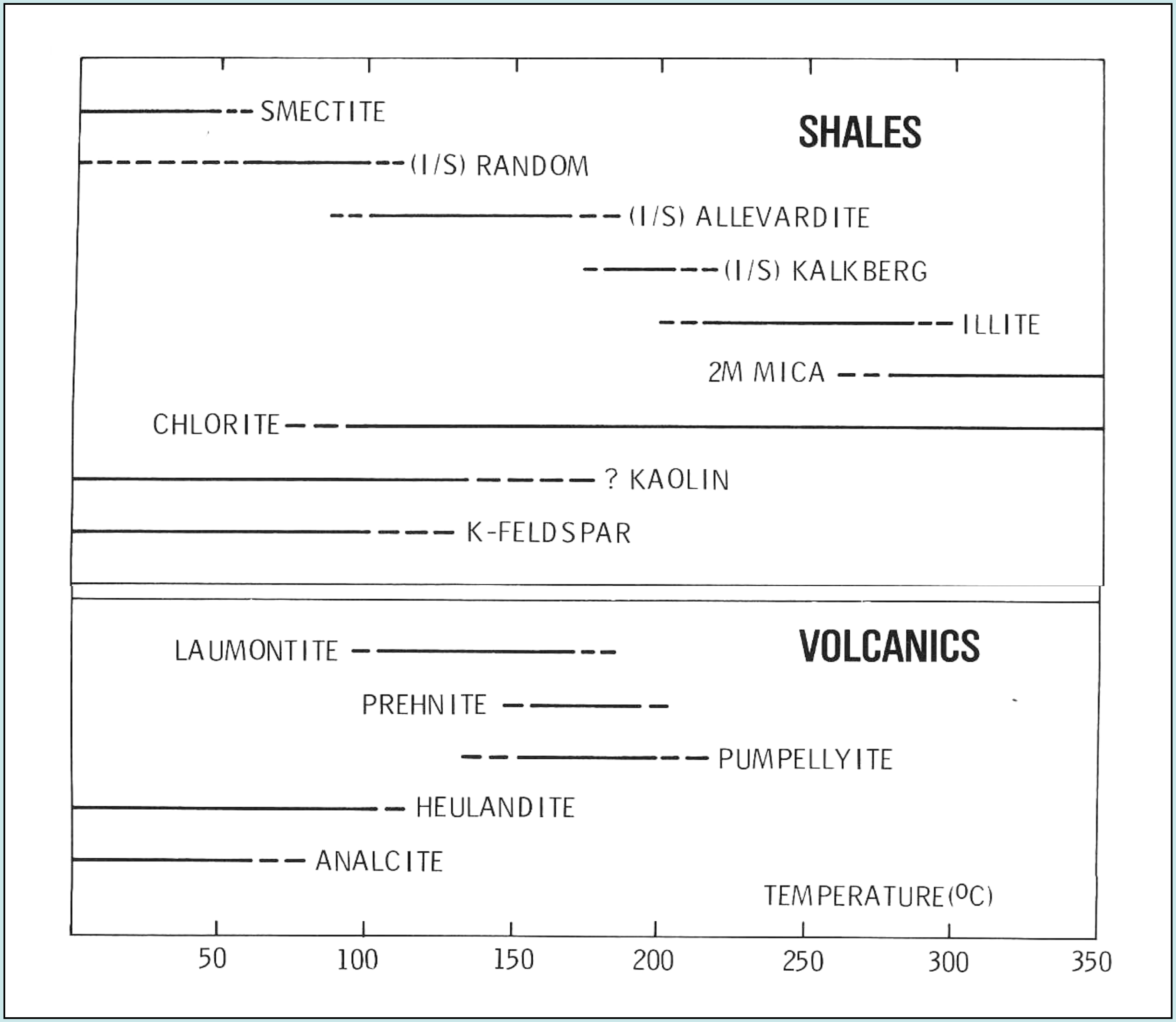
Nontronite on Mars

- Nontronite has long been speculated to occur on Mars and has been identified spectrally.

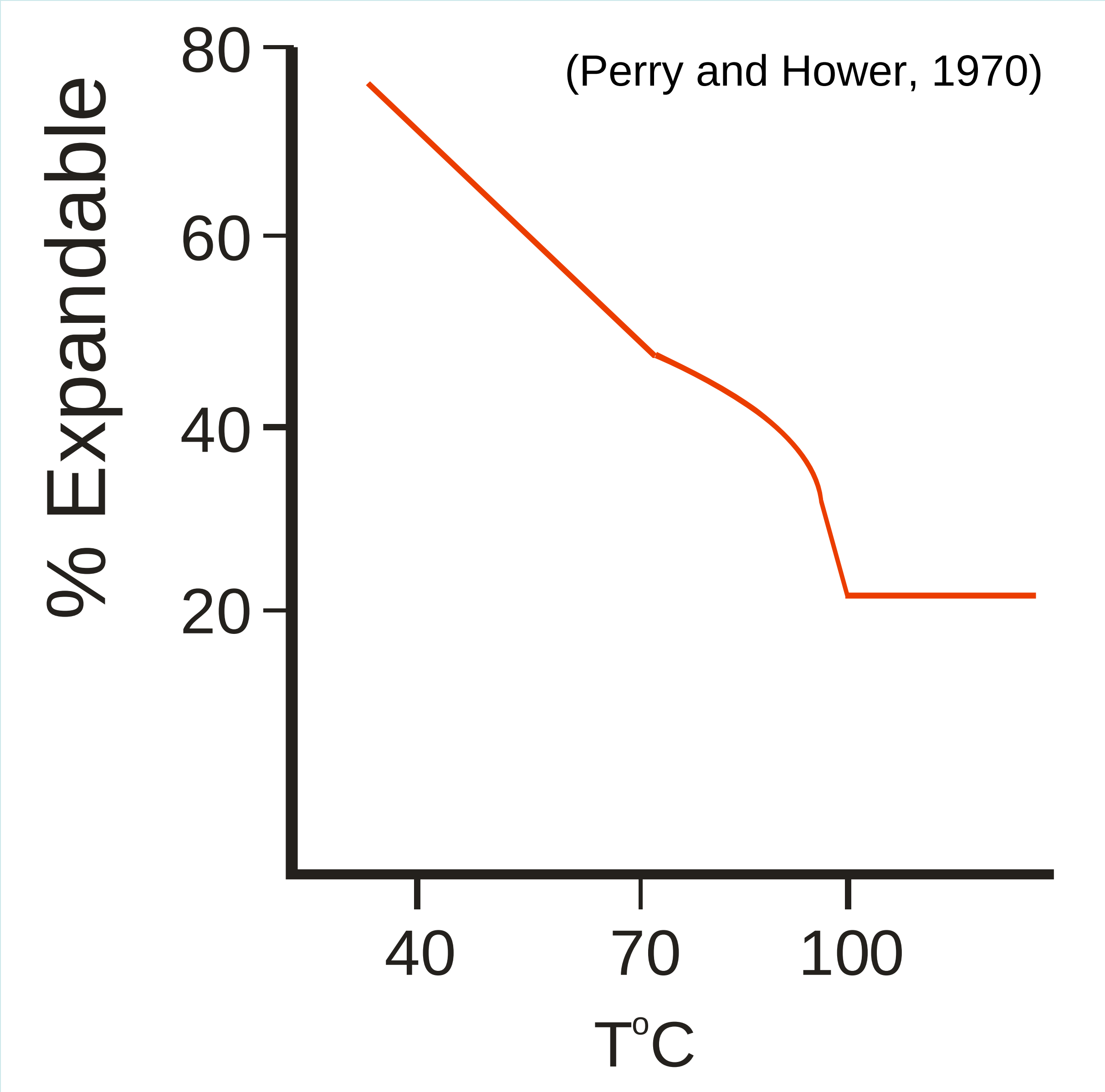
- Generally considered that nontronite forms at *low temperatures* under *reducing* conditions (where Fe is soluble).



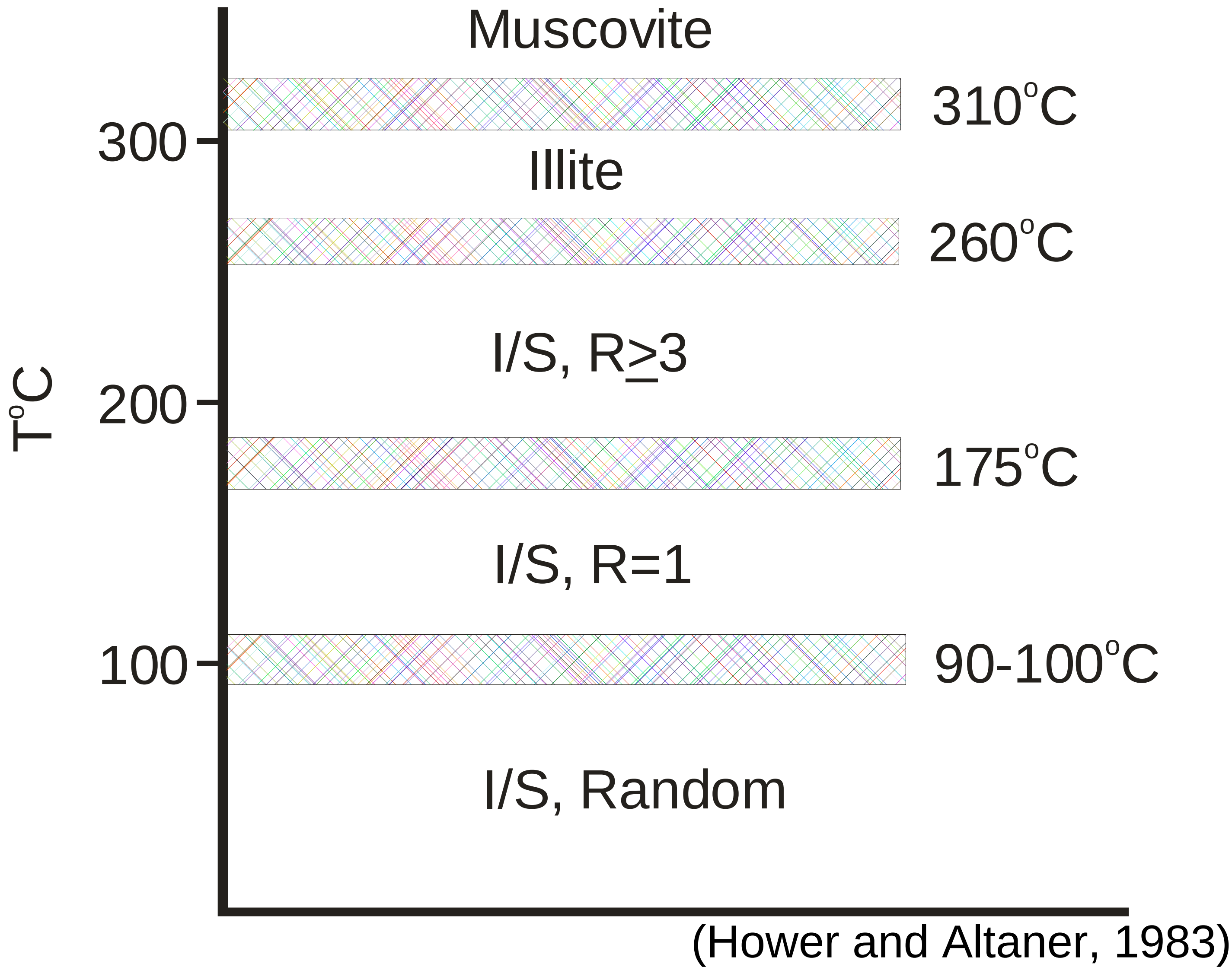
+ : nontronite formation; -•- : no formation
Stability fields from Garrels & Christ (1965)
(Harder, 1976).



Correlation of T-dependent mineral assemblages in shales and volcanic rocks (Hoffman and Hower, 1979)

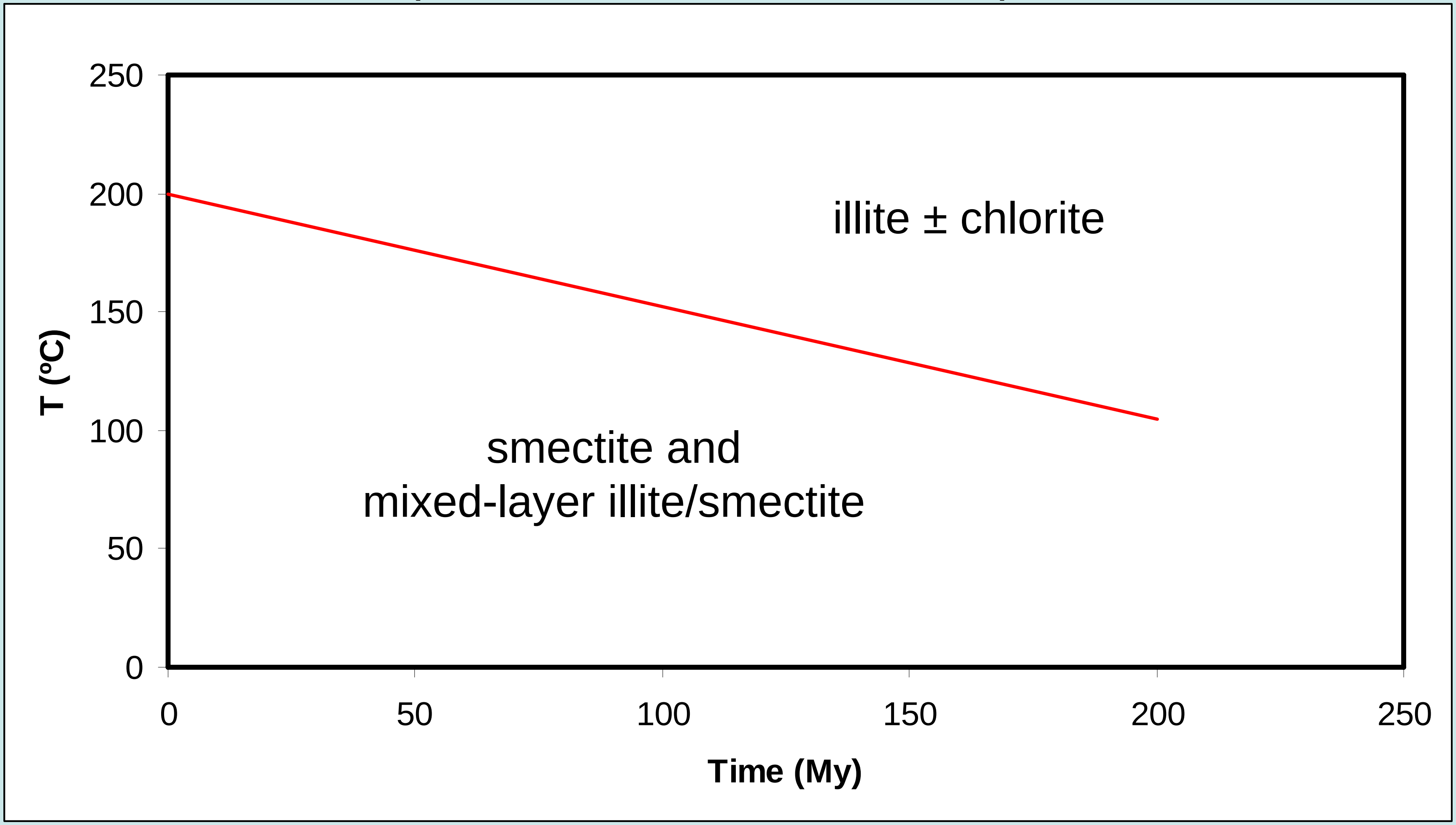


The occurrence of “higher-grade” clay minerals such as illite and illite/smectite would suggest the occurrence of diagenetic and low-grade metamorphic reactions.



Relationship between T and extent of smectite-to-illite reaction

Time-temperature limits on clay minerals (modified from Velde, 1992).



This figure implies that mixed-layer illite/smectites are not stable over long times even at low temperatures.

Long-Term Clay Mineral Stability on Mars

- Poorly ordered clay minerals (e.g., smectites and illite/smectites) do not occur in old rocks on Earth
  - often assumed that they gradually transform to more stable phases such as illite, micas, and chlorites.
- Discovery of smectites in Noachian terrains has important implications for the long-term stability of clay minerals and suggests an alternative hypothesis
  - tectonic activity on Earth eventually results in the progressive alteration of low-temperature minerals to higher-temperature assemblages.
- Smectites on Mars in rocks >3 Gya would rewrite our understanding of clay mineral stability
  - in the absence of (plate) tectonic activity, "metastable" clay minerals may be "stable" for times on the order of the age of the planet.

Summary

- **The occurrence of clay minerals ⇒ aqueous alteration has occurred.**
- **Specific clay minerals can put limits on the conditions of mineral formation, e.g.,**
  - **–kaolin ⇒ high water:rock, low pH**
  - **–zeolites ⇒ low water:rock, closed system, high pH**
  - **–smectites ⇒ open system, med pH, I/S ⇒T**
- **ID of “old” smectites on Mars can rewrite our understanding of clay stability.**
- **Clay mineralogy can clarify alteration mechanisms—the *entire* mineral assemblage can greatly constrain processes responsible for today’s martian mineralogy.**

Cheto bentonite