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When worlds collide: Asbestos analysis in the regulatory, health, and mineralogical communities

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What is a mineral?

- Naturally occurring
- Definite (but not fixed) chemical composition
- Definite crystal structure and atomic arrangement
- Homogeneous solid (cannot be further broken down)

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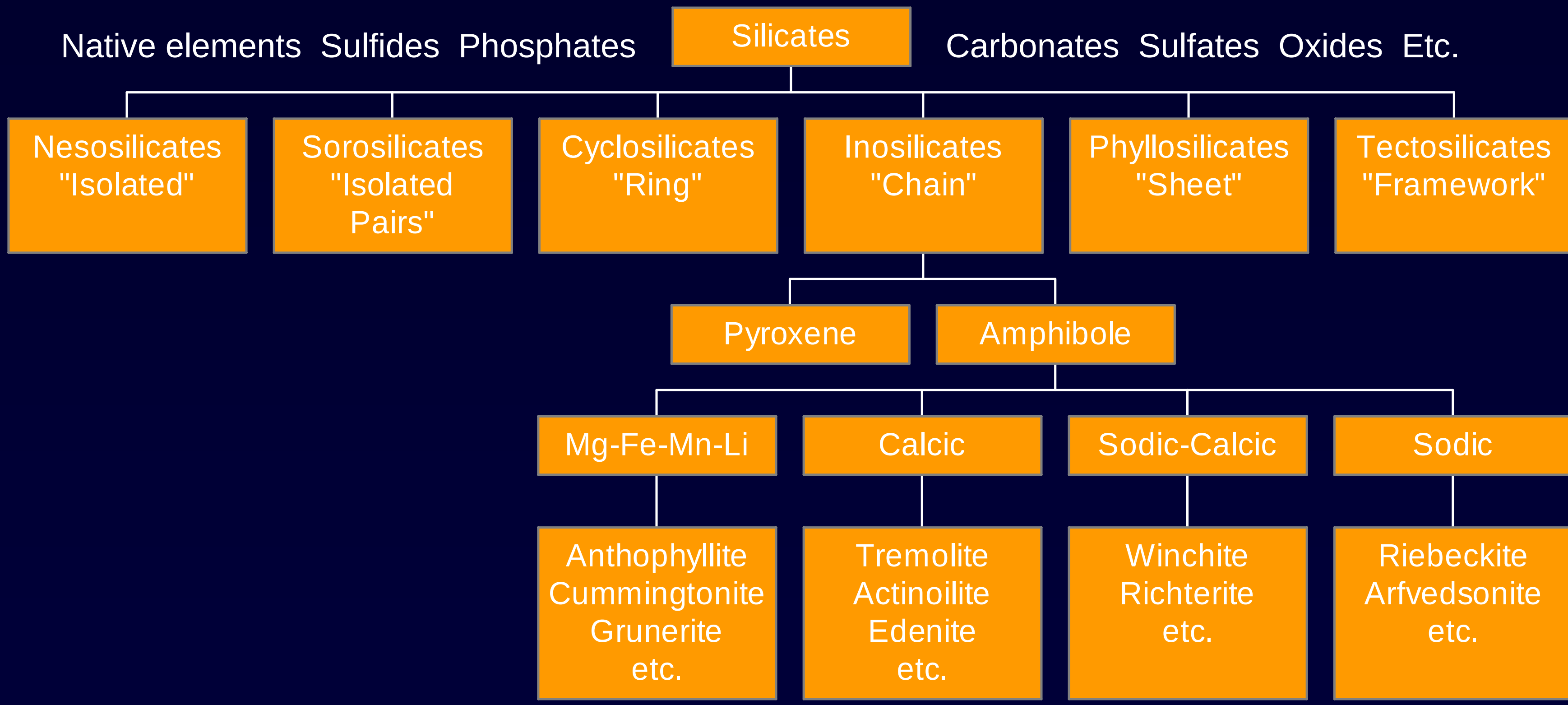
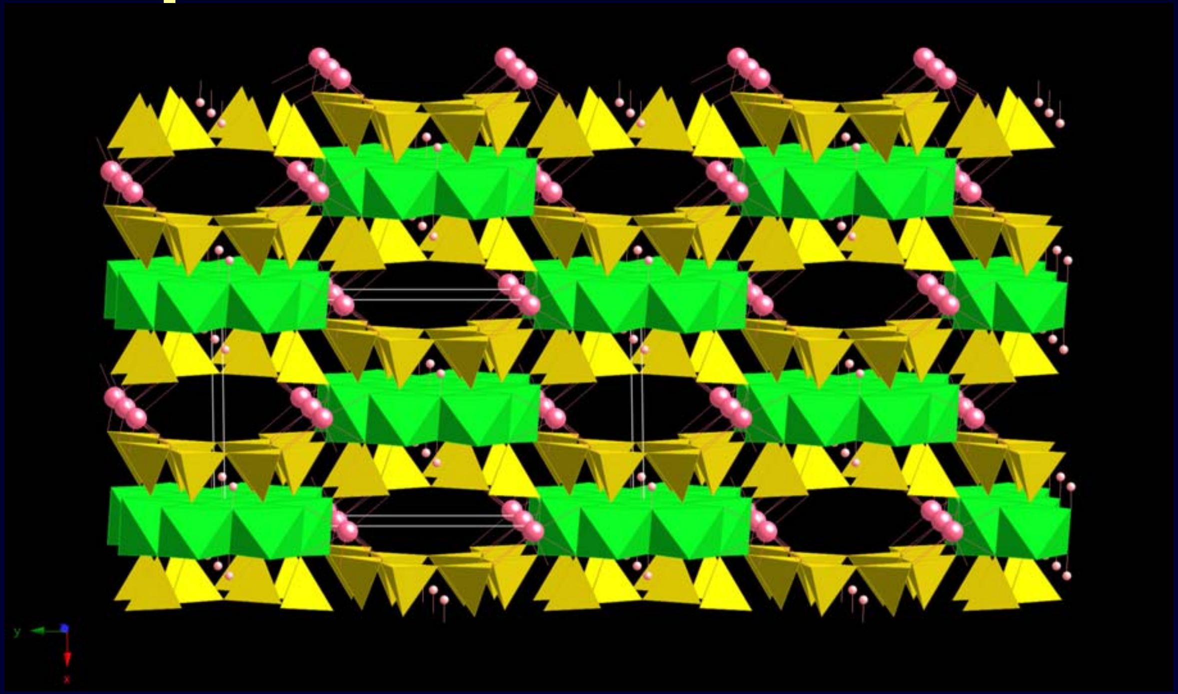
Klein and Hurlbut (1993) Manual of Mineralogy

Mineral Groups



International Mineralogical Association (IMA) Amphibole Nomenclature



- $AB_2C_5T_8O_{22}(OH,F,Cl)_2$ (General Formula)
- A = K, Na
- B = Na, Ca, Mn^{2+}, Fe^{2+}, Mg, Zn, Ni, Co
- C = Mn^{2+}, Fe^{2+}, Mg, Al, Fe^{3+}, Ti^{4+}, Zr^{4+}, Mn^{3+}, Cr^{3+}
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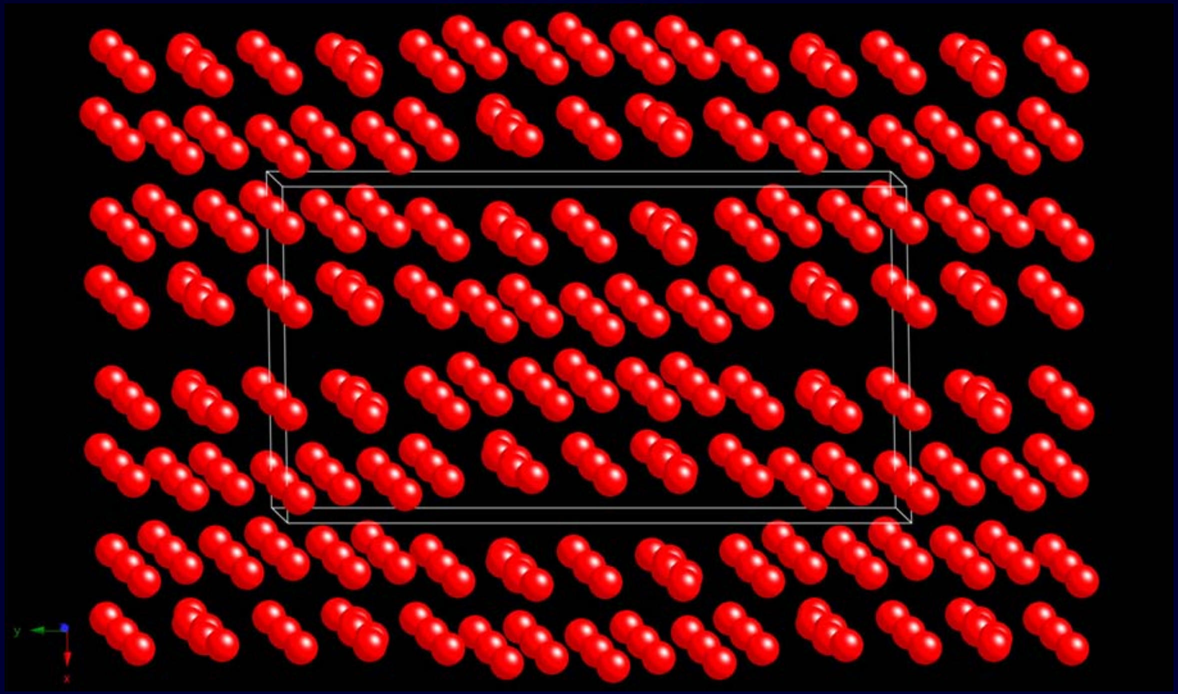
IMA Amphibole Nomenclature



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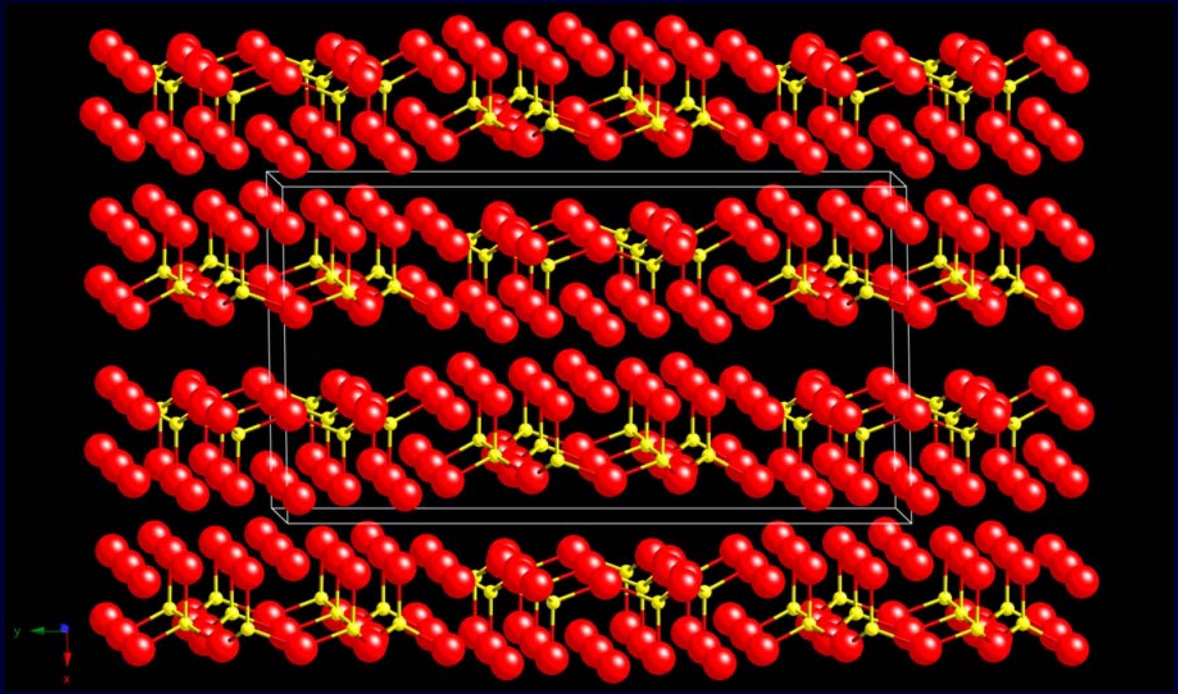

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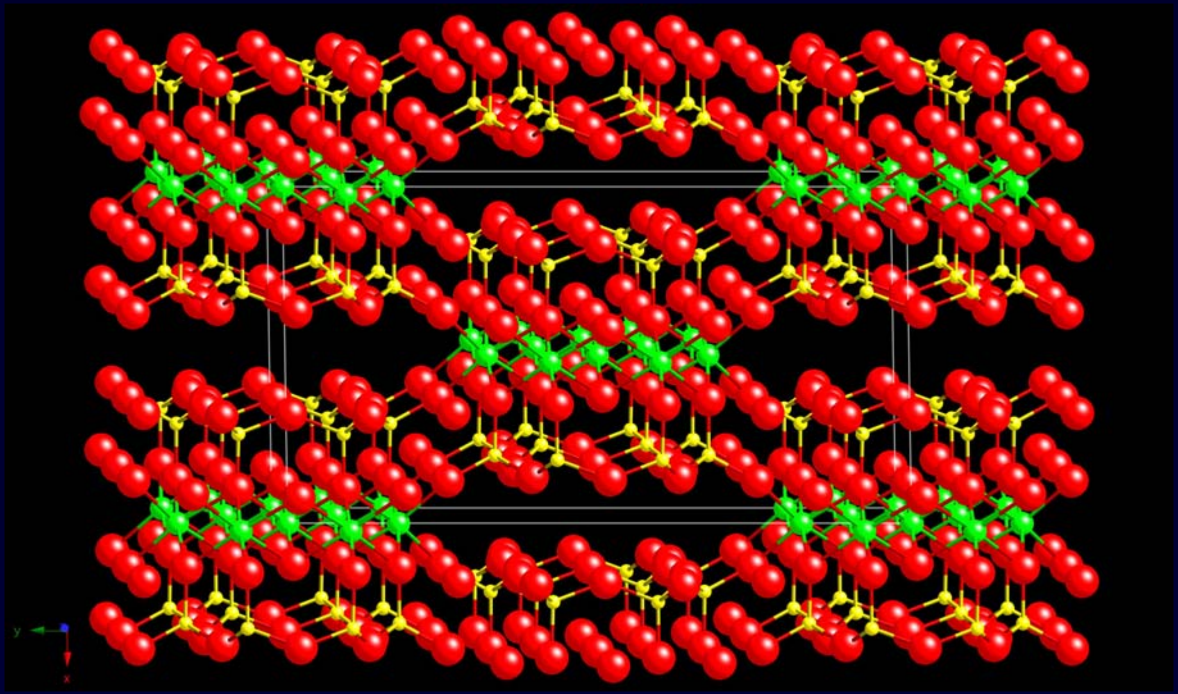

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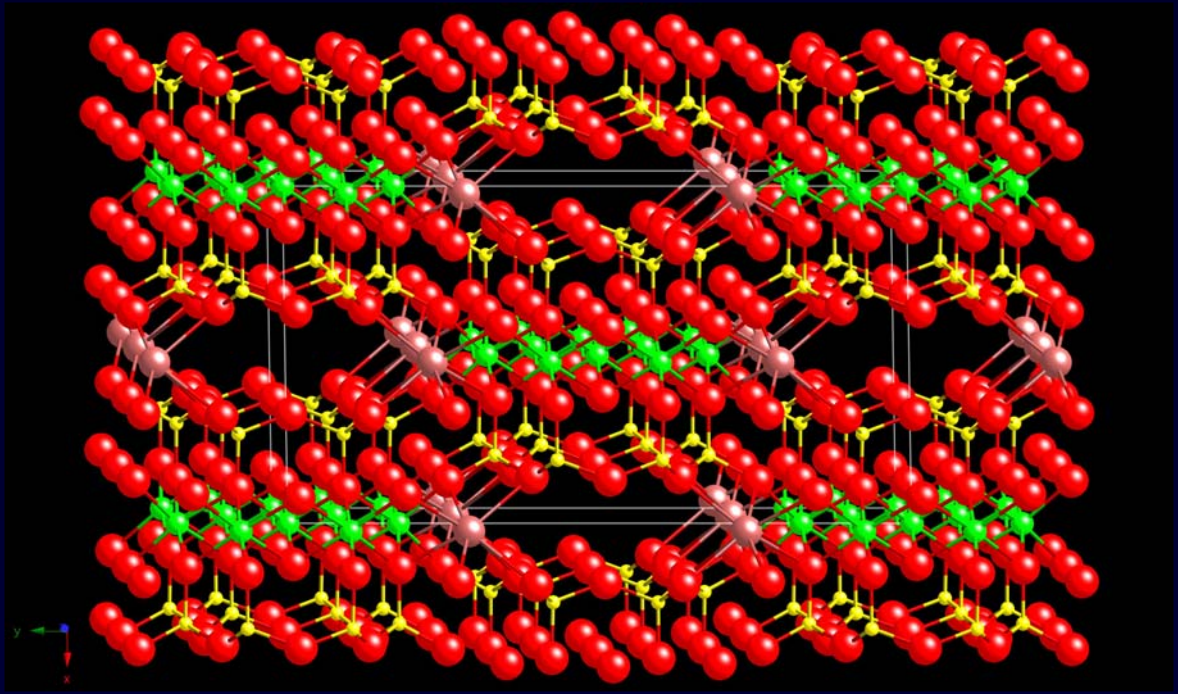

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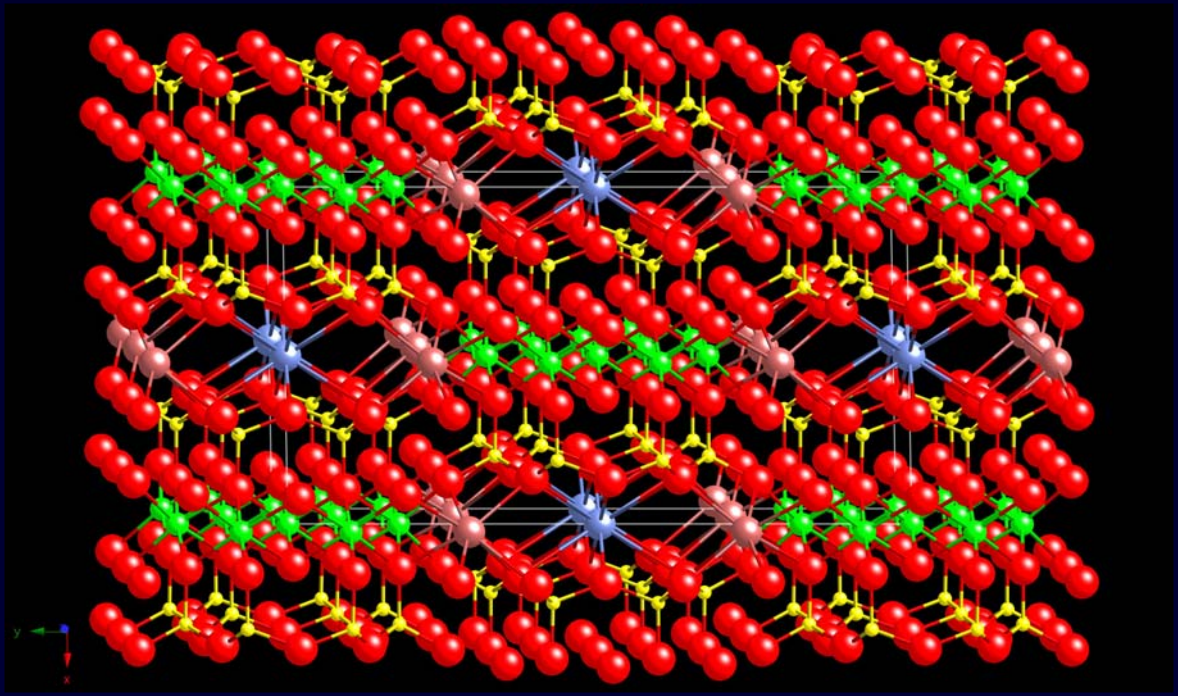

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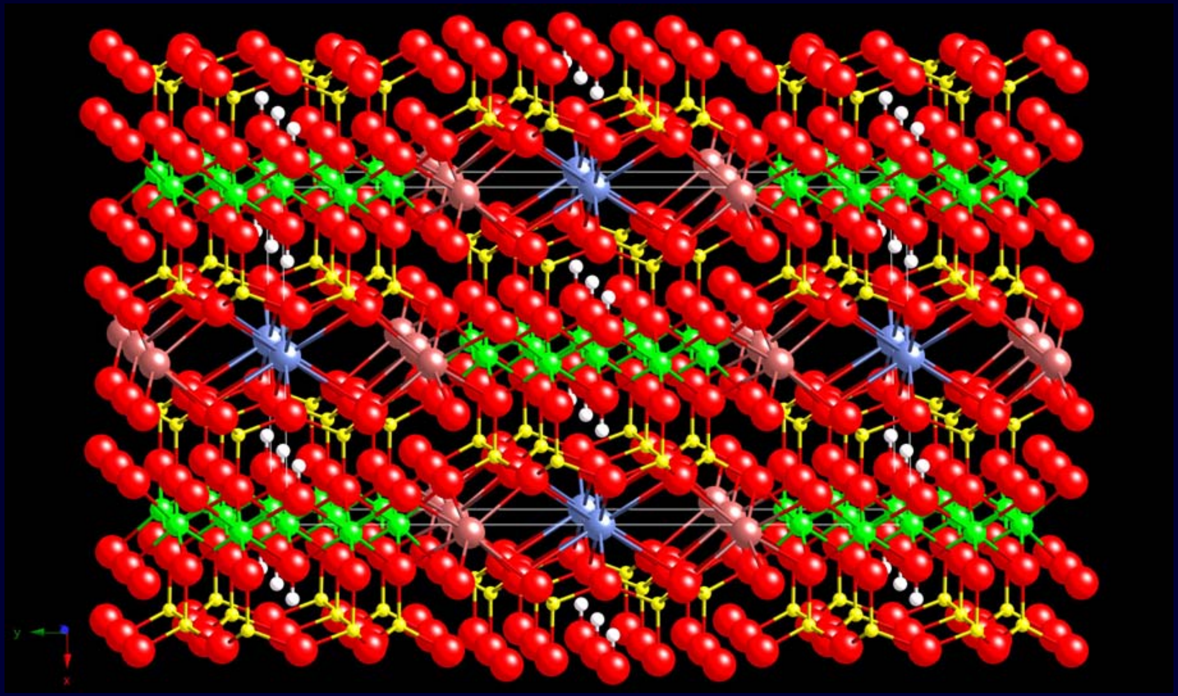

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How do analysts/mineralogists assign a name to an amphibole mineral?

Optical properties

Crystal structure

Chemical properties

Amphibole nomenclature for mineralogists

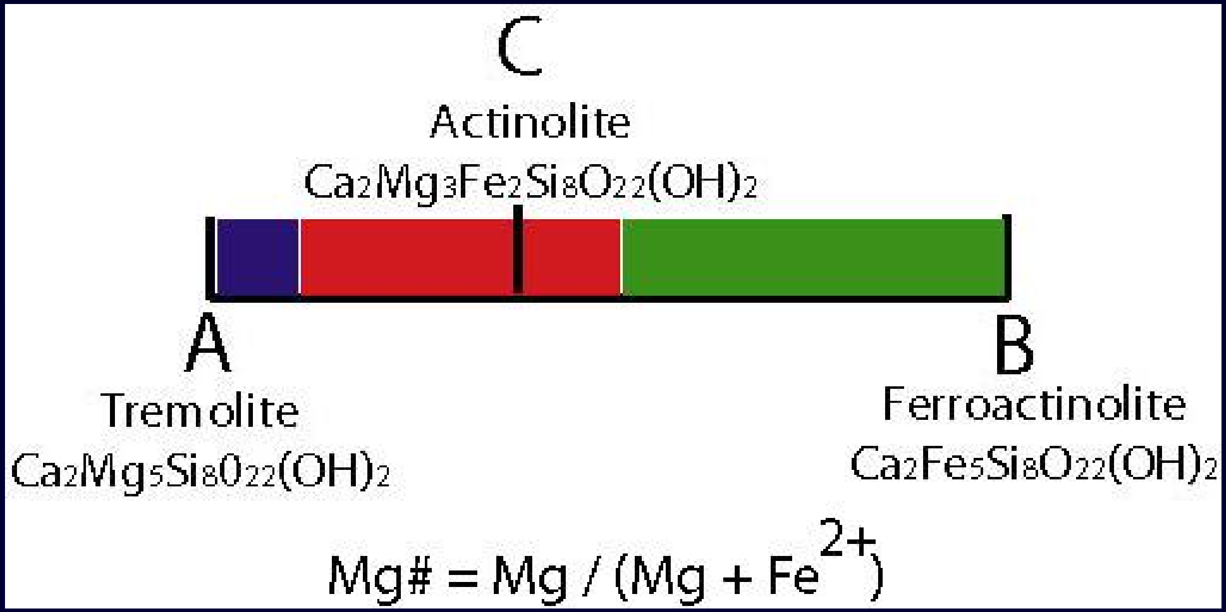
Prior to 1978 over 200 amphibole names due to small variations in chemistry of endmembers. The current nomenclature of 1978 and 1997 has been reduced to ~75 endmembers.

- **Leake (1978)**
- **Leake et al. (1997)**
- **Leake et al. (2004)**
  - **Added 5th group based on analyses of Li**
- **Hawthorne and Oberti (2006)**
  - they suggested a different approach to amphibole classification based on the *dominant cation* (or *group of cations*) rather than on a specific number of cation(s)
- **Hawthorne and Oberti (2007)**
  - "In particular, it must be realized that all communities (crystallographers, mineralogists, petrologists, geochemists) must relax their requirements in order for a consensus to emerge with regard to amphibole classification"

Amphibole Asbestos Nomenclature

Industry	vs.	Mineralogy
▪ Chrysotile	⇒	Clinochrysotile
		Orthochrysotile
▪ Amosite	⇒	Cummingtonite-asbestos
	⇒	Grunerite-asbestos
▪ Anthophyllite-asbestos	⇒	Anthophyllite-asbestos
▪ Crocidolite	⇒	Riebeckite-asbestos
▪ Tremolite-asbestos	⇒	Tremolite-asbestos
▪ Actinolite-asbestos	⇒	Actinolite-asbestos

Solid Solution



- **In a simple solid solution, 1 dimension can describe all compositions that may exist. A and B are endmembers and C is a solid solution composition between these endmembers.**
- **For amphiboles, to completely describe all possible solid solutions (substitutions) at least 4 dimensions are needed.**

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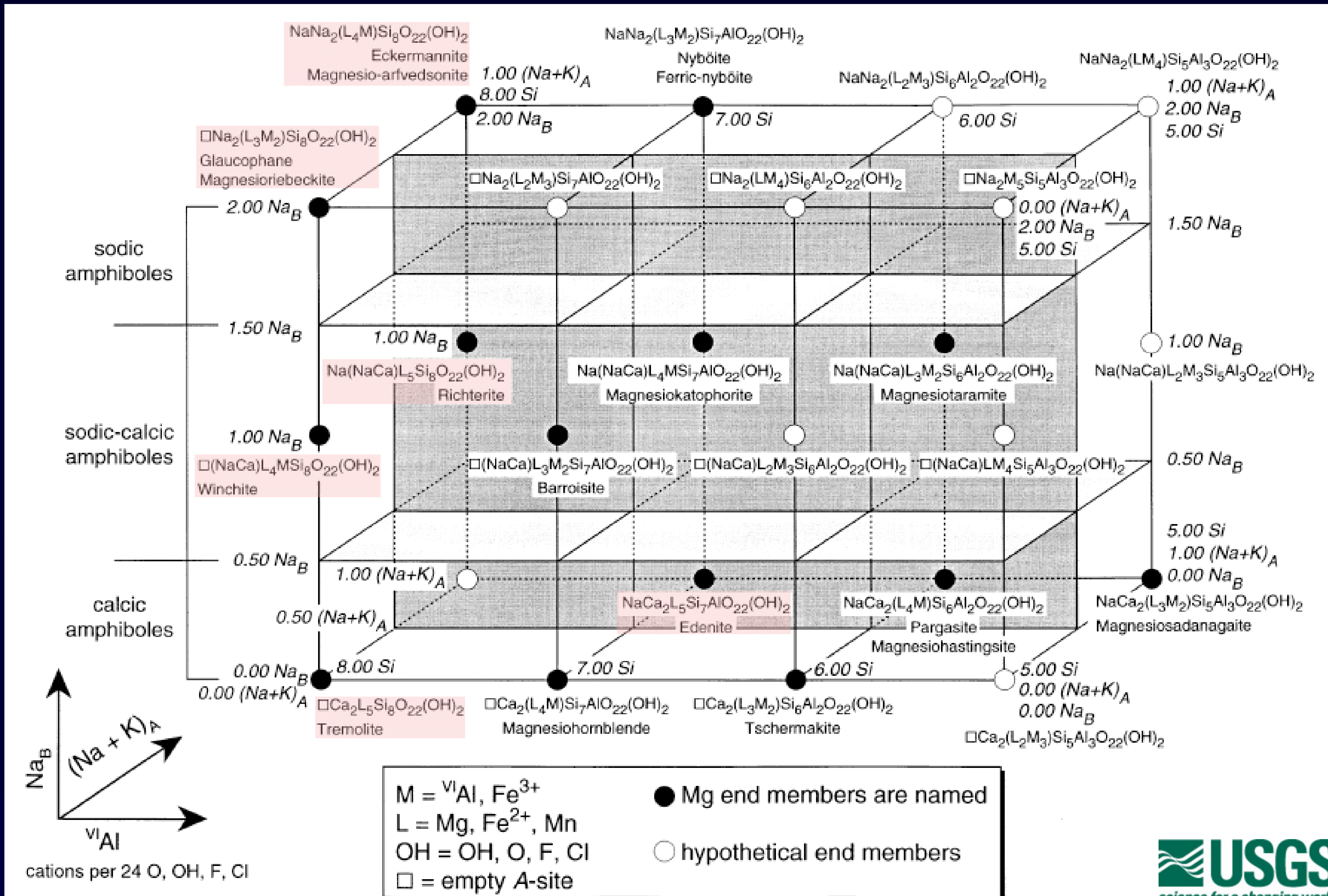
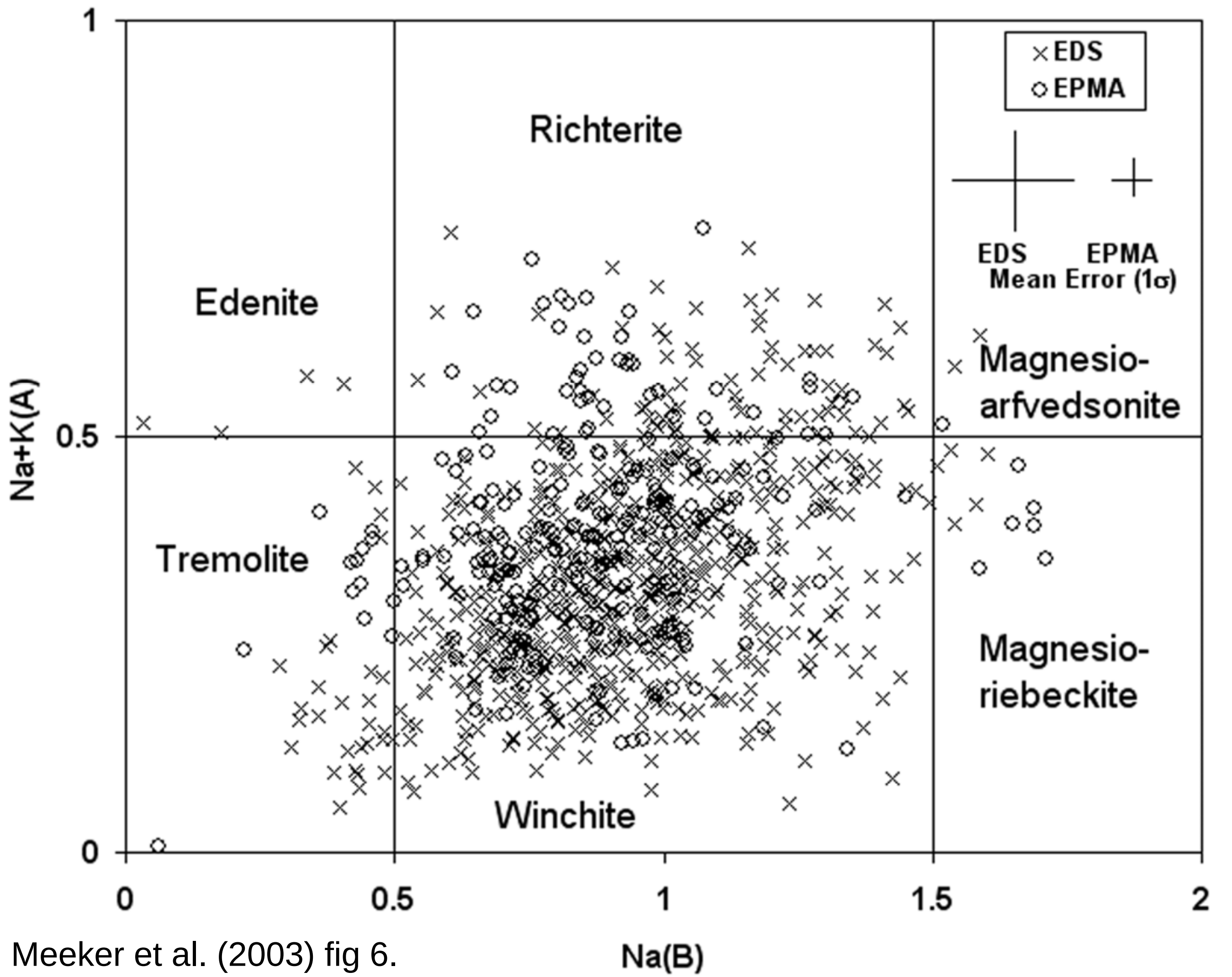
Amphibole Solid Solution in 3-D

The endmembers shaded pink are those identified or tentatively identified at Libby, MT.

Diagram from Leake et al. (1997) American Mineralogist, v. 82, p. 1019-1037



Libby Amphiboles, Leake et al. (1997) nomenclature



Meeker et al. (2003) fig 6.

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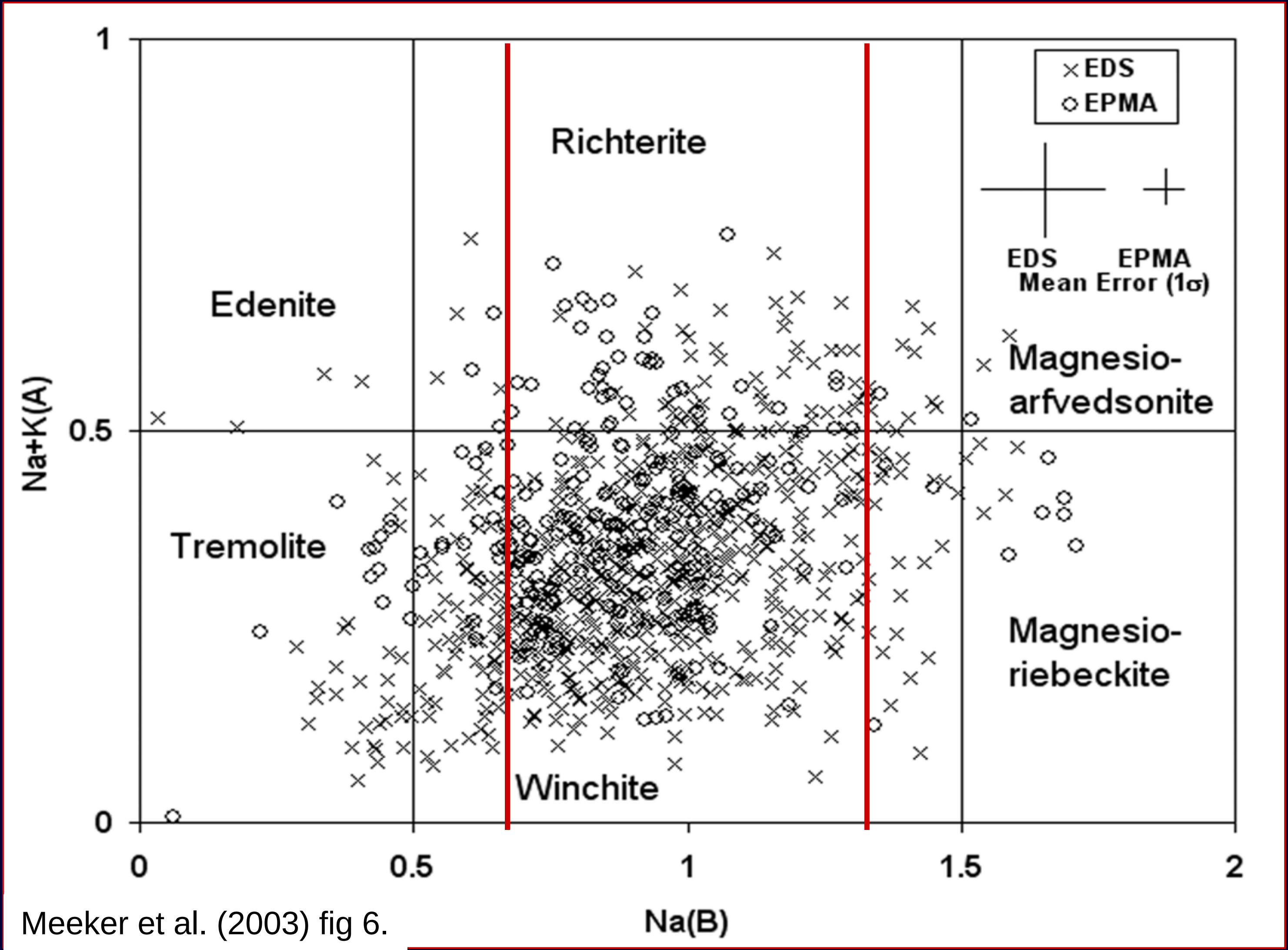
Libby Amphiboles, Leake 1978 nomenclature (red)



Meeker et al. (2003) fig 6.

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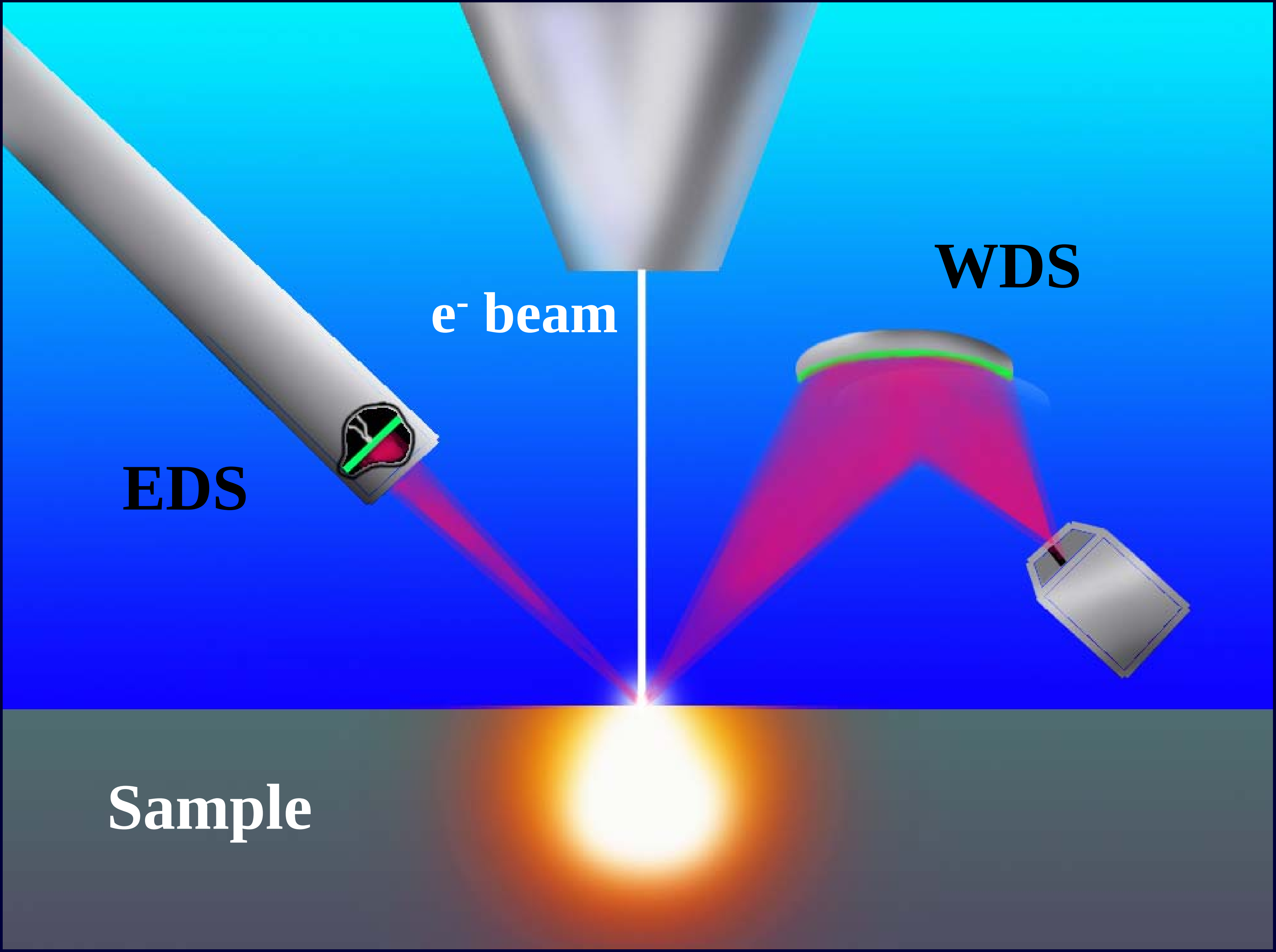
WDS
e^- beam
EDS
Sample

Sources of error for EDS analysis of particles

- Counting statistics
- Instrument error
- Na & K loss
- Fe oxidation state
- Matrix corrections or lack thereof
- Secondary fluorescence from other materials
- Calibration or lack thereof
- Particle geometry
- Operator inexperience

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Errors Associated with Analysis and the Effects on Nomenclature

- Inability to precisely determine Fe^{3+}/Fe^{2+} using EDS and (or) optical microscope techniques
- Inherent errors associated with EDS techniques on unpolished structures (count times, count rates, standards, instrument drift, particle morphology, volatile loss, etc.) can lead to errors as large as ±20% or more in the measurement of specific elements.

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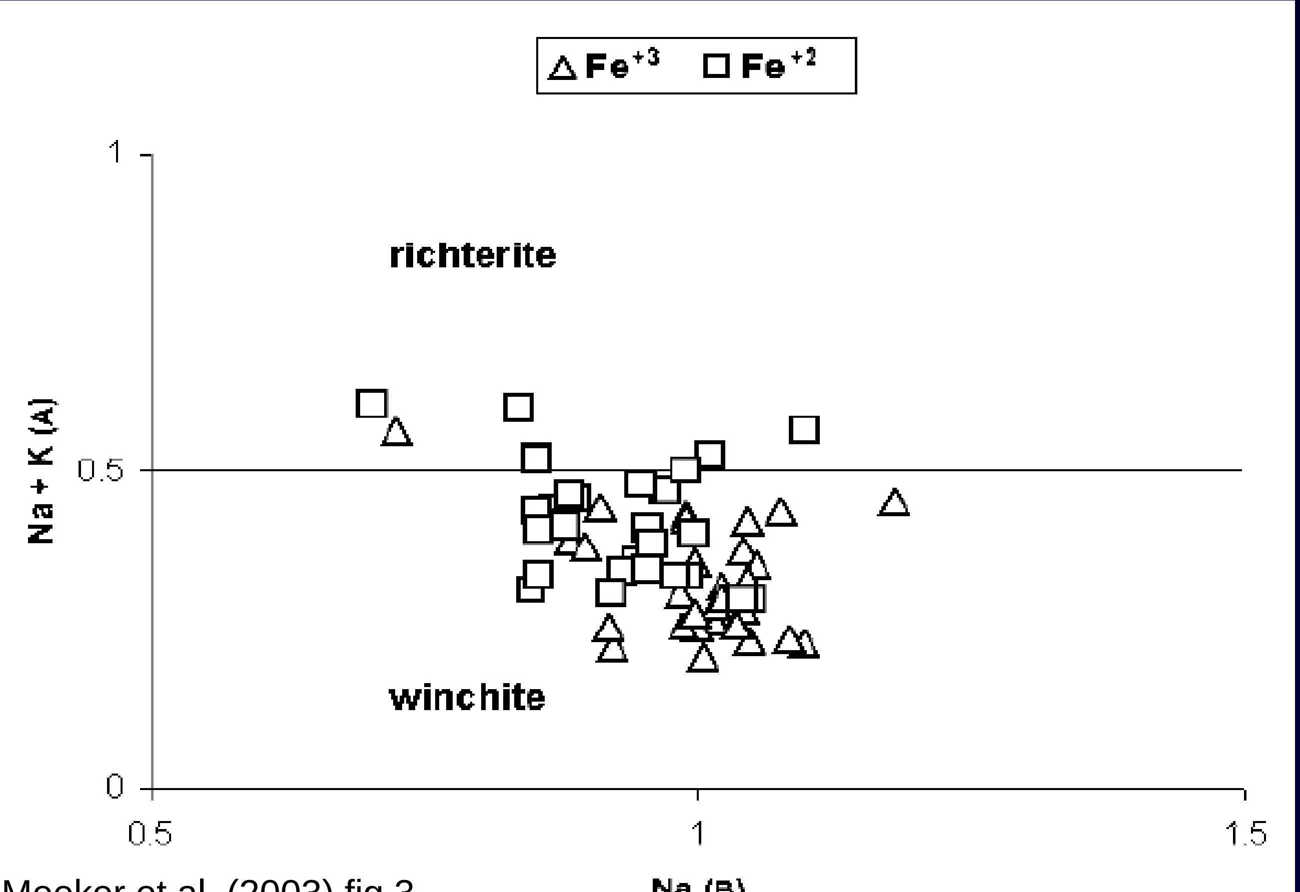
Fe^{3+} vs Fe^{2+} calculations



Meeker et al. (2003) fig 3.

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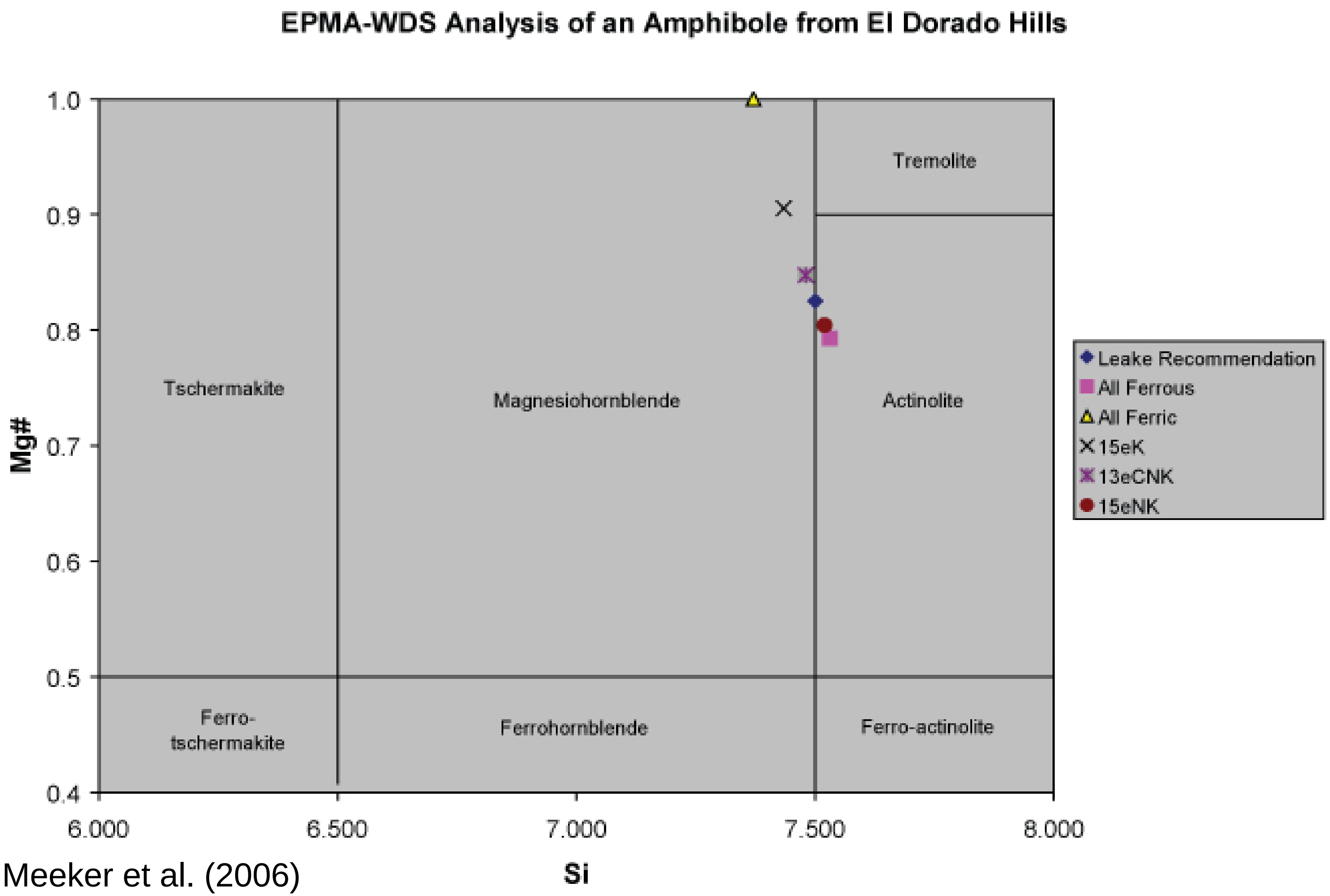
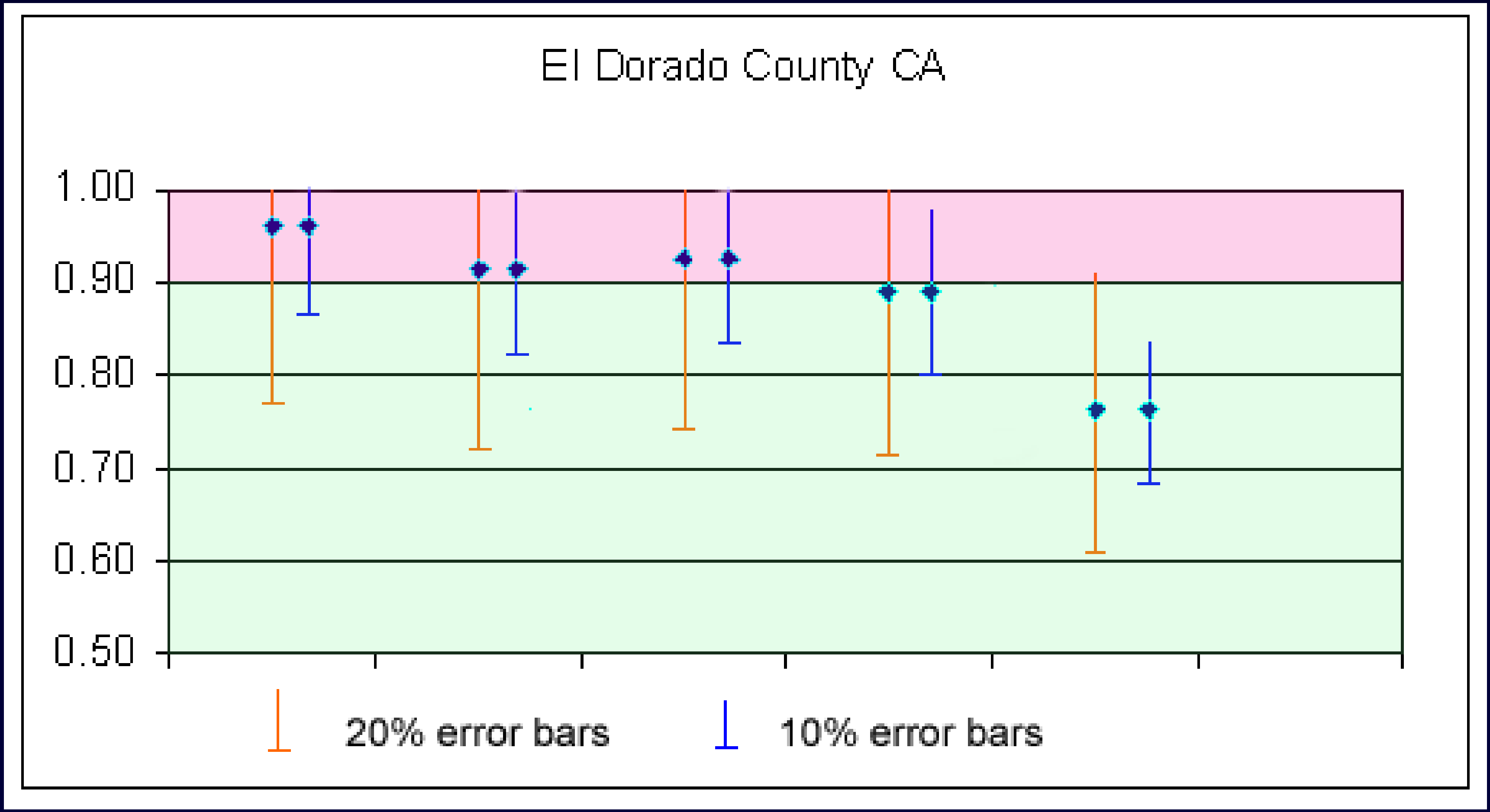
Fe^{3+} vs Fe^{2+} calculations



Meeker et al. (2006)

Tremolite-Actinolite Relative error in Mg#



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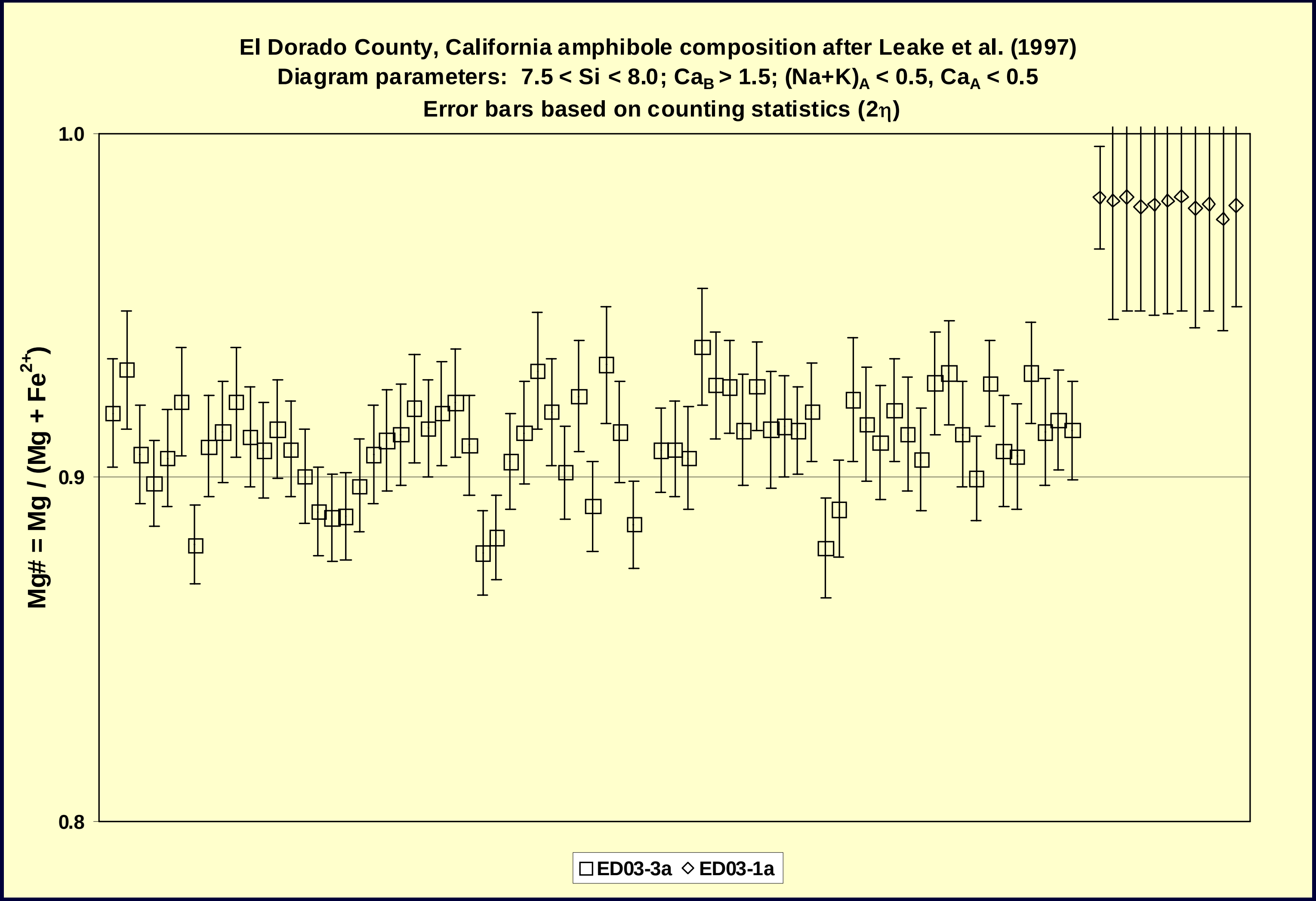
Tremolite-Actinolite Relative error in Mg#



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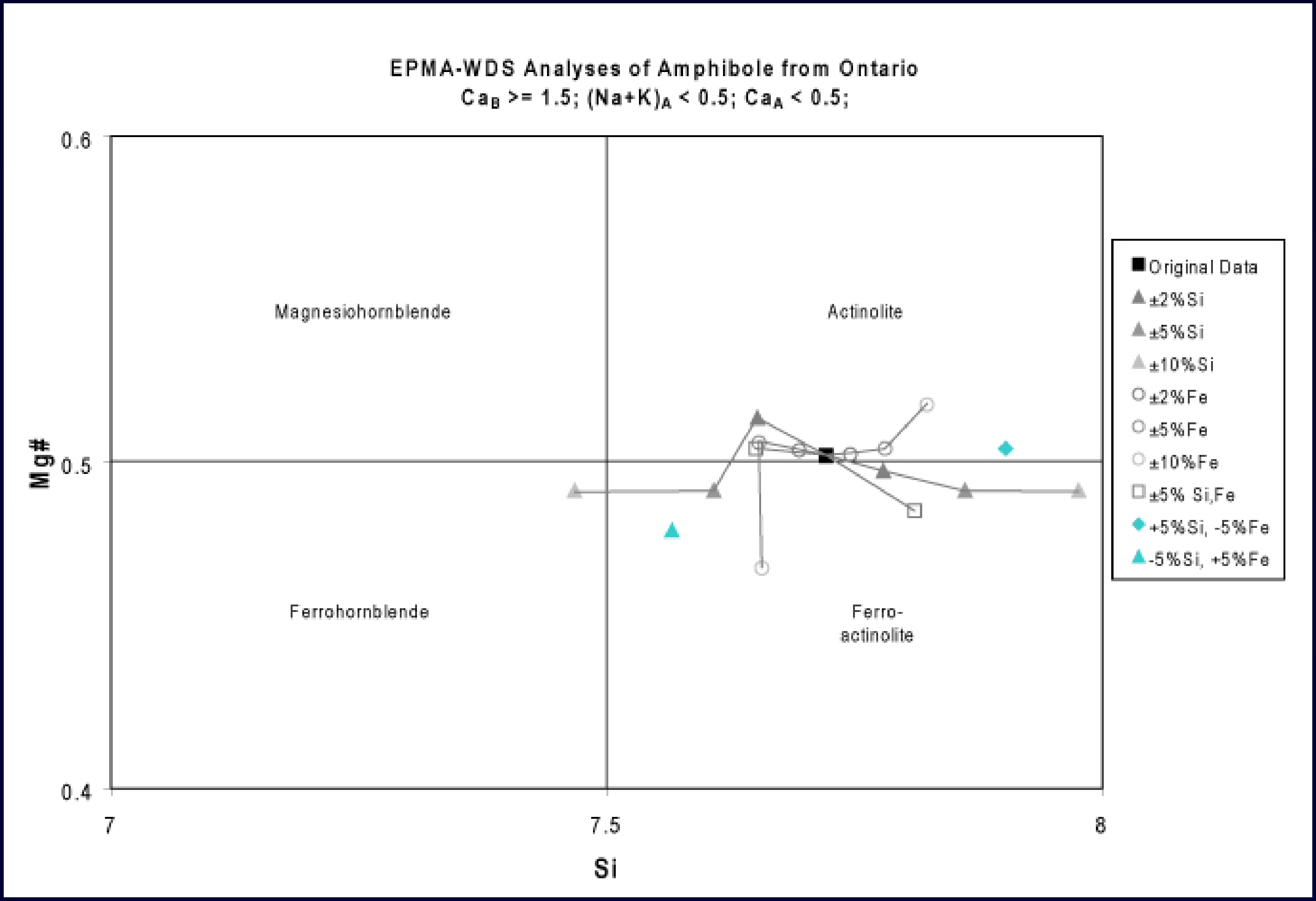
Actinolite-ferroactinolite: Relative errors in Fe and Si



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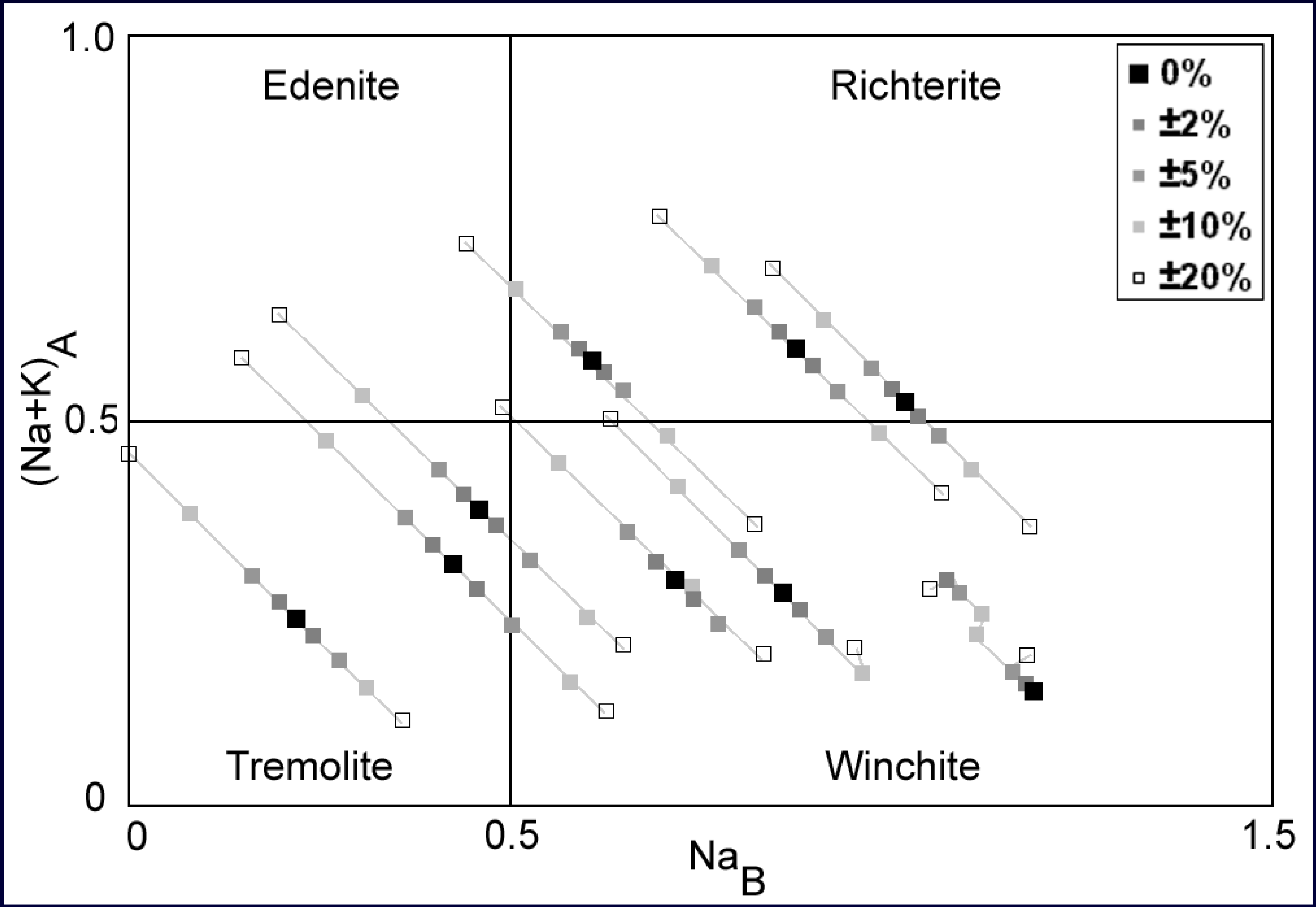
Analytical Relative Error in Ca



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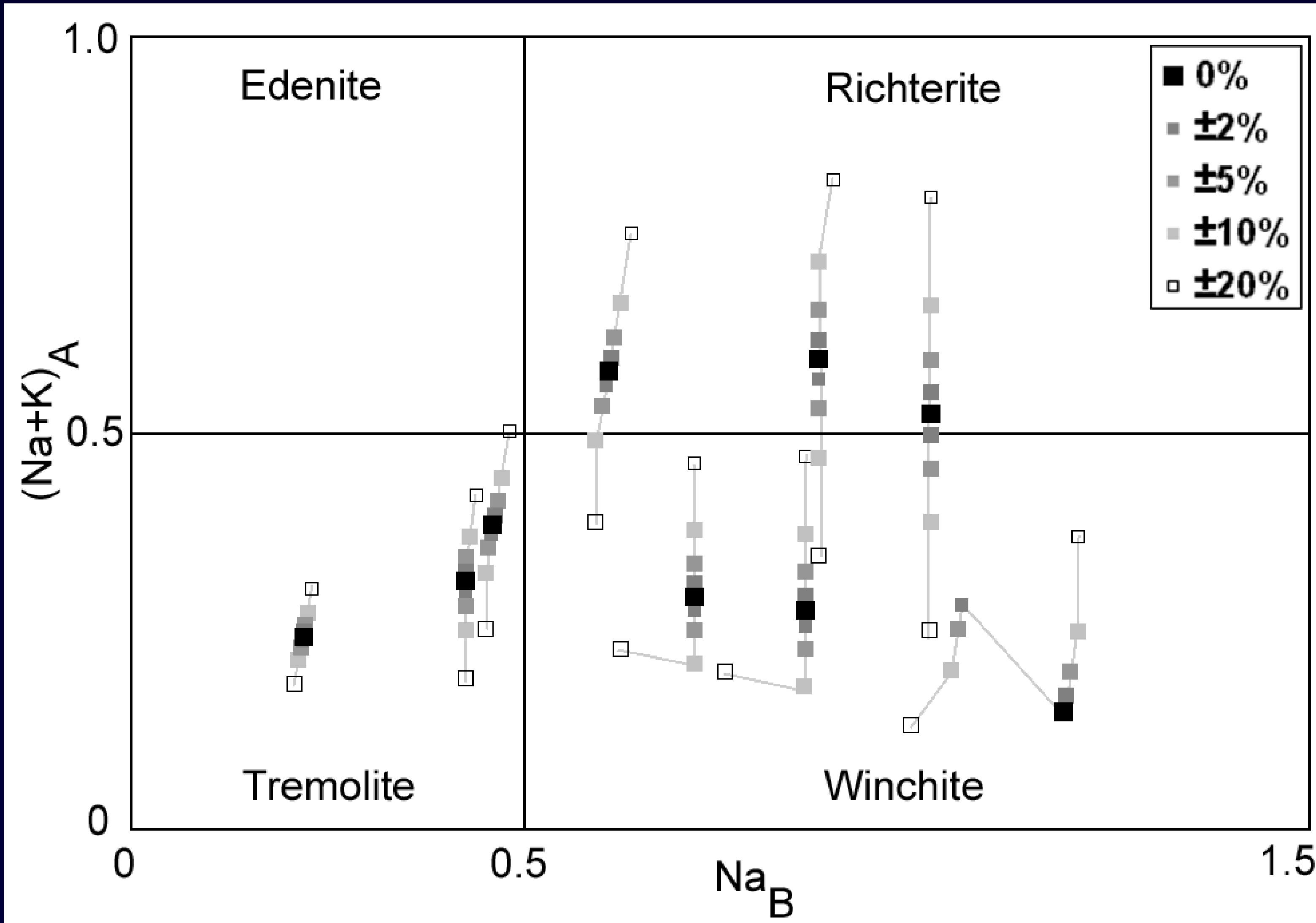
Analytical Relative Error in Na



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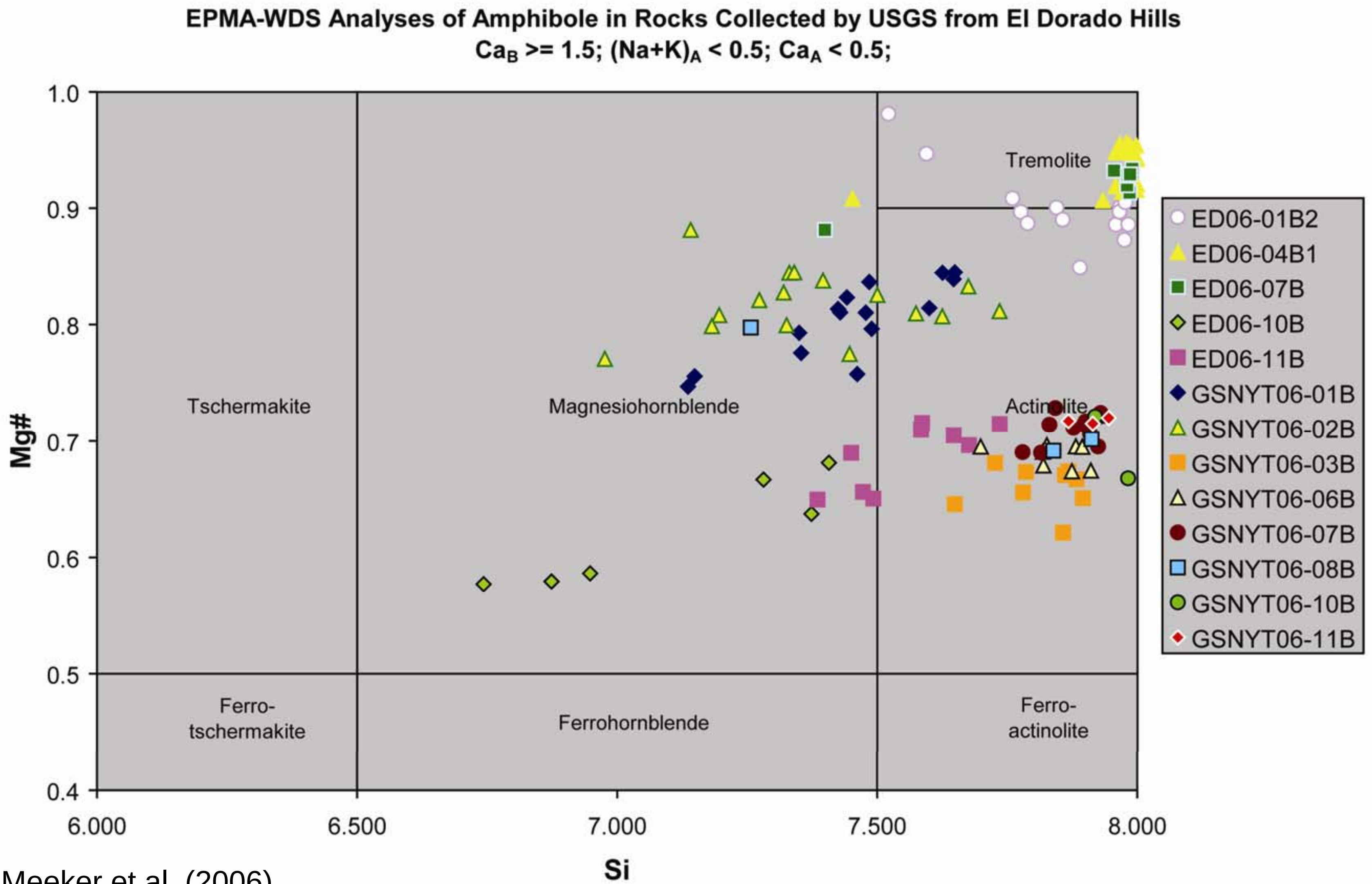
Meeker and Lowers, Microscopy & Microanalysis, 2004



Meeker et al. (2006)

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Particle geometry effects

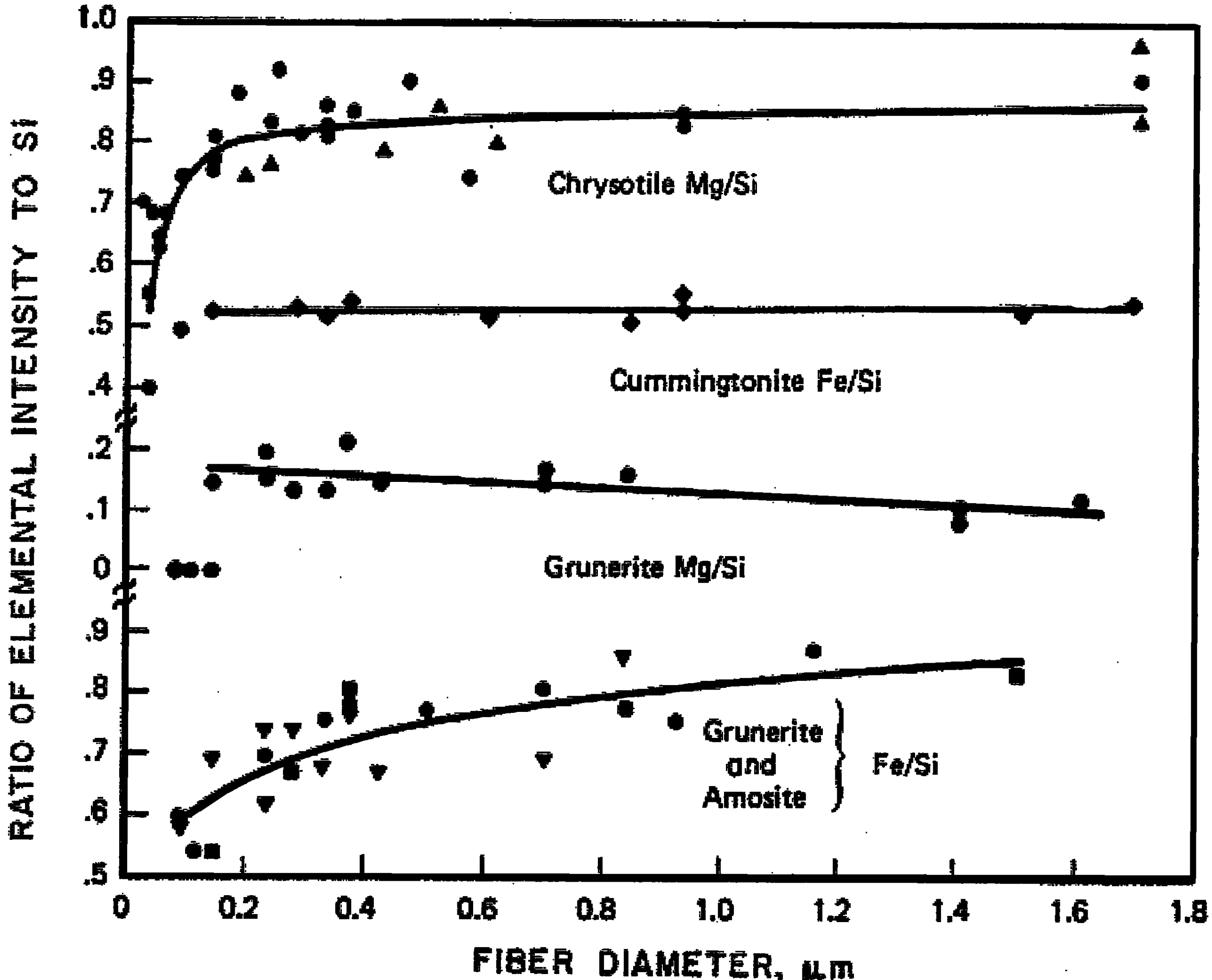

Figure 34 from Campbell et al. (1977)

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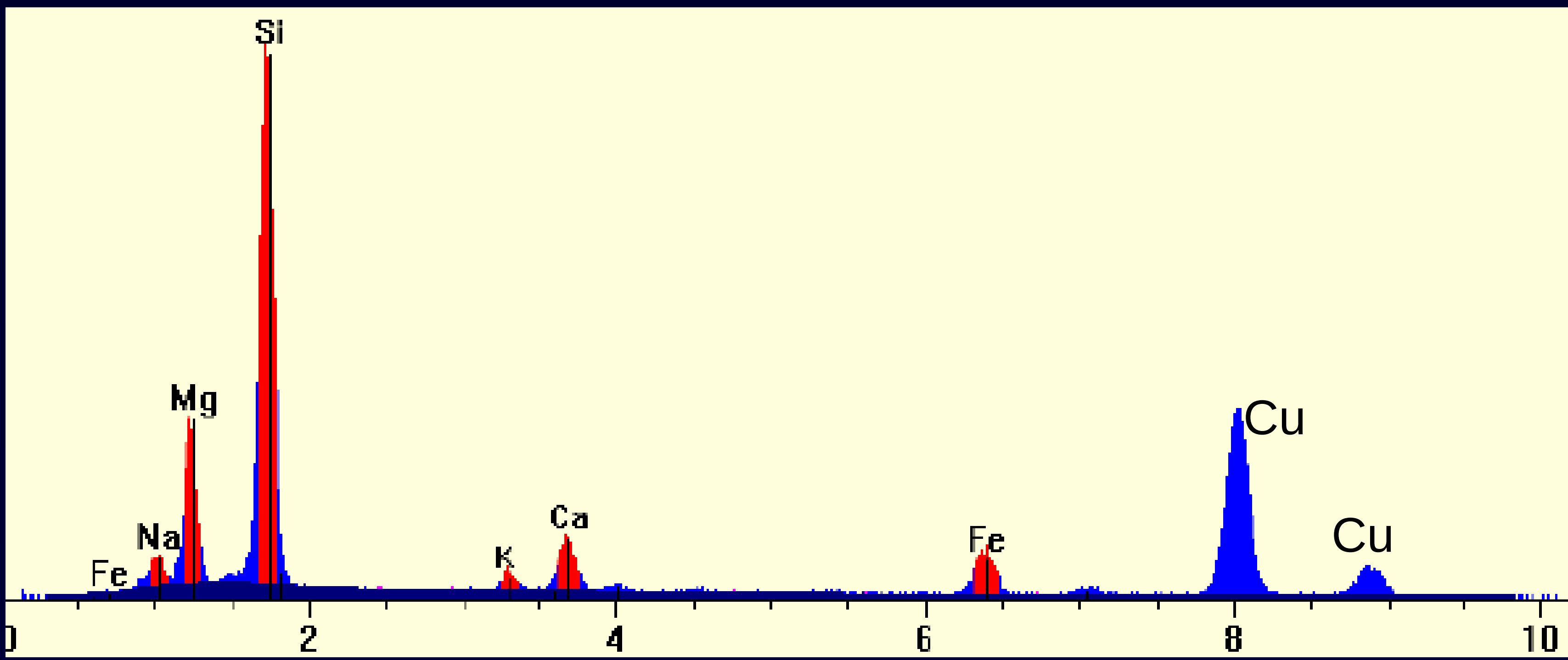
Secondary fluorescence effects



- Detector effects
  - Thin window vs. Be window
  - Position, tilt of sample

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Particle correction routines

- Small and Armstrong (2000) have shown that, at 10–15 kV accelerating voltage, geometry-induced errors on particles can be relatively small.
- Armstrong and Buseck (1975) developed an analytical routine for calculating correction factors for particle geometry effects

Conclusions

- Amphibole classification scheme of Leake et al. (1997) was developed for mineralogists, not regulators.
- Leake et al. (1997) is not appropriate for asbestos regulation because data are not reproducible between labs unless accurate particle analysis methods are developed
- Given the errors associated with particle analysis, regulators may consider adopting "asbestiform amphibole" instead of citing individual species
  - "Where the nature of the mineral is uncertain or unknown, asbestos alone or amphibole-asbestos may be appropriate. If the approximate nature of the mineral only is known, the above recommendations should be followed, but with the word amphibole replaced by asbestos, *e.g.*, anthophyllitic asbestos, tremolitic asbestos." Leake et al. (1997).

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