A Model for Fibrous Illite Nucleation and Growth In Sandstones *

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Abstract

We have developed a model for fibrous illite in sandstones where kaolinite is a primary reactant and potassium is derived from in-situ K-feldspar grain dissolution or imported into the model reference frame. Illite fiber nucleation and growth are modeled using Arrhenius expressions that consider saturation state in addition to temperature and time. Nucleation occurs on pore walls, and muscovite and detrital illite are energetically favorable substrates. The model is integrated with other Touchstone models to account for interaction of diagenetic processes on surface area and reactant volumes and to incorporate results into permeability and microporosity models.

We tested the model on two datasets with differences in sandstone characteristics and burial histories: Jurassic samples from offshore mid-Norway experienced maximum temperatures ranging from 108-172°C and are quartzose in composition whereas samples from offshore Southeast Asia are Miocene in age, rich in lithic fragments, and have maximum temperatures ranging from 154-173°C.

The model matched measured illite, kaolinite, and K-feldspar abundances within measurement uncertainties for both datasets using identical kinetic parameters. Predicted K-Ar ages agree with published data from mid-Norway for samples with comparable maximum temperatures. Although no illite particle size data are available from the analyzed samples, modeled crystallite thicknesses are comparable to published measurements of ~40-120 Å from Jurassic North Sea samples with similar temperature histories. Predicted K-Ar dates for the southeast Asia dataset trend are comparable to measured values assuming 2 vol% detrital contaminants. Calculated $\delta^{18}O$ values for samples from this dataset are within 1‰ of the measured values based on models that assume a constant water value comparable to the present-day value of ~ -4‰ $\delta^{18}O$ SMOW.

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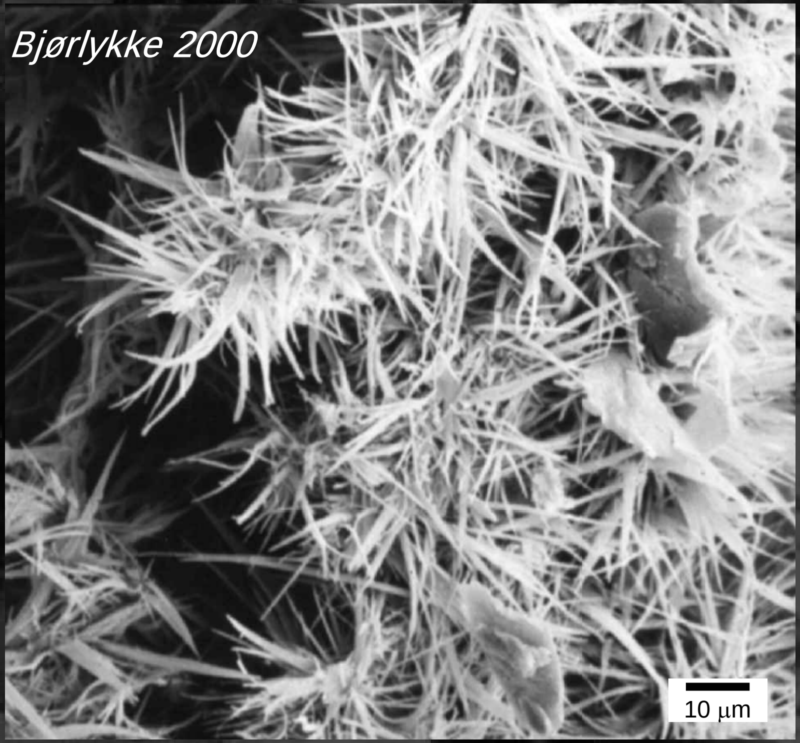
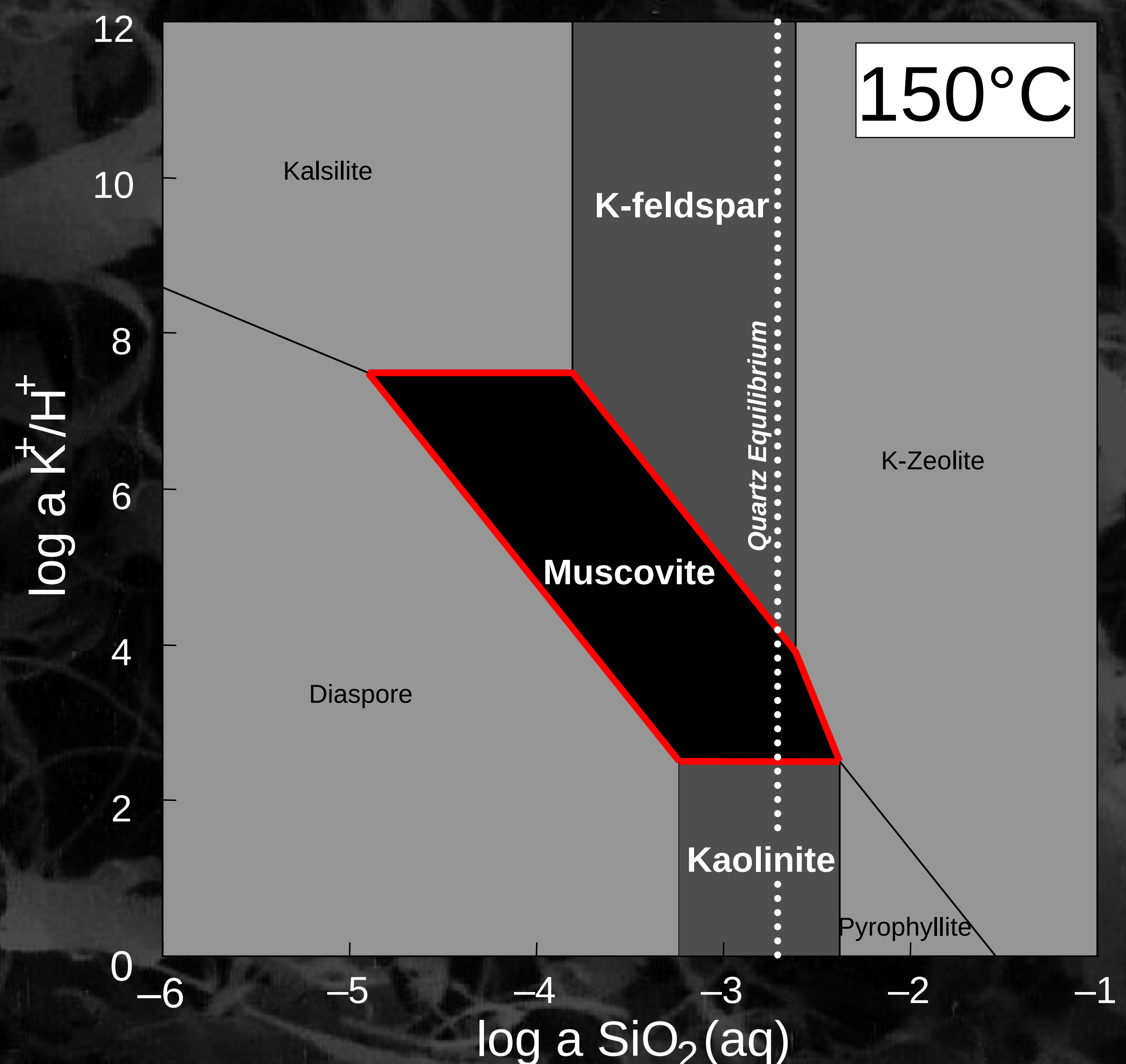
Geocosm

Fibrous Illite Model

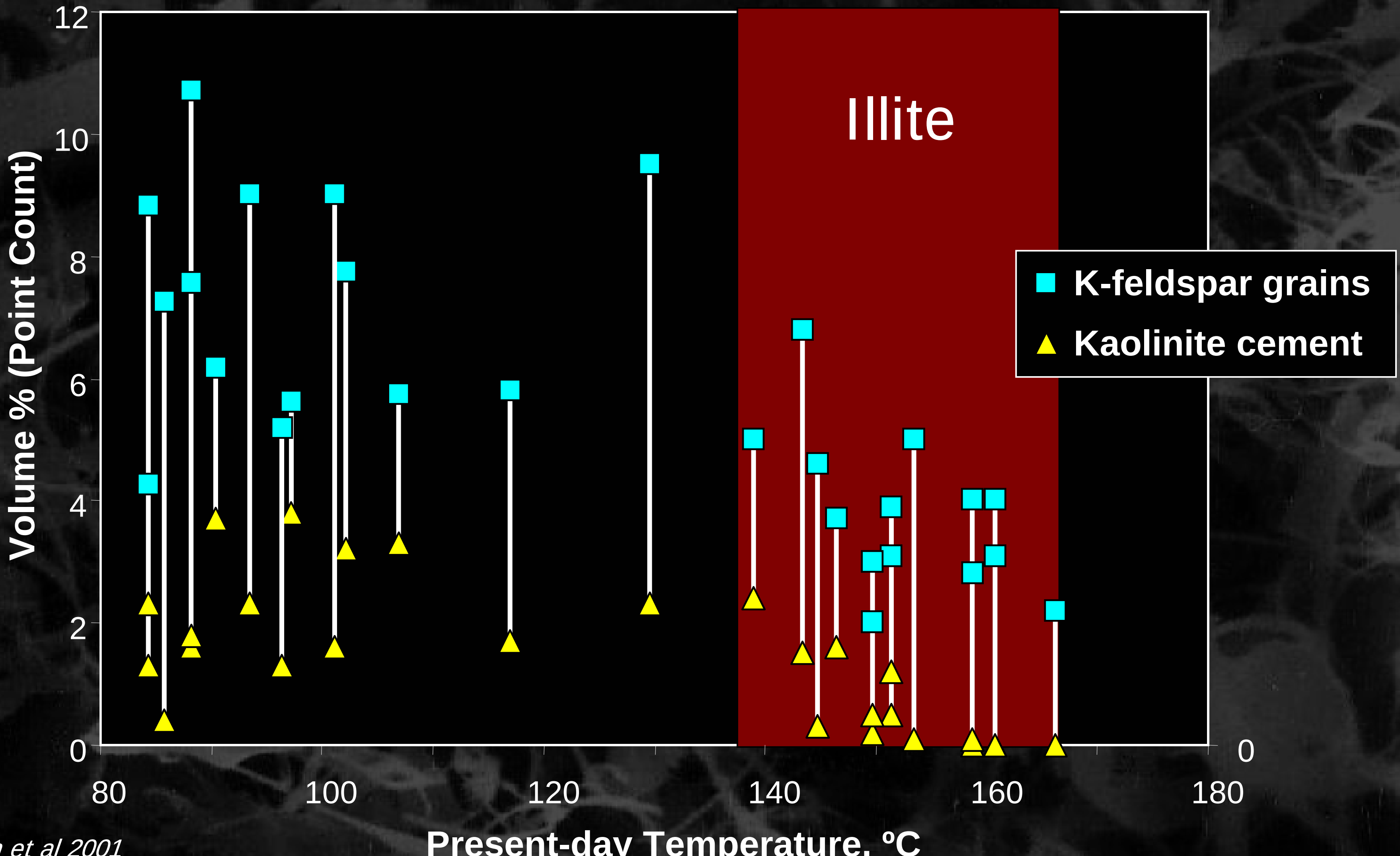
- **Reactants**
  - Kaolinite
  - K-feldspar (or K-rich brines)
- **Products**
  - Fibrous illite
  - Secondary porosity
- **Nucleation & growth kinetics**
- **Results**
  - Reactant & product volumes
  - Illite properties
    - Crystallite size distribution
    - Surface area & microporosity
    - K-Ar & $\delta^{18}O$
- **Coupled with Touchstone models**
  - Compaction & cementation
  - Permeability & core equivalent porosity



Thermodynamic Drive for Kaolinite + K-feldspar → Illite



Data from Jurassic Sandstones, Offshore Norway



Chuhan et al 2001

Nucleation Controls

$$N = \left(A_N \, e^{\frac{-E_a}{RT}} \Delta t\right)\left(\frac{Q}{K} - 1\right) S_A$$

- **Controls on nucleation rate**
  - Temperature
  - Supersaturation
    - Al^{+3}: kaolinite
    - $SiO_2(aq)$: quartz
    - K^+: K-feldspar or manually defined
  - Nucleation area
    - Intergranular and secondary pore walls
    - Preferential nucleation on illitic / micaceous materials

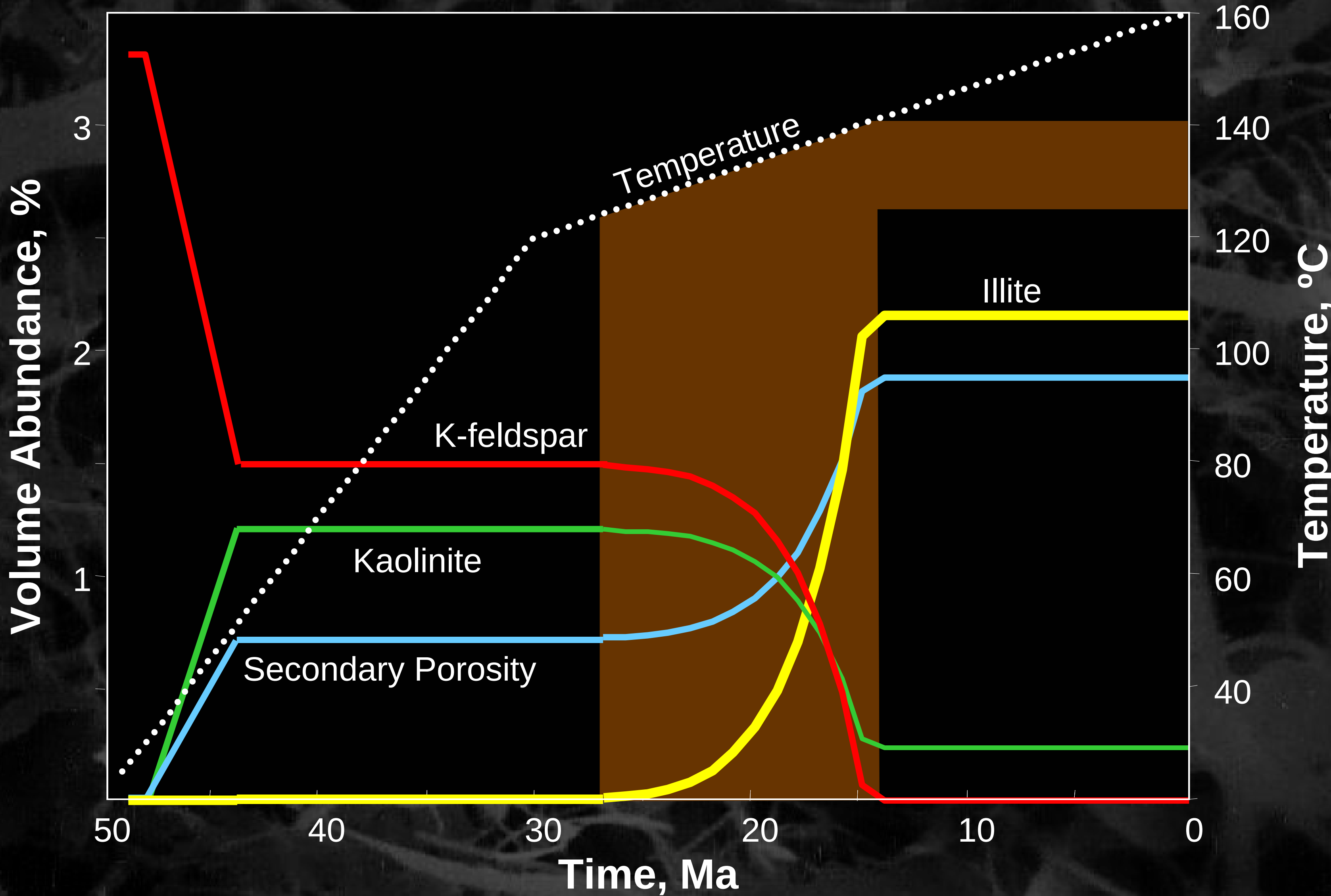
Growth Kinetics

$$I_a \propto \left(A\,e^{\frac{-E_a}{RT}}\,\Delta t\right)\left(\frac{Q}{K}-1\right)$$

- **Proportional growth**
  - Width = Thickness * 17
  - Length = Width * 100
- **No Ostwald ripening**
  - Nagy (1994) observations about finest size fraction
    - More abundant in deeper samples
    - Younger K-Ar ages

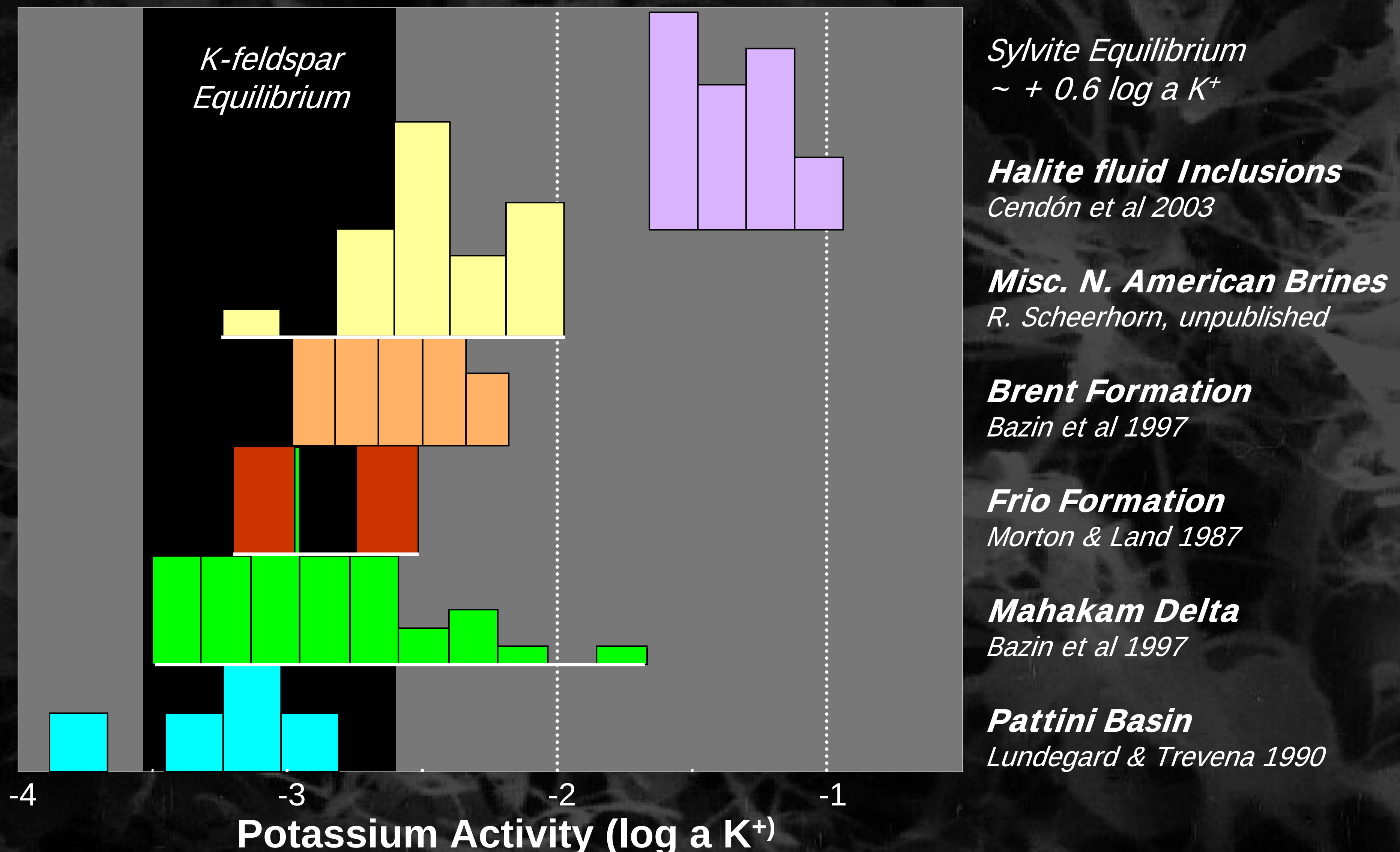
Modified from Lasaga, 1998

Illitization Assuming K-spar Equilibrium

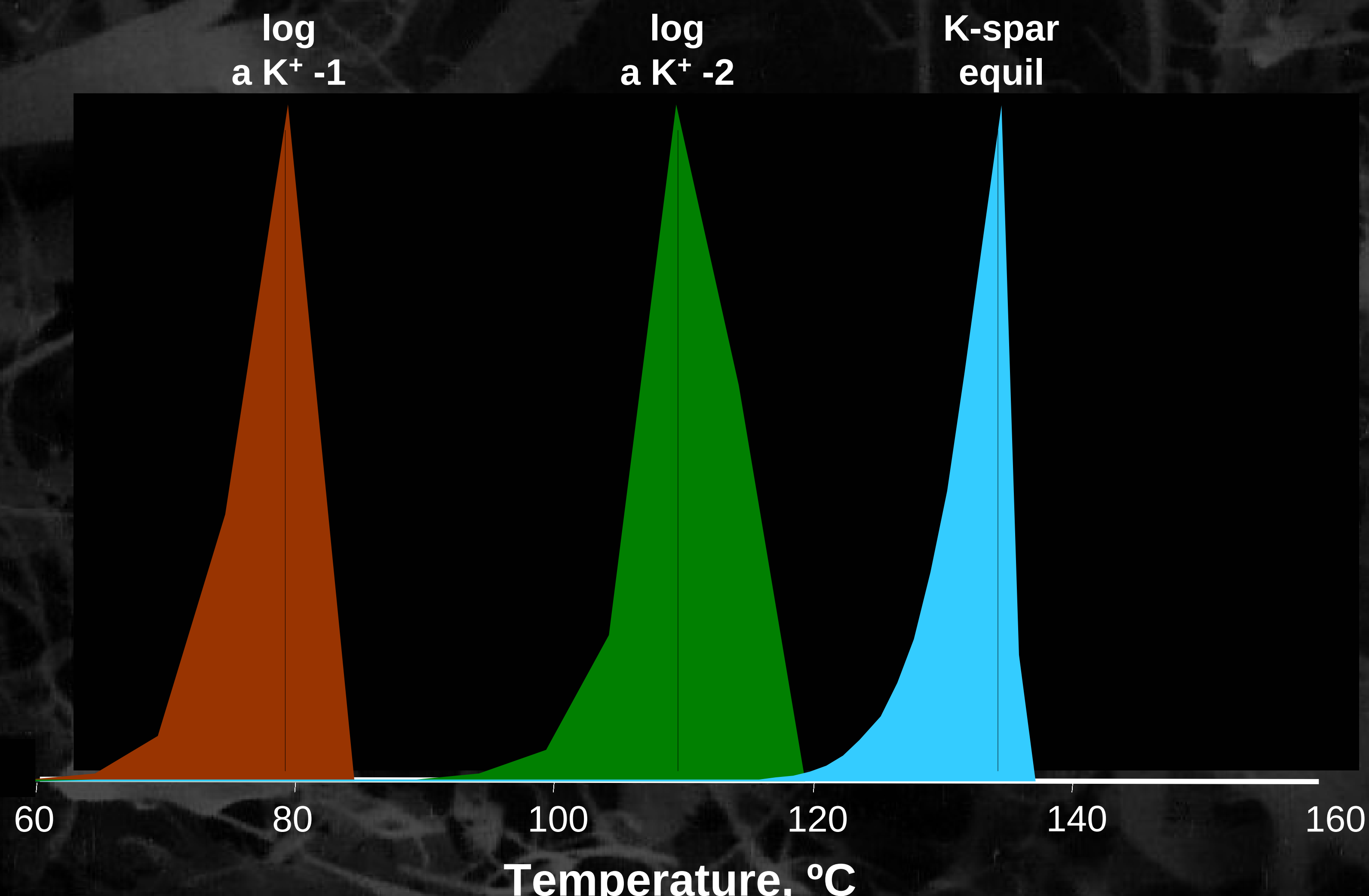


Potassium Activities in Natural Brines

Activities determined using the Debye-Hückel method in Geochemist's Workbench except for halite fluid inclusion data where the Pitzer method was used

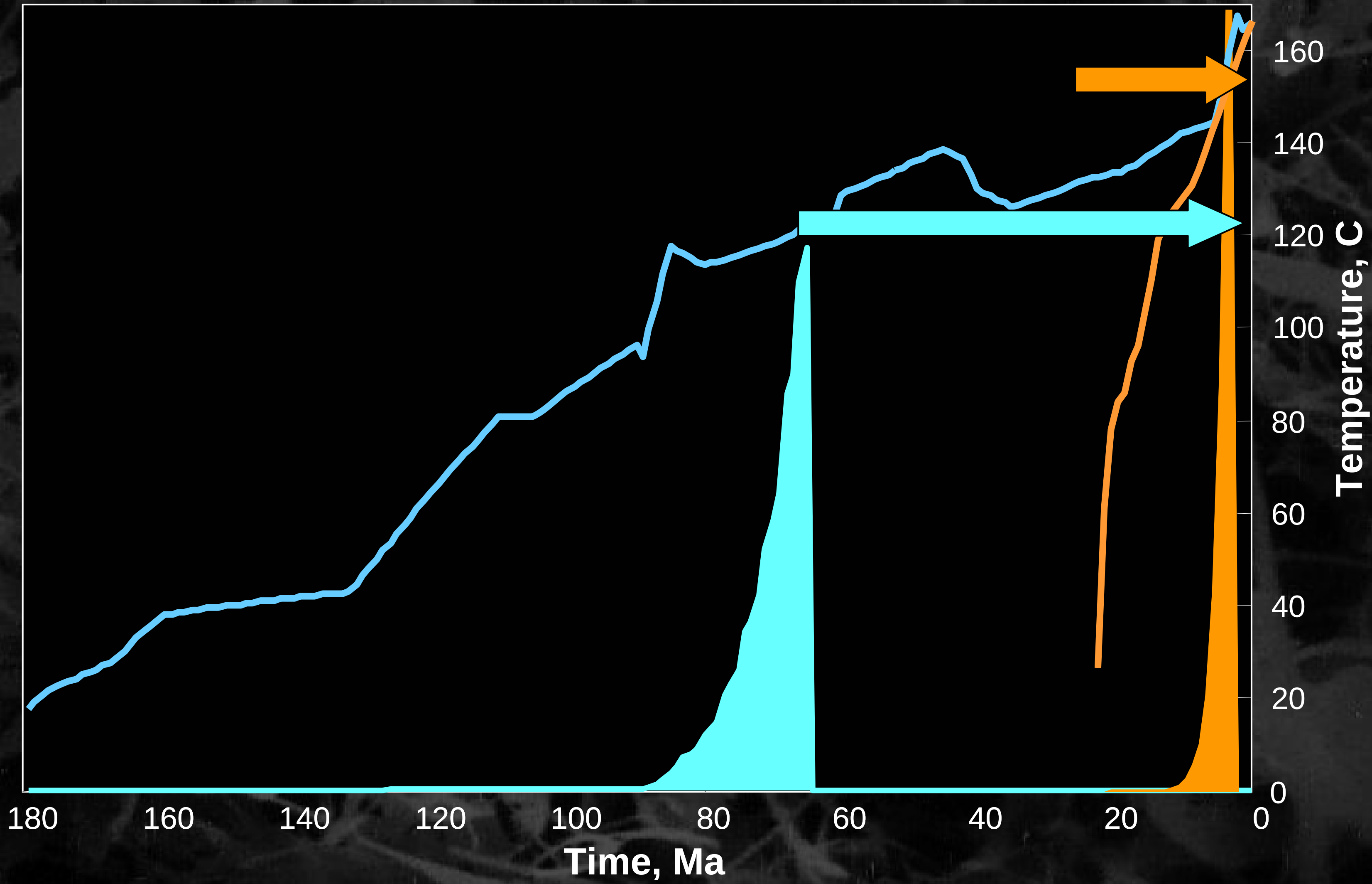


Sensitivity to K+ Activity



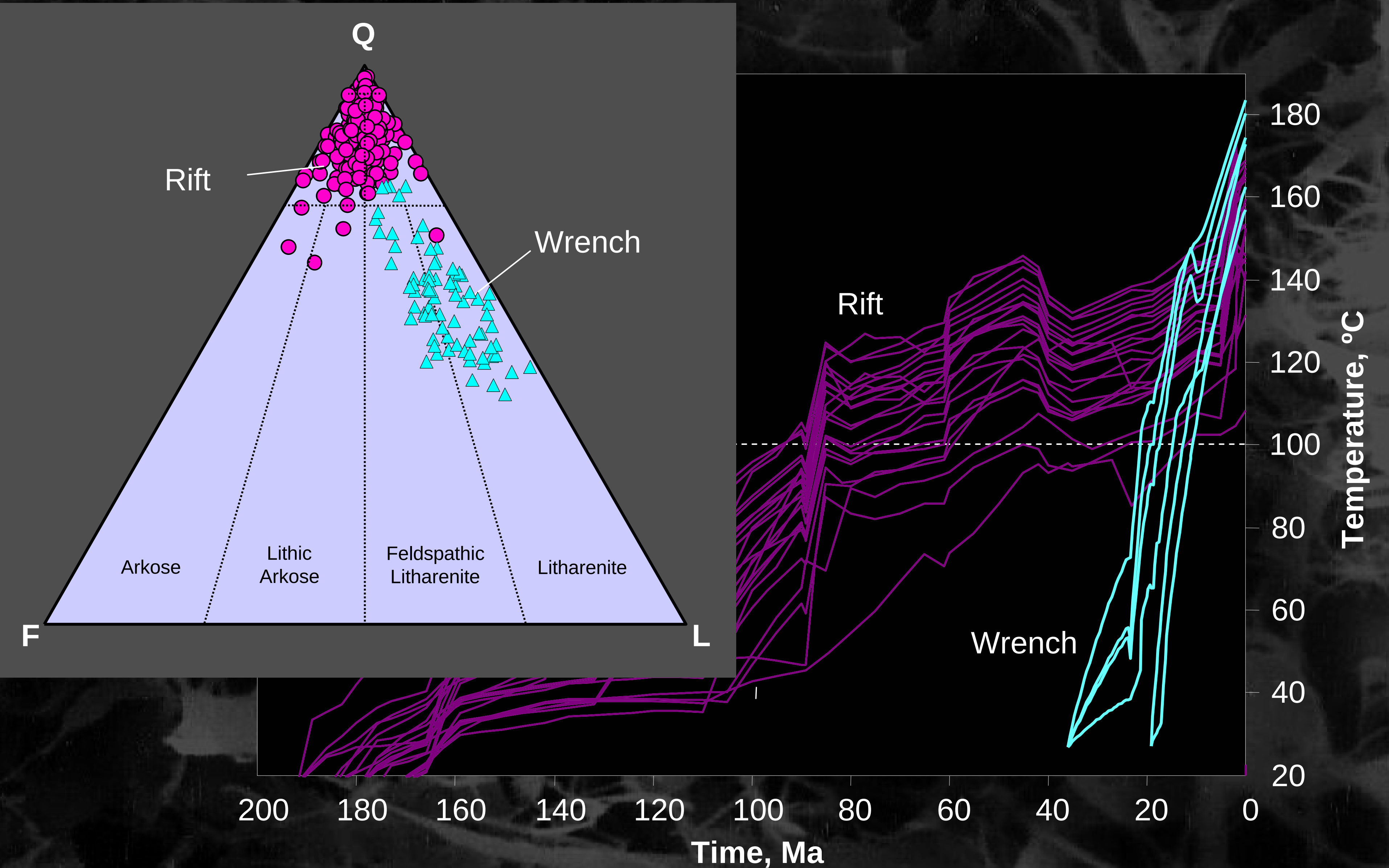
Timing and Rate of Illitization

Similar Maximum Temperatures Using Identical Model Parameters

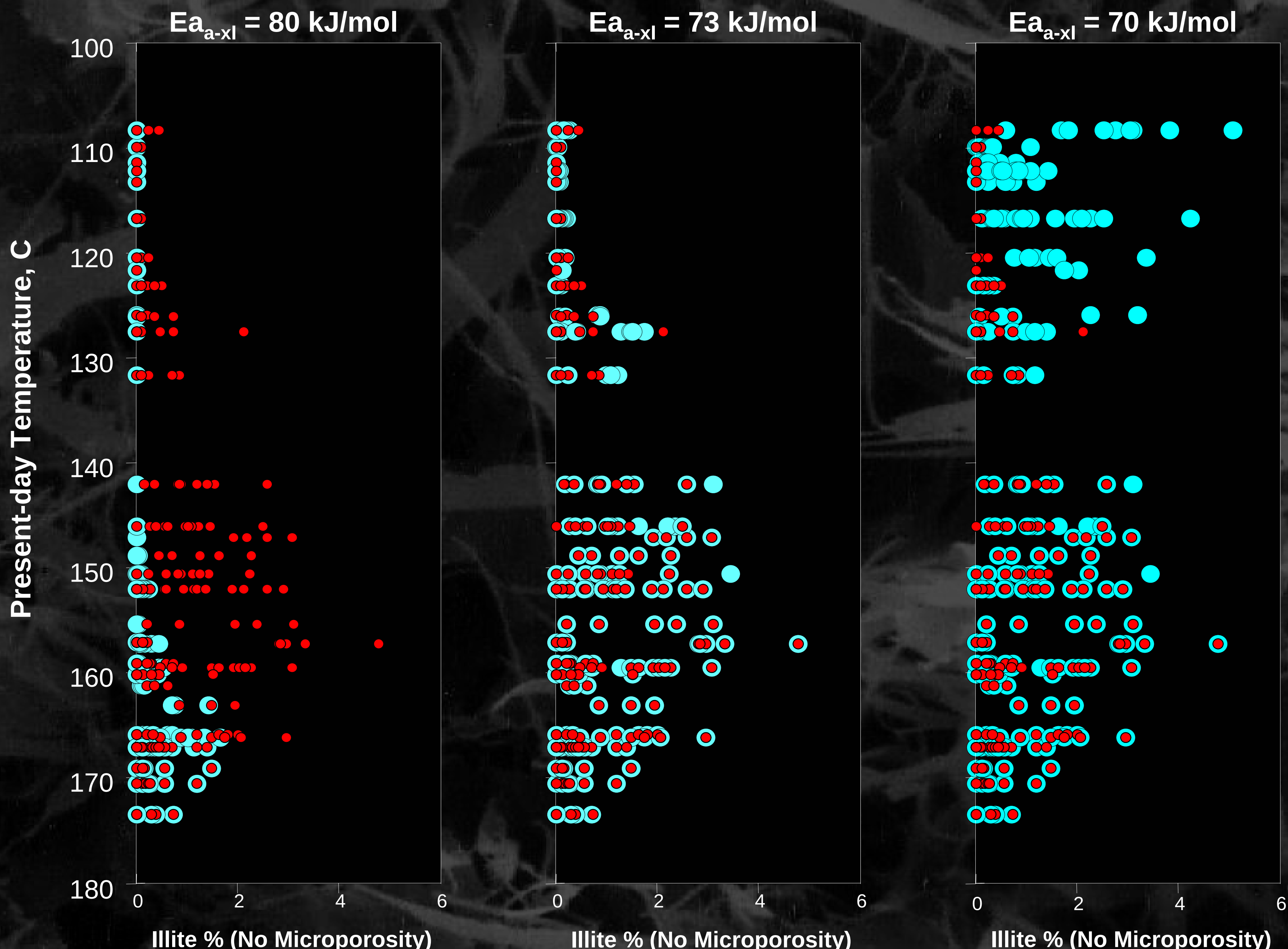


Cement Model Performance

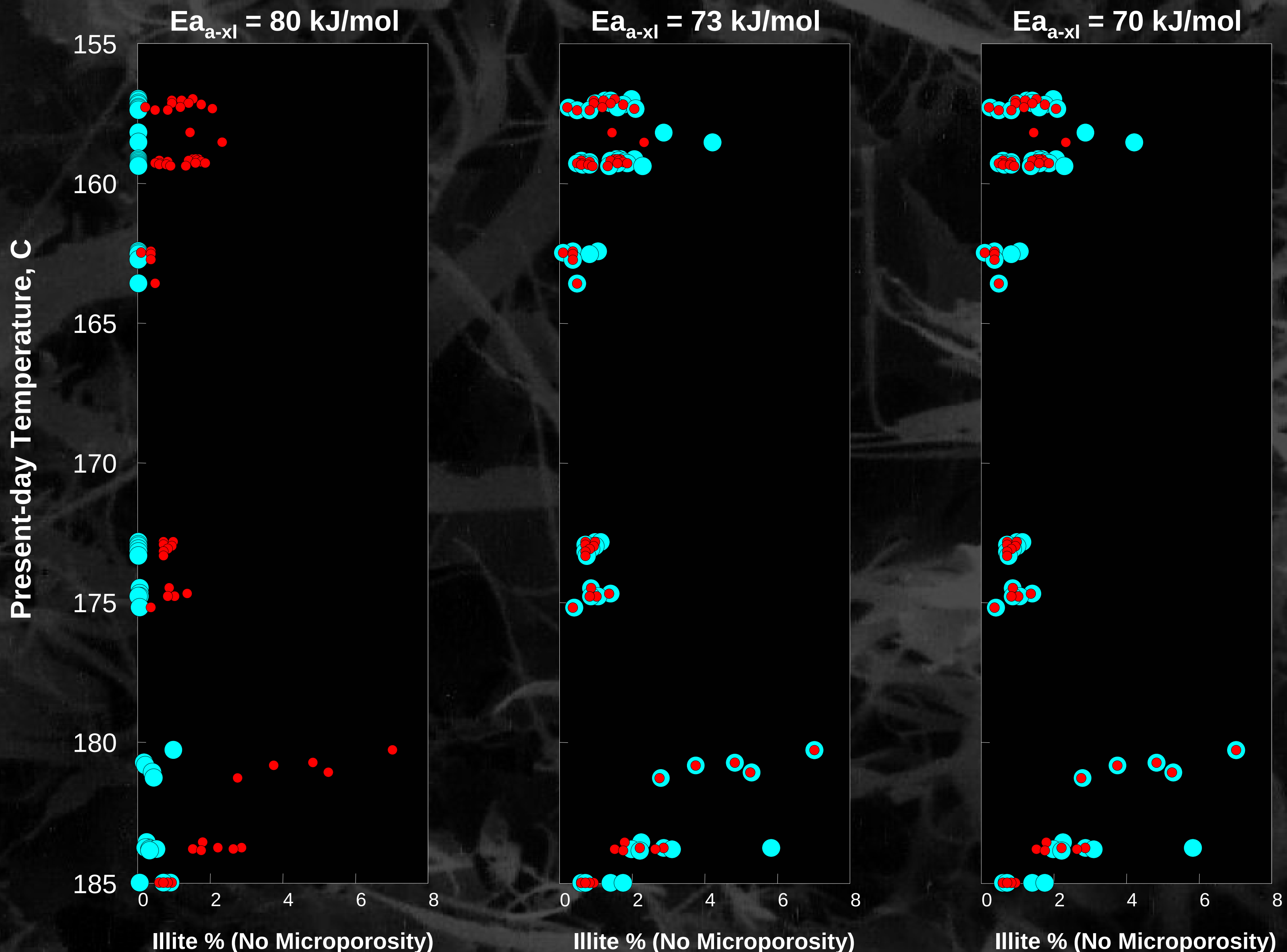
Test Datasets



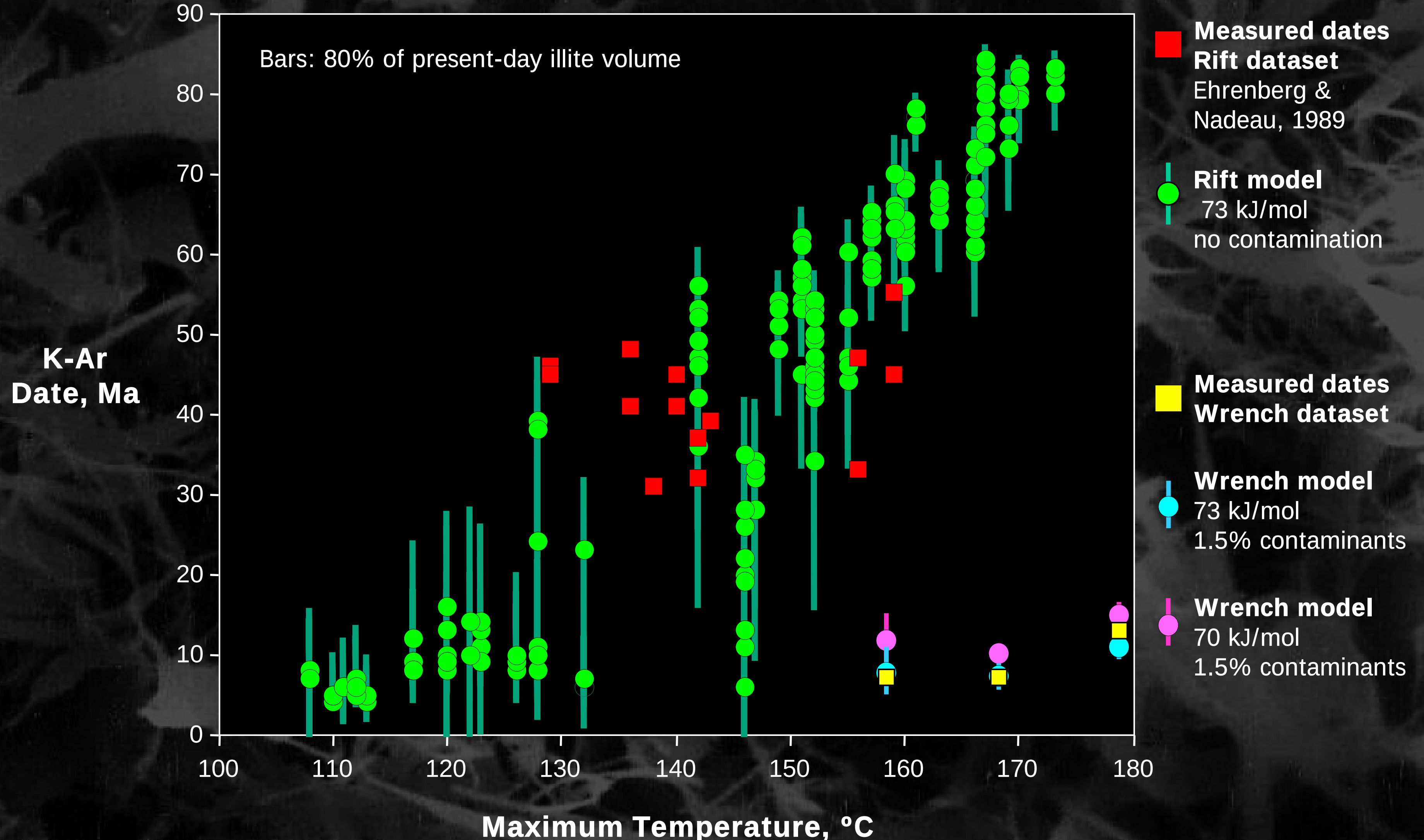
Rift Dataset



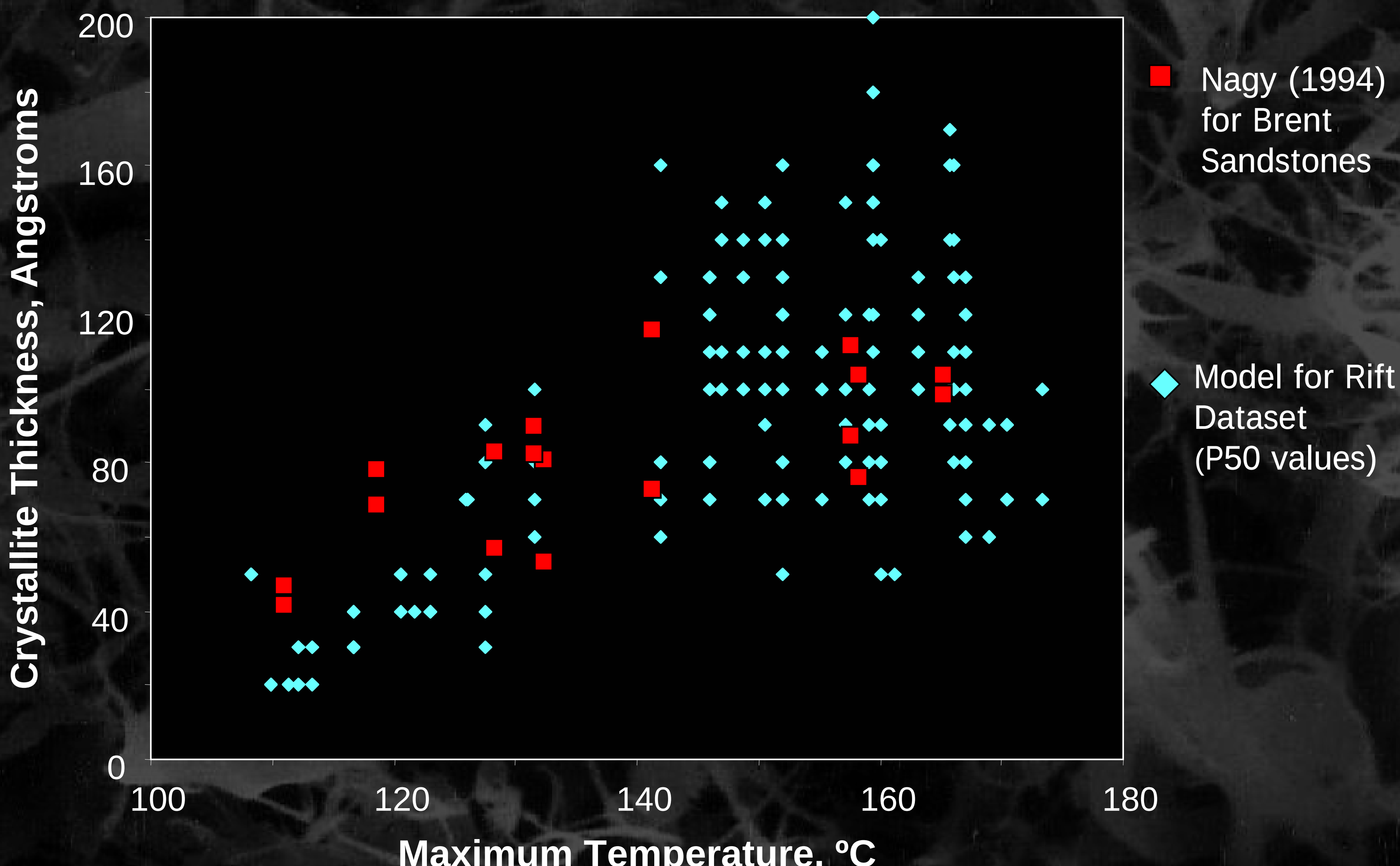
Wrench Dataset



Modeled vs. Measured Illite K-Ar Ages



Modeled vs. Measured Illite Particle Thicknesses



Conclusions

- **Model performance appears to be good for two natural datasets**
  - Illite occurrence and abundance
  - Extent of K-feldspar dissolution
  - Crystallite size distribution
  - K-Ar dates and $\delta^{18}O$

Acknowledgements

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