Kinetics of the Opal-CT to Quartz Phase Transition Control Diagenetic Traps in Siliceous Shale Source Rock from the San Joaquin Basin and Hokkaido*

Danica Dralus[1], Kenneth E. Peters[2], Mike D. Lewan[3], Oliver Schenk[4], Michael Herron[5], and Kunihiro Tsuchida[6]

Search and Discovery Article #40771 (2011)
Posted July 18, 2011

*Adapted from oral presentation at AAPG Annual Convention and Exhibition, Houston, Texas, USA, April 10-13, 2011

[1]Stanford University, Stanford, CA (dralus@stanford.edu)
[2]Schlumberger, Mill Valley, CA
[3]U.S. Geological Survey, Denver, CO
[4]Schlumberger, Aachen, Germany
[5]Schlumberger, Cambridge, MA
[6]Japan Oil, Gas and Metals Corporation, Chiba, Japan

Abstract

Porcelanite and chert originate from marine diatoms as diatomite, which undergoes diagenetic conversion of amorphous opal (opal-A) to cristobalite and tridymite (opal-CT) and finally quartz. Porosity decreases during this process, but permeability increases during transformation of opal-CT to quartz and results in stratigraphic traps for petroleum like those in recent discoveries in the San Joaquin Basin (Grau et al., 2003). The ability to accurately predict locations of these diagenetic traps would be a valuable exploration tool.

Ernst and Calvert (1969) determined zero-order kinetics for the opal-CT to quartz phase transition based on hydrothermal experiments using distilled water. However, the transition is a dissolution and re-precipitation process, where both the silica dissolution rate and solubility contribute to the rate of the reaction. We determined first-order kinetic parameters for the opal-CT to quartz transition based on hydrous pyrolysis of weathered Monterey Formation porcelanite from Lompoc, California, which also contained dolomite; and a Wakkanai Formation porcelanite from Hokkaido, Japan, which also contained quartz, albite, and some organic material. Temperatures were kept below the critical temperature of water and the aqueous solution was buffered so that final fluid pH values measured between 7.0 and 8.2. Under these conditions, the samples showed large variations in opal-CT to quartz conversion rates, where the rates of the Monterey and Wakkani conversions were approximately five times faster and three times slower, respectively, than that predicted by Ernst and Calvert.

We built a module in our petroleum system modeling software and used the hydrous pyrolysis kinetics to determine the depth of the opal-CT to quartz phase transition along a cross-section in the east-central portion of the San Joaquin Basin. The kinetics and software module may be useful to identify silica-phase-transition stratigraphic traps throughout the Pacific Rim where siliceous source rocks are common.

References

Bloch, R.B., 1991, Studies of the stratigraphy and structure of the San Joaquin Basin, California: Ph. D. thesis, Stanford University, California, 2 v., 319 p.

Ernest, W.G., and S.E. Calvert, 1969, An experimental study of the recrystallization of porcelanite and its bearing on the origin of some bedded cherts: American Journal of Science, v. 267-A, p. 114-133.

Grau, A., R. Kidney, and R. Sterling, 2003, Success! Using seismic attributes and horizontal drilling to delineate and exploit a diagenetic trap, Monterey Shale, San Joaquin Valley, California *in* T.C. Chidsey Jr., (chair) 2003 AAPG Annual Convention with SEPM: AAPG Annual Meeting Expanded Abstracts, v. 12, p. 66-67.

Peters, K.E., F.D. Hostettler, T.D. Lorenson, and R.J. Rosenbauer, 2008, Families of Miocene Monterey crude oil, seep, and tarball samples, coastal California: AAPG Bulletin, v. 92/9, p. 1131-1152.

Kinetics of the Opal-CT to Quartz Phase Transition Control Diagenetic Traps in Siliceous Shale Source Rock from the San Joaquin Basin and Hokkaido

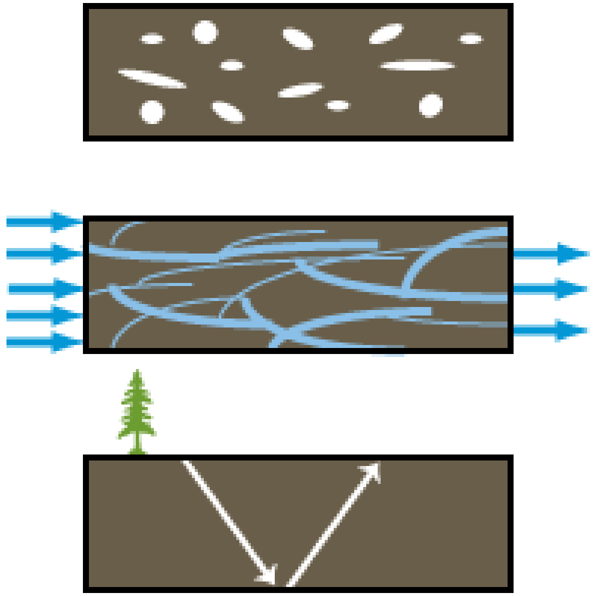
AAPG ACE
April 11, 2011
Houston, TX

Danica Dralus, Michael Lewan,
Oliver Schenk, Michael Herron,
Kunihiro Tsuchida, Kenneth Peters

Key points

- Phase transitions in minerals affect petroleum trapping and migration (storage and transport).
- Our experiments show the opal-CT to quartz transition occurs at a very different rate than a previous study.
- Controlling mechanisms for this transition are poorly understood.

Rock physics meets geochemistry



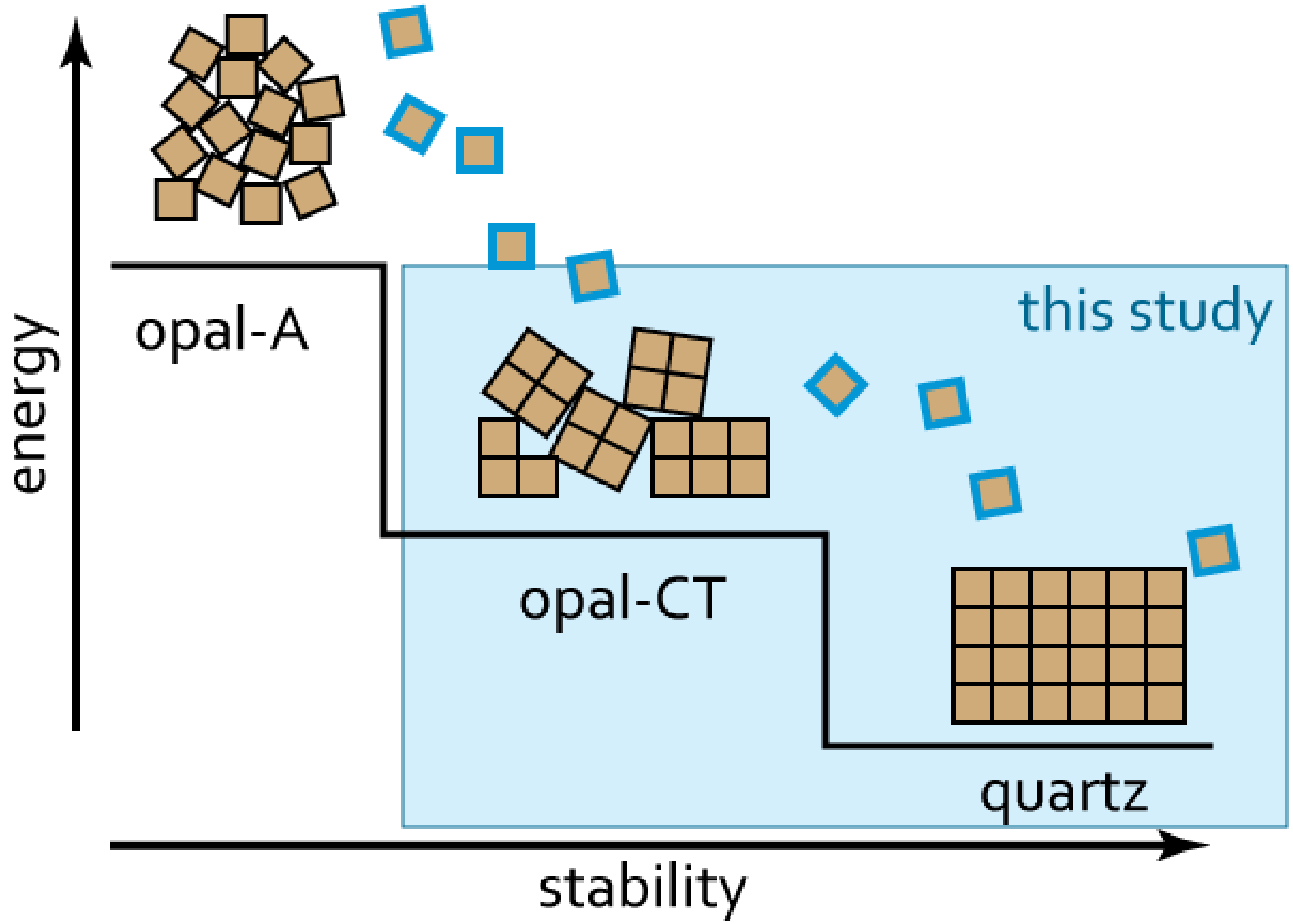
porosity

permeability

acoustic velocities

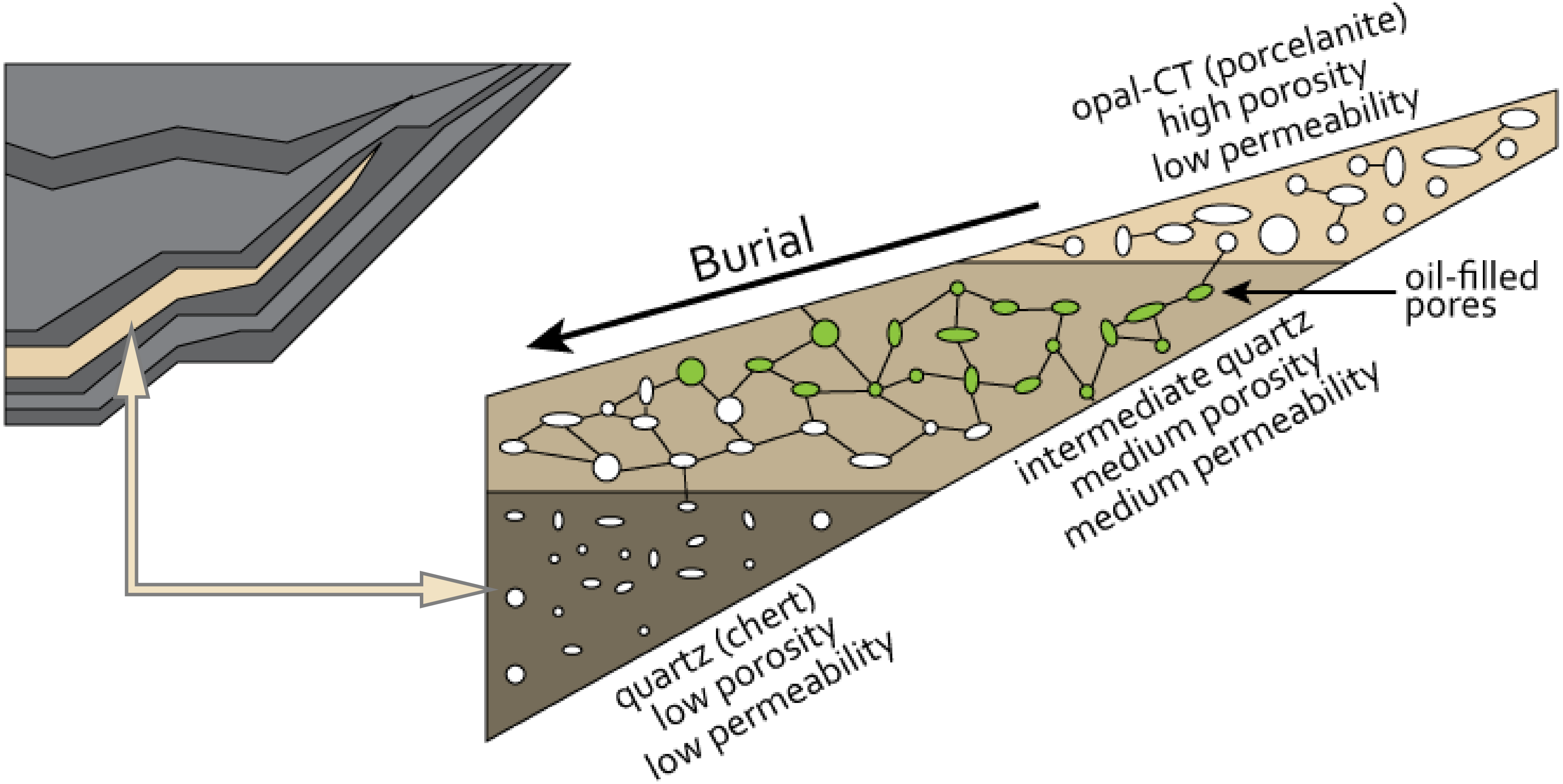
- effects of mechanical alterations are (relatively) well known
- effects of chemical alterations are largely mysterious

Silica polymorphs dissolve in water



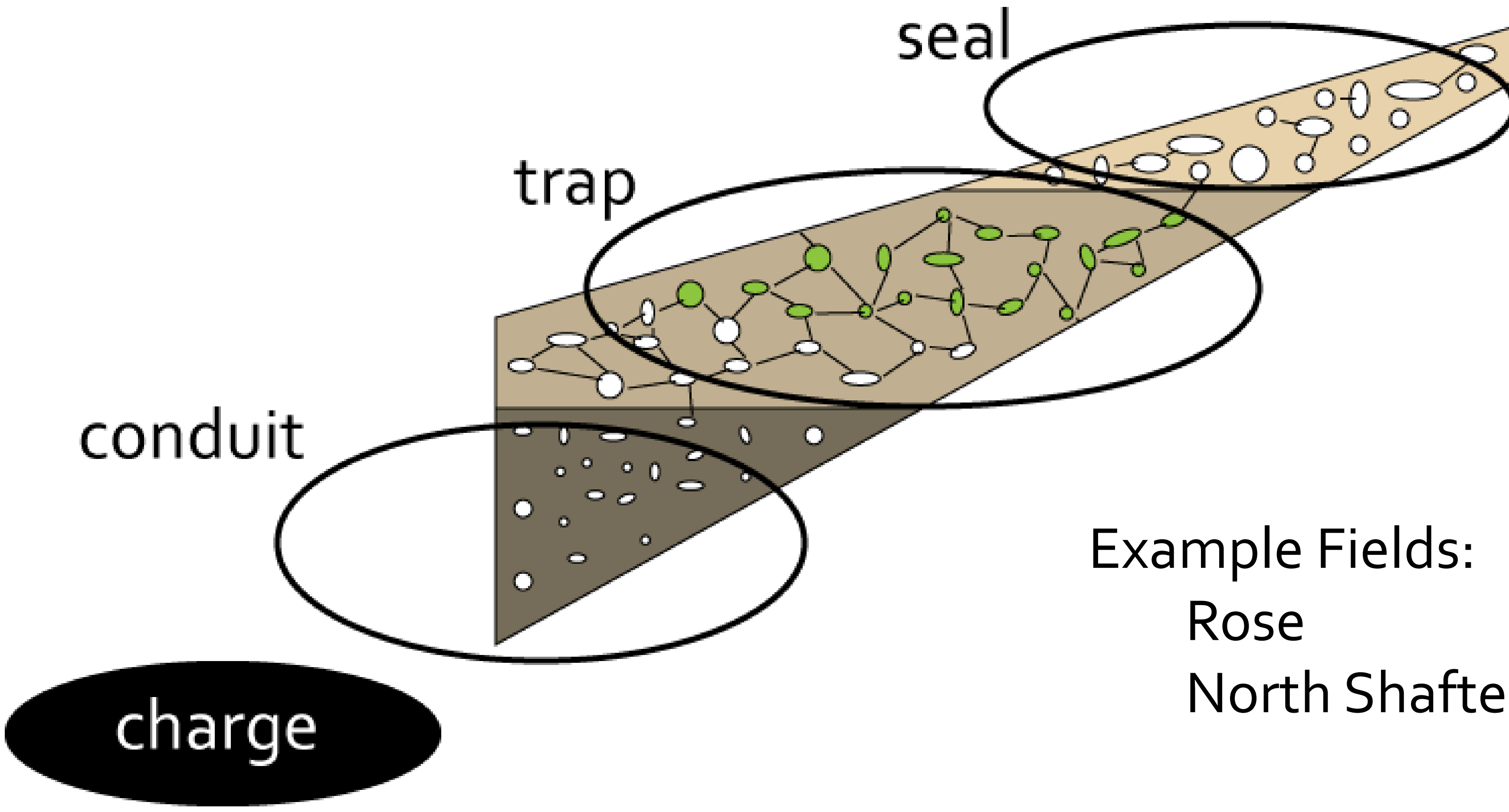
Phase changes affect HC trapping

Diagenetic traps can form within a depositional layer



Phase changes affect HC trapping

Diagenetic traps can form within a depositional layer



Example Fields:

- Rose
- North Shafter

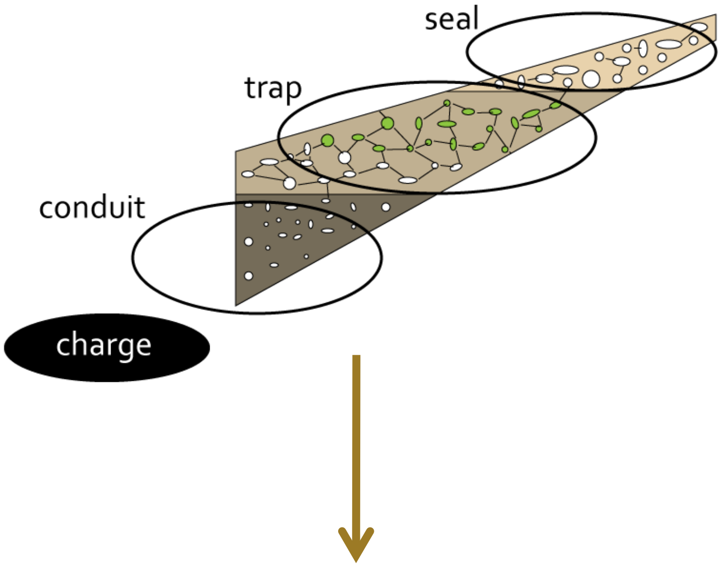
Variable silica phase transitions

Chico Martinez Creek; Courtesy of R. Behl, CSULB

Monterey Fm. chert, cored

Field to laboratory

- If you want to predict this type of diagenetic trapping in your basin modeling, you need kinetics for the reaction.



- To the laboratory!
- We use hydrous pyrolysis to determine these kinetics.

Kinetics from hydrous pyrolysis (HP)

HP: T1 (-)
HP: T1 (---)
HP: T1 (-----)
HP: T1 (--------)

reaction rate at Temp 1

HP: T2 (-)
HP: T2 (---)
HP: T2 (-----)
HP: T2 (--------)

reaction rate at Temp 2

HP: T3 (-)
HP: T3 (---)
HP: T3 (-----)
HP: T3 (--------)

reaction rate at Temp 3

Arrhenius equation

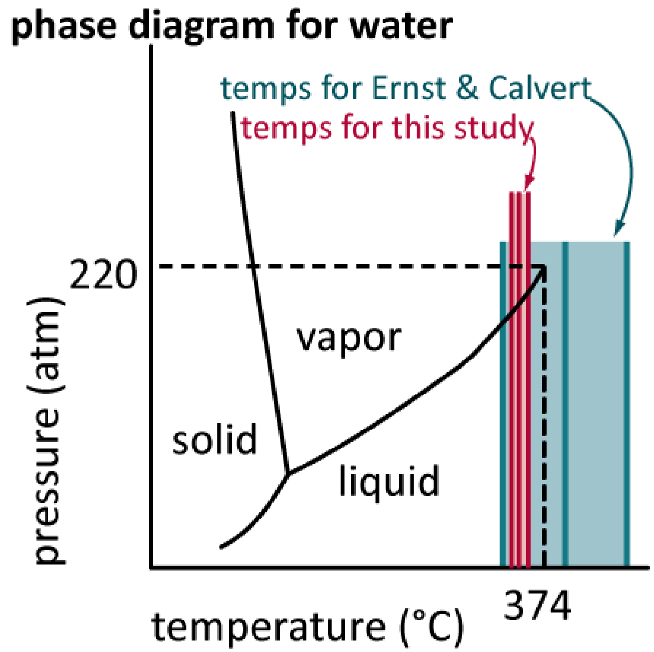
$$k_t = A_0 e^{-E_a/(RT)}$$

to calculate rate at any temperature

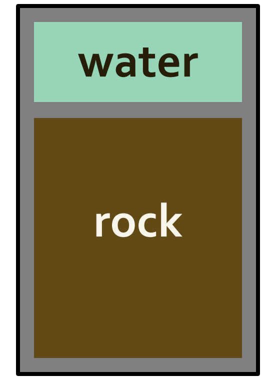
Comparing experimental conditions

This study

- 310, 333, 360 °C
- buffered aqueous solution
- grain size 177-250 µm
- Lompoc, CA



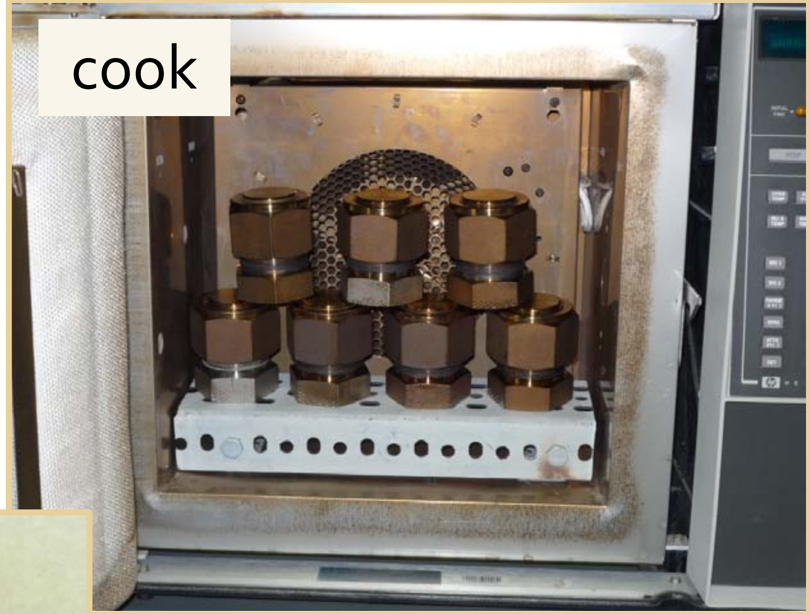
Ernst & Calvert (1969)



- 300, 400, 500 °C
- distilled water
- grain size “fine”
- San Luis Obispo, CA

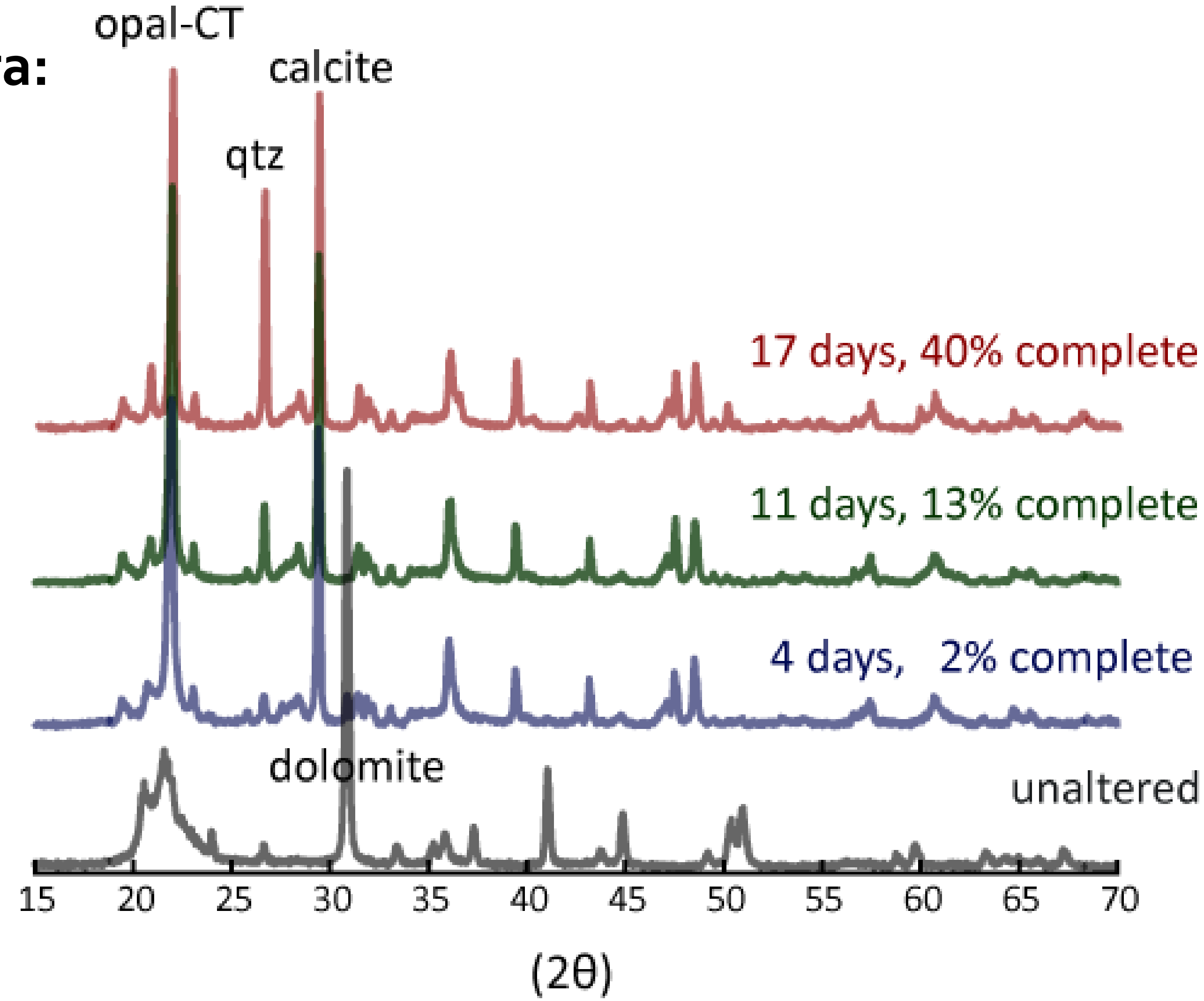
Porcelanite from Monterey Fm.

Experiments

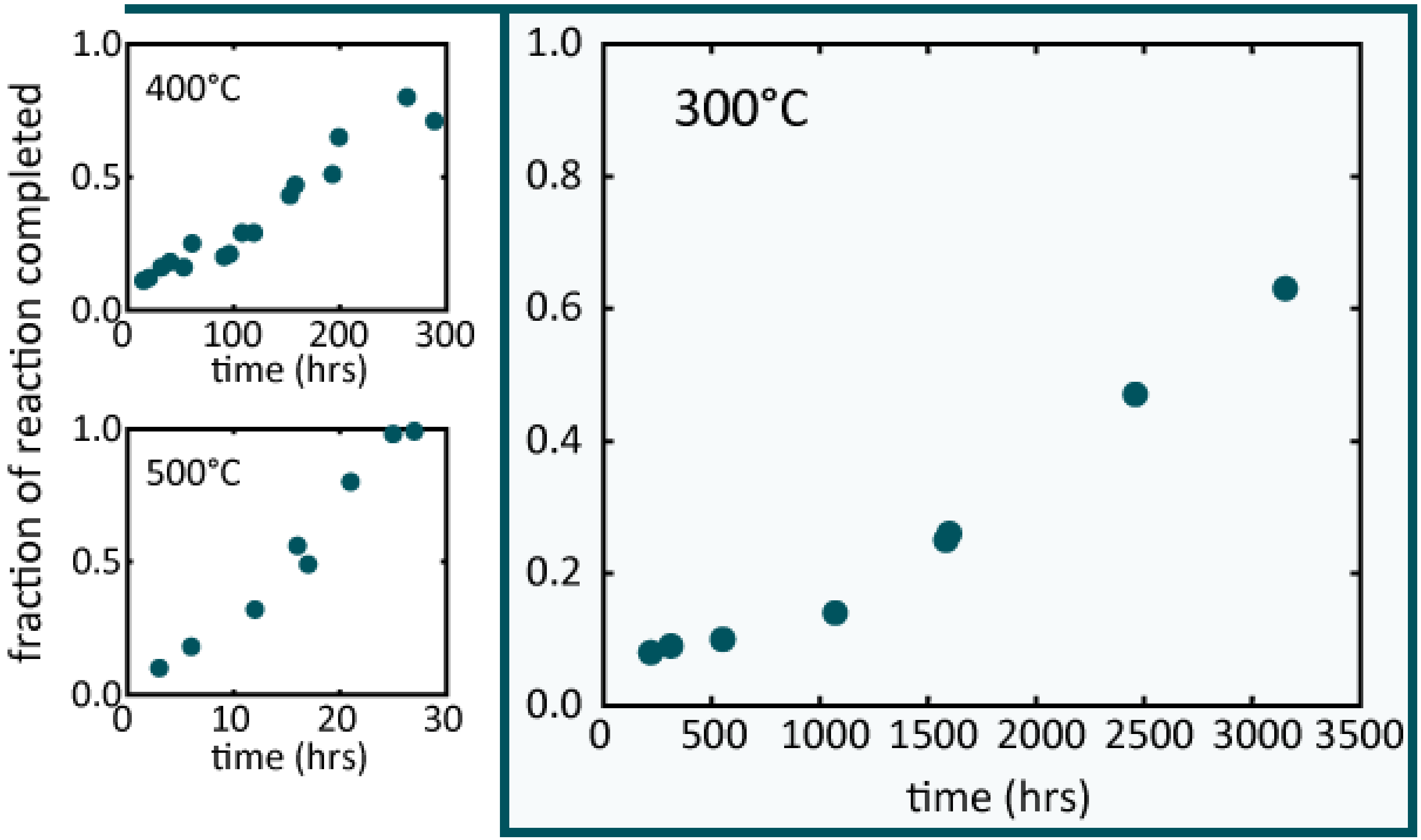


XRD gives converted fraction

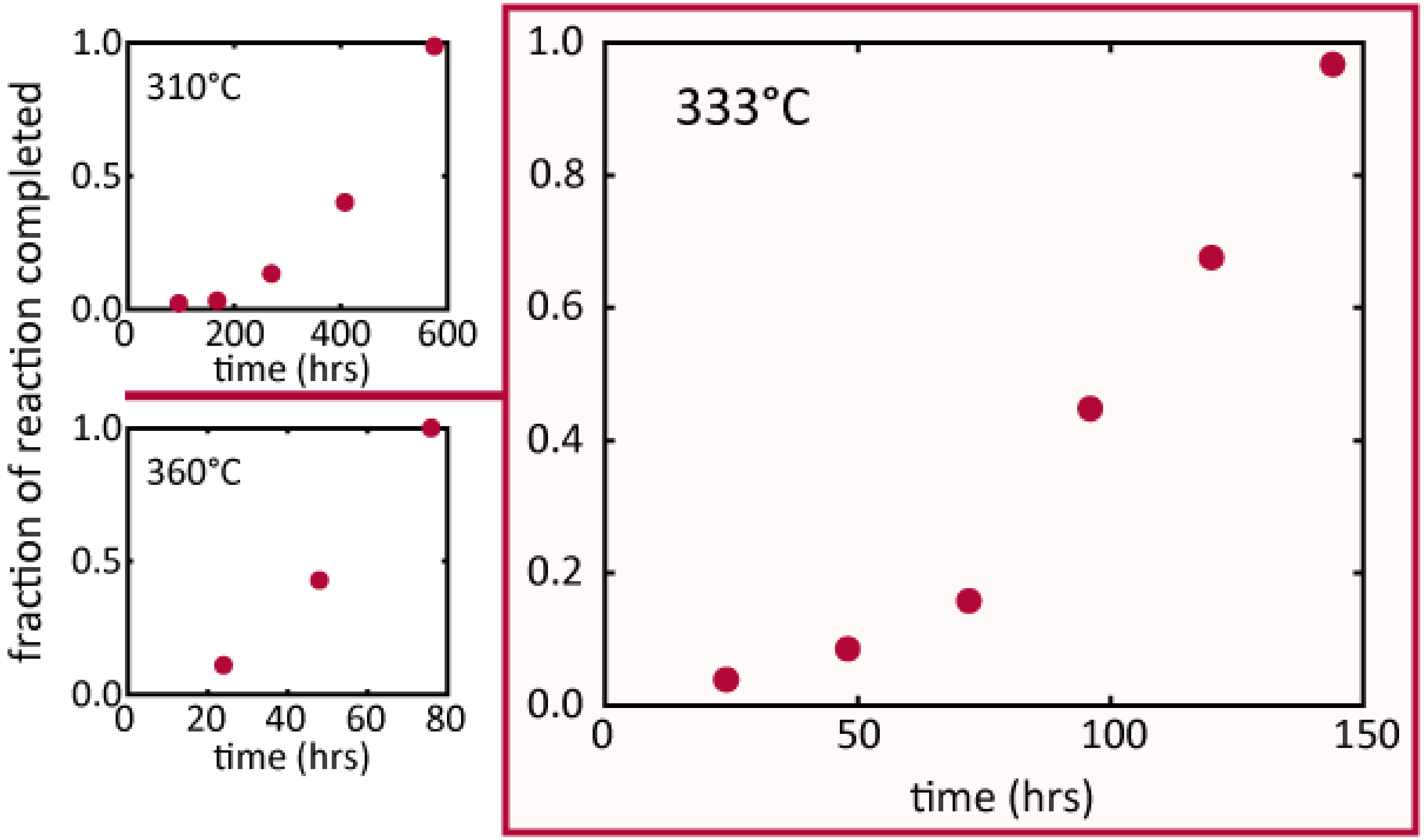
Sample spectra:
310°C



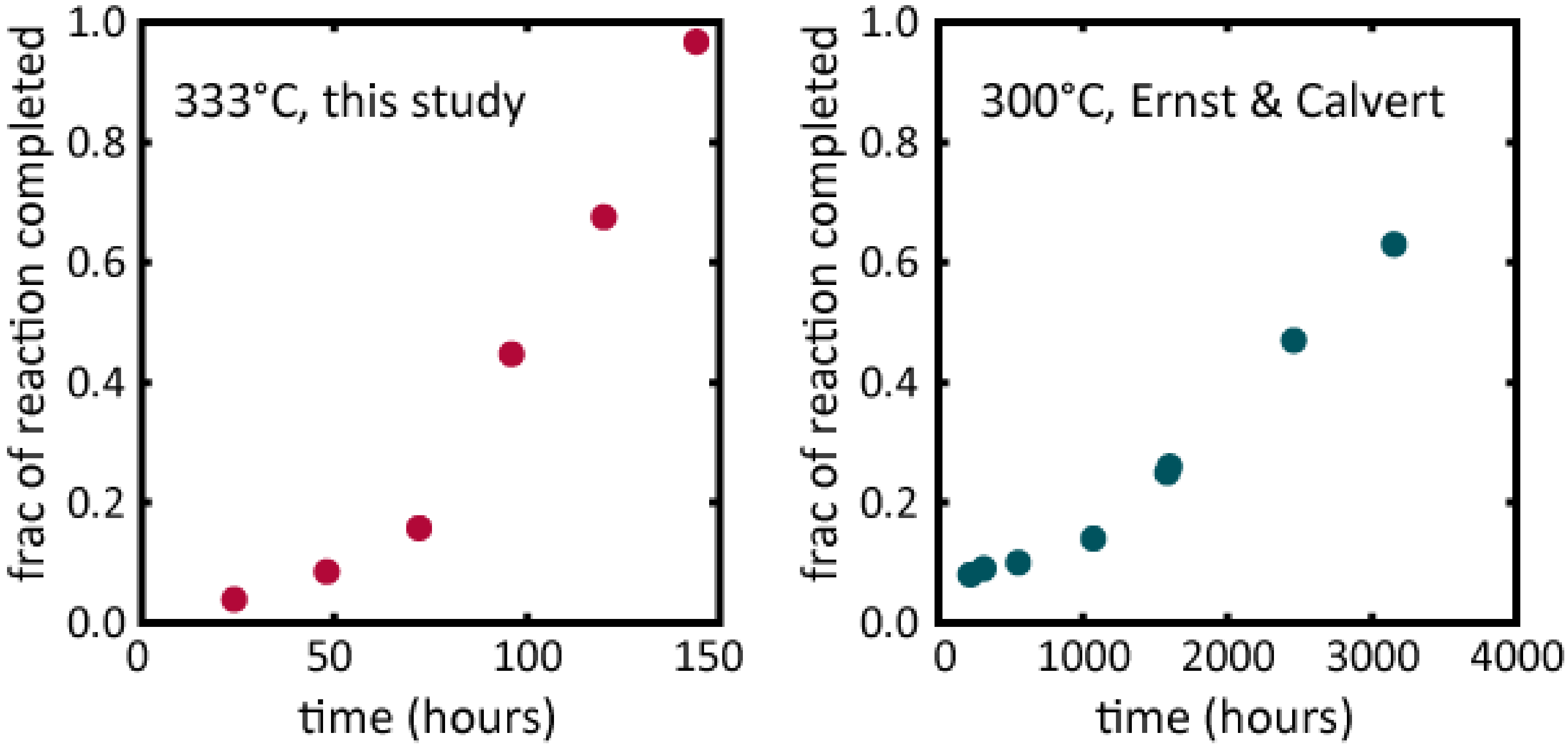
Ernst & Calvert data



This study's data

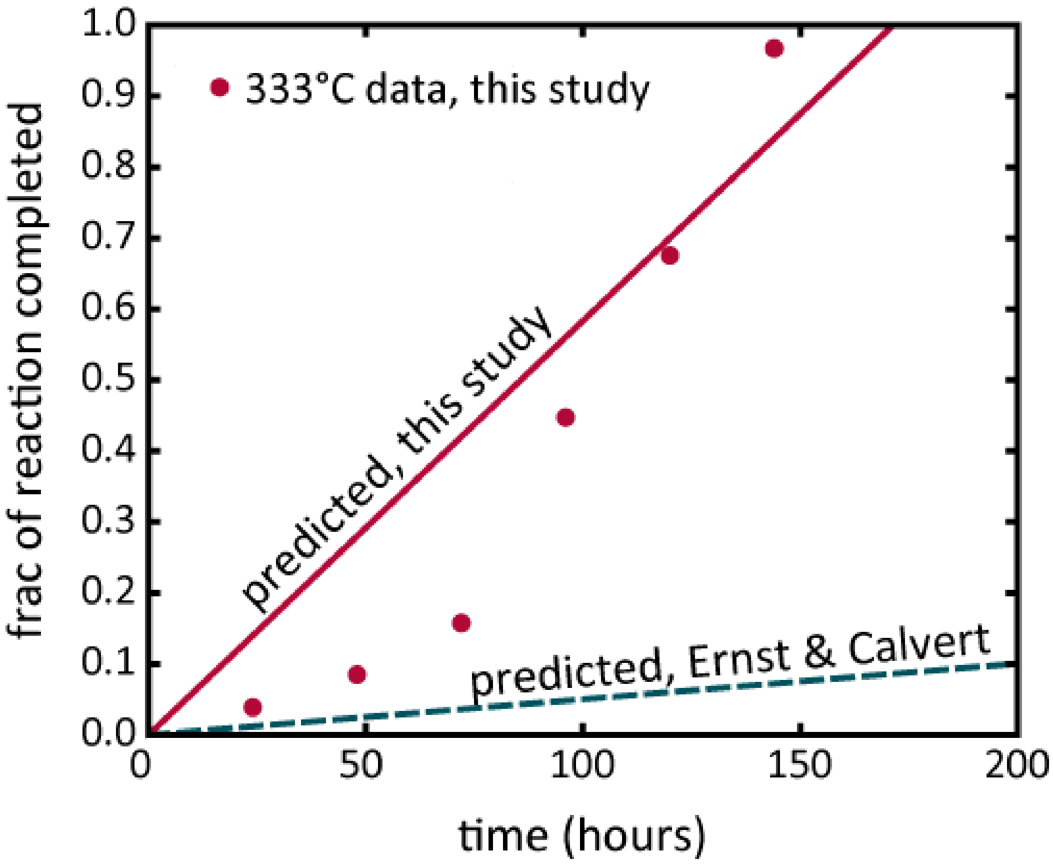


Data show changed conversion rate



- Does the reaction speed up?
- If so, why?

Comparing kinetic parameters



kinetic parameters

this study:

$A_0 = 4.84 \times 10^7\ hr^{-1}$

$E_a = 27.49$ kcal/mol

Ernst & Calvert:

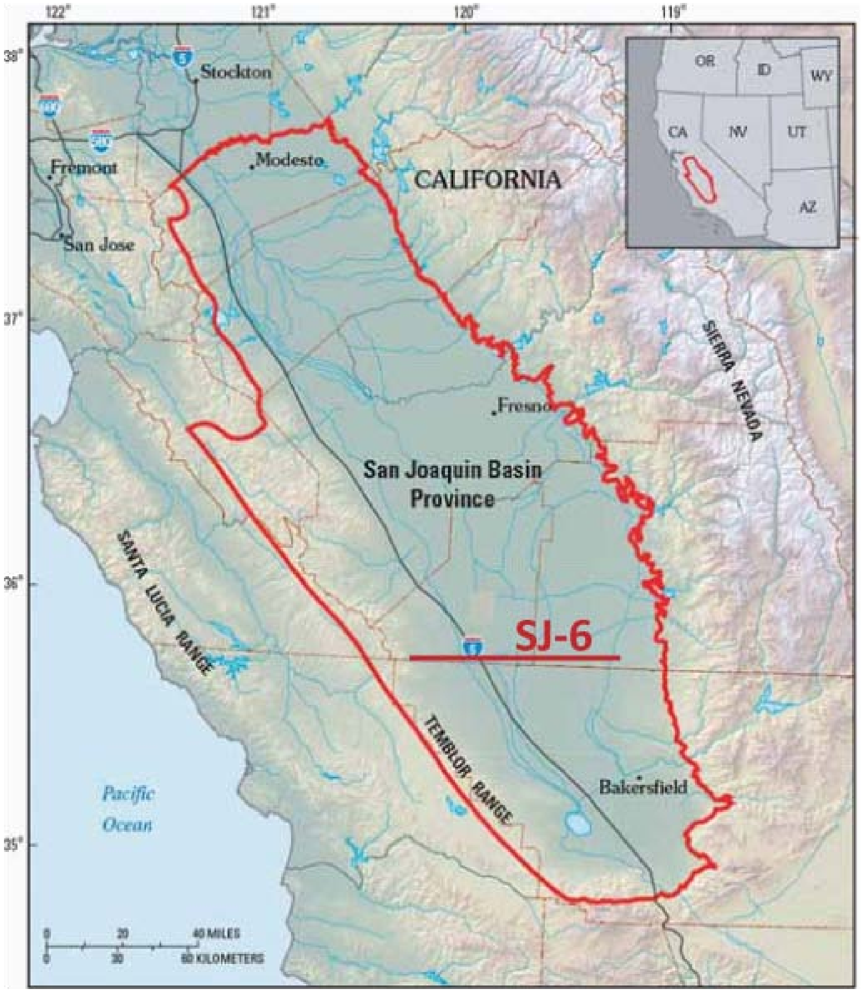
$A_0 = 0.0134 \times 10^7\ hr^{-1}$

$E_a = 23.36$ kcal/mol

That's well and good, but…

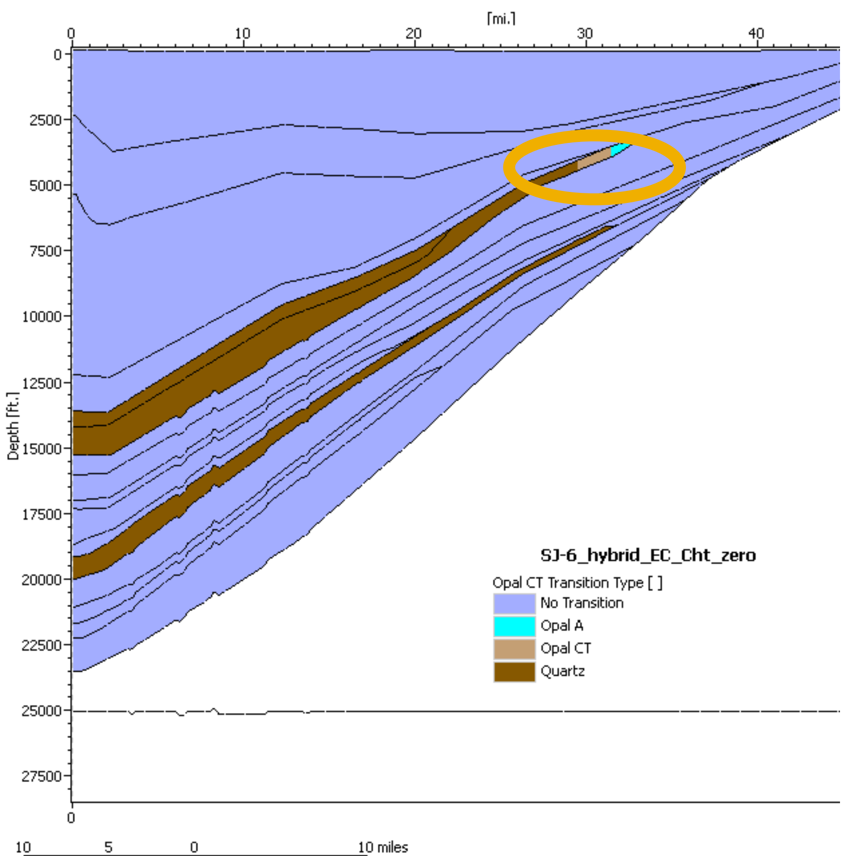
does this really affect a petroleum system model?

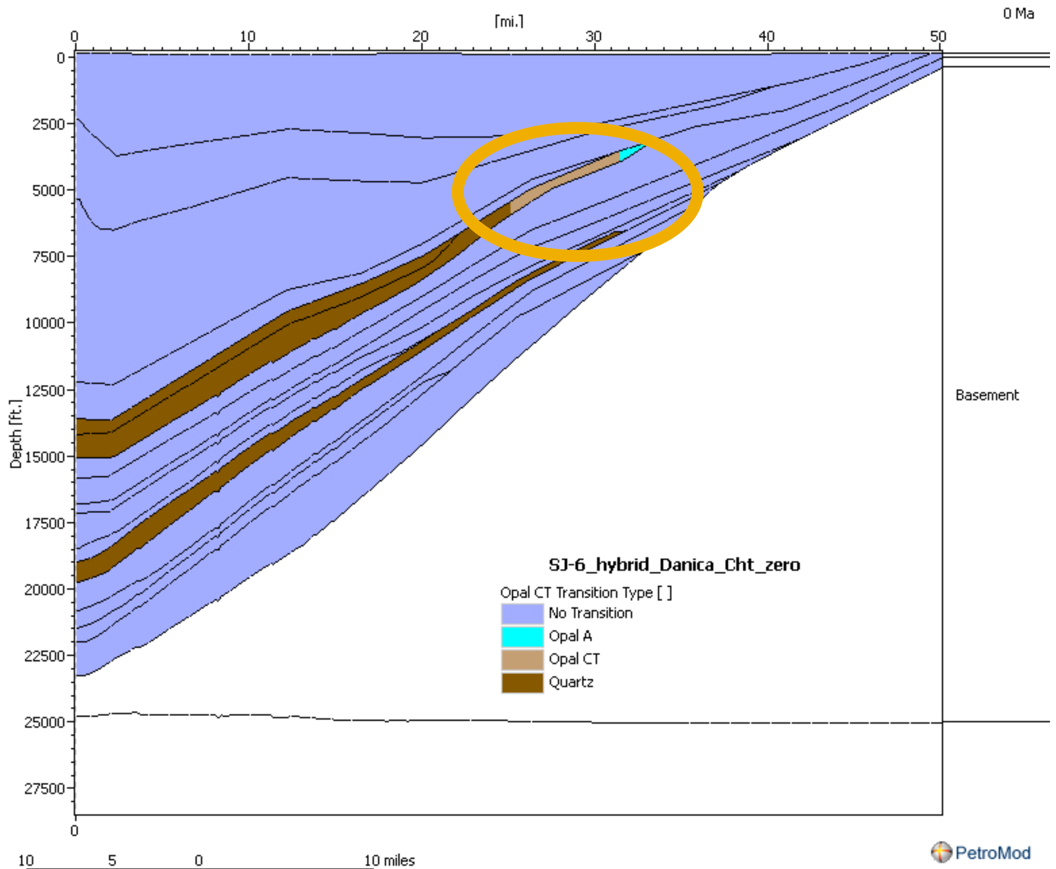
Example:
SJ-6 line in the
San Joaquin Basin, CA



Peters et al. (2008); Bloch (1991)

Opal-CT layer persists



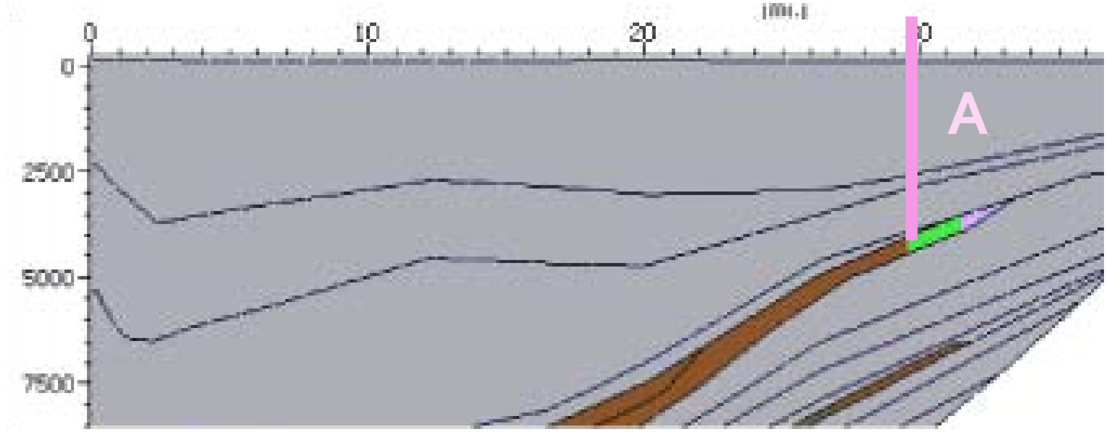


Ernst & Calvert **this study**

San Joaquin Basin

Well locations change

Ernst & Calvert

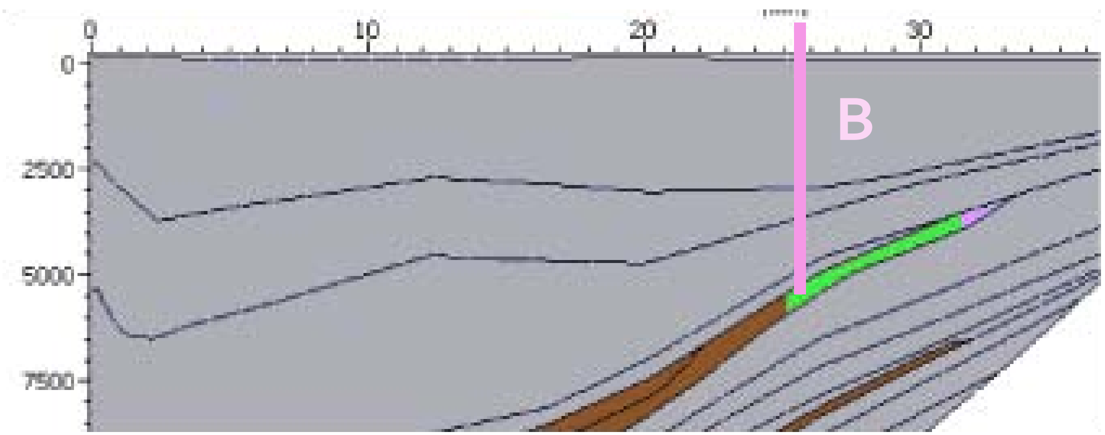


Well A

30 miles

4000 feet depth

this study

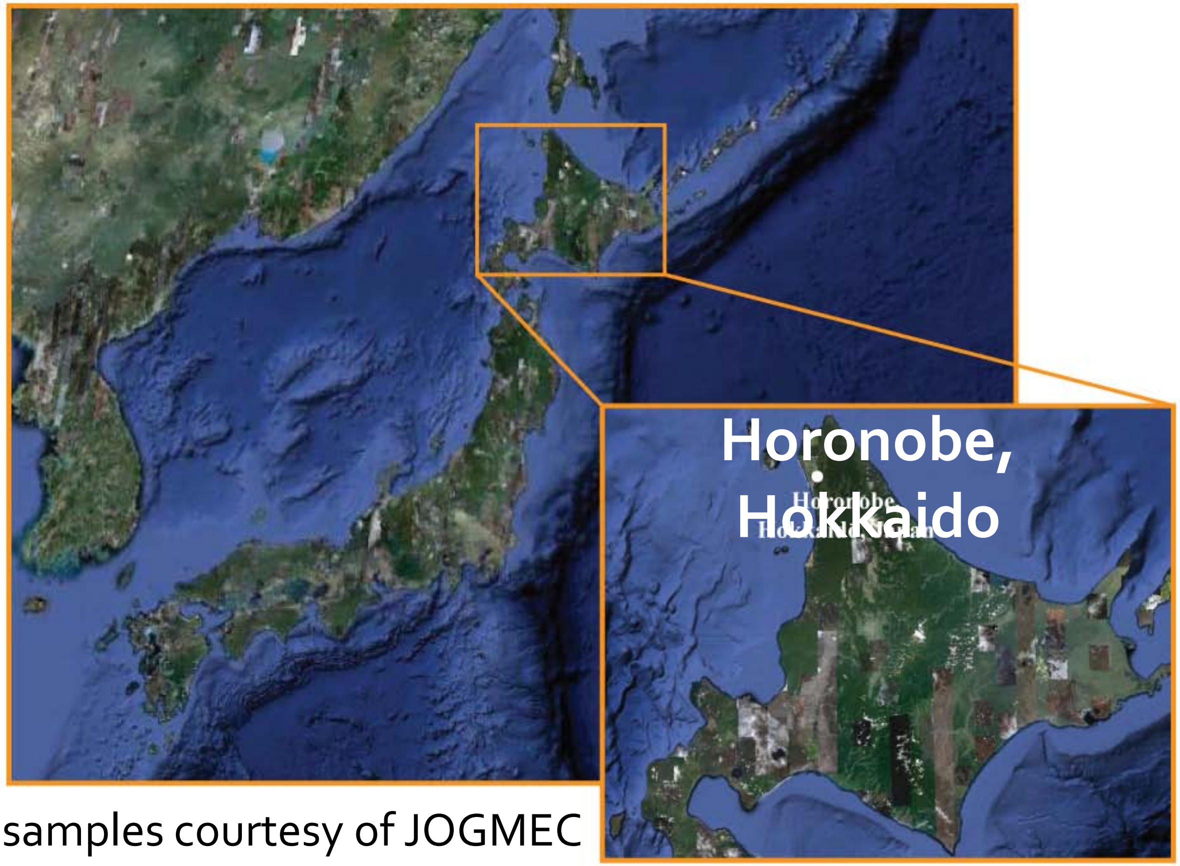


Well B

35 miles

5500 feet depth

And other basins?



samples courtesy of JOGMEC

No detected transformation in Wakkanai Fm samples from Horonobe, Hokkaido, Japan

Conclusions

- Phase transitions in minerals affect petroleum trapping and migration (storage and transport).
- Basin models are sensitive to kinetic parameters.
- Kinetics customized to a basin may be required until all controlling mechanisms for the reaction are understood.

Acknowledgements

- Stanford Basin and Petroleum System Modeling industrial affiliates
- Stanford Rock Physics and Borehole Geophysics industrial affiliates
- Bill Benzel (USGS, Denver)