SCEC 25133 Workshop report: Integrating friction into the Community Rheology Model

Conveners: Alexis Ault (USU), Sylvain Barbot (USC), Caroline Seyler (USC)
Date: September 6, 2025
Location: Palm Springs Hilton
Website: https://www.scec.org/events/2025-scec-crm-workshop/

WORKSHOP SUMMARY

The 2025 Community Rheology Model (CRM) Workshop (SCEC Award 25133) was held on September 6, 2025, in Palm Springs, California, and convened by Alexis Ault (USU), Sylvain Barbot (USC), and Caroline Seyler (USC). The CRM is a foundational CEM but, to date, is underdeveloped because it does not include brittle rheology. On- and off-fault frictional properties within and above the seismogenic zone in the San Andreas fault system (SAFS) are critical components of quasi-static and dynamic rupture simulations and probabilistic earthquake hazard forecasts for the state of California. Overcoming this challenge, filling data gaps, and expanding the CRM statewide, requires community-led input from the experimental/rock mechanics, earthquake geology, geophysics, and computational communities (Fig. 1).

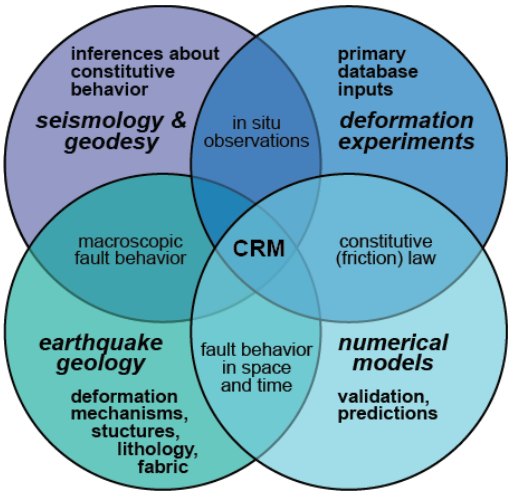

Figure 1. *Relationships between communities invested in integrating friction into CRM.*

This one-day, pre-SCEC Annual Meeting workshop brought together 31 chiefly experimentalists and earthquake geologists across career stages was designed to develop a framework for integrating frictional properties into the CRM. The workshop had three major goals: (***1***) design the foundational components of a new geo-referenced frictional database for California; (***2***) identify persistent unknowns in brittle rheology relevant to SCEC's statewide mission; and (***3***) advocate for the importance of rheology and frictional properties in the future of SCEC science, including synergies with CRESCENT.

Logistics The agenda combined invited science talks in three sessions with plenary synthesis discussions, structured breakout discussions and readouts, and lightning talks advertising upcoming poster presentations at the full SCEC Meeting. Each session had two scribes to capture key elements of the science, questions and answers, and discussions. Two breakout sessions involved dividing the participants into 5 groups each, with scribes and dedicated prompts motivating discussion.

SYNTHESIS AND FINDINGS

Setting the stage

The current CRM provides a 3-dimensional description of ductile rheology for southern California based on a simplified geologic framework model and a combination of ductile flow laws for each rock type (Hearn et al., 2020). An invited talk from *Laurent Montesi* provided the context for the origin and evolution of the CRM and other CEMs, and the development of the CEM explorer or interface for querying the data.

SESSION 1: Building a Frictional Database for California

Session 1 was moderated by Caroline Seyler, with scribes Monica Barbery (Brown) and Zach Smith (Berkeley). Invited talks by *Srisharan Shreedharan* (USU; heterogeneity, grain-size controls, and frictional healing) and *Kristina Okamoto* (Minnesota; microphysical controls, dilation vs. fracturing, plasticity, and/or contact-scale behavior) framed emergent research required for a frictional CRM. Both emphasized that frictional behavior depends strongly on grain size, distribution of weak phases, evolving microstructures, and conditions such as normal stress and pore fluid state. These talks positioned lithology, material dependence, and heterogeneity as considerations for a statewide frictional model.

Key themes from the plenary discussion included the need to clarify the intended users and use-cases for the frictional CRM, to define the appropriate scales of interest (microns to kilometers), and to consider whether the database should prioritize lithology-based properties, fault-specific data, or both. Participants noted that frictional behavior cannot be characterized solely by end-member experiments (e.g., Westerly granite) or applying mixtures, and that a lithology-informed framework is essential.

Breakout Discussion 1

Breakout groups focused on identifying the data, metadata, and structural features required for a robust frictional database. Across the five groups, recurring priorities emerged:

- **Frictional parameters:**
  - Provide statewide friction values, rate-and-state parameters (a–b) for common lithologies
  - Document dynamic weakening, critical slip distance, and healing behavior
- **Lithology and material dependence:**
  - Begin with a practical set of common California lithologies
  - Consider both gouge and intact rock behavior
  - Explicitly address mixed-phase systems and weak mineral phases (clays, phyllosilicates)
- **Microstructure and fabrics:**
  - Quantify localization, grain size, porosity, etc. where possible
  - Identify fabrics that evolve with strain and govern stability
- **Implementation and scope:**
  - Maintain modularity so the CRM can grow over time
  - Potentially connect with StraboExperimental to avoid duplicating effort
  - Start small: test database structure using a handful of well-characterized faults
  - Ensure the CRM captures both on-fault and off-fault behaviors

Groups emphasized that the database must balance completeness with usability: an initial, practical framework should be quickly deployable, with the option to add depth and complexity as the community contributes more data.

Breakout Discussion 2

The second breakout session asked participants to envision how the CRM should evolve to serve future constitutive relationships and SCEC science needs. Across groups, several key themes emerged:

- Focus on static and quasi-static friction first, providing a backbone for statewide modeling.
- Healing must be incorporated in a meaningful way, as it affects fault stability and cycle dynamics.
- Develop physics-based laws in parallel with empirical laws, enabling the CRM to evolve as new experiments and observations become available.
- Create a modular structure that separates lithology models from rheology models, allowing flexible combinations.
- Establish pathways from lithology to seismic hazard, identifying target faults and geological settings for initial testing.
- Include constitutive components relevant to low-temperature plasticity, fracture mechanics, granular/cataclastic flow, pressure solution, rate-and-state friction.
- Embrace a hierarchical implementation strategy: start simple with well-characterized examples, then broaden to statewide coverage.
- Address “off-fault” deformation explicitly, recognizing its importance for slip partitioning and seismic hazard forecasts.

Across groups, participants agreed that a static friction database including a–b is both achievable and valuable, and that such a database should serve as the foundation for more sophisticated constitutive relationships and multi-physics coupling.

SESSION 2: SCEC Science – Outstanding Questions & the Role of Rheology

Session 2 was modulated by Sylvain Barbot, with scribes Folarin Kolawole (Columbia) and Binhao Wang (USC). Invited talks by *Josie Nevitt* (USGS, fault rheology from field to lab) and *Matěj Pěc* (MIT, innovative methods for quantifying brittle deformation) highlighted the need to integrate diverse observations, from exhumed fault zones, laboratory friction experiments, geophysical and geodetic observations, and microstructural analyses, to understand how brittle rheological processes localize strain. The session discussion underscored several major scientific questions:

- How do we distinguish the rheology of fault cores vs. surrounding wall rocks?
- What role does clay content play in frictional properties and localization?
- How do mechanical mixing, grain-size evolution, and metasomatism alter fault rock rheology?
- What governs the transition between velocity-strengthening vs. velocity-weakening behavior?
- How do fluids, pore pressure evolution, and chemistry shape frictional response across depth?
- Can lab experiments meaningfully capture fault creep, brittle–ductile transition processes, and distributed off-fault deformation?

Participants emphasized that wall-rock (bulk) rheology, often absent from rate-and-state frameworks, is essential for modeling interseismic strain accumulation and shallow slip deficits. Observational tools such as LiDAR, shallow and deep creepmeters, GNSS, and microstructural analysis are critical for constraining models that span multiple depths and deformation regimes.

LIGHTNING TALKS: Emerging Science and Community Connections

The workshop included a series of *Lightning Talks* to advertise posters presented at the full SCEC Annual Meeting. The talks captured the breadth of SCEC science related to fault mechanics and brittle rheology. Topics, as reflected in the titles listed on the website, spanned experimental investigations of frictional behavior, field-based characterization of fault zone materials, advances in dynamic rupture modeling, development of rheology toolkits and laboratory methods, analysis of creep and slow slip phenomena, grain-size dependent deformation mechanisms, and early efforts to assemble frictional datasets relevant to the CRM. Collectively, the lightning talks highlighted the exciting methodological approaches and emergent datasets and showcased strong participation by early-career researchers.

SESSION 3: Advocating for Rheology in the Future of SCEC

Session 3 was moderated by Alexis Ault, with scribes Alex DiMonte (USU) and Terry Lee (UNR). The joint invited talk by *Cailey Condit* (UW) and *Greg Hirth* (Brown) emphasized how exhumed fault zones and subduction interfaces provide valuable analogs for understanding brittle–ductile transition processes, grain-size sensitive creep, pressure solution, and role of weak phases (i.e., talc, antigorite) in accommodating deformation. Their examples demonstrated how microstructures, mineralogy, and fluid-rich environments produce mechanically weak zones that localize strain and influence seismic cycle behavior.

In discussion, SCEC Director Designate *Ahmed Elbanna* (USC) outlined how improved frictional models will benefit both short-term dynamic rupture simulations and long-term earthquake cycle analyses, strengthening the connection between CRM development and seismic hazard forecasting. Participants noted the need for standardized terminology and documentation and emphasized the importance of developing constitutive laws that incorporate mixed deformation mechanisms, time-dependent processes, and off-fault deformation.

LOOKING TO THE FUTURE

Reflecting on workshop outcomes and looking ahead, the conveners noted several structural and scientific challenges that emerged from the workshop discussions. Attendance was dominated by experimentalists and earthquake geologists, with relatively limited participation from researchers who specialize in numerical modeling of seismic processes. For many attendees, this workshop represented their first engagement with a SCEC-sponsored event, underscoring both the novelty and the opportunity of

the growing CRM community. Participants did not converge on a single pathway forward, an outcome that reflects the genuine scientific obstacles the community faces rather than any lack of enthusiasm or engagement. Several barriers remain:

- **Constitutive behavior of fractured rocks:** There is no community consensus on the appropriate constitutive descriptions for fractured or damaged rocks, nor on the microphysical mechanisms that dominate deformation under different conditions.
- **Fault composition and structure at depth:** The composition, mineralogy, and fabric of faults across depths, including within the seismogenic zone, remain poorly constrained due to the inherent difficulty of sampling natural fault materials at relevant conditions.
- **Sampling limitations:** It is neither feasible nor desirable to attempt exhaustive sampling of all lithologies potentially involved in California faulting, making an all-encompassing frictional database an impractical goal.
- **Sensitivity of friction to conditions:** Because rock friction depends strongly on slip rate, temperature, confining and pore-fluid pressure, and evolving microstructure, fully characterizing any lithology requires an extensive suite of experimental conditions.

Despite these challenges, the community is not starting from scratch. A growing body of frictional data already exists for many lithologies relevant to California fault systems, including foliated mica-rich cataclasite (Beltzer and French, 2024), glaucophane–lawsonite blueschist (Sawai et al., 2016), tremolite and talc schists, argillite, serpentinite, and foliated cataclasites (Hirauchi et al., 2020). Extensive datasets also exist for samples from the San Andreas Fault Observatory at Depth (SAFOD) and surrounding regions (Carpenter et al., 2009, 2011, 2015; Moore et al., 2016; Nie and Barbot, 2024), as well as Pelona, Portal, and Rand Mountain schists (Barbot et al., 2025; Guvercin et al., 2025) and the shallow southern San Andreas fault gouge (DiMonte et al., 2025). These studies provide a meaningful point of departure for a frictional CRM and demonstrate a clear, pre-existing community investment in understanding the brittle rheology of California's fault systems.

Together, these challenges and opportunities underscore the importance of a coordinated, modular, and community-driven approach. The frictional CRM can build on this growing empirical foundation while creating a framework flexible enough to incorporate different, emergent constitutive laws, lithologies, and future advances in experimental, field, and modeling techniques.

Figure 2. *Group photo of workshop conveners, speakers, scribes, and participants.*

WORKSHOP AGENDA
CRM Workshop: Integrating Friction into the Community Rheology Model
Saturday, September 6, 2025

09:00 – 10:00 — Coffee, breakfast, check-in
10:00 – 10:15 — Welcome and workshop goals – Ault, Barbot, Seyler
10:15 – 10:30 — *Laurent Montesi*: State of the CRM and CEM interface

Session 1: Building a Frictional Database for California
Session reporters: Monica Barbery, Zach Smith

10:30 – 10:35 — Introduction and moderator – Seyler
10:35 – 10:55 — *Kristina Okamoto*: The role of normal stress on the microphysics of gouge deformation

10:55 – 11:15 — *Srisharan Shreedharan*: Impact of heterogeneity on fault friction in space and time

11:15 – 11:45 — Breakout Group Brainstorm #1 – Lithologies, data, and metadata for database
11:45 – 12:05 — Group Read-outs and Compilation
12:05 – 13:00 — Lunch

13:00 – 13:05 — Developing constitutive laws – Barbot
13:05 – 13:30 — Breakout Group Brainstorm #2 (new groups) – "Futurecasting the CRM," how can the CRM serve future constitutive relationships?
13:30 – 13:50 — Group Read-outs and Compilation
13:50 – 14:10 — Group Discussion – What's missing and what is needed?

Session 2: Outstanding Rheological Questions
Session reporters: Folarin Kolawole, Binhao Wang
14:10 – 14:15 — Introduction and moderator – Barbot
14:15 – 14:35 — *Josie Nevitt*: Observational opportunities and challenges for understanding natural fault behavior
14:35 – 14:55 — *Matěj Pěc*: How do rocks fail? Strain localization and microstructural transformations in the earthquake cycle
14:55 – 15:10 — Group Discussion

Lightning talk session + Coffee Break
15:10 – 15:20 — Coffee Break
15:20 – 16:00 — Coffee and **lightning talks** (3 min each) for rheology posters at SCEC

Binhao Wang	Simulating Earthquake Cycles with Lab-derived, Physics-based Friction
Monica Barbery	Effects of roughness on fault friction from slow to fast velocities
Roland Bürgmann	Probing Frictional Fault Properties From Tidal and Hydrological Seismicity Modulations
Tamara Jeppson	Evolution of fault properties at geothermal conditions
Zachary Smith	Impacts of hydrothermal alteration on spatiotemporal evolution of fault zone properties
Folarin Kolawole	Emergent bimaterial slip zones and relationships with off-fault deformation and space-time strain distribution on evolving plate boundary faults, Walker Lane, California
Nairong Du	Creep experiments results of the SAF damage zone rocks and their viscoplastic properties
Christie Rowe	Fault zone healing: time-dependent rheology changes
Hiroki Sone	Viscoplastic rheology for characterizing the bulk rheology of fault zone rocks.

Ashley Griffith	Geological and Frictional Characterization of Damage Zone Structure of the Southern San Andreas Fault at Ferrum and Implications for Coseismic Off-Fault Deformation
Alexandra DiMonte	Frictional properties and K-Ar geochronology reveal a multi-million year history of earthquakes and slow slip events in the southern San Andreas fault gouge
Heather Savage	Efforts to create an experimental database

Session 3: Advocating for Rheology in the Future of SCEC

Session reporters: Alex DiMonte, Terry Lee

16:00 – 16:05 — Introduction and moderator – Ault
16:05 – 16:10 — Comments from SCEC Director Designate Ahmed Elbanna
16:10 – 16:35 — *Cailey Condit & Greg Hirth*: Rheology across the brittle-ductile transition leveraging insights from subduction settings: What's useful for SCEC
16:35 – 16:45 — Group Discussion

Wrap-up and Next Steps
16:45 – 17:00 — Summary and closing remarks – Ault, Barbot, Seyler

PARTICIPANTS

Last Name	First Name	Organization
Ault	Alexis	USU
Barbery	Monica	Brown
Barbot	Sylvain	USC
Bürgmann	Roland	UC Berkeley
Cebry	Sara	USGS
Condit	Cailey	UW
DiMonte	Alexandra	USU
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Elbanna	Ahmed	USC
Griffith	Ashley	Ohio State
Hirth	Greg	Brown
Jeppson	Tamara	USGS
Kolawole	Folarin	Columbia
Krogh	Julia	UC Santa Cruz
Kruger	Ilene	UC Santa Cruz
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Nevitt	Josie	USGS
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