A Preliminary Characterization and Kinematic Analysis of Fractures within the Miocene Vaqueros and Topanga Formation, Point Mugu Rock, Ventura County, California*

John P. Detring[1]

[1]Department of the Interior, Bureau of Safety and Environmental Enforcement, Camarillo, CA, United States (john.detring@gmail.com)

Abstract

A complex, transpressive kinematic history exists within the Transverse Ranges. Deformation is observed to be consistent with roughly N-S shortening. The structural trends and fracture patterns are in response to this deformation. This study analyzes the kinematic indicators, structural geometries and fracture patterns within California's western Transverse Ranges. Fracture systems provide permeability as well as create traps in petroleum reservoirs. An understanding of the orientation and timing of fracture systems can test current tectonic models and allow for predictions of subsurface fracture orientation and permeability. This data will increase the understanding of regional fracture sets and identify fractures which may be ideal fluid pathways for the transmission of hydrocarbons. Data from minor fault stations (4) and joint stations (2) were systematically collected throughout the area within the Topanga and Vaqueros Formations to obtain average joint orientations and to calculate the ideal $\sigma 1$ orientations of minor faults. Shear sense was determined using Petit's (1987) RO criteria. When possible, cross-cutting relationships were observed so that timing relationships between different faulting events could be assessed. Joint surfaces were discriminated from faults by lack of gouge, slicks, or cataclasite, and whether plumose structures (hackles, ribs, or arrest lines) were present. The full data set was systematically analyzed to reveal kinematic relationships. Stereonet software was used to create plots of the data split by type of measurement or calculation (i.e. joint or fault plane, slickenline, or sigma 1), and type of fracture (i.e. Mode I, II, or slip sense). Rose plots, rounded with a smoothing increment of 10 degrees, of average $\sigma 1$ trend, average slickenline trend, average joint strike, and average shearband trend were created using kinematic analysis software. The angle used for the calculation of the ideal sigma 1 for preliminary analyses was assumed to be 25 degrees in accordance with Byerlee (1978). Preliminary analyses of minor faults are underway. Joint measurements are bimodal in distribution, with average strikes of N0E and N78E. Abutting relationships suggest that the N0E-striking joints are primary (J1) and the N78E-striking joints are secondary (J2). Calcite mineralization is present along J1 joint planes suggesting fluid flow. Shearbands, fault zones and intrusive diabase dikes are found parallel to both J1 and J2.

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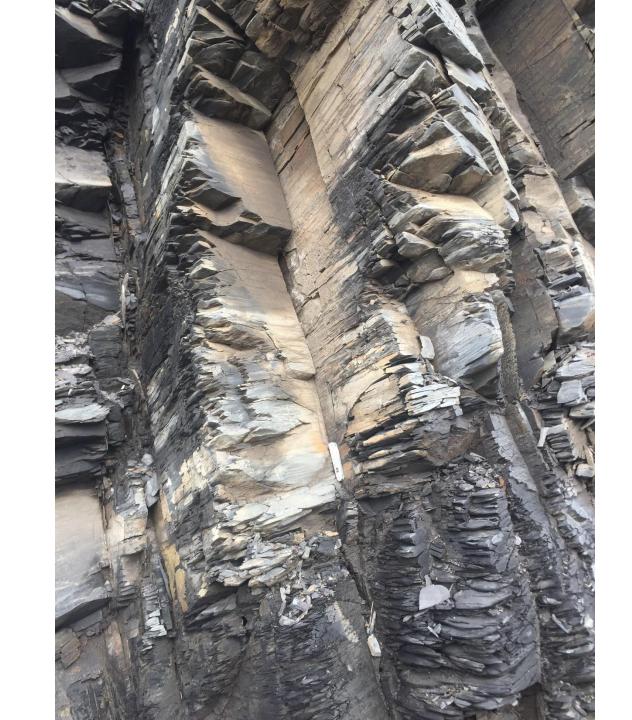
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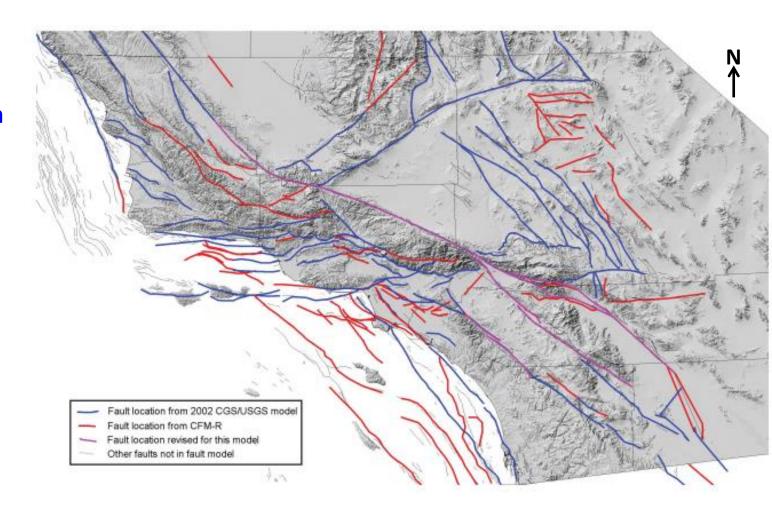
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John P. Detring, PG
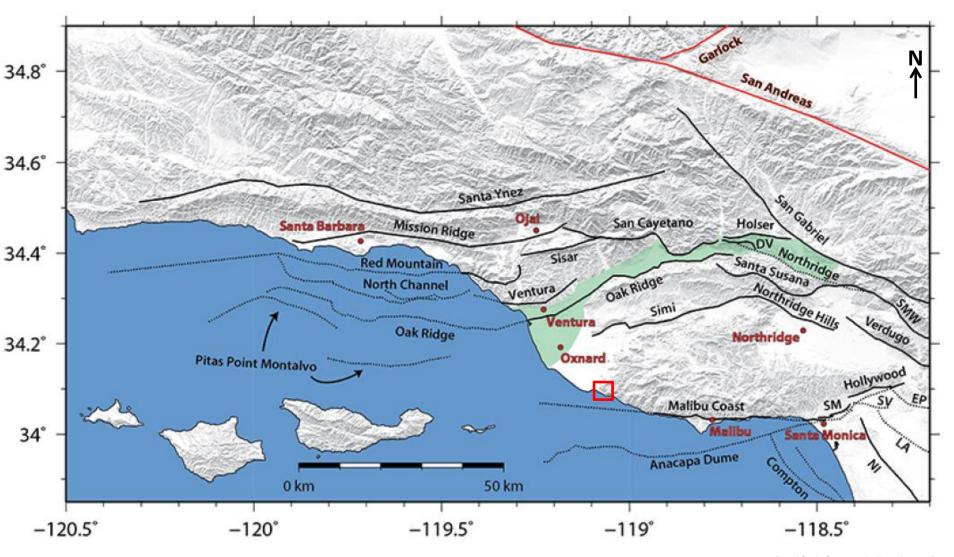Department of the Interior, BSEE

Outline

Transverse Ranges

- **TR extend from Point Conception, 500 km into the Mojave and Colorado Deserts**

- **Uplifted ~5 Ma**

- **The Transverse Ranges are oblique to the regional trends of the Coast, Peninsular Ranges their associated faults**

- **Characterized by controversial E-W oriented folds and fractures of rotational and/or compressional origin**

- **Sedimentary and volcanic rocks in the west and granitic and metamorphic rocks in the central and east**

N

Fault location from 2002 CGS/USGS model
Fault location from CFM-R
Fault location revised for this model
Other faults not in fault model

(Wills et. all, 2008)

Transverse Ranges

- **Major faults are E-W-striking and display left- or reverse-slip**

- **Contrasted to the prevalent NW-striking right-slip of the San Andreas system just to the north**

- **Fold axis in the Western Transverse Ranges are consistent with N-S to NNE-SSW shortening**

- **Study area located in Ventura County California**
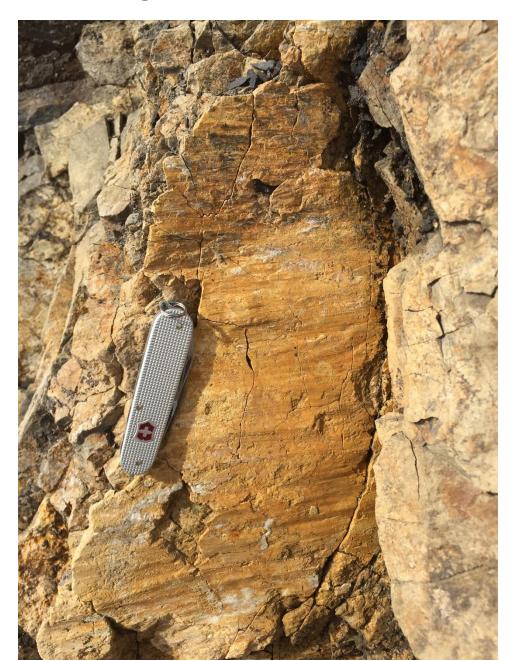

(Modified after Marshall et al., 2019)

Hypotheses proposed to explain range formation and regional fracture sets

- **Large magnitude rigid body rotation**

  - **Clockwise rotation of crustal blocks along left-lateral/obique fauts** (Jones et al., 1976; Crouch, 1979; Hornafius, et al., 1986; Luyendyk et al., 1980, 1985, 1991; McKenzie and Jackson, 1986; Cowan et al., 1986; Liddicoat, 1990; Nicholson et al., 1994; Shermer et al., 1996)

  - **Extension and rigid body rotation (**Crouch and Suppe, 1993)

  - **Transtension followed by transpression resulting in folding and reactivation of normal faults** (Bartolomeo and Longinotti, 2010)

  - **Oblique faulting and N-S crustal shortening concurrent with NW-motion and vertical axis block rotation** (Meigs and Oskin, 2002)

  - **Left-lateral slip and antithetic faulting within a right-lateral shear field** (Platt and Becker, 2013)

  - **Absorbtion of differential rotation within a boundary zone** (Onderdonk, 2005)

- **Thrusting and Detachment**

  - **Contemporaneous thrusting and strike-slip motion along a horizontal detachment or low-angle fault** (Namson and Davis, 1988b; Davis et al. 1988; Davis and Namson, 2017)

Problems

- **What are the timing and mechanisms controlling fracture genesis within zones of spatially and temporally coeval tectonics?**

- **What is the fracture response within zones of concurrent compression and transform tectonics?**

- **Are fractures observed in response to compressive and transform forces?**

- **If so, what do their abutting and cross-cutting relationships suggest?**

Significance

- Fracture systems provide permeability as well as create traps in petroleum reservoirs.

- Test current tectonic models and allow for predictions of fracture orientation.

- Prediction of open, closed, and fluid conducting fractures.

- Integration of surficial and subsurface fractures can give a clear understanding of the paleostress and/or present day S_{Hmax}.

- Potential insights into fracture patterns within adjacent oil and gas producing basins.

Methods

- **Systematic joint and minor fault collection**

- **Kinematic analyses**

- **Geologic mapping**

- **Cross-section analyses**

- **Integration of 2D seismic/cross-sections**

Fracture data collection methodology

- Measurement locations: numerous laterally continuous joints and slickensided surfaces, >25 measurements per stations.

- Bedding measurements were taken at each station, noting layer thickness, formation, and lithology.

- Joint surfaces were discriminated from faults by lack of gouge, slicks, or cataclasite, and whether plumose structures, hackles, ribs, or arrest lines were present.

- Data were collected using a Brunton compass and (RHR) to measure strike, dip, trend, and plunge of minor fault planes and slickenlines, and strike and dip of joint surfaces.

- Data from minor fault and joint stations were systematically collected directly off fault planes, to avoid bias, not more than one measurement was collected from within the area of about a clipboard.

- Shear sense was determined using Petit's (1987) RO criteria.

- Abutting and cross-cutting relationships were carefully observed so that timing relationships between different fracturing events could be assessed.
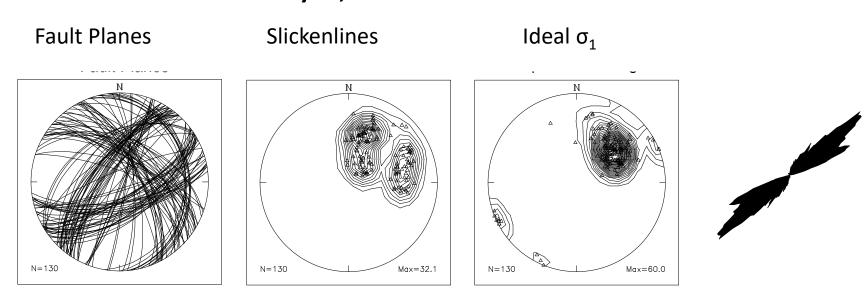
Kinematic analyses methodology

- Data was restored to pre-fold orientation.

- The kinematics of minor fault data collected will be analyzed by stereonets, rose diagrams, and eigenvector analyses to calculate average fault plane strike, slickenline trend, PT axes, and ideal σ_1.

- These analyses will be conducted for the full data set and then subdivided by station, unit, and slip-sense.

- The full fracture data set will then be systematically analyzed to reveal kinematic relationships.

- Stereonet 10/Orient 3.8 for plots of the data split by locality, age of strata, type of measurement or calculation (i.e. joint or fault plane, slickenline, or PT/σ_1), and type of fracture (i.e. Mode I, II, or slip-sense) (Cardozo and Allmendinger, 2013, Vollmer).

- Creation of rose plots, of average σ_1 trend, average slickenline trend, average joint strike, and average shear-band trend will be created.

- The angle used for the calculation of the ideal σ_1 for preliminary analyses will be assumed to be 25 degrees in accordance with Byerlee (1978). If a different angle is deemed more accurate then that will be utilized in the final analyses.
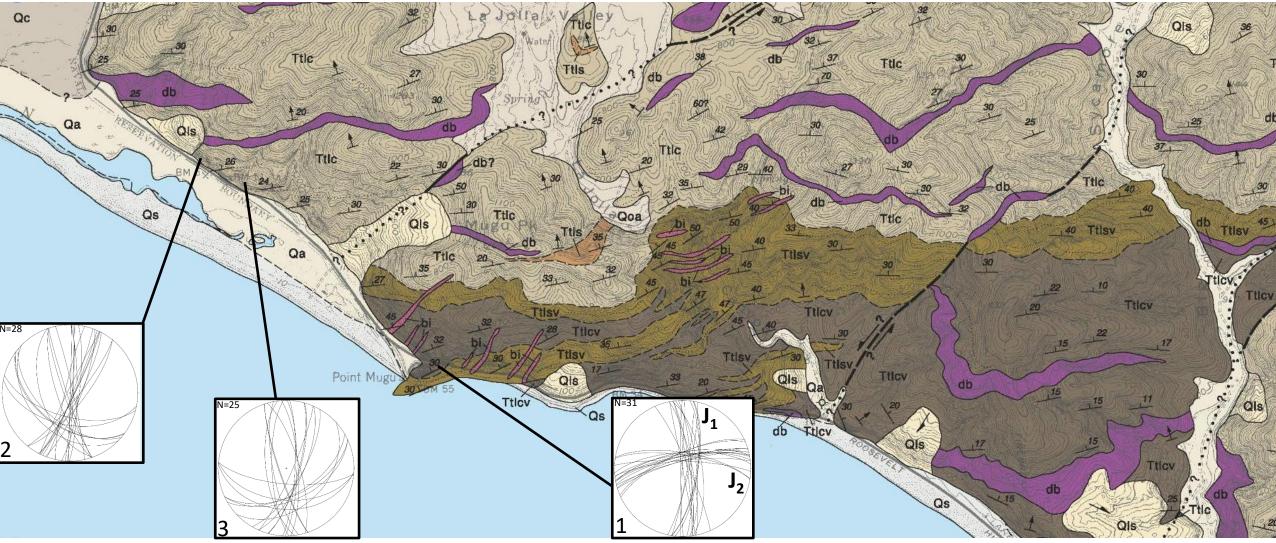
Example of kinematic data collection and analyses results

- **722 minor fault and 996 joint measurements**

- **Ideal σ_1 determined using Compton's (1966) method**

- **Eigenvector and Eigenvalue analyses of σ_1 axes and slickenlines**

Irish Canyon, NW Colorado

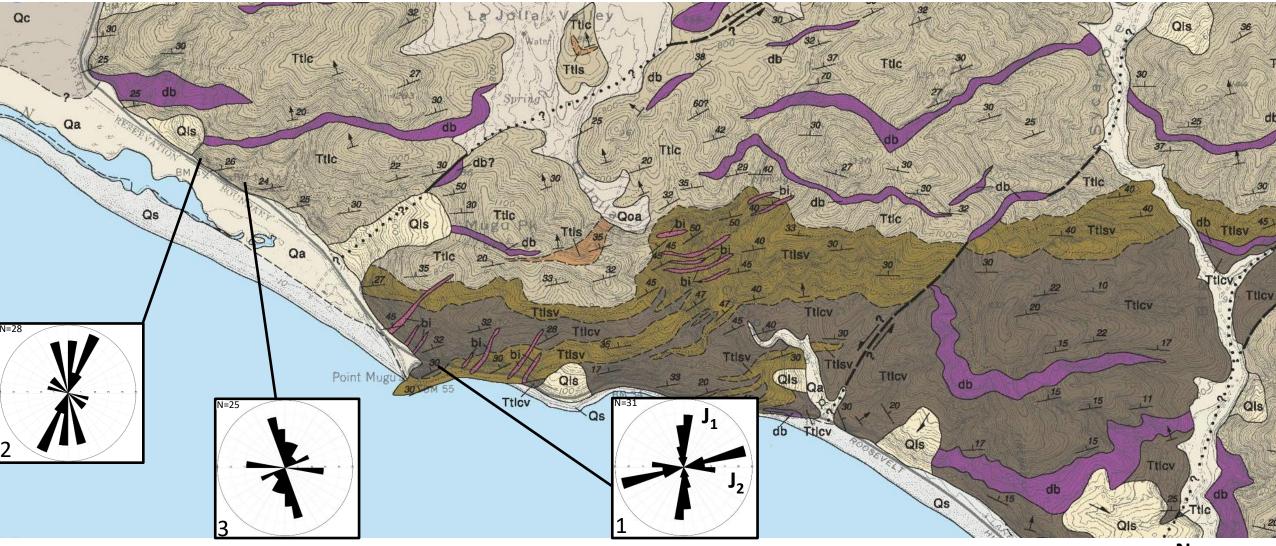| Fault Planes	Slickenlines	Ideal σ_1

Joint stations

- **Systematic joints and nonsystematic joints**
- **Mineralization present primarily on N-S oriented set**
- **Mineralization suggests N-S set may be open and conducting fluid**
- **Joint spacing 12-18" on the more massive SS and 4-12" on the finer grained layers**

N
1000'

Map reproduced from (Dibblee and Ehrenspeck, 1990)

Plots created in Stereonet (Cardozo and Allmendinger, 2013)
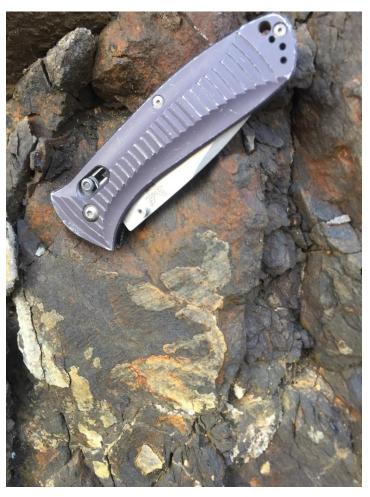
Joint stations

- Typically the N-S oriented set was J_1
- Dihedral angle of nearly 90° - orthogonal set
- Cross-joint and strike-joint pair
- J_1 in response to N-S compression and J_2 formed later as longitudinal set during folding

N

1000'

Status and next steps

Status
- Literature review
- 3 joint stations
- 3 fault stations (analysis underway)

Progression
- Locate additional areas within the TR containing sufficient rock exposures and shear fractures
- Mapping
- Cross-sections
- Additional analyses
- An addition to the compendium of paleostress data
- Added insights into TR formation

Questions?
John.detring@gmail.com