Community Near-Fault Observatory: Spatial Variations of Rock Properties and Deformation Processes across Rupture Zones, October 6 Breakout Session Notes:

Notetaker: Ashley Griffith

Moderator: Ramon Arrowsmith

Additional open-forum discussion notes located at: https://docs.google.com/document/d/1l15RZfUbRlSAEgK_Vx2mC9SSUC8vwmviq1zruPO_3yY/edit?usp=sharing

Discussion started at: 1:23PM ET

Yehuda – Did Chelsea work on time-dependent topographic changes?

Chelsea Scott – Yes. Topographic differencing can be used to quantify off-fault deformation. But there have not been sufficient data to resolve time variable changes in topographic changes?

Yehuda: Would cameras be useful here? Do we need drones?

Chelsea: The challenge is these data have higher noise levels than InSAR. It would be important to get frequent acquisitions following the earthquake.

Ramon – Reminder to everyone about entering their thoughts in the Google Doc. Also reminder to workshop participants about the science questions and general questions.

Ben Brooks – Rates of interseismic deformation are too slow to measure with LiDAR

Alba – From the coseismic point of view – deflections are best captured with LiDAR, but can't see fractures, so we need all types of observatons (e.g., optical imagery) to stitch together the whole picture…perhaps even interseismic

Ramon – With high enough resolution can start to pick up changes at 10% of pixel resolution

Kate Scharer – Broadening the discussion… Looking at RuFZO concept, there seems to be a disconnect between finer near-fault zone work and broader information from, say, Vs30 or geotechnical layer. If anyone has thoughts/info connecting these things, would be helpful

Ramon – Can we do delta Vs30 to see evolution?

Yehuda – Kate brings up an important point. A big part of the effort would be to integrate information near the fault with the larger scale regional picture – regional community rheology model, for example

Ramon - Comment from Doug Schmidt: "the Lidar people are claiming the ability to make repeat measurements on time scales that one could measure surface wave displacement propagating, I have no idea how one could implement this to study fast deformations during an event given that the 'reference' is likely moving too but something to think about."

Ramon - Comment from William Harbert: "Great talk--no response needed. You might apply Empirical Bayesian Kriging to estimate a higher resolution. Could be interesting. Thank you for this presentation."

Frank Vernon: One thing to do in response to Doug Schmidt, could house local drones at each of the subarrays, and launch automatically to do LiDAR and optical surveying simultaneously. Need to plan in advance.

Ramon – Yes. Robotic observations are going to be key.

Frank – Could do in rapid response mode fast enough to get them going once rupture detected somewhere else in the network

Ben Brooks – Ground based radar is the appropriate technique for a lot of near fault observatons

Doug Schmidt – Was just at SEG conference and they was a company claiming to do LiDAR in very short time/fast response. Also could do high rate strain measuremnets.

Yehuda – We currently have two cameras that have been looking for several years at the damage zone on the San Jacinto fz. If anyone wants to practice on this kind of data, please send an email to Yehuda or Frank Vernon.

Chelsea Scott - Important to not underestimate the importance of good georeferencing to resolve small-scale displacements. I have tried to do differencing on creeping fault and observation density was not good enough to get good georeferencing. Need connection with good positioning from differential GPS.

Art Frankel – A lot of large ground motions coming from local places around the fault. Need close seismometers to measure how changes in surface features affect strong ground motions.

Pieter Share – I would welcome Art to join next week's call because that is a key part of it. To Kate – what do you propose about sensor deployment (regarding your earlier comments)

Kate Scharer – The Vs30 measuremnts are easy to measure and non-invasive. Other approaches than Vs30 too

Josie Nevitt – connection between near surface measurements and ground motions is important and we have an observation gap. For larger pieces of ruptures, Andy Michael found the displacement of pebbles were less indicative between high frequency ground motions than near surface fracturing (not sure I captured this one).

Nic Barth – Adding to thought of rapid deployment drones. A high frame rate camera would be helpful. To help understand FGFs, PBRs, pebbles, and other surface indicators of ground motions, could set up some physical experiments of – say – discs of known mass and size as natural experiments.

Joann Stock – Other types of things we could measure? Dust? Particulate matter?

Yehuda – Anything we can measure regarding volumetric changes

Ashley - Everything we've talked about so far are primarily measures of displacement or velocity fields. What about heat flow? Gas chromatography?

Joann Stock - It would be great to have gas sensors, soil flux accumulation chambers, constantly monitoring

Lauro Chiarluce – In Europe we have been working on near fault observatories for a few years. We monitor radon and CO_2 constantly. One idea was to look at connection between fluids and ground deformation. We are interested in increases resolution of our observations temporally and spatially to study precursory and postseismic relationships, measure diffusion processes, etc. Looking forward to seeing what we do here.

Roger Bilham – With Ben Brooks and Josie – we take gas measurements at 10 of the creepmeters. Have started measuring strain in addition to dilation across the fault. From initial results, I would like to see gas measurements at every creep meter (btw we are measuring once per minutes). We should measure gas in the fault zone and outside/in damage zone of fault zone to distinguish between gas sources

Josie Nevitt – Something we are lacking right now are true coseismic displacements because rapid postseismic response is a problem. Need immediate, on fault measurements

Ben Brooks – Seems like an elephant in the room is that proposing a near fault observatory is that it has a low probability of actually capturing a large earthquake. Would be good to ensure we are also focusing on collecting data that we can use regardless, and should not ignore creep processes

Alba – Still need to understand how faults behave interseismically too.

Discussion Ended at 2:02PM ET with closing remarks by Ramon followed by Kasey

October 6, 2022 Rupture and Fault Zone ObservatoryBreakout Session on "Spatial Variations of Rock Properties and Deformation Processes across Fault Zones"

<u>Science Questions</u>:

1. What do we see geologically and geomorphically when we look across fault zones? Shear products? Volumetric products?
2. What are the implications of these products? What is the time variability of these signals?
3. How could we observe these using a purpose-built observatory? What do we need in the observatory?

<u>In the context of each science question:</u>

1. Signals that inform us about the science questions
2. Properties of the observatories that are required to record these signals
3. How to involve the next generation and training

Ben Zion, et al., SRL opinion piece:
https://pubs.geoscienceworld.org/ssa/srl/article/doi/10.1785/0220220266/617754/A-Grand-Challenge-International-Infrastructure-for

Your Name, contact info (optional)	Comment (or Questions)
Christie Rowe	There's no standard nomenclature for fault rocks (pretty bad in hard rock settings, non-existant for near-surface / unconsolidated materials. With Randy Williams, I'm working on a new vocabulary based on the most common observations and hoping to connect with interested researchers to share observations and criticize the new scheme (timeframe 6 months). This aims to create the vocabulary for Science Question 1 and 2. E.g. what rocks/structures are responsible for "plastic yielding" at different depths. "Gouge" is non-unique and insufficiently detailed to distinguish between different fault rocks. /end{rant} johanna.nevitt@gmail.com I would very much love to look at your PSZ napa cores @christie-this is great! Please connect w trenches on this as we have our own goofy vocab that would benefit from formalzing. -Kate Scharer

Michael Oskin	Q to Josie: Is the fault sample a transect into the fault? Mirabilite (hydrous sodium sulfate) loses water rapidly when exposed to air.
William Harbert	Q to Josie: Did you investigate InSAR ascending/descending datasets, including processed (SqueeSAR, TRE Altamira) datasets for this region pre/post sequence? A from Josie: I did not look at InSAR data, but others have
Katherine Scharer/Christie Rowe	Q to Josie: Wondering if you are getting age control on the playa seds?/how are these dated? maybe 14C A from Josie: I have no age controls, would love to talk to you more about it!
Ben Zion	Q to Josie: Fault normal observations A from Josie: These were not collected Comment from Ben Brooks: re: fault-normal deformation in many of the creepmeters we have been also been installing complimentary creepmeters (Roger B's innovation) to measure orthogonal as well as fault-parallel deformation
William Harbert	Could we combine and investigate InSAR ascending/descending datasets, including processed (SqueeSAR, TRE Altamira) archived and open datasets, with field calibration, for regions pre/post sequences? Github distribution of relevant poroelastic FEM code with input/output examples. Using Deep Learning methods to superscale smaller scale fractures in key areas from coarser historical data (DOQQ images) using sUAS datasets for training. All code on github. Could high spatial/high time resolution monitoring from CO2 studies be leveraged in this activity? A permanent vertical DAS fiber observatory with frequent vertical seismic profiles for example. Potentially also using permanently mounted orbital seismic sources at key locations for rapid raypath voxel parameter change detection. Please check: Spackman, T. W. (2019). Novel orbital seismic sources at a CO2 storage monitoring site, Newell County, Alberta (Unpublished master's thesis). University of Calgary, Using data science to increase spatial resolution of topography datasets and superscaling historical datasets to higher resolution. All code shared on github. Differential absorption LIDAR (DIAL) airborne gas detection surveys could be interesting with soil flux measurements.

Douglas Schmitt	Just a comment, the Lidar people are claiming the ability to make repeat measurements on time scales that one could measure surface wave displacement propagating, I have no idea how one could implement this to study fast deformations during an event given that the 'reference' is likely moving too but something to think about. Continuing some additional comments before I go, as Bill just said above one can use a combined seismometer/ fiber optic sensing to provide a lot more information on a much finer spatial scale. There are different fiber optic technologies that could be employed. I expect many reading this already know it, it be some of the technologies available now include: 1. Strain or strain rate monitoring at frequencies <500 Hz to nearly static over a distance of 50 km or more at spacings of 1 m. This is being used now to monitor surface wave dispersion curves that could be inverted for near surface structure. 2. Repeatable strain measurements along distances about the same (also requires fiber optic temperature to correct properly) The fiber technology can only give measures along the fiber direction, so cannot give full displacement. That is why having other traditional seismic sensors could be important. Trying to do some of this from boreholes too would be useful to try to calibrate the in situ properties and get some material. We are currently working on combined geophone/DAS monitoring from a borehole along the Alpine Fault (data collected a while ago but have been slow on this for a variety of reasons) where we have a very good idea of the in situ fracture orientations/density from the DSDP-2 borehole. We are currently trying to invert active source seismic into this borehole with the fracture observations and laboratory physical property measurements on the mylonites. Just some thoughts!
Kate Scharer	Looking for ways to leverage local info we might capture from the EQ to other areas- what pre-, or episodic info about the near surface should we collect now? Vs30, nodal, fiber optics provide way to extend this info to the next next earthquake if we have characterized the first one well. OVerall, my question is also driving at densifying or extending the types of data/info that Josie and Alba are utilizing w/o permanent installations.
Kate Scharer	THe RuFZo is missing dip slip faults…. Perhaps a need to consider one of these to look at directivity/HW vs FW differences in gm etc.

Ramon Arrowsmith	We need a quantum leap in observations to make a quantum leap in understanding Success will come from well articulated questions and opportunities, and from authentic community engagement Capturing a few ideas during the talks: Nevitt: Mechanical factors (Napa, Hayward, Ridgecrest) --Frictional properties, preexisting structures, and orientation --mobile laser scanning, seismic imaging, mechanical modeling, seismic imaging --slip gradient updip and plastic yielding --why did the rupture stop so shallowly --primary observations of the shallow fault zone from drilling --role of saturation much weaker when materials are wet --slip reduction towards the surface as it traverses saturated to unsaturated zone --Fault displacement hazards may be seasonally dependent --role of inherited rupture geometry to improve the fit of the offset distribution --shallow fractures are pre existing --seismic slip velocities and dynamic weakening Questions: Fault normal deformation; materials Rodriguez Padilla: --Inelastic deformation--what do we mean? --Can rupture maps tell us about damage/inelastic deformation? --many fractures, different processes; how to distinguish? --Need to observe the fractures as they form--RuFZO --heterogeneity of the fracturing is a challenge --see Nat Geo and BSSA (in review) papers: fracture density decay vs fault perpendicular distance (log log) --importance of different base data sets --coseismic decrease in the shear rigidity from fracturing--bedrock vs. sediment --other processes include long wavelength deflections/warping (100s m to kms), in spite of the fracturing ear the fault; and block rotations (localized near the fault)

	--questions: Coseismic--processes to drive fracturing? Postseismic: how much damage is inherited, healed, interseismic Long wavelength --need coverage near the fault, across different material (bedrock and sediment), maybe also long wavelengths, and don't forget about the cameras to do differencing --question: importance of fault maturity? Have not had a rupture along a more mature California fault (yet…) Chelsea Scott --Topographic differencing --topography data types --differencing methodology --example from Kumamoto --another measure of straining and inelastic deformation --what do we gain from the topography differencing? Shallow fault geometry and resolve more shallow slip --Creeping section: topographic differencing add an important insight: where is the fault active over the decadal time scale versus what might be suggested by the fault zone geomorphology and geology --Topography needs ---map the faults based on the geomorphology ---measure displacements coseismic and post seismic ---pre event ALSM with good breadth; sUAS data high resolution with good georeferencing, and ~annual updates ---post event topography: ASAP and monthly acquisitions thereafter --Questions: time dependent differencing? --Reminder of airborne insar --need frequent acquisitions to address noise Observe: saturation? Longer term observations both deformation and surface process changes Discussion: --Different tools to measure different things --interseismic deformation --disconnect with the VS30 data? Relatively easy to measure. Geotechnical layer; field deployments and rely on these properties to help us beyond the geomorphology; need to integrate --real time laser scanning and real time sUAS launching --ground based radar apt technique for high res --lots of fiber optic technology DAS/straining --practice on the current cameras along the San Jacinto fault zone --need to have the high accuracy geodesy to some of the real time observations --What seismological signal are produced form those shallow sources? See also next week's call; near field ground motions not

	well recorded; see also flipped and displaced rocks; see also fault zone plasticity work --high frame rate camera watching rupture evolution in real time --go for the classic fault perpendicular wall and other calibrated objects in the fault zone as physical experiments --trail of dust! And aftershocks kept lofting dust so that might be an issue for optical and lidar imaging --Modeling: near fault zone environment is not well characterized, esp. Volumetric changes and properties --Feedback loop between modelers and observers --Heat flow, gas sensors, soil flux accumulation, constant monitoring; gas monitoring at 10 of the creepmeters; sample in and on the flanks of the fault zone --observe foreshock or other precursory behavior --need true coseismic observations --challenge of actually capturing an earthquake of any significance… question about maybe doing something along creeping faults? --so much from the interseismic period

Add more rows if needed