Predicting Off-fault Deformation Using Experiment-Trained Convolutional Neural Networks on Faults of Different Maturity in Southern California

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Introduction

Surface offsets from earthquake ruptures might not represent slip at seismogenic depths because earthquakes produce shallow distributed off-fault deformation (OFD). But we lack constraints on the degree of off-fault deformation.

Scaled-physical experiments that simulate crustal processes provide direct observations of deformation partitioning during fault evolution. In particular, the evolving fault geometry during these experiments controls the degree of OFD.

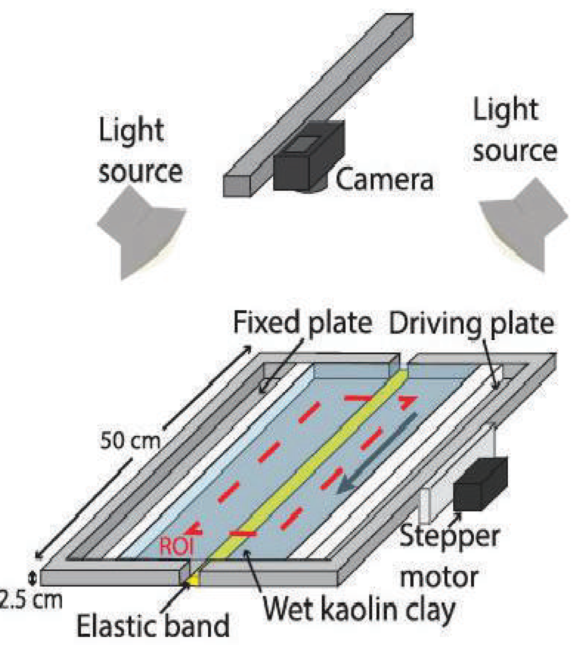
We build from the Convolutional Neural Network (CNN) developed by Chaipornkaew et al (2022) from wet kaolin and include dry sand in order to expand the range of rheology and boundary conditions. The CNN is trained to predict kinematic efficiency (KE), which is the ratio of strike-slip rate accomodated along the faults to the total velocity across the system. We assess the predictive power of the CNN by testing on unseen experimental fault maps and consequently apply the CNN to crustal fault maps of different maturity in southern California.

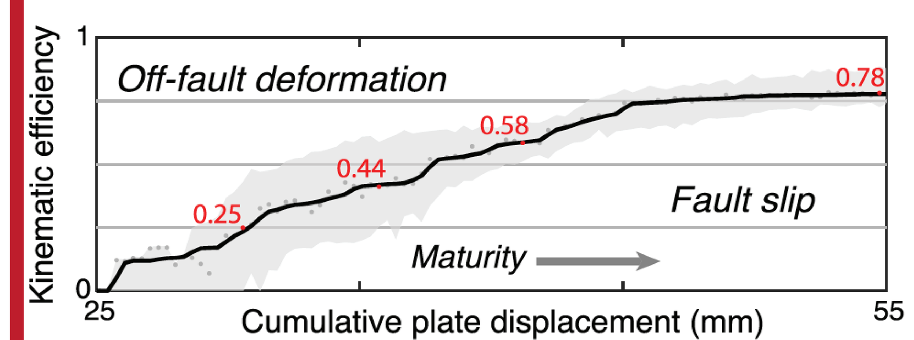
Scaled-Physical Experiments

The clay and sand are carefully scaled to represent faulting processes within the upper crust. Because the experiments are 5 orders of magnitude smaller than the crust, the analog material needs to be 5 order of magnitude weaker than crustal rocks.

To simulate a wide range of strike-slip fault experiments, the clay experiments have two basal conditions, distributed shear over a elastic band between the basal plates and localized shear over the juxtaposed plates, and various loading velocities.

The sand experiments conducted by the Université de Cergy-Pontoise have different thicknesses and basal conditions generated by materials such as PVC, sandpaper, and alkor-foil.

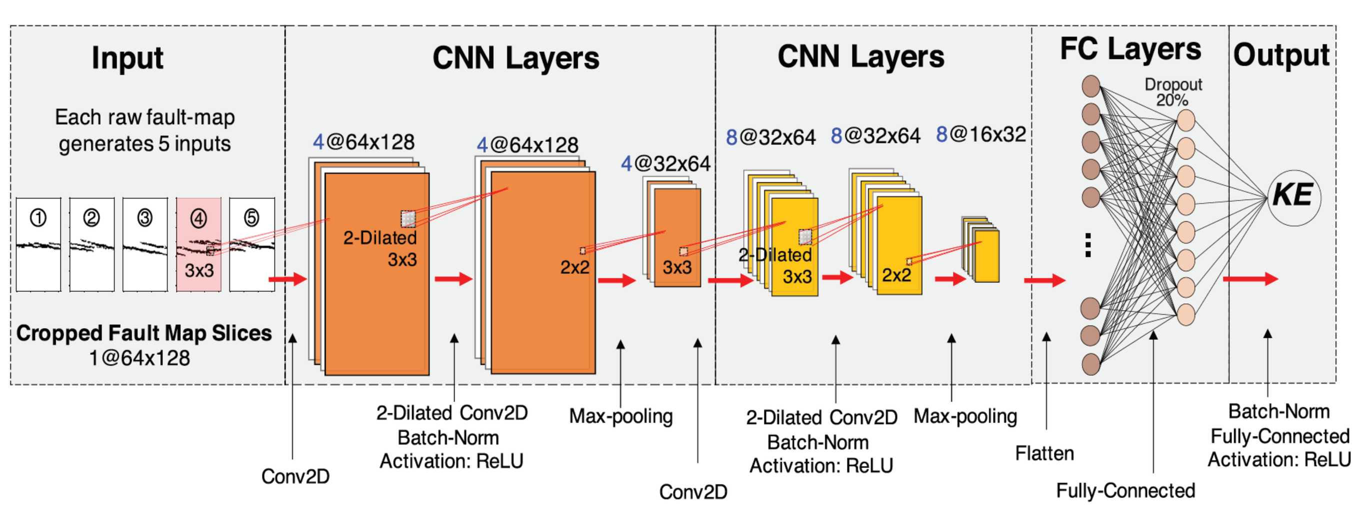




The kinematic efficiency (KE) increases with fault maturity as off-fault deformation (OFD) decreases.

CNN Methodology

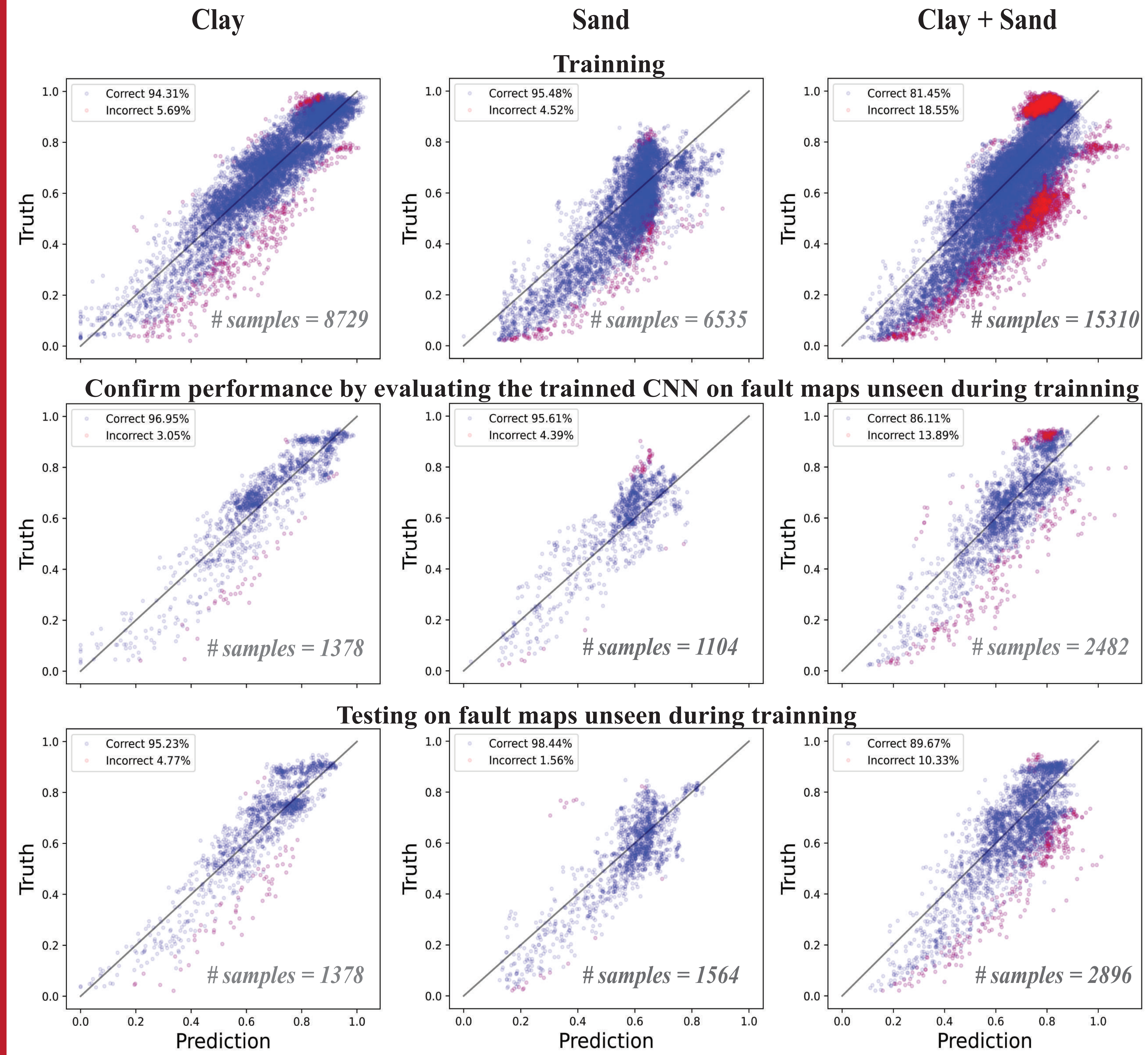
We train the CNN on experimental strike-slip faults in both wet kaolin and sand with various loading rates and basal conditions to simulate a wide range of conditions that may control evolution of fault geometry and OFD.



CNN architecture by Chaipornkaew et al (2022) utilized to train clay and sand strike-slip fault experiments

Since the CNN was strictly trained on experimental fault maps that are scaled to represent the Earth's crust. **It has the potential of predicting KE of crustal fault maps**, which provides an innovative and possible alternative to estimate OFD along active crustal faults that do not have geologic estimates available.

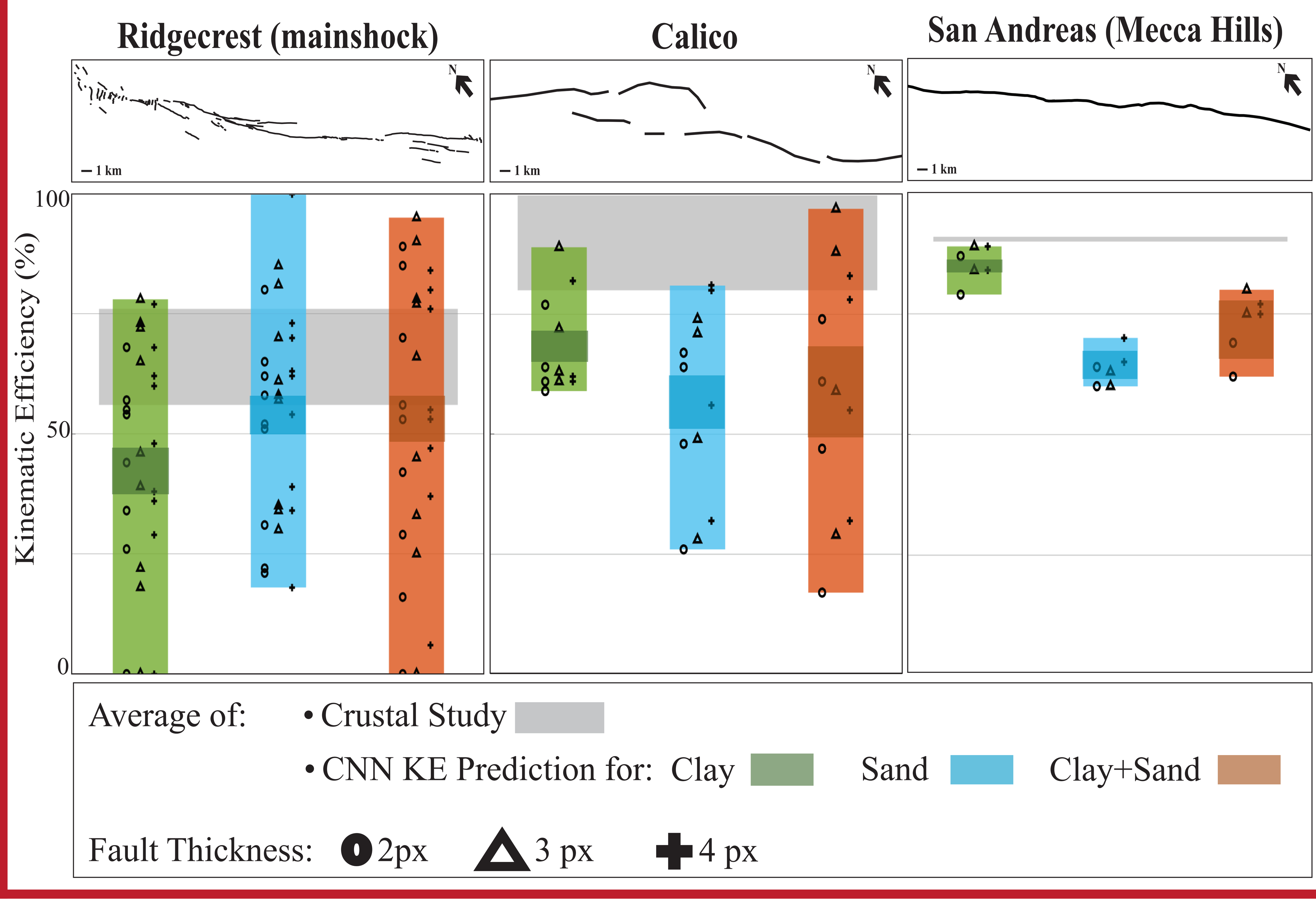
CNN Results of Experimental Faults



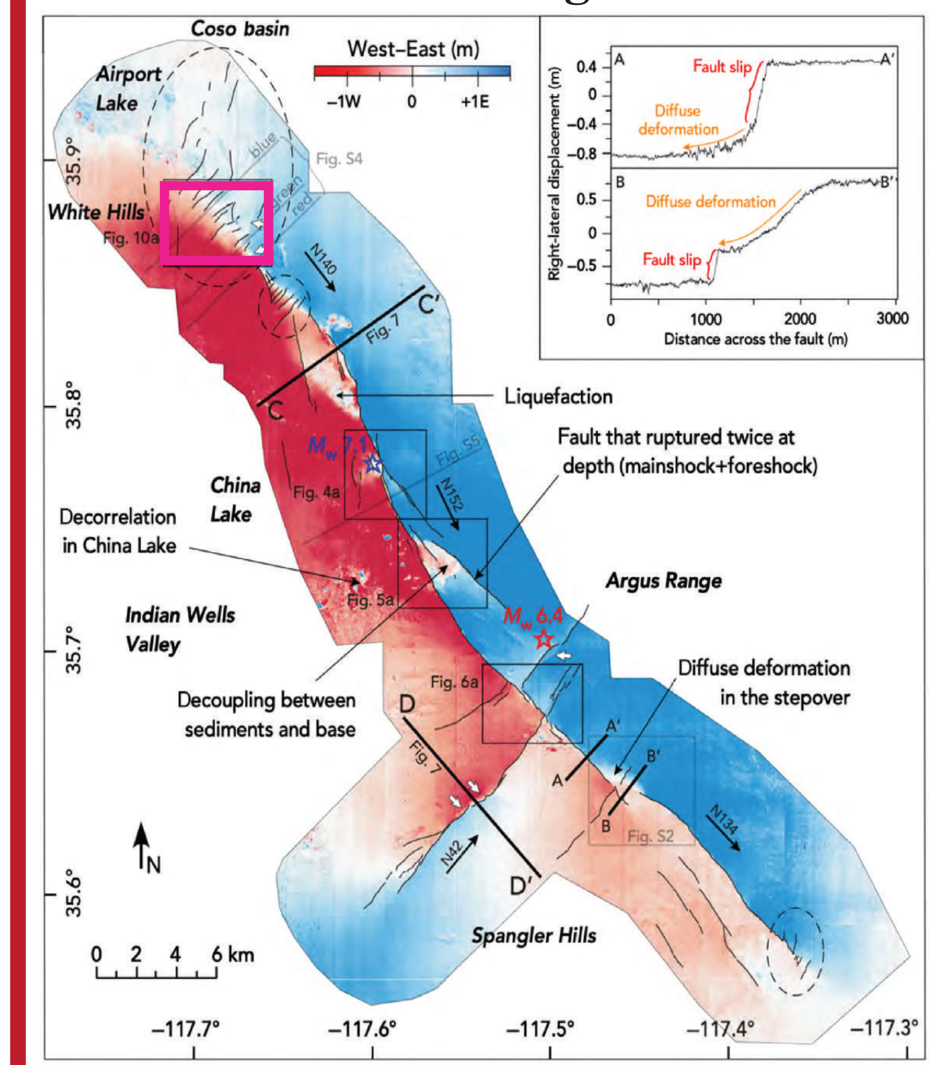
Blue dots are within 2 standard of deviation of the label (KE) while **red** dots fail to predict KE.

On unseen fault maps, the CNN performed ***well***. It acheived accuracy of **95%** on clay, **98%** on sand, and **90%** on clay+sand fault maps combined together.

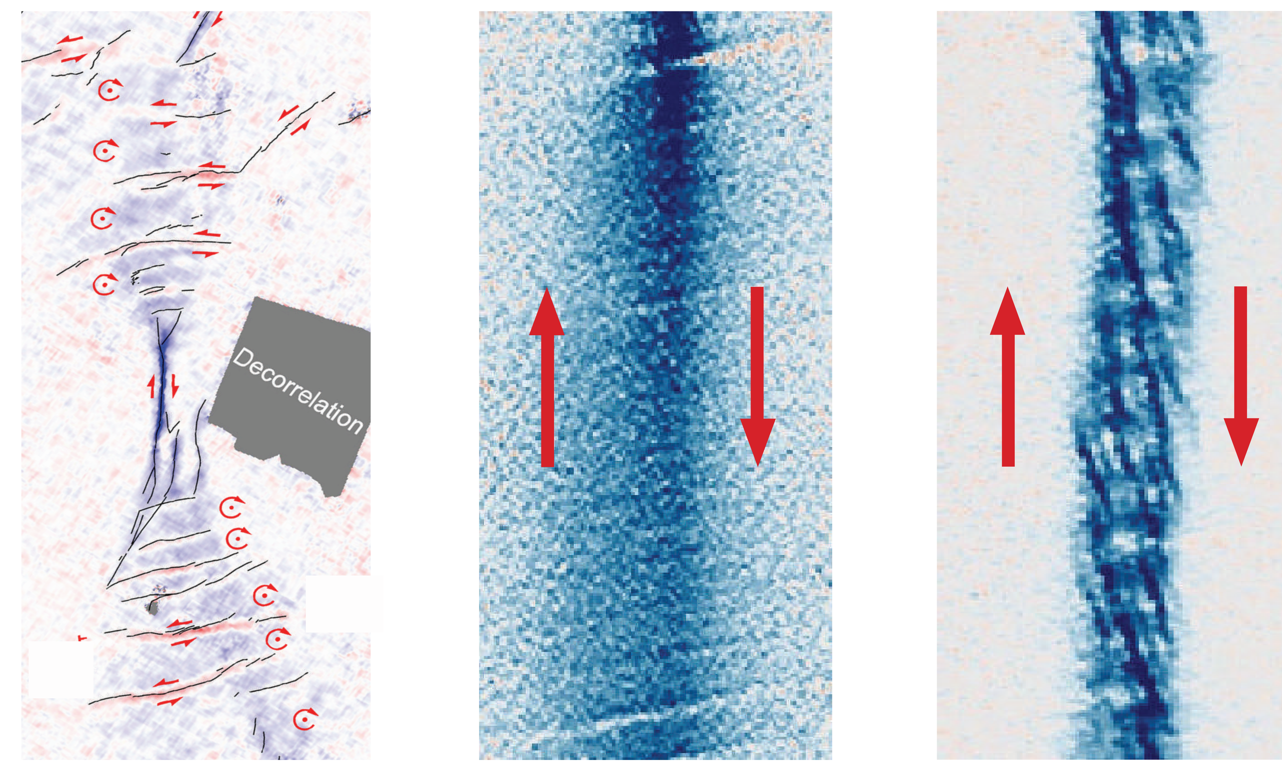
CNN Aplication to Crustal Fault Maps in Southern California



Experimental Strike-Slip Fault Similarities to Ridgecrest's Coso Basin



The Coso Basin is characterized by northeast-trending left-lateral faults that are perpendicular to the mainshock and manifest the rotation of blocks within the dextral shear zone of the northern section of the Ridgecrest's mainshock.



Coso Basin | Wet kaolin- early stage | Wet kaolin- later stage

These faults are similar to left-lateral faults that develop along pre-existing weaknesses prior to the onset of right lateral faulting ***in wet kaolin strike-slip experiments***. This suggests that during early fault evolution, pre-existing weaknesses at high angles to regional shear can be activated in left-lateral slip but that these features are not long-lived.

Future Work

- I will iterate between different network architectures and hyperparameters to find the most suitable convolutional neural network that suits the clay+sand dataset and performs efficiently. Subsequently, I will analyze the San Jacinto fault to provide an estimate of off-fault deformation.
- We will also expand our dataset to include a wider variation of clay and sand strike- slip fault experiments.

Acknowledgments

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