100 years of Accumulated Deformation at Depth Observed in the Elizabeth Lake Tunnel, Southern San Andreas Fault

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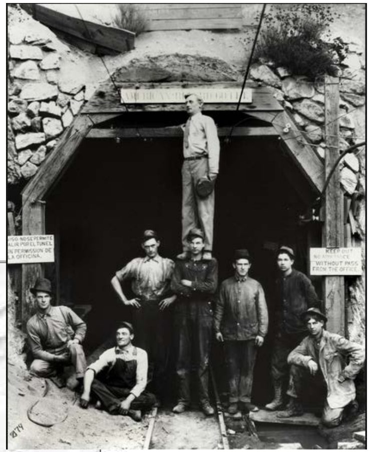
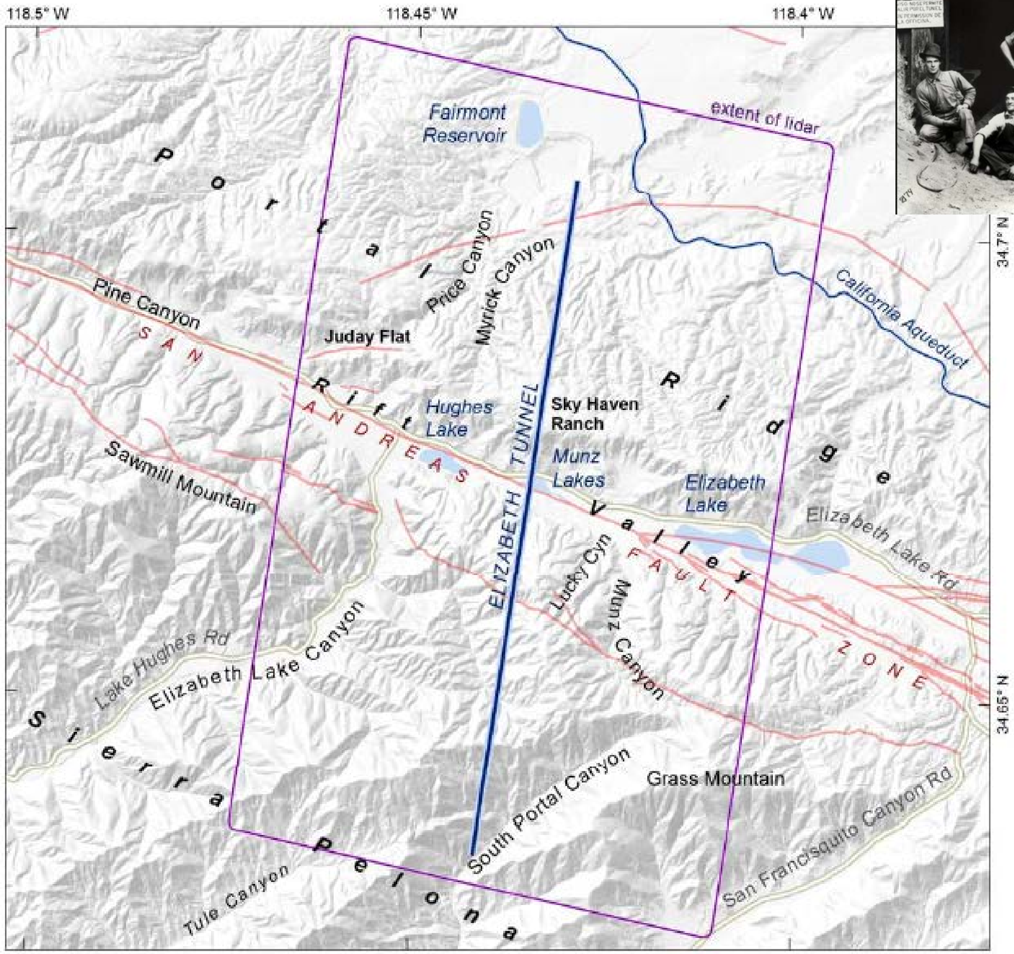
Elizabeth Tunnel, CA

- Constructed between 1907 and 1911
  - Transport water from Owens Valley to Los Angeles
  - Elizabeth Tunnel crosses the San Andreas Fault (SAF)
  - 8 km in length, 87 m below Elizabeth Lake Valley
  - Dug simultaneously from both ends
  - N and S sides met within 2.9 cm horizontally and 1.6 cm vertically (1)
  - Finished 450 days ahead of schedule





2 km

Photo Credit: LADWP Archives
Map Credit: LCI Report (2015)

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Data and Research Questions

- Terrestrial Laser Scanning
  - Collected in 2012
  - Nearly 200 TLS scans
  - Cross section example on right
- Research Questions
  - Has the tunnel shifted since it's construction?
  - What scale of change can be detected given the variability in the tunnel itself?
  - Can the tunnel – fault intercept be isolated to a narrow region for re-engineering?

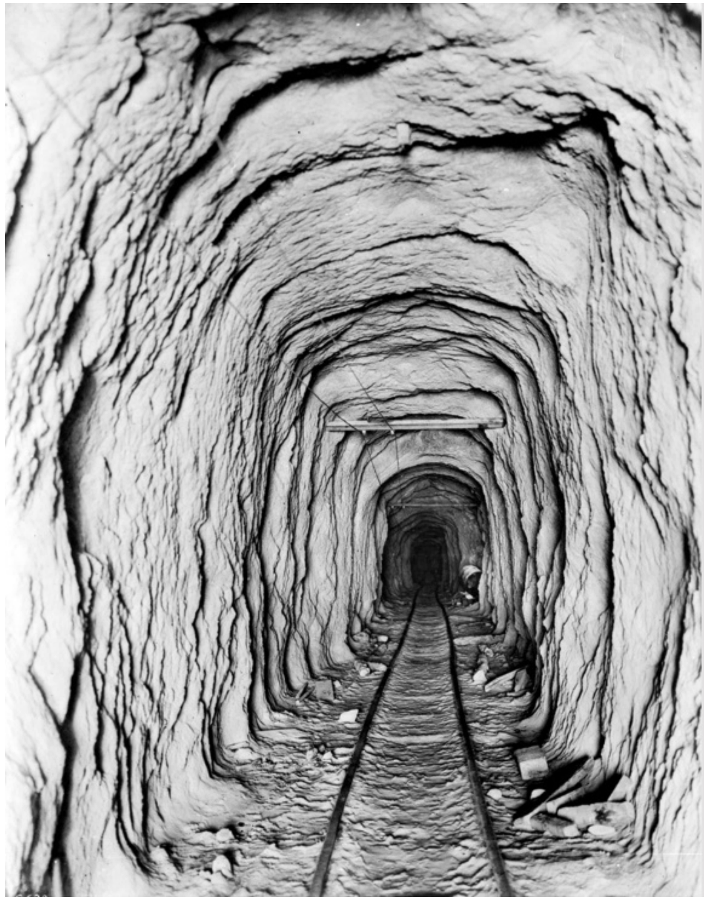
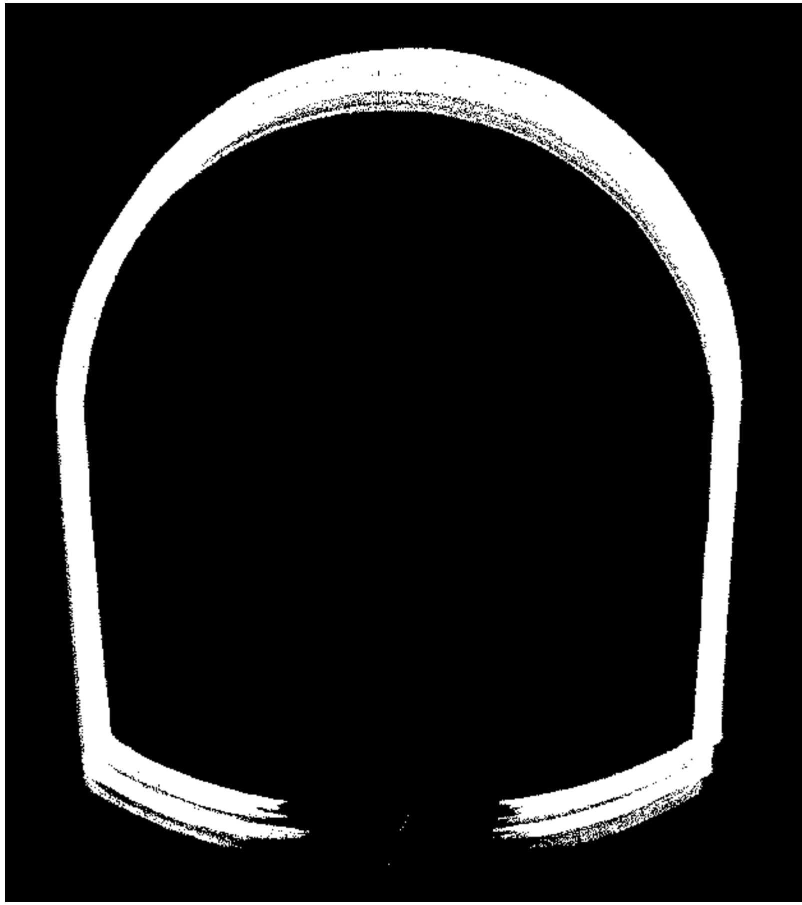


Photo Credit: Water and Power Associates, CA



5 ft

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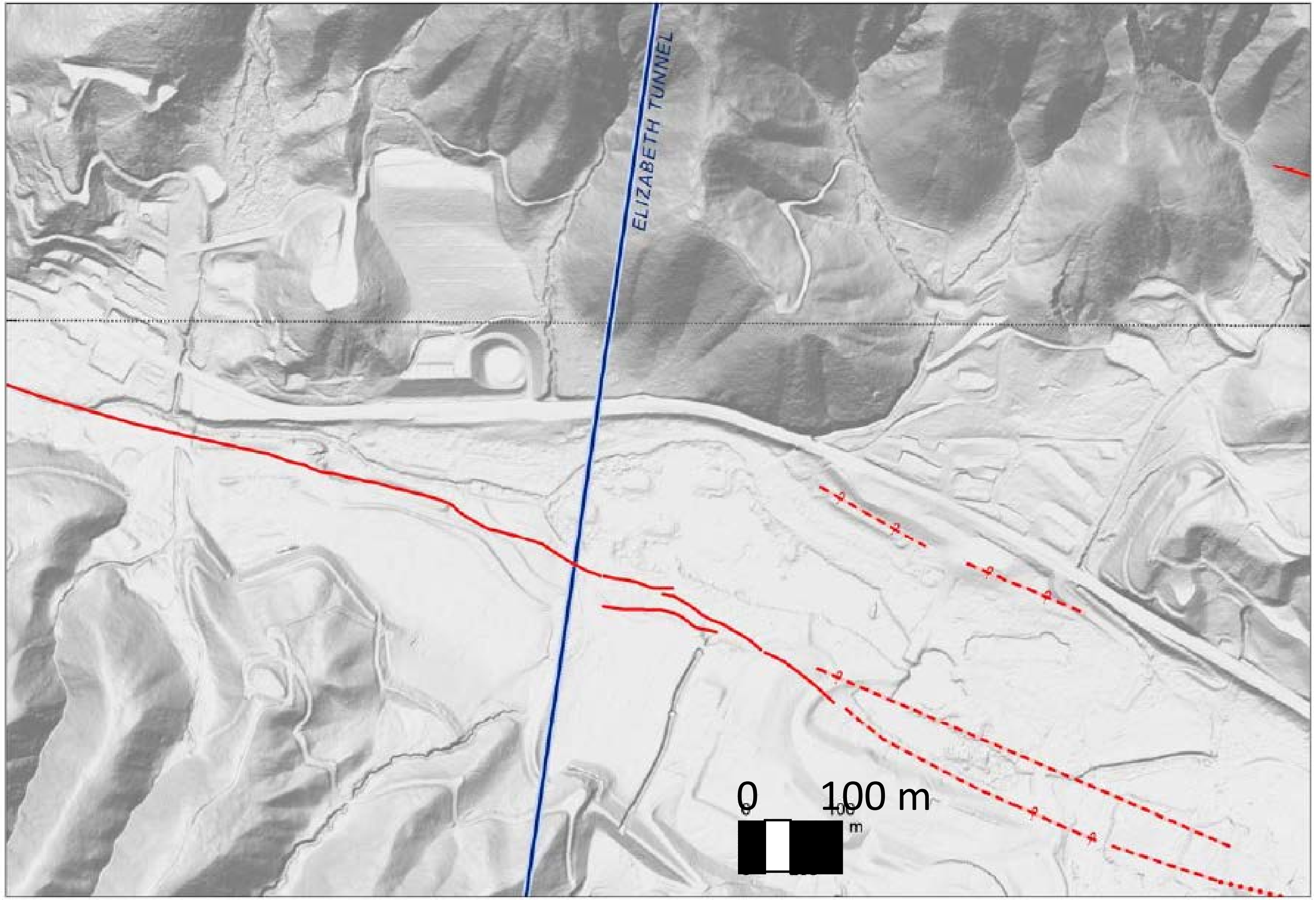
Tunnel – SAF Intercept

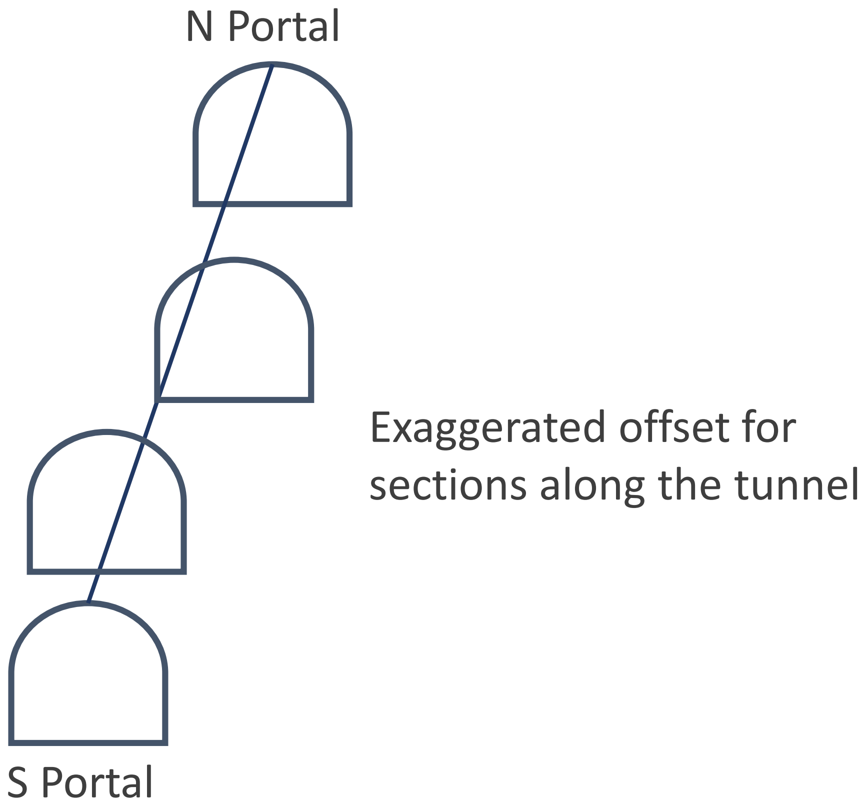
- Active strands of the SAF in red
- Inferred SAF strands dashed
- Queried SAF strands uncertain
- Most recent coincident rupture took place in 1857 (2,3), prior to tunnel construction

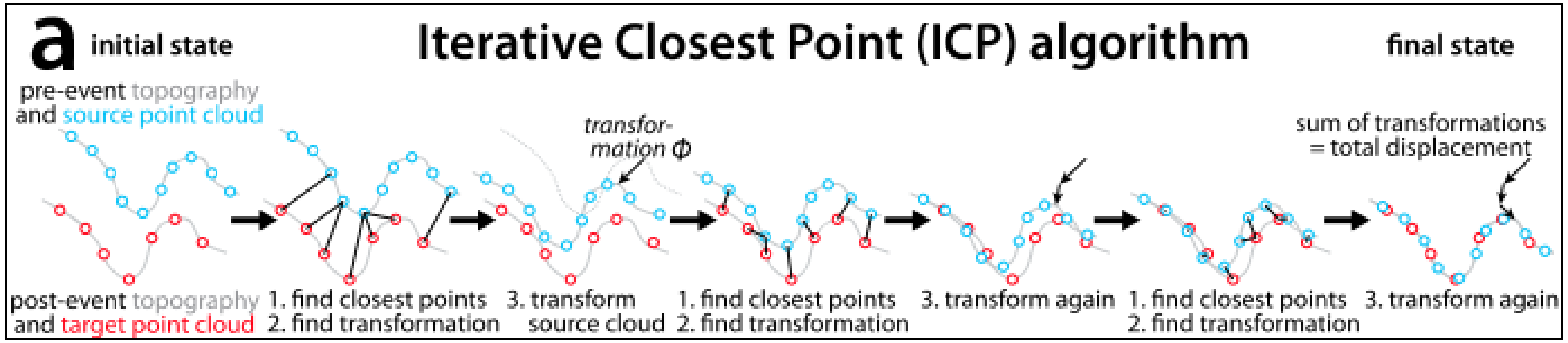


Map Credit: LCI Report (2015)

Methods – ICP

- The beginning and end of the tunnel are assumed to make a straight line
- The offset of each tunnel segment, in 5' intervals, from this straight line was calculated
- Cross section thickness – 5'
  - Whole tunnel data set is used
- Iterative Closest Point – Point to Plane
  - Chen and Medioni (1991) (4)
  - Figure from Besl and McKay (1992) (5)





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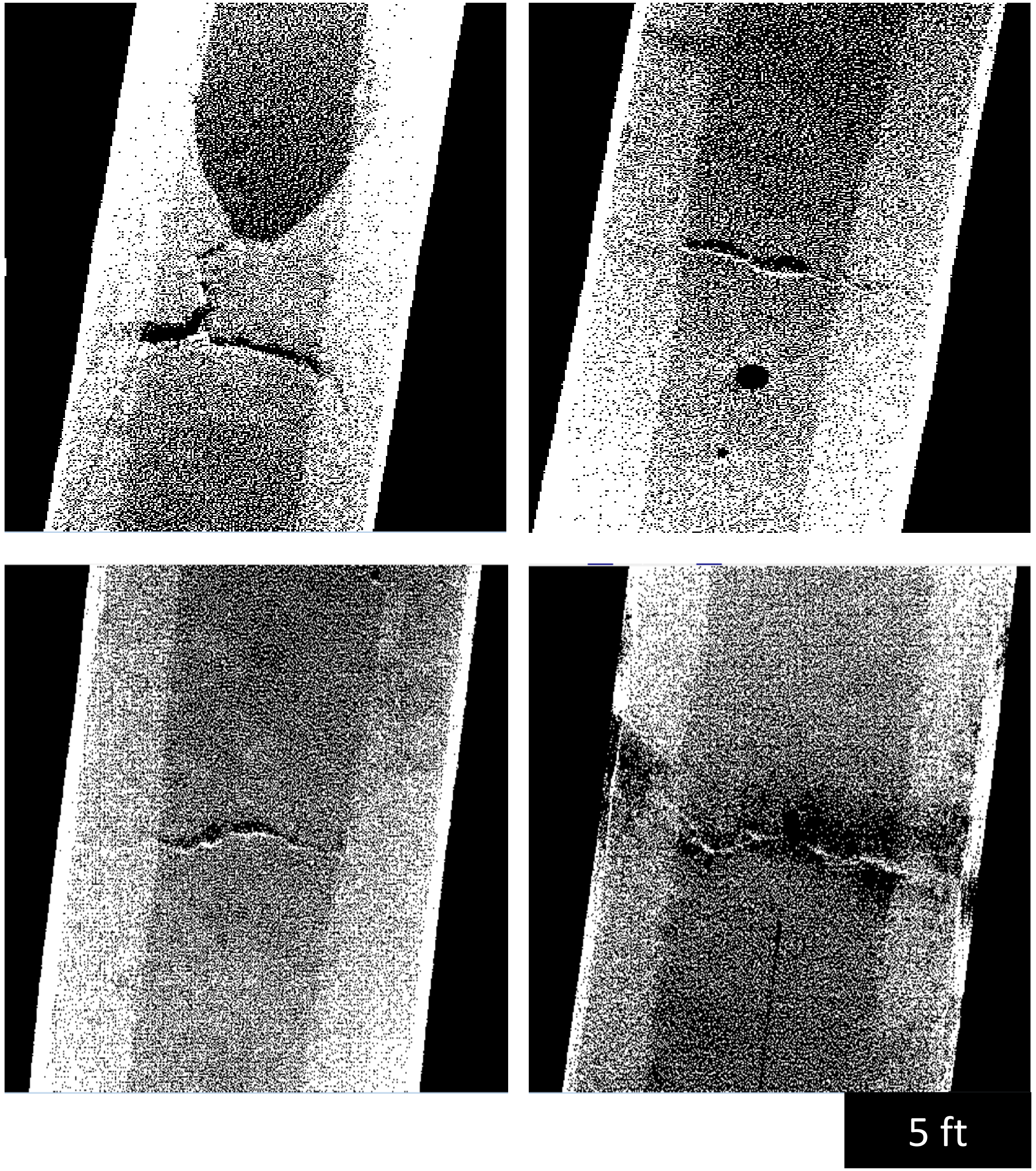
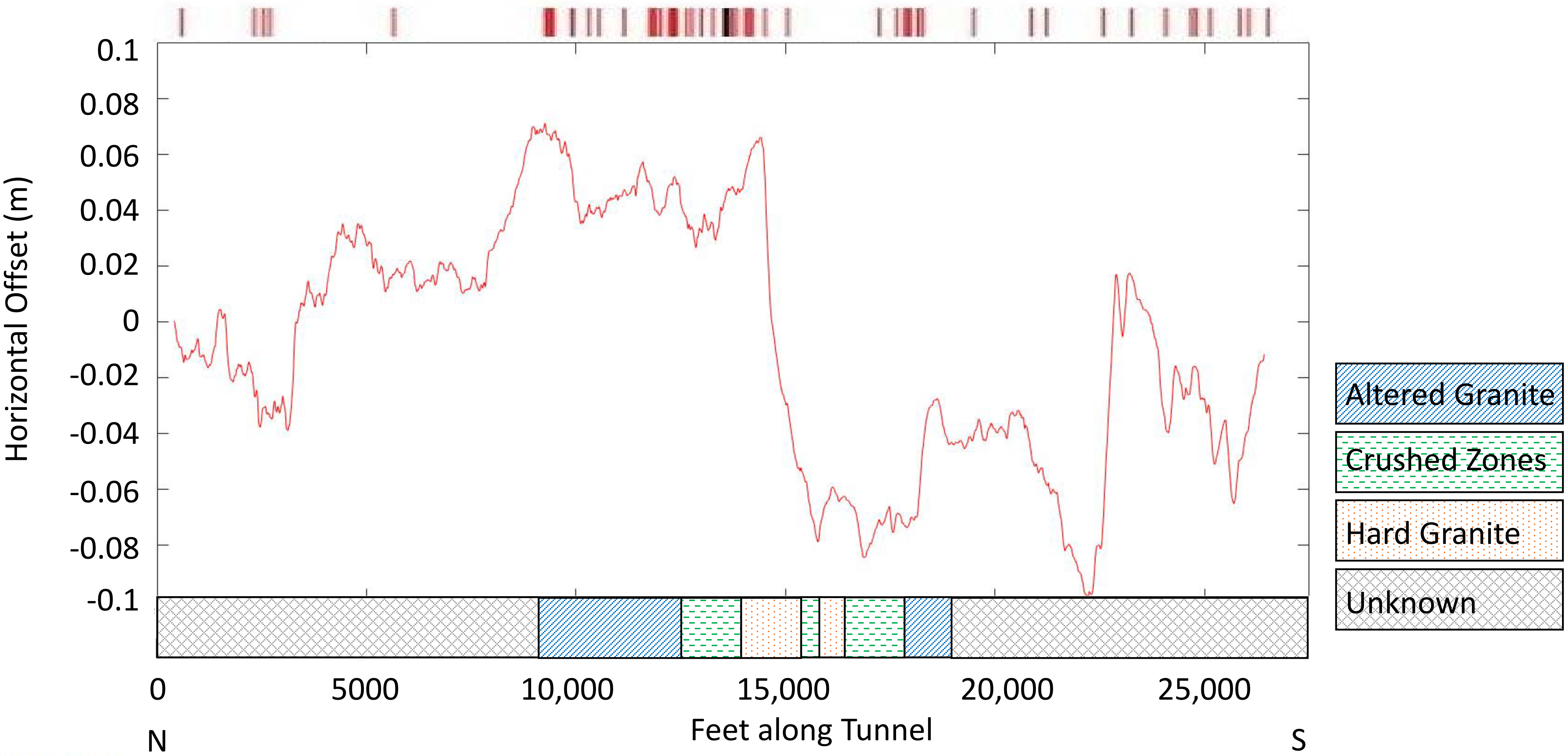
Methods – Cracking Analysis

- Cracks were visually detected along the tunnel within the TLS data
- Only cracks in high point density regions were included in the analysis to eliminate false identifications
- Examples to the right of what cracks look like in the TLS data



Results



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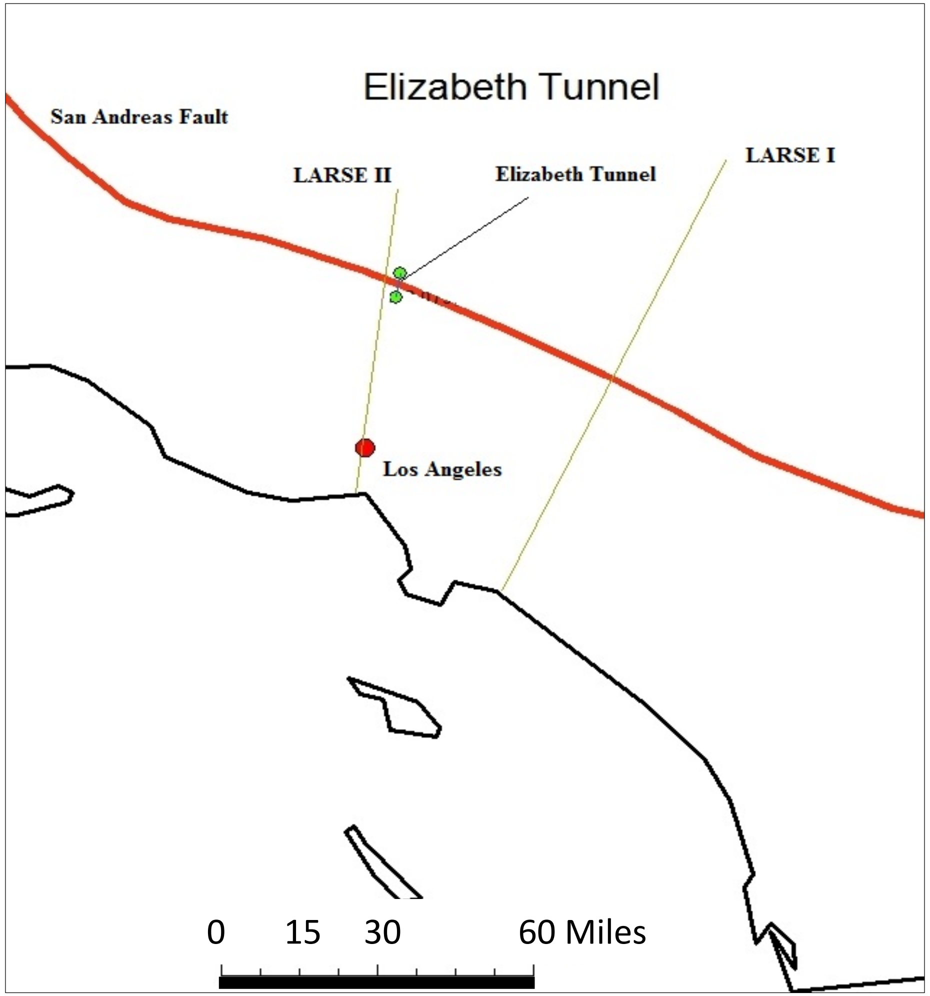
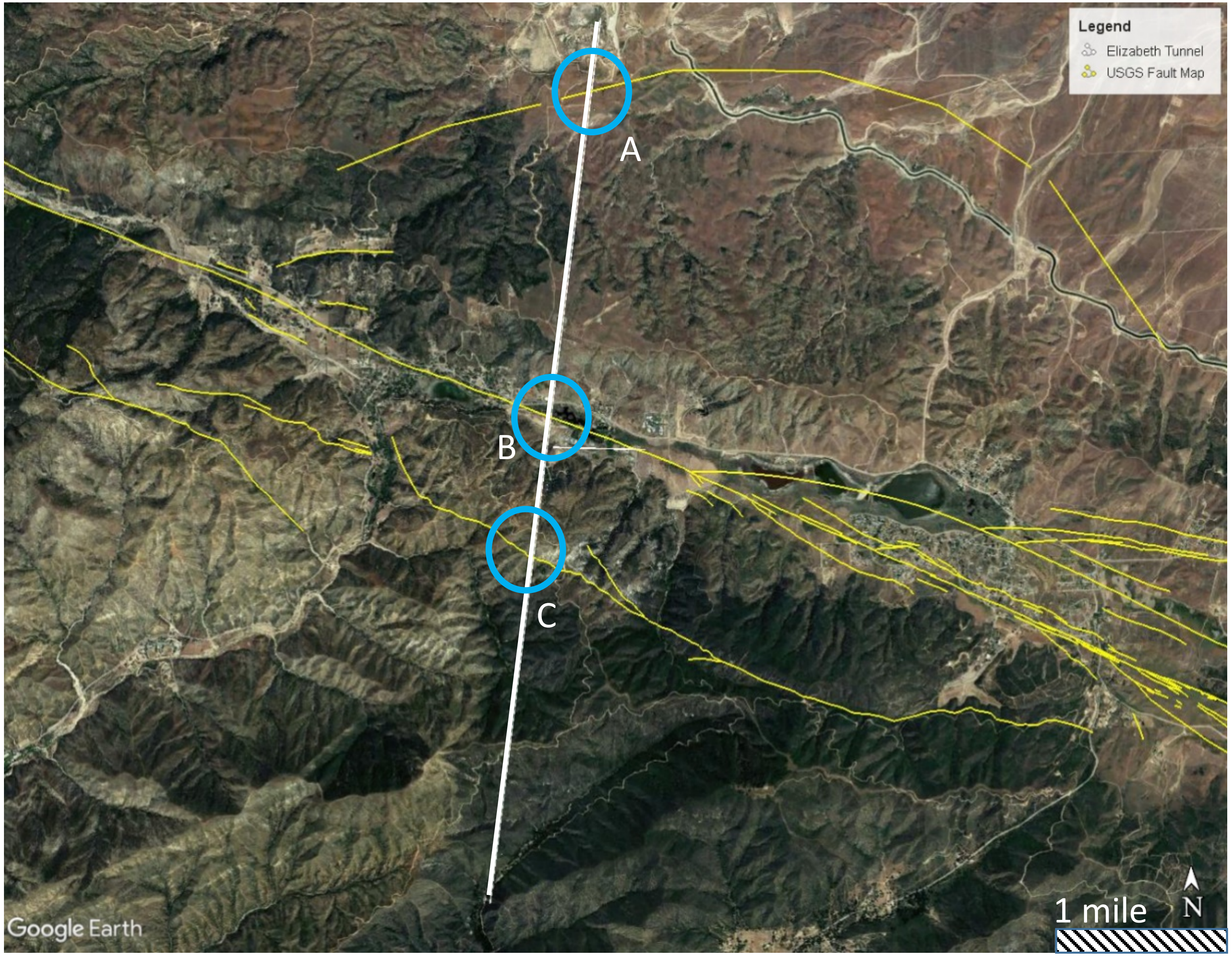
Slope at the Tunnel – SAF Intercept

- Los Angeles Regional Seismic Experiment (LARSE) I and II experiments bracket the tunnel (6)
- LARSE I dip ~ 83°
- LARSE II dip ~ 90°
- Inferred SAF dip at the intercept with the tunnel is 90°
- Using this dip, the intercept between the fault and the tunnel at depth can be projected



Local SAF Segments

- Three known fault tunnel crossings (A, B, and C from North to South) (8)
- The center (B) strand was active in the 1857 earthquake
  - Slip rate ~15-35 mm/yr
  - Eberhart-Phillips et al. (1990) (7)
- Less work on slip rate and fault dip has been completed on the northern and southern strands (A and C)



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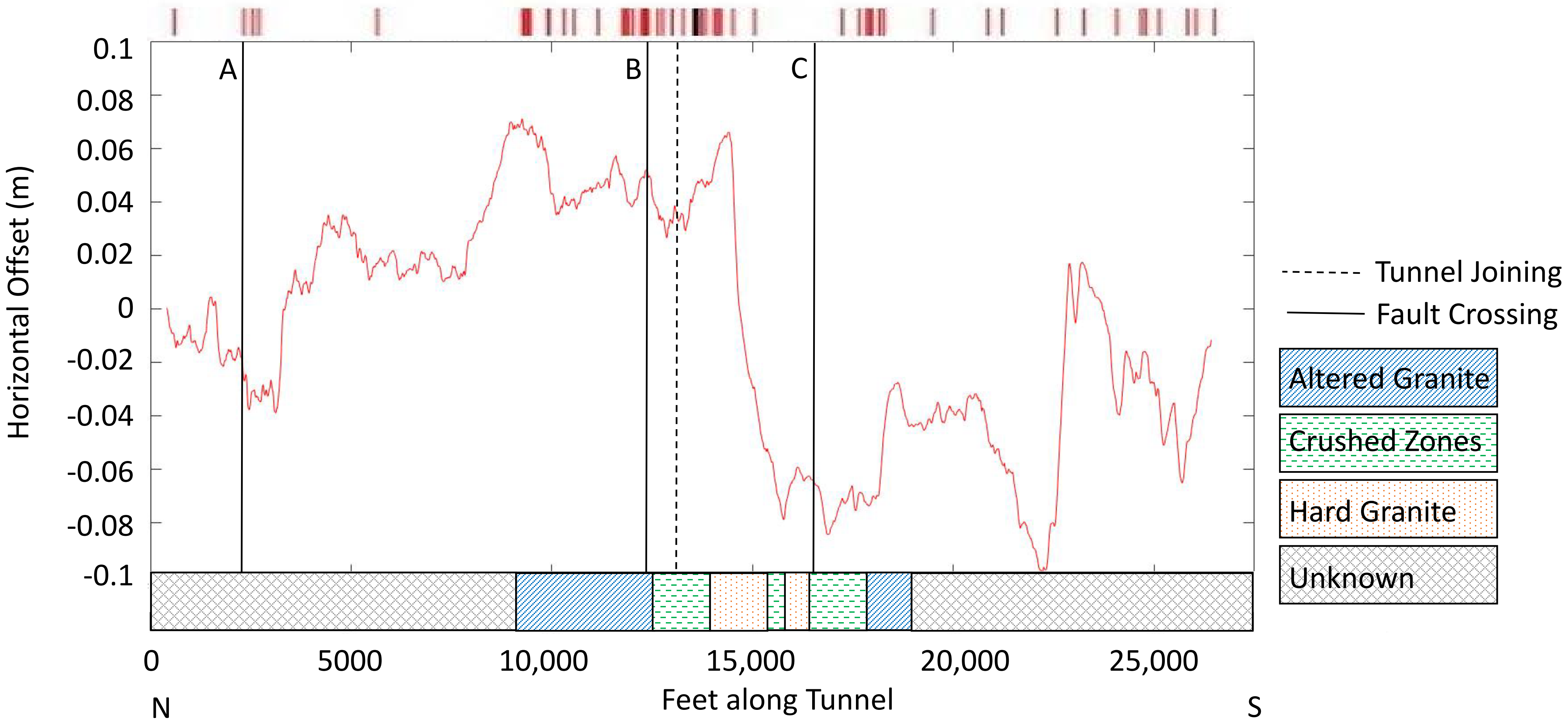
Projected SAF – Tunnel Intercept



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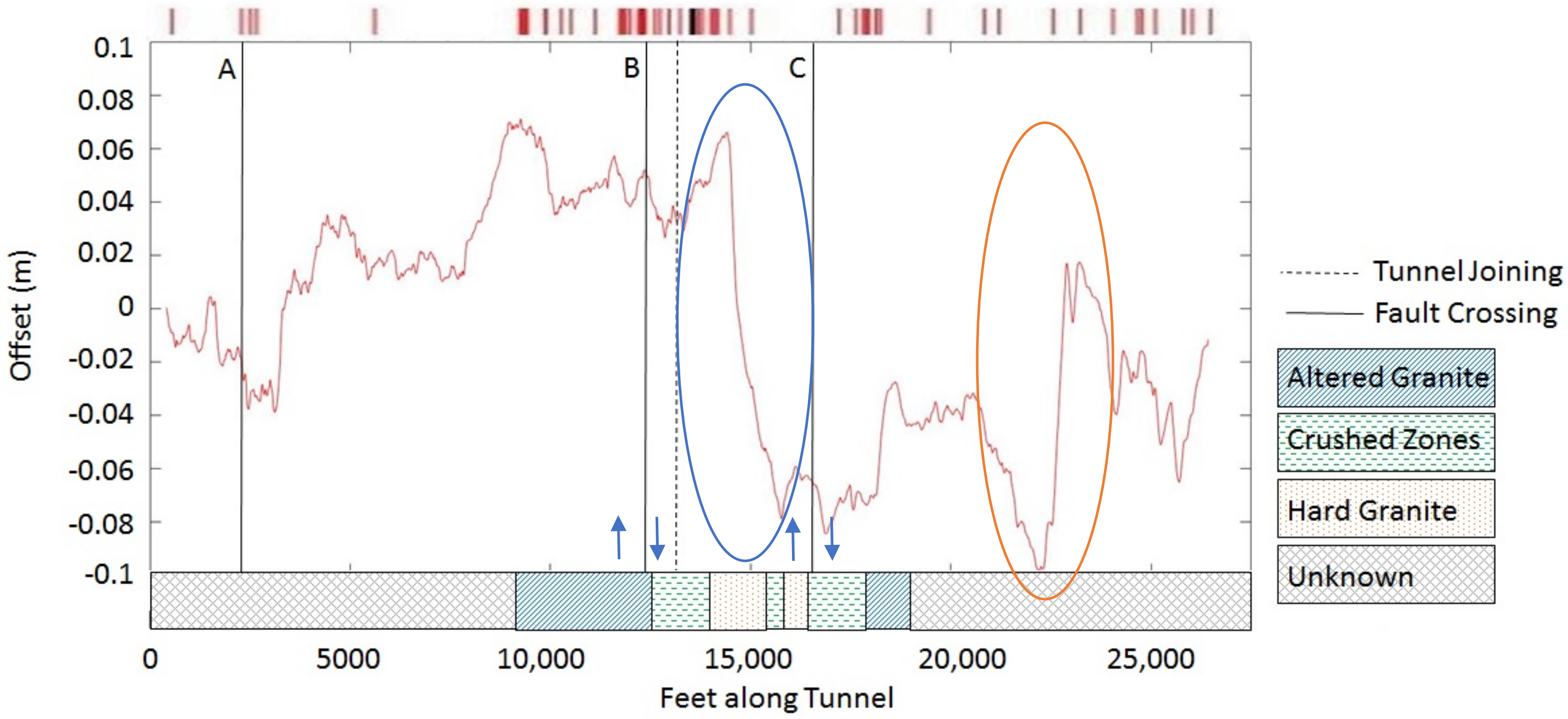
Discussion

- Central offset
  - 14 cm
  - Visible curve in the TLS data
  - 2000’ between tunnel joining and offset feature
  - Increased rate of cracking near offset
- Southern offset
  - 11 cm
  - Visible curve in the TLS data
  - No mapped faults near offset
  - Lack of change in cracking frequency may point to a construction deviation



Conclusions

- Tunnel construction records indicate that the tunnel was fairly straight when constructed since the tunnel joining was only off by ~ 3 cm horizontally and ~ 2 cm vertically
- TLS data throughout the tunnel was analyzed with ICP to determine along tunnel offsets at over 5000 cross sections
- Two notable offsets were found along the tunnel
  - Southern offset, unrelated to known faults or major cracking
  - Central offset, between two known strands of the SAF, surrounded by a notable increase in cracking on the tunnel walls
- Observed central offset ~ 14 cm but predicted deformation along the SAF would suggest that there should be ~ 2 m of deformation (20 mm/yr, 100 yrs) (7)
- Further modeling and analysis will seek to understand why we do not see more deformation

References

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Questions?

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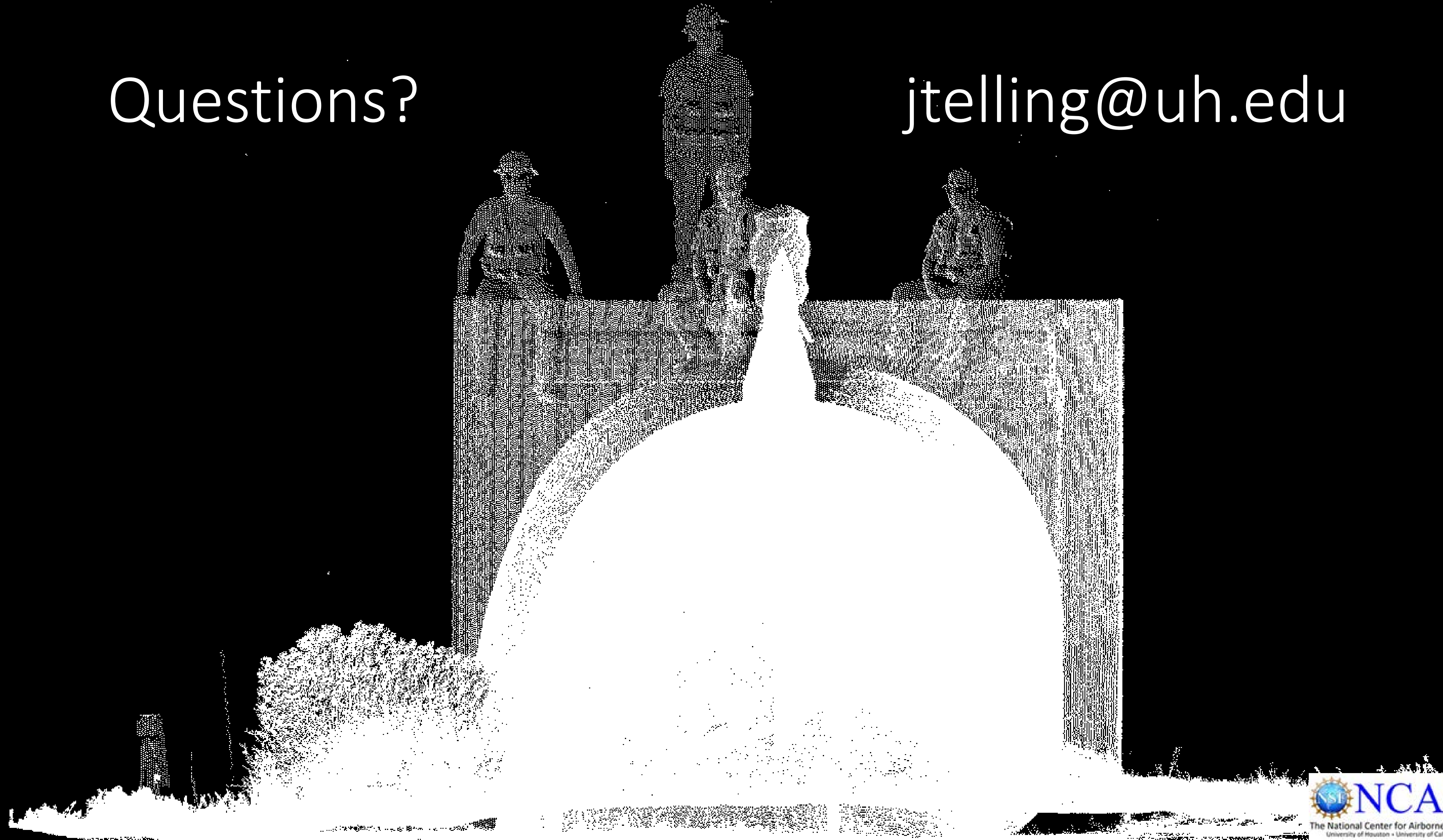

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