

# 1200 years of large earthquakes in the southern San Andreas fault system: Variations in local and regional seismicity on a fast-slipping plate boundary

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(SDSU, USGS, EOS)



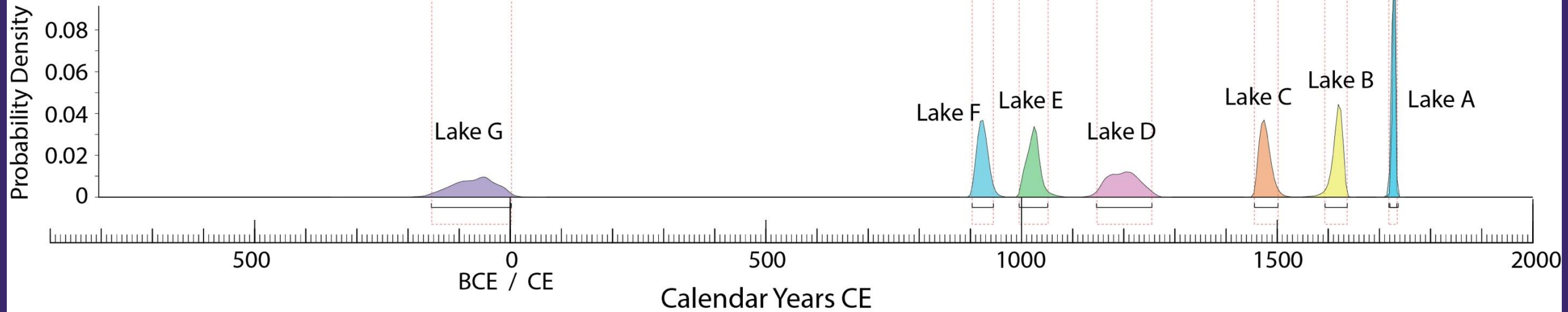
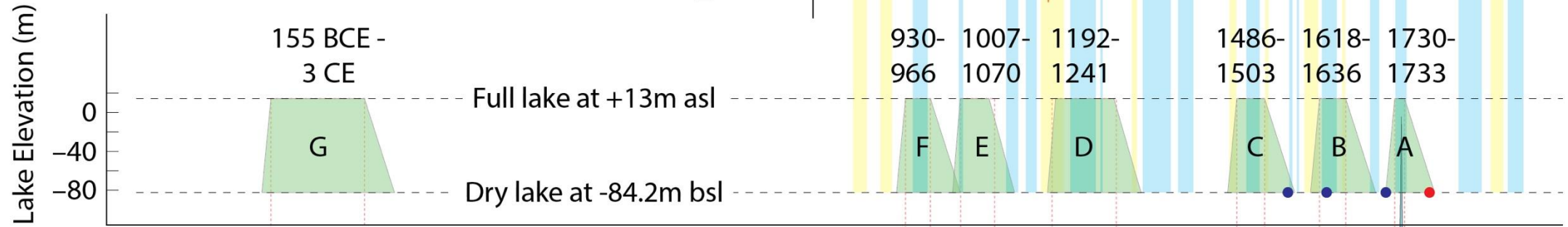
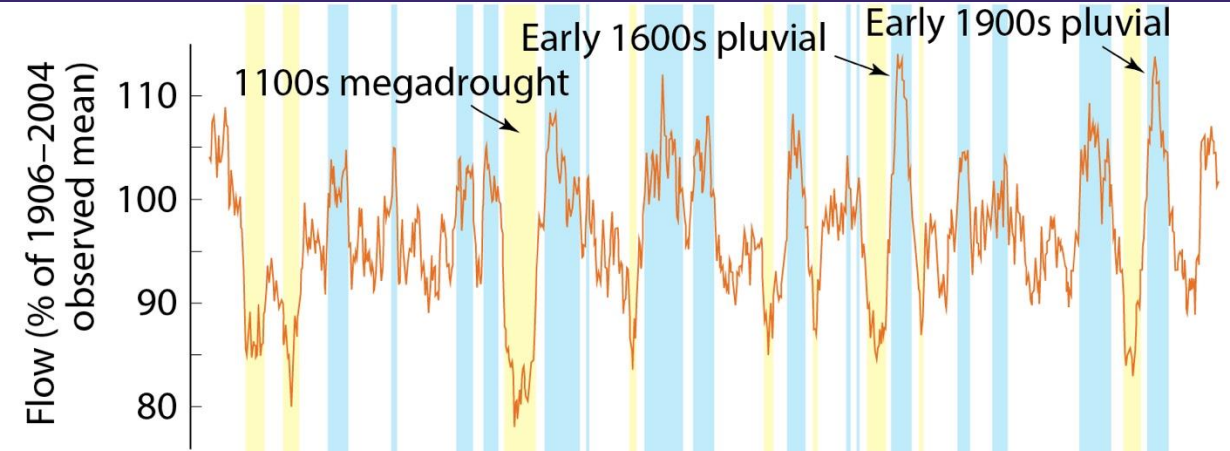


# Late Holocene high-stands of Lake Cahuilla

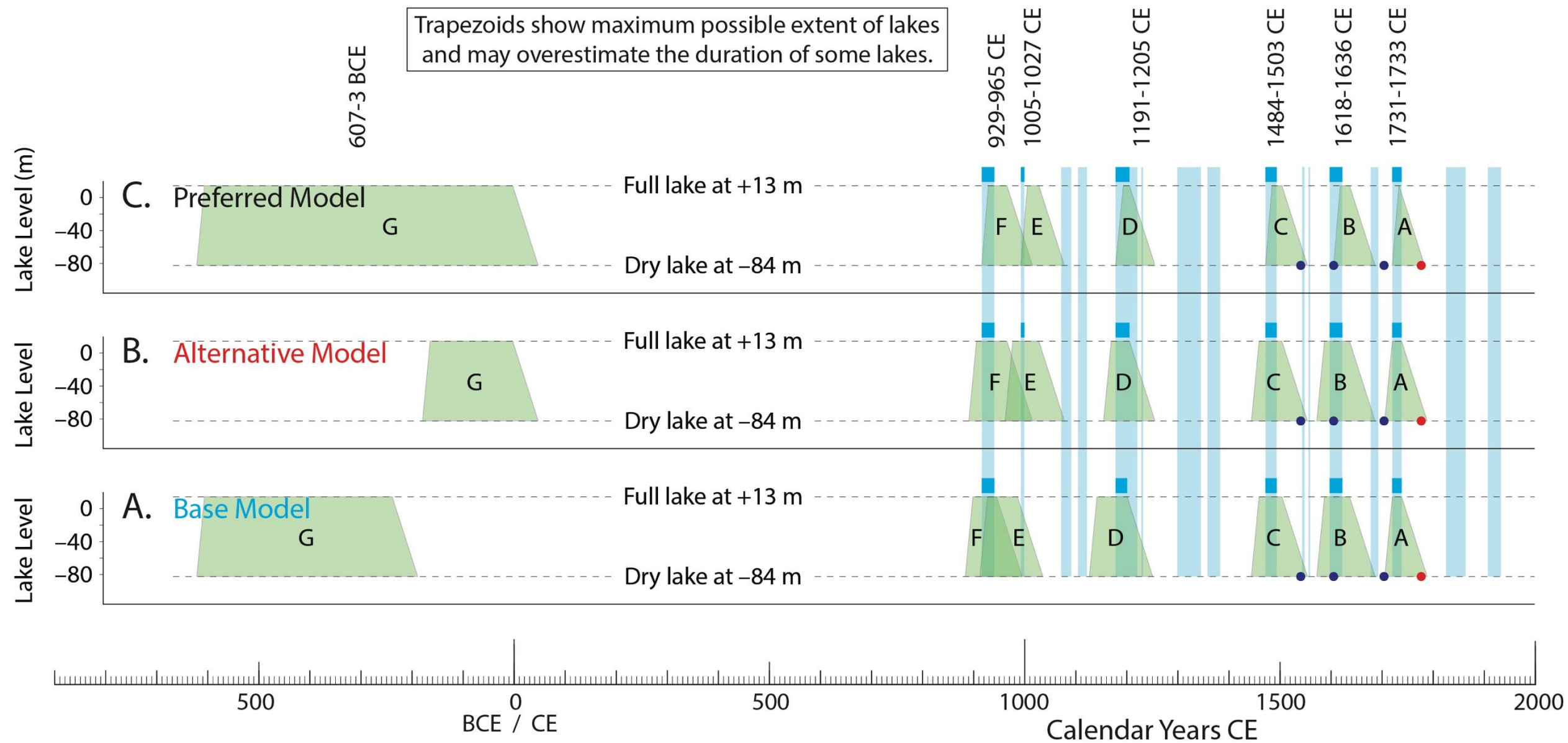
Rockwell et al., 2022

## Current model with Salt Creek dates

- Wet: >100% of mean 1906–2004 flow
- Dry: < 90% of mean 1906–2004 flow



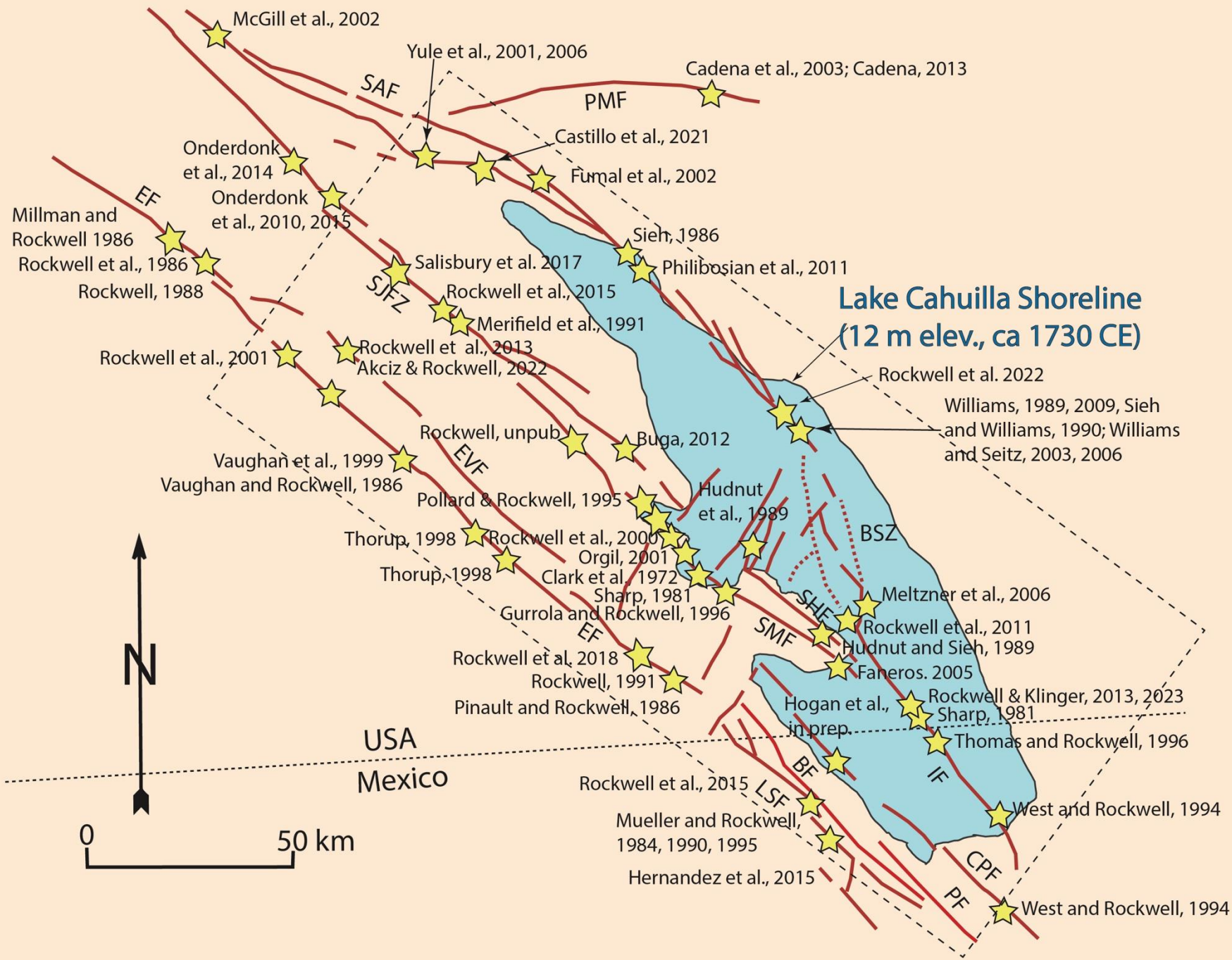
# Preferred model trimmed by climatic events (Rockwell et al., 2022; Meltzner et al., 2026 in review)



# 40+ years of paleoseismology

Many unpublished (until now) studies from student thesis projects and SDSU neotectonic class field trips

All summarized in the supplement to our new paper that is being submitted for the special BSSA issue on Quantifying the Long-Term Paleoseismic Records

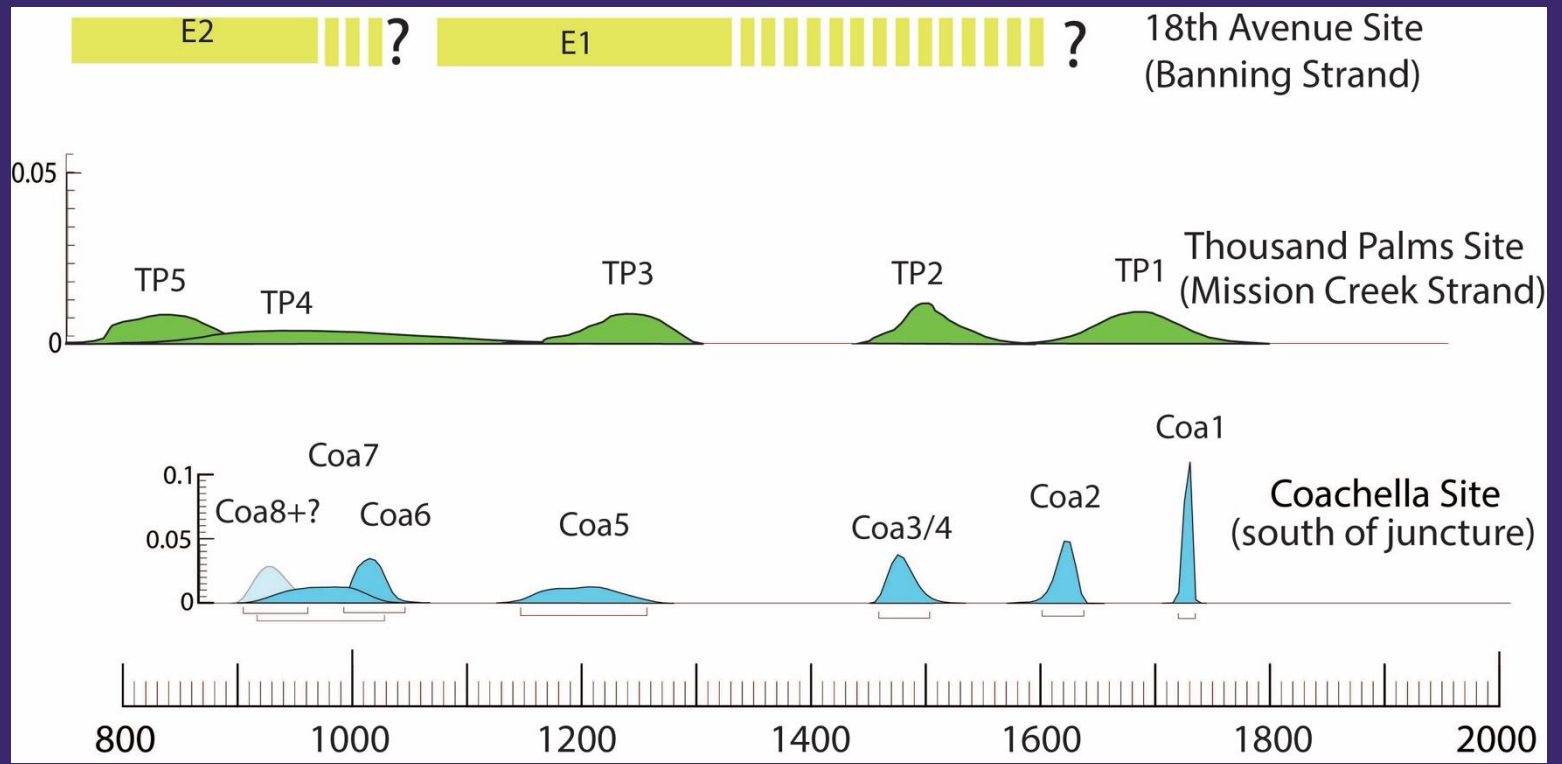


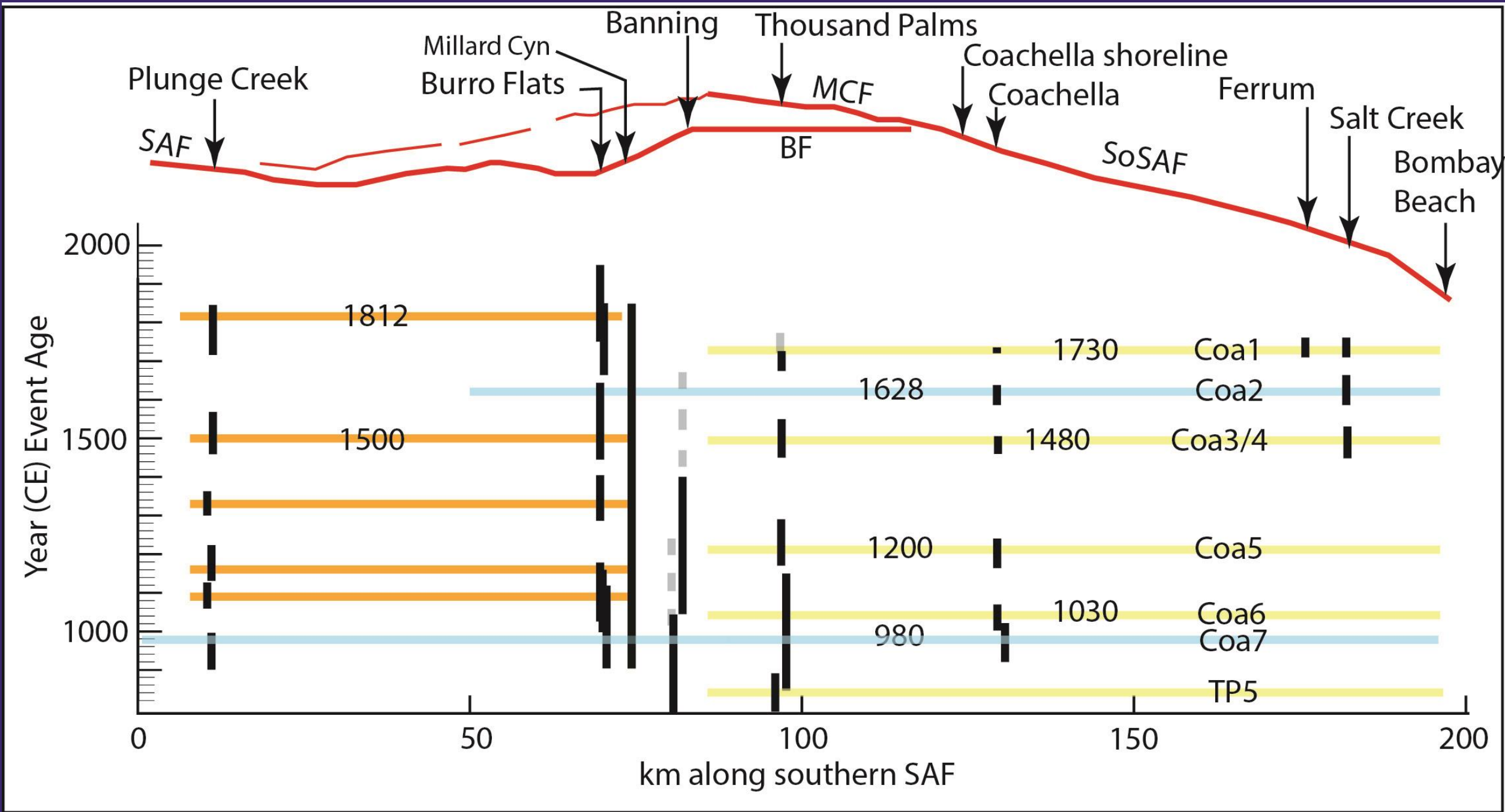
# San Andreas fault calculations

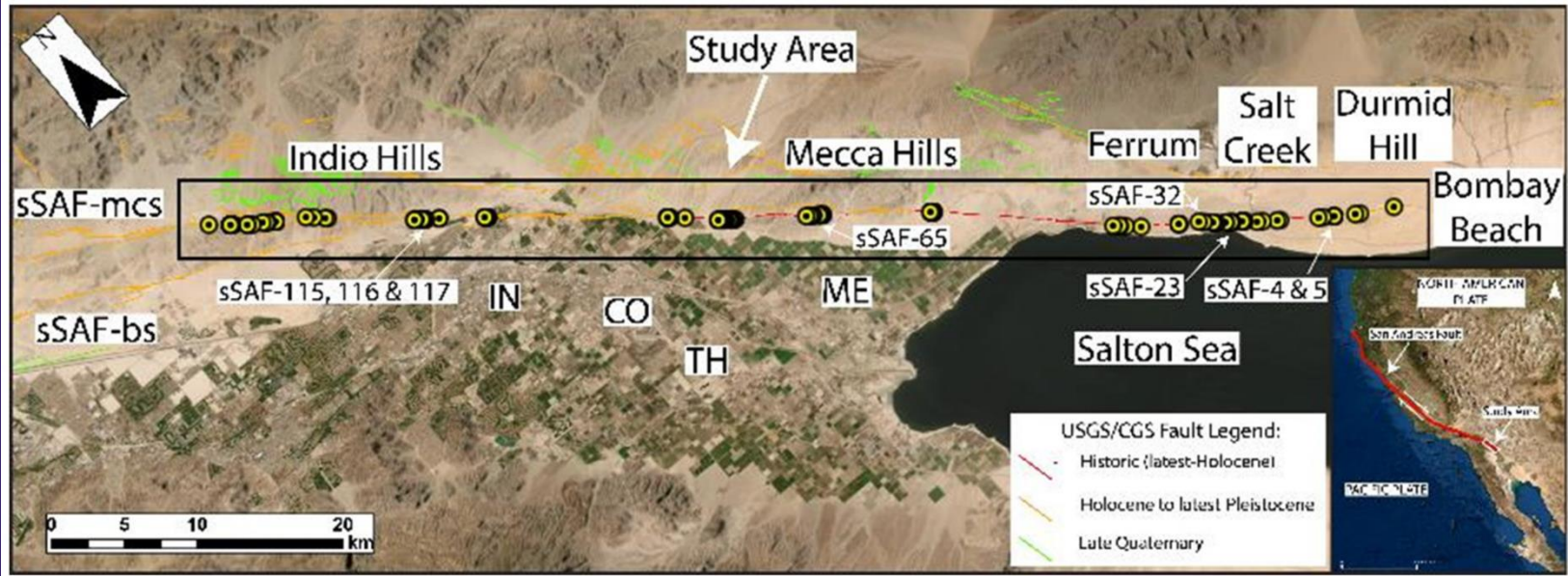
Coastal San Andreas Fault	Coa 1	Coa 2	Coa 3/4	Coa 5	Coa 6	Coa 7	TP5
Coa 1	1732	1731-1733	7.44	3.5	110	11.9	1.65E+27
Coa 2	1627	1618-1636	7.52	3.3	150	11.9	2.12E+27
Coa 3/4	1485	1484-1501	7.36	2.6	110	11.9	1.23E+27
Coa 5	1191	1191-1200	7.42	3.2	110	11.9	1.51E+27
Coa 6	1016	1005-1027	7.31	2.2	110	11.9	1.04E+27
Coa 7	974	931-1017	7.46	2.7	150	11.9	1.74E+27
TP5	830	770-890	7.44	3.5	110	11.9	1.65E+27
							1.09E+28

San Andreas F							
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Timing of events modified from Philibosian et al. (2011) based on Lake Tehuilla ages (Rockwell et al., 2022; Meltzner et al., 2026 in review), and from Fumal et al. (2002)

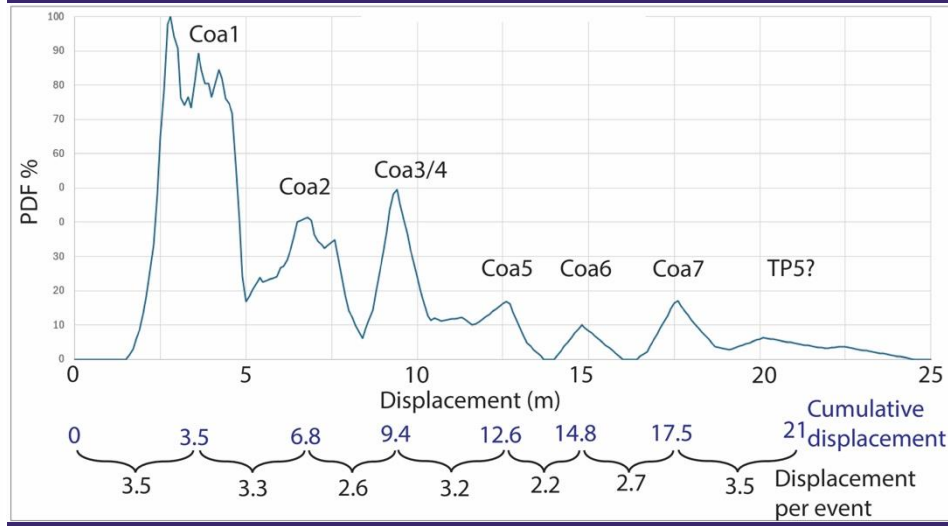
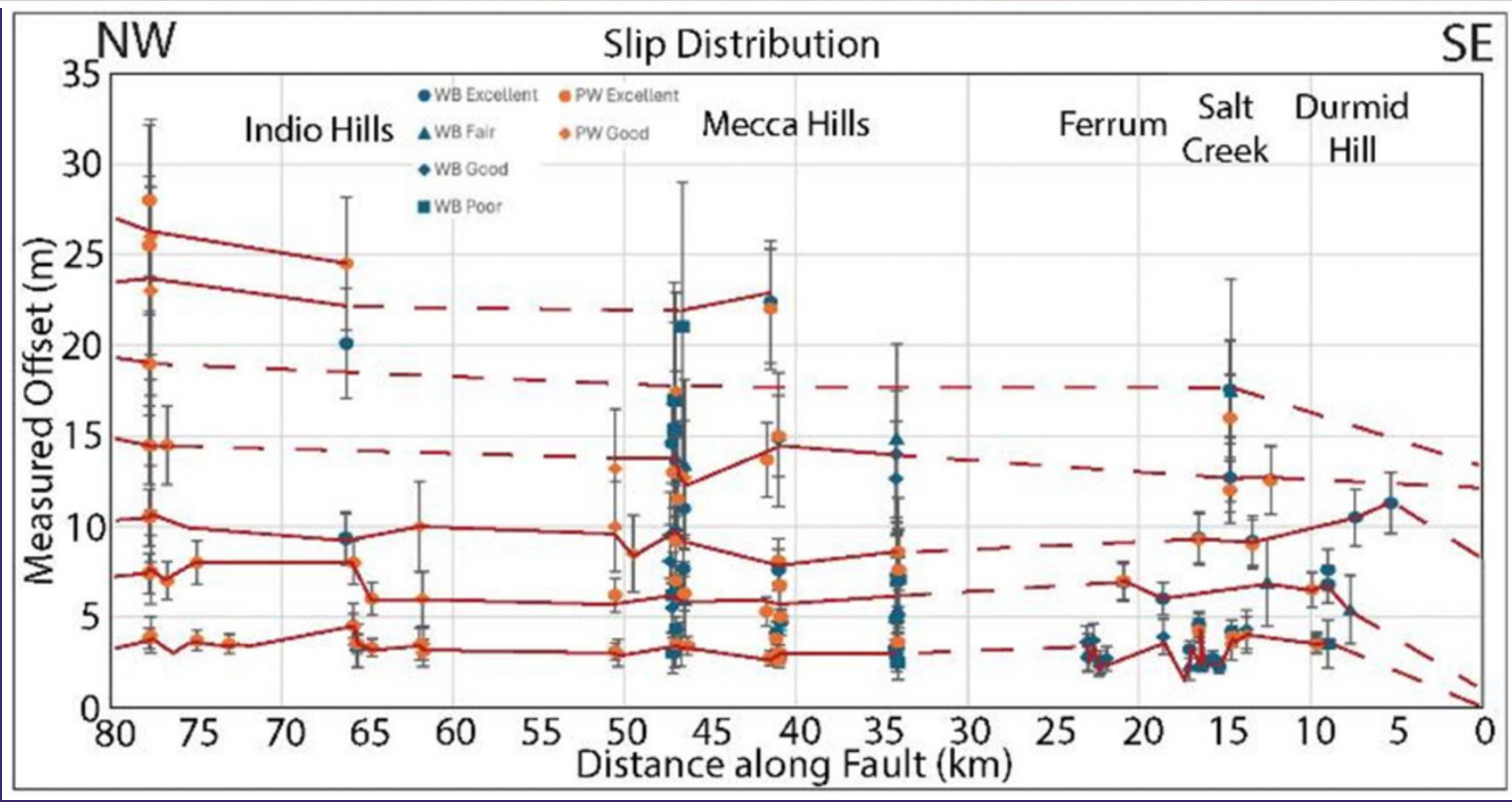




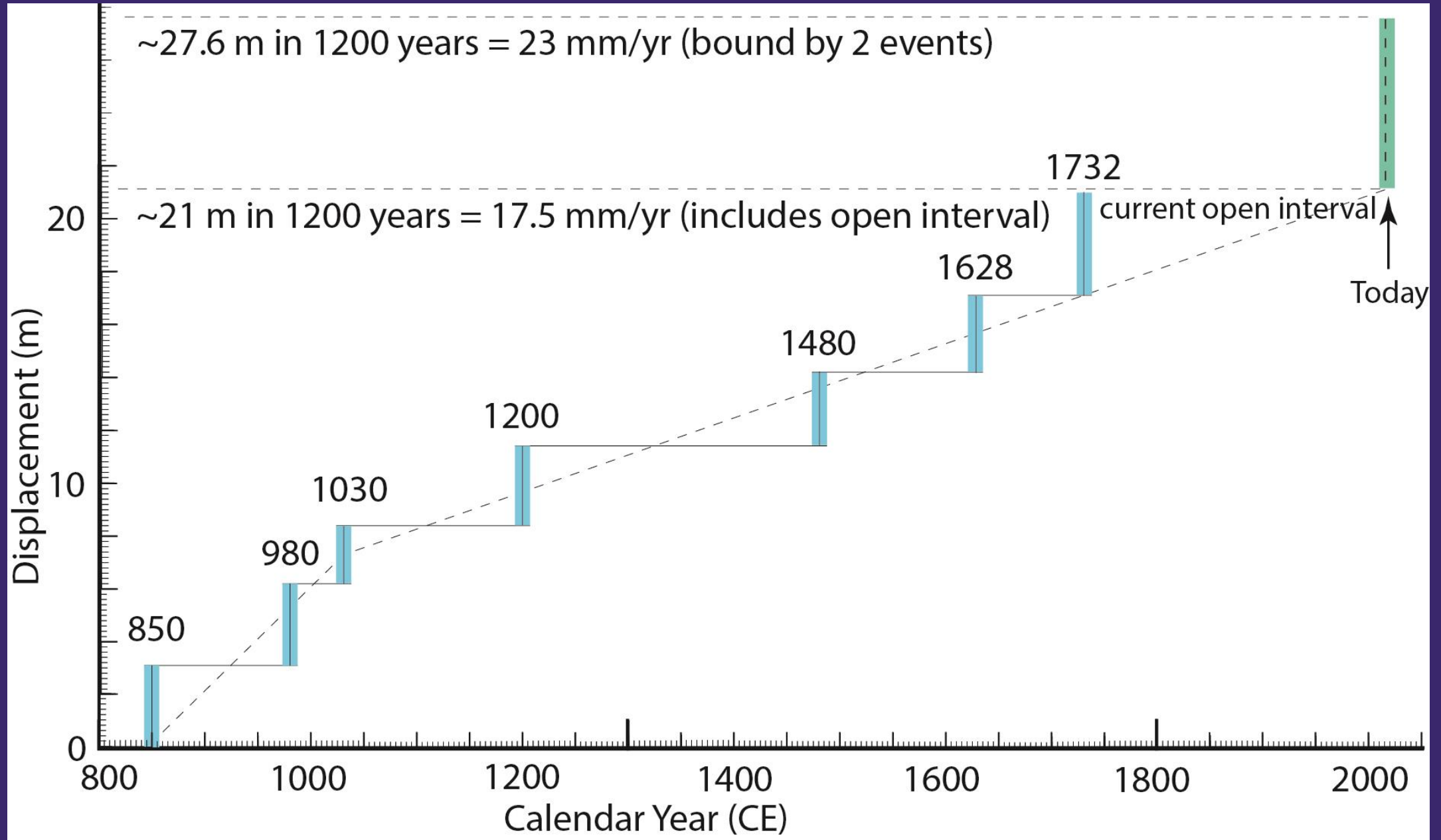


Displacement data from mapping of small offset channels and other geomorphic features (Blanton et al., 2020; Buckley et al. 2025).

We calculate the moment for each event ( $M_0 = sA\mu$ ) applying a rupture width of 11.9 km for the SAF (Nazareth & Haulsson, 2004) and a rigidity of  $3.6 \times 10^{11}$  dyne/cm<sup>2</sup> (Trugman & Benzion, 2022)

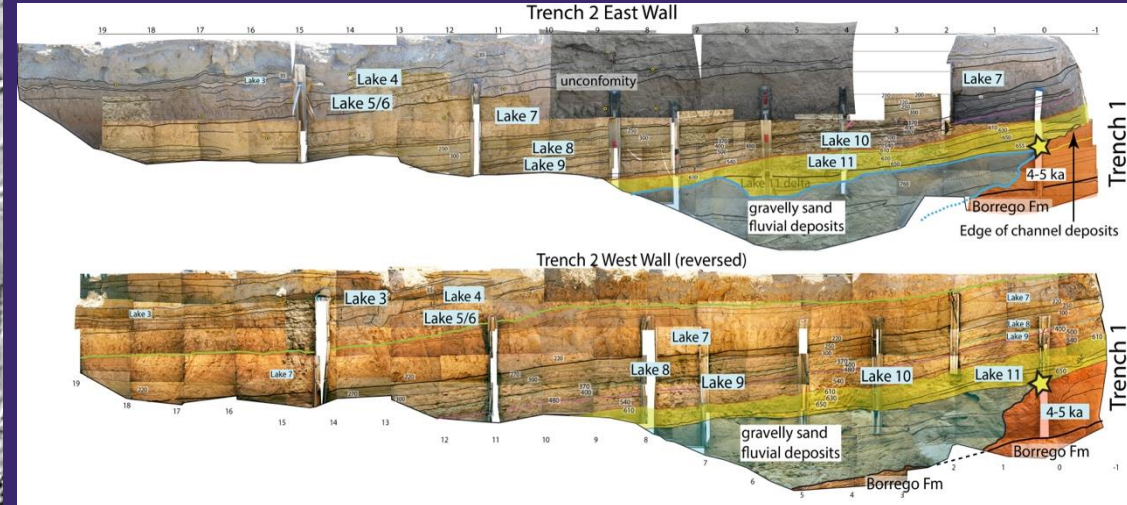
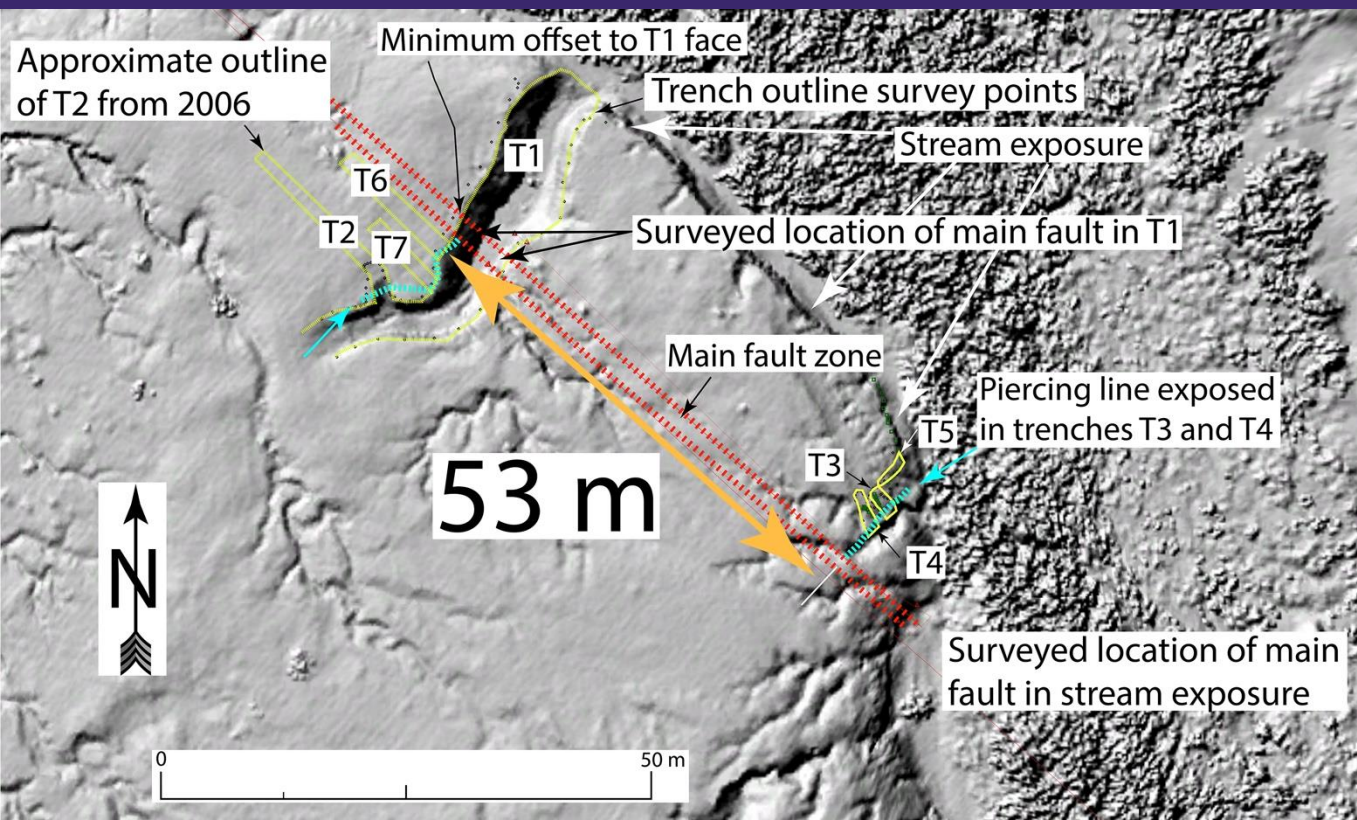


Combining the slip per event with the earthquake ages yields 17.5 mm/r (long open interval)

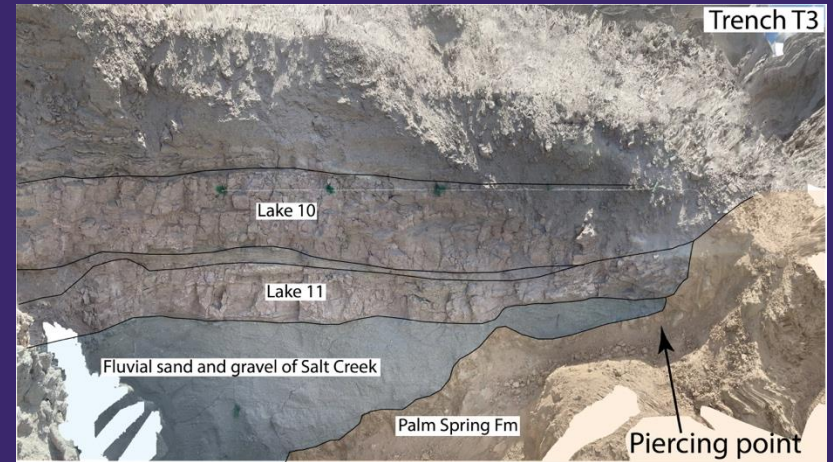
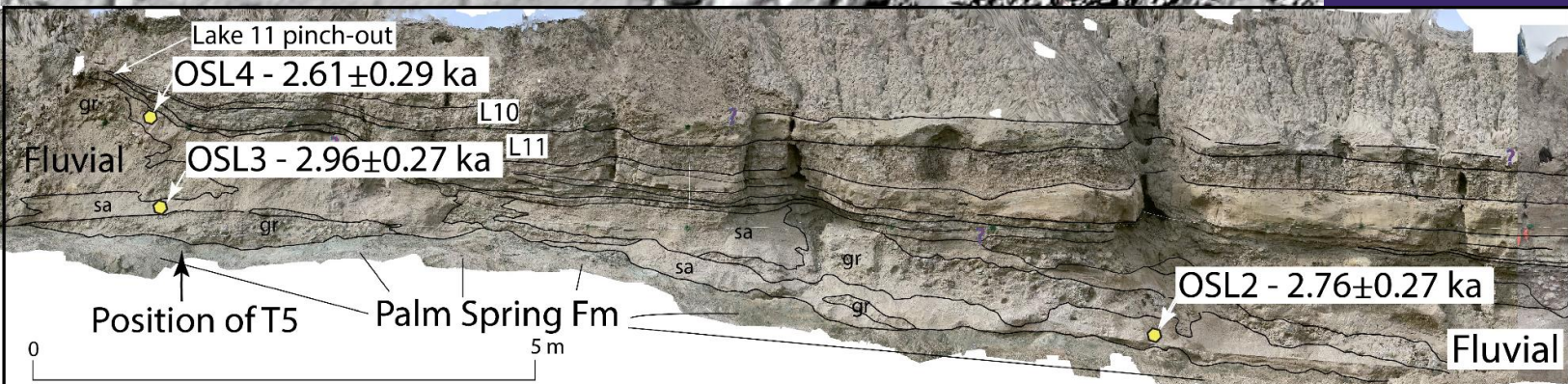


How does this compare to the Holocene slip rate?

# Salt Creek slip rate site



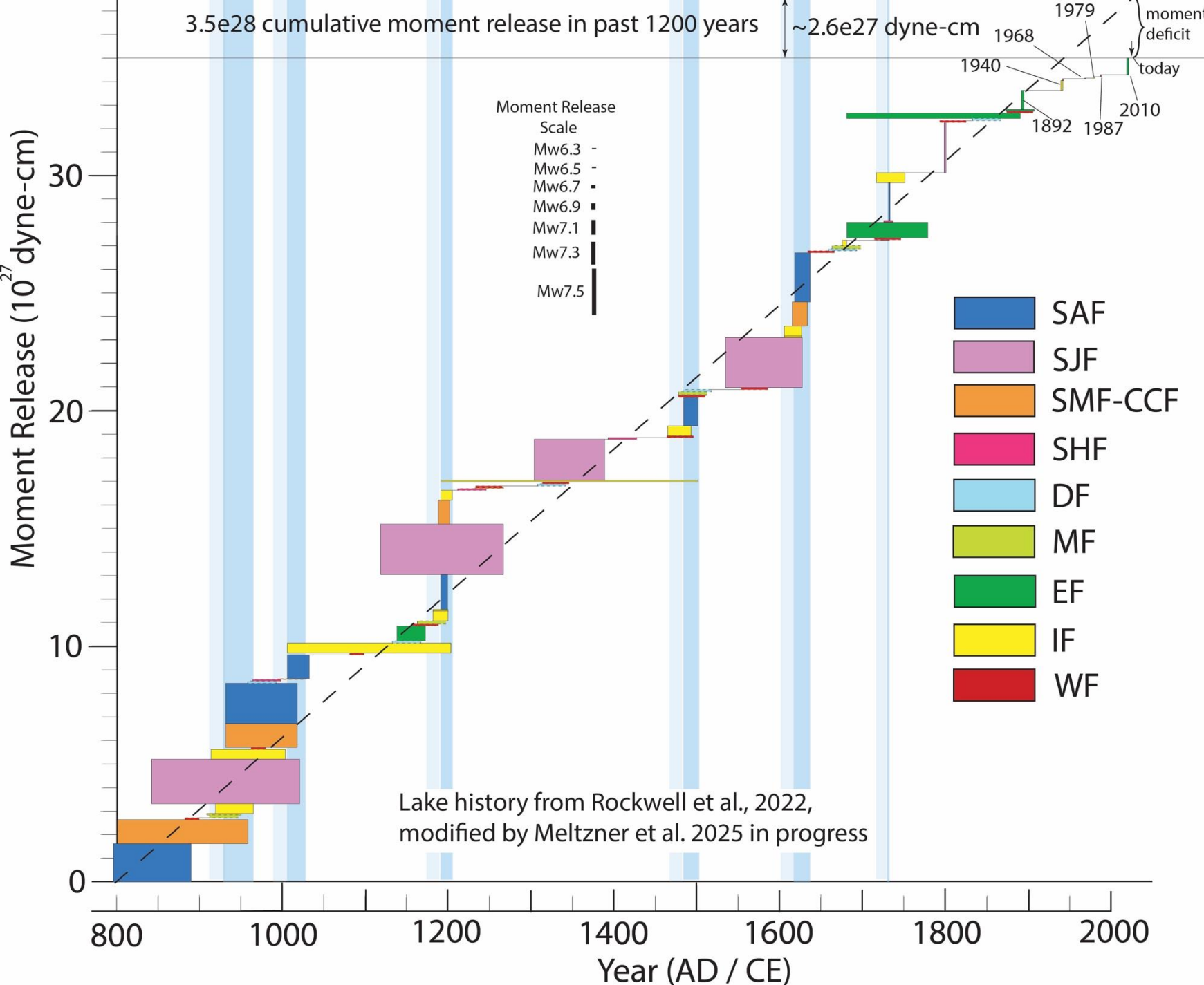
SW side of fault



NE side of fault

Rockwell, Scharer, et a. in progress

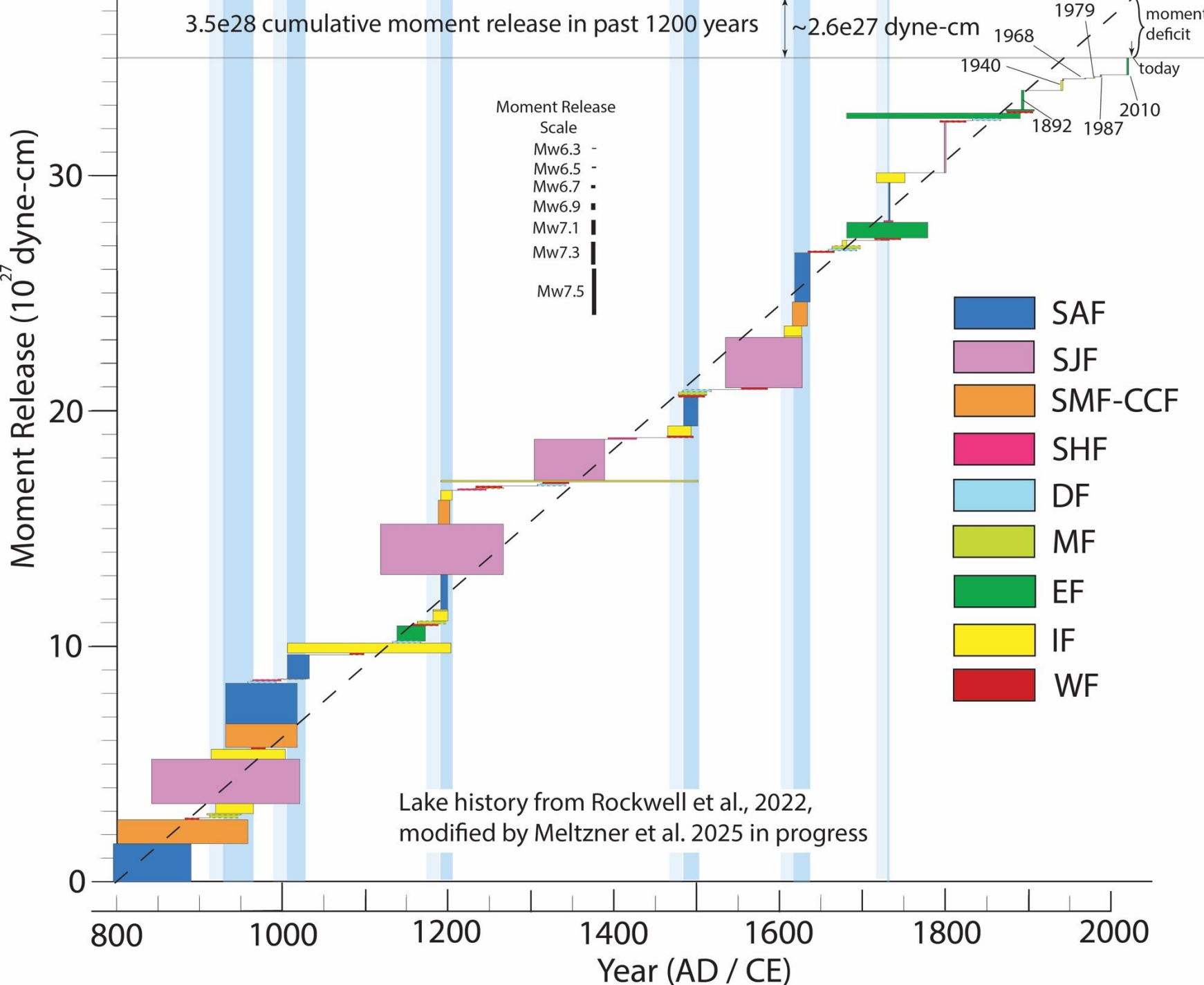
$53 \pm 2 \text{ m in } 2.61 \pm 0.29 \text{ ka} = 17.6\text{-}23.1 \text{ mm/yr}$



Paleoseismic events account for about  $3.5 \times 10^{28}$  dyne-cm over the past 1200 years. The width of the bar represents the uncertainty in event age. The vertical bar is the calculated moment release.

Record may be incomplete between 800 and 900 CE.

Doesn't account for the northern 25 km of the Cerro Prieto fault in Baja California, which ruptured in large earthquakes in 1934 and 1855. The slip rate is estimated at 42 mm/yr by Bennett et al. (1996), although that rate includes faults to the west of the Cerro Prieto fault, including the 2010 rupture.



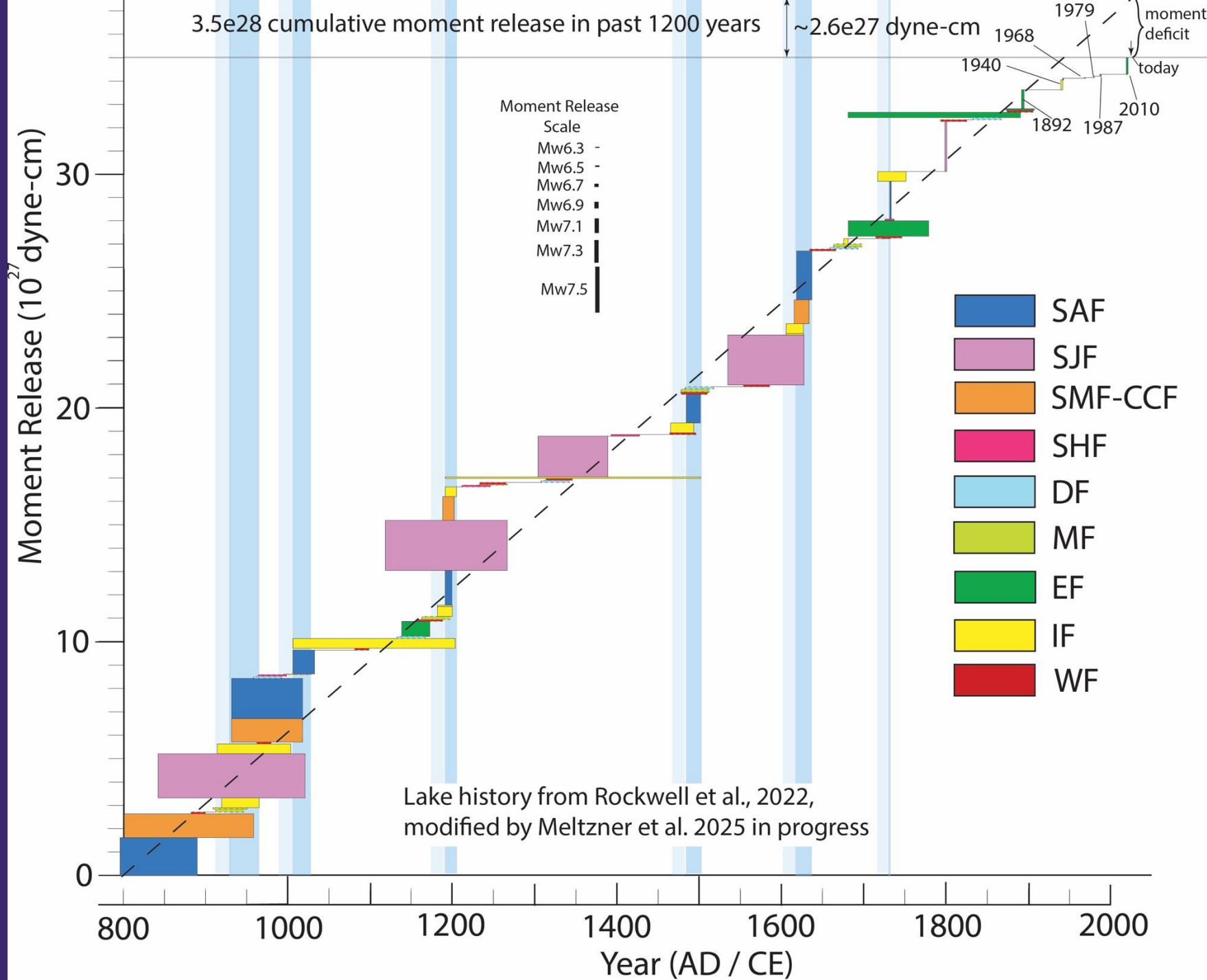
There are three periods of elevated moment release, with the first during the period of inundation of Lake Cahuilla (Lakes F and E) after a thousand-year dry period.

The second occurred after a 150-year dry spell during the inundation of Lake D.

The third occurred prior to and during the inundation associated with Lake B.

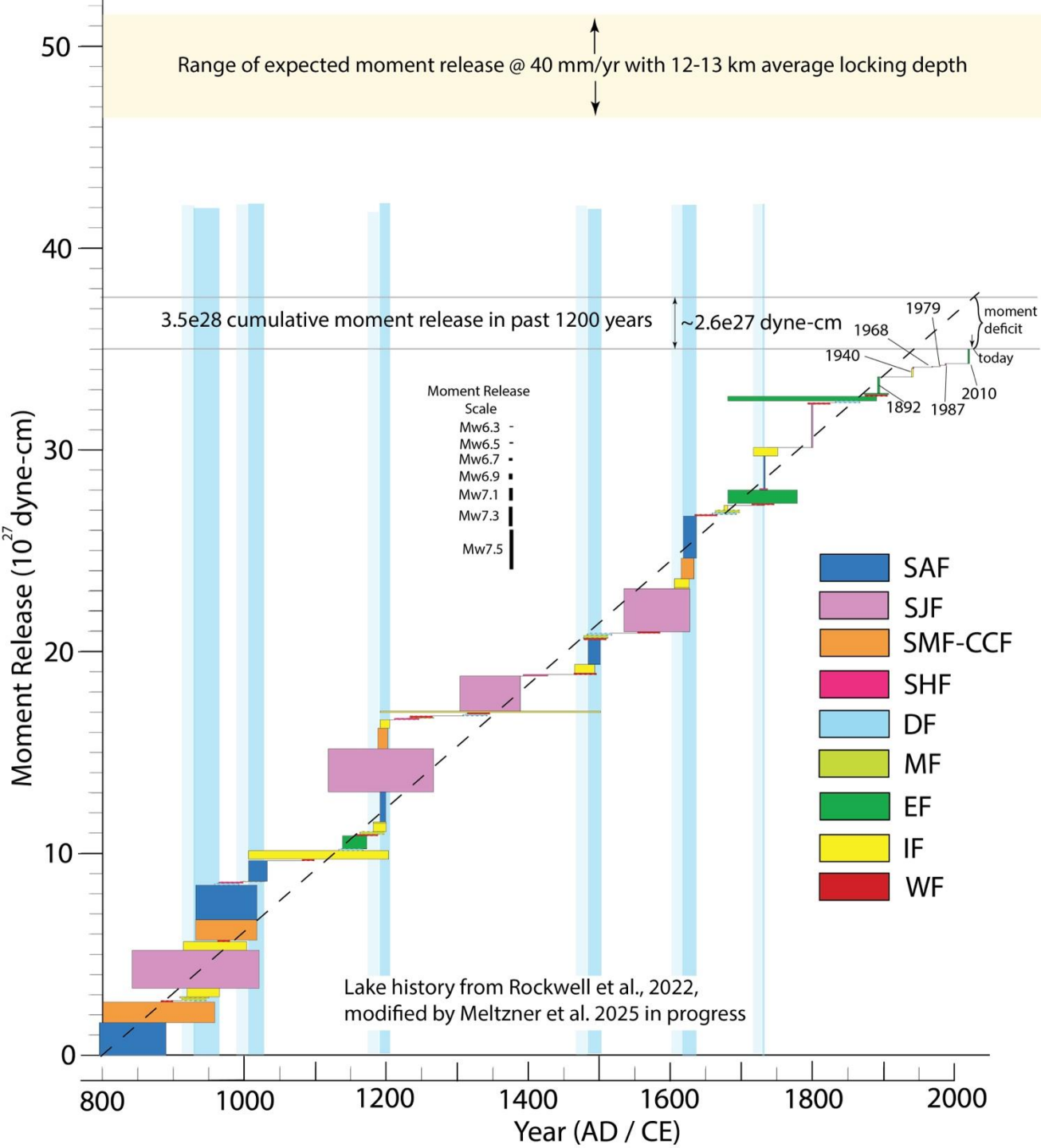
The most recent lake filling was ca 1732 and was coincident with the most recent San Andreas rupture.

$\sim 300$  years with no lakes,  $\sim 300$  years with no large southern San Andreas earthquakes....



Notably, it has been nearly 300 years with strain accumulating at  $\sim 21$  mm/yr so about twice the average slip in the past several earthquakes. Will it all go at once? Or be more characteristic?

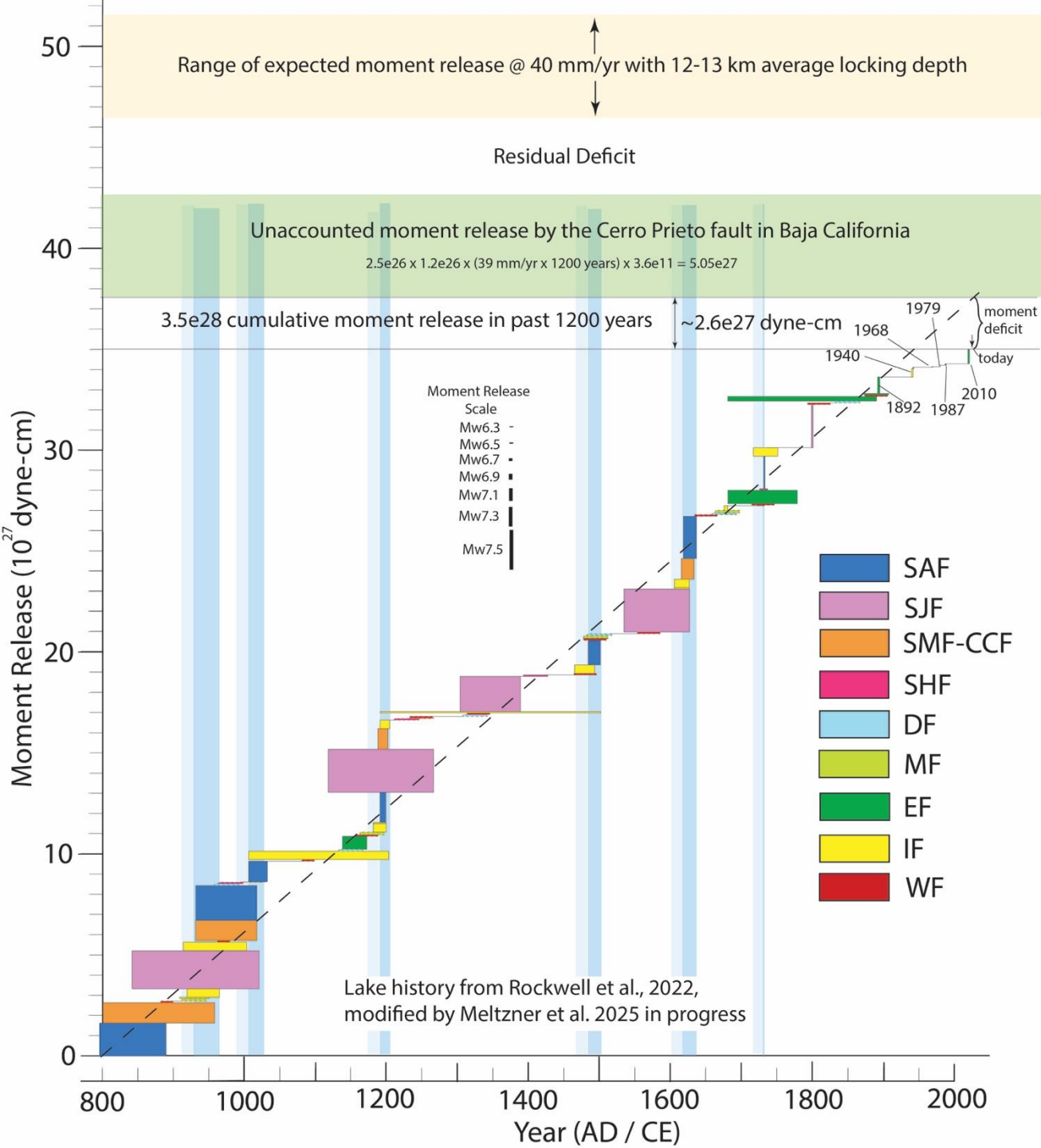
The dash line is an eye-ball estimate of the 1200-year average for moment release. The deficit from the past 1200-year average is  $\sim 2.6e27$ , equivalent to a Mw7.5 earthquake – just what is expected on the southern San Andreas fault.



At 39-40 mm/yr (geodetic rate) across the Salton Trough, the long term expected moment release calculates to **4.65-5.17e28 dyne-cm** using the average seismogenic thickness of 12-13 km.

The paleoseismic record accounts for 3.5e28, which is **68-75%** of the expected moment release.

So how much are we not accounting for with the Cerro Prieto fault?



The geodetic rate across the fault latitude of the Cerro Prieto fault south of Cerro Prieto volcano is on the order of 40 mm/yr (Bennett et al. 1996 has the rate at 42 mm/yr), but that also covers slip on faults to the west, such as ruptured in 2010. The Laguna Salada rate is about 3 mm/yr, so subtracting that rate, we have on the order of 39 mm/yr to account for, similar to the geodetic rate to the north.

Assuming 12 km of seismogenic crust, and only accounting for the 25 km of fault within “the box”, we calculate a total 1200-year moment of 5.05e27 dyne-cm, which accounts for a lot of the deficit.

Hence, a first order interpretation is that 82-91% of the expected moment release is occurring on the known major faults.

The rest of the deficit is likely accommodated by 1) open intervals; 2) cross-fault ruptures; and 3) off-fault deformation.

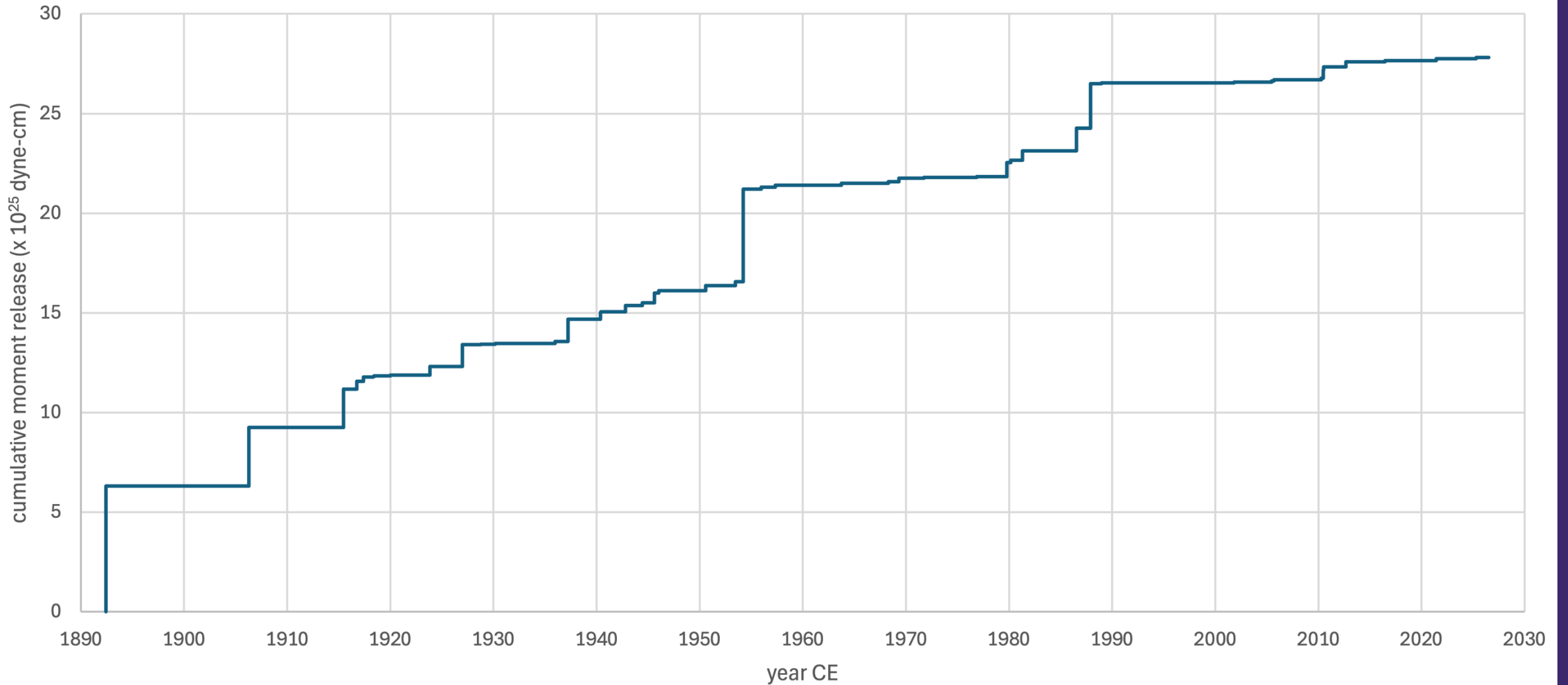
## Open intervals

San Andreas fault	294 years	~21 mm/yr	~6.2 m of potential slip
San Jacinto fault	226 years	~12 mm/yr	~2.7 m of potential slip
Superstition Mtn fault	~419 years	~7 mm/yr	~2.9 m of potential slip
Total for just these three faults:			~11.8 m

If these three faults were to fail in the next couple of decades in another “cluster”, they would release about  $5e27$  dyne-cm, which would bring the total 1200-year moment release to about  $4.54e28$  dyne-cm, or 88-98% of the expected moment

Cross-faults have historically been moderate events as they are limited in length, so we account for them in our assessment of historical moderate (Mw5-6.4) earthquakes since 1890. In total, they account for about 1% of the expected moment.

M5–6.5 Earthquakes Within Study Area



## Mw7+ earthquakes release most of the moment

We summed up the total moment release by the moderate Mw6.5-6.9 earthquakes vs the Mw7+ events

Mw6.5-6.9            Total moment =  $3.71e27$  dyne-cm

Mw7+                Total moment =  $3.13e28$  dyne-cm

Large earthquakes account for ~89% of the moment release in the southern San Andreas fault system

## Summary

- 1) The entire southern San Andreas fault system appears to be moment deficit, with the San Andreas fault itself very late in its' cycle
- 2) We suggest that this is due, in part, to the absence of a lake filling since the last large earthquake.
- 3) Moment release has clustered to some degree over the past 1200 years, possibly due in part due to the fillings and desiccations of Lake Cahuilla.
- 4) The vast majority of moment was released in the largest earthquakes, the most recent of which occurred on the San Jacinto fault in November, 1800.
- 5) Hence, it is plausible that the next century will see a flurry of large earthquakes on the southern San Andreas fault system – the century of terror?







# General structure of this talk

- 1) Brief late Holocene History of Lake Cahuilla
- 2) Paleoseismology of the southern 230 km of the San Andreas fault system
- 3) 1100+ years of seismic moment release in the plate boundary fault system: How do faults within a system interact to accommodate plate motion. How much of the plate motion is captured in the paleoseismology. What is the deficit in moment, and what is the regional effect of open intervals on the moment deficit?