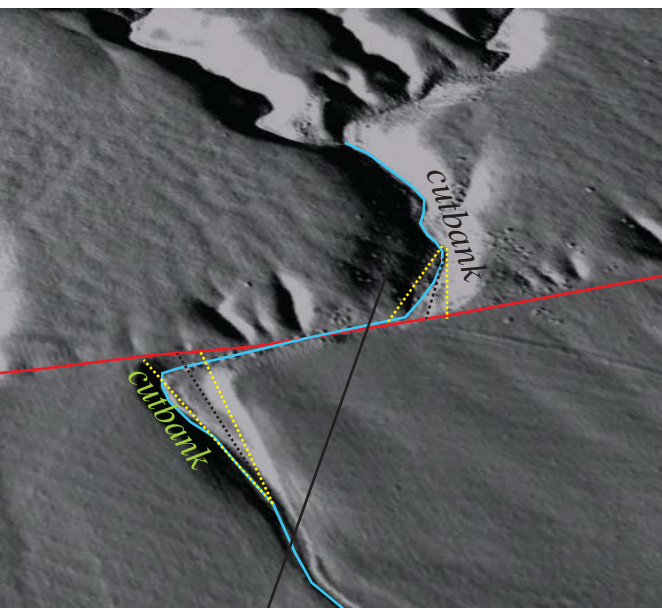# Symmetrical Bias in Reporting Slip Rates: Asymmetric Probability Density Functions are Inherent Outcomes of Accounting for Uncertainties in Displacement and Age

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Uncertainties in Long-term Geologic Slip Rates

Displacements
Initial Geomorphic Geometry

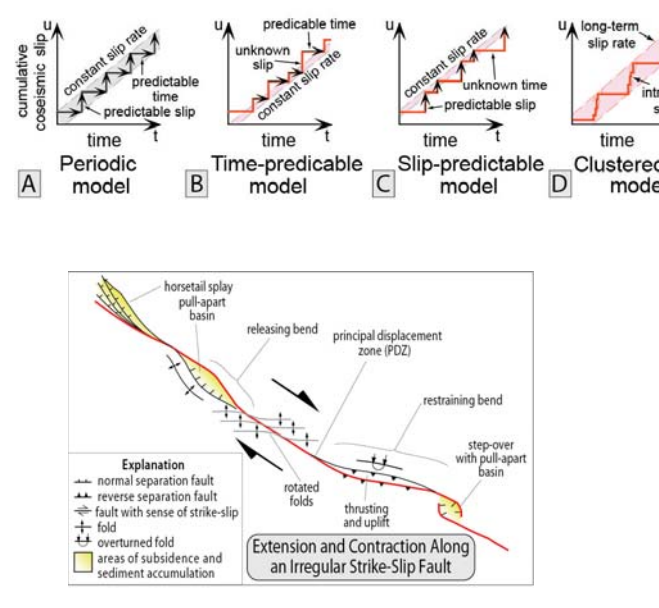**Displacements**
Surface Modifications

Displacements
Timing of Formation, Measurement and Seismic cycles

Faulting
Fault Geometries and Kinematics

Ages-
Min vs Max Rates
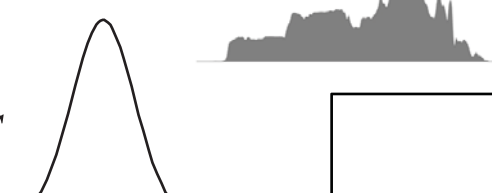
Ages
Inheritance

Ages-
Geochronology Precision
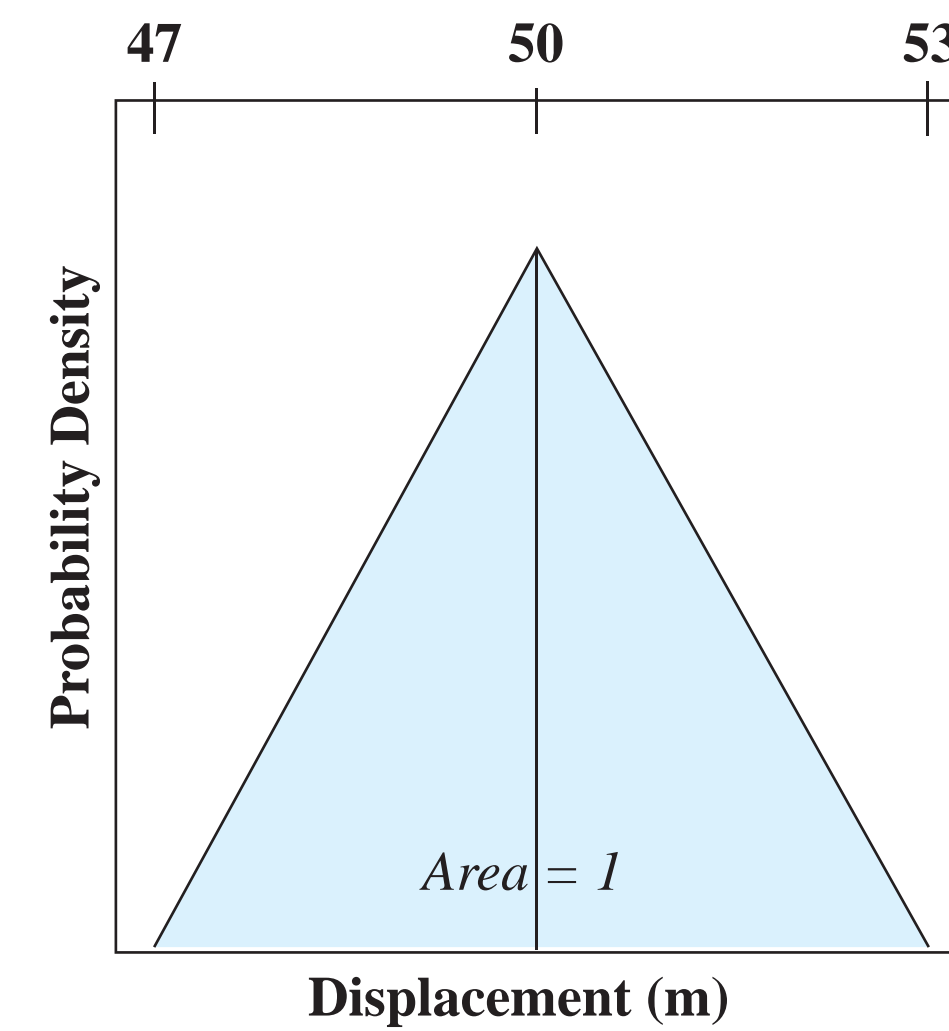
Uncertainty
Appropriate PDF Shapes

Among 849 active and potentially active faults in the conterminous western USA, only 48 have well constrained offset rates (95% Confidence Interval Width < Median Slip Rate: Bird, 2007)

Simplistic Example of Slip Rate PDF Asymmetry

Displacement of Feature

Preferred Displacement:	50 m
Symmetrical Uncertainty:	+/- 3 m
Uncertainty:	*12%*
Minimum Displacement:	47m
Maximum Displacement:	53m

47   50   53

Probability Density — *Displacement (m)* — Area = 1

Age of Displaced Feature

Preferred Age:	1500 yrs BP
Symmetrical Uncertainty:	+/- 100 yrs
Uncertainty:	*13.3%*
Maximum Age:	1600 yrs BP
Minimum Age:	1400 yrs BP

1400   1500   1600

Probability Density — *Age of Displacement (yrs BP)* — Area = 1
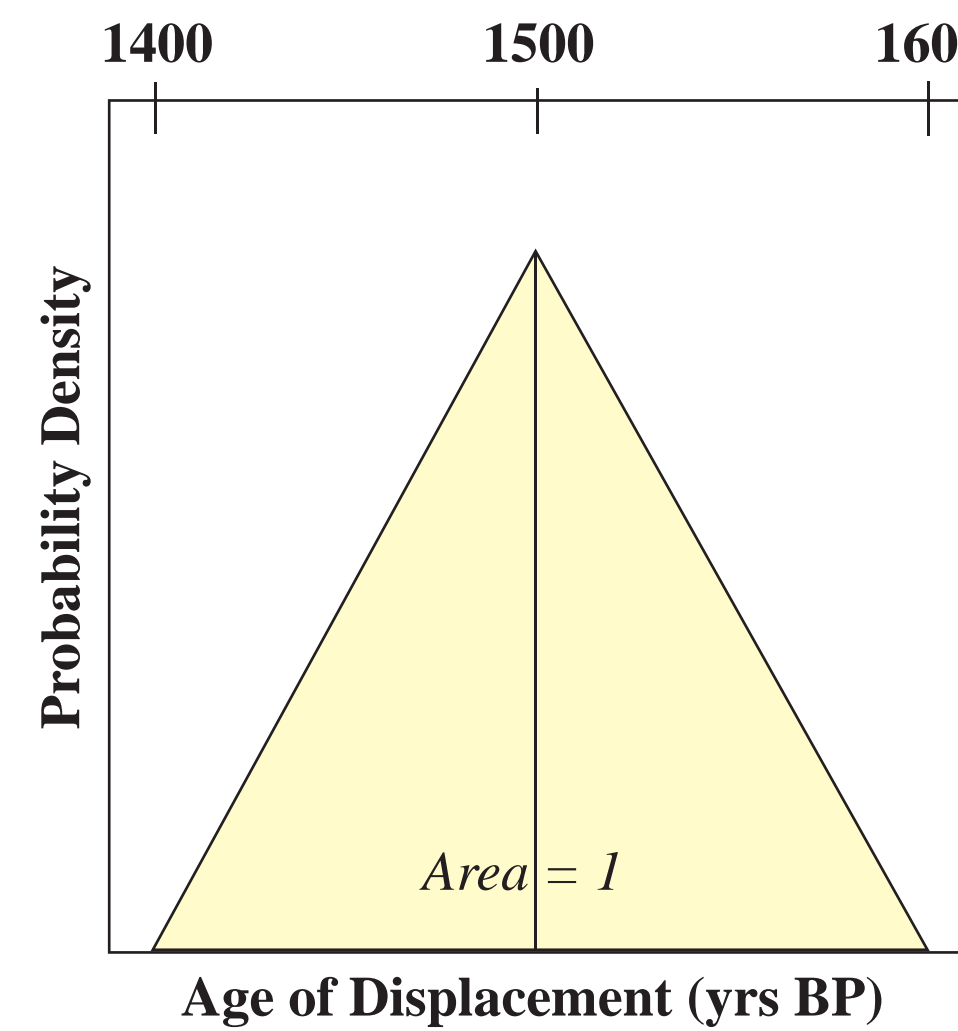
Slip Rates

Mode (*Most Probable*):	33.3 mm/yr
Midpoint (*Most Reported*):	33.65 mm/yr
Percent skewed	*4.1%*
Minimum SR:	29.4 mm/yr
Maximum Age:	37.9 mm/yr

29.4   33.7   37.9

33.3 mm/yr Peak Probability

Probability Density — *Slip Rate (mm/yr)* — Area = 1
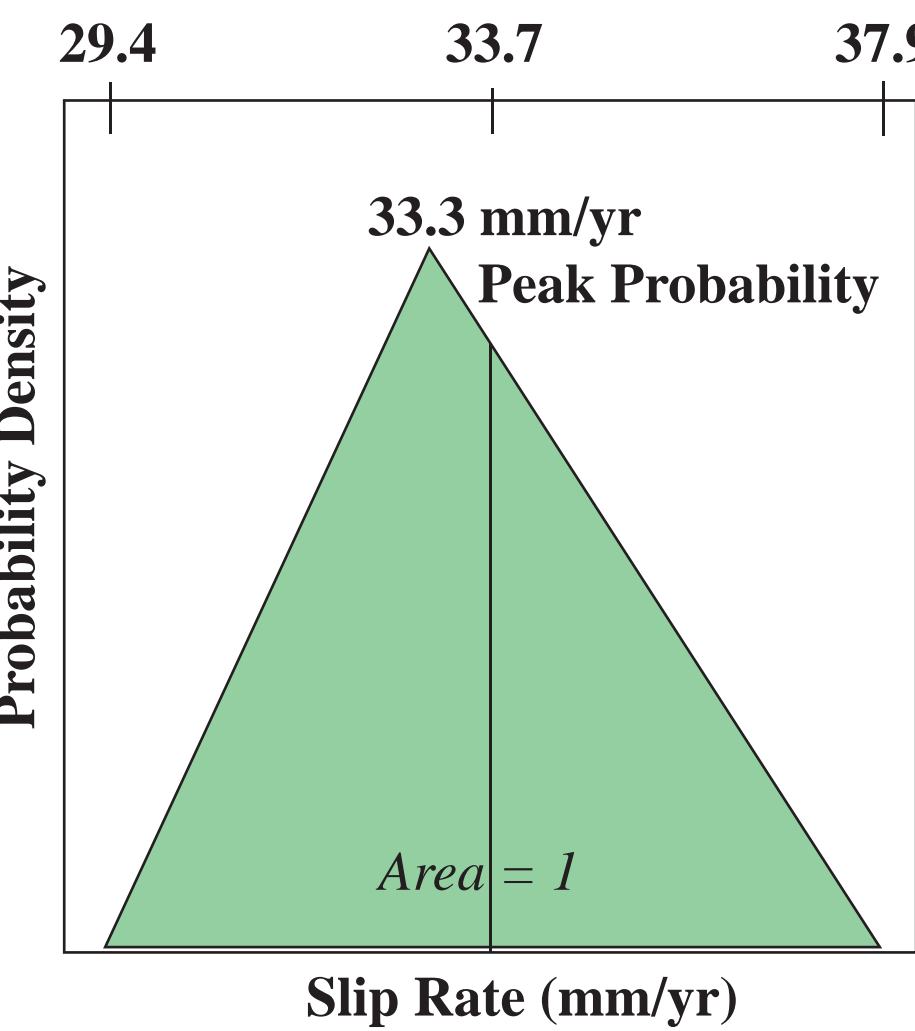
References

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Kellum, L.T. and N.A. Toke, 2013, "Using LiDAR DEMs for geomorphic assessment of Lake Bonneville wave-cut terraces and post-Bonneville displacement along the Wasatch fault." 2013 GSA Annual Meeting, Paper No. 347-3

Noriega, G.R., J R. Arrowsmith, L.B. Grant, and J.J. Young, 2006, "Stream Channel Offset and Late Holocene Slip Rate of the San Andreas Fault at the Van Matre Ranch Site, Carrizo Plain, California." Bulletin of the Seismological Society of America, v. 96, no. 1

Sieh, K.E. and R.H. Jahns, 1984, "Holocene activity of the San Andreas fault at Wallace Creek, California." Geological Society of America Bulletin, v. 95, no. 8

Toke, N.A., J R. Arrowsmith, M.J. Rymer, A. Landgraf, D.E. Haddad, M. Busch, J. Coyan, and A. Hannah, 2011, "Late Holocene slip rate of the San Andreas fault and its accomodation by creep and moderate-magnitude earthquakes at Parkfield, California." Geology, v. 39, no. 3

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Parkfield: Creep + Moderate Magnitude EQs, Fast Slip Rate

Slip Rates

Mode (*Most Probable Rate*):	**20.3 mm/yr**
Median (*50th percentile*):	**24.7 mm/yr**
Midpoint (*Most Reported*):	**27.5 mm/yr**
Percent skewed	*34%*
Minimum SR:	**18.2 mm/yr**
Maximum SR:	**37.0 mm/yr**

Displacement of Feature

Preferred Displacement:	**20.75 m**
Symmetrical Uncertainty:	**+/- 2.25 m**
Minimum Displacement:	**18.5 m**
Maximum Displacement:	**23.0 m**

Age of Displaced Feature

Preferred Age:	**840 yrs BP**
Symmetrical Uncertainty:	**+/- 280 yrs**
Maximum Age:	**1120 yrs BP**
Minimum Age:	**560 yrs BP**

Parkfield data obtained from Toke et al., 2011

PDF Analyses Following Zechar and Frankel, 2009
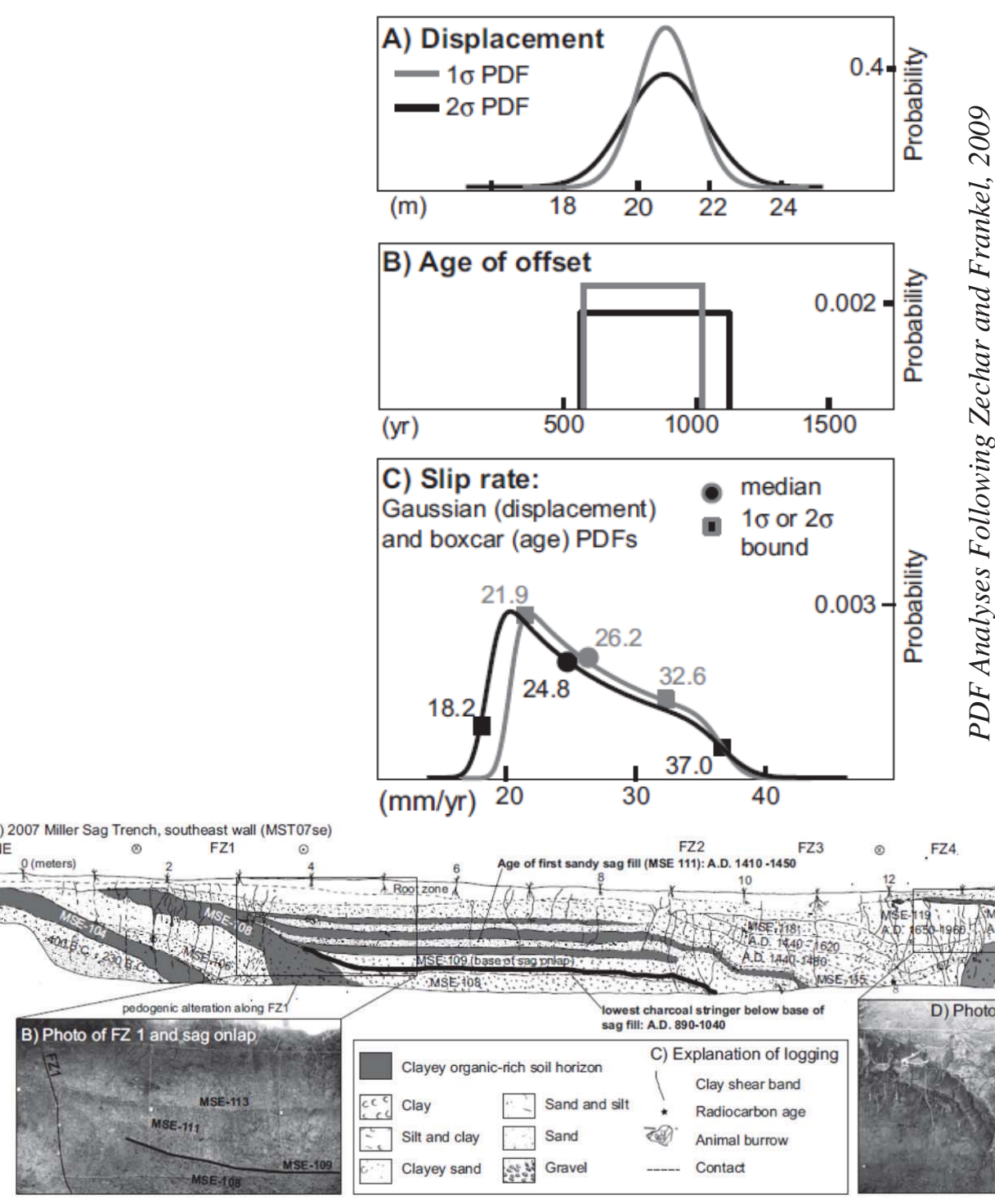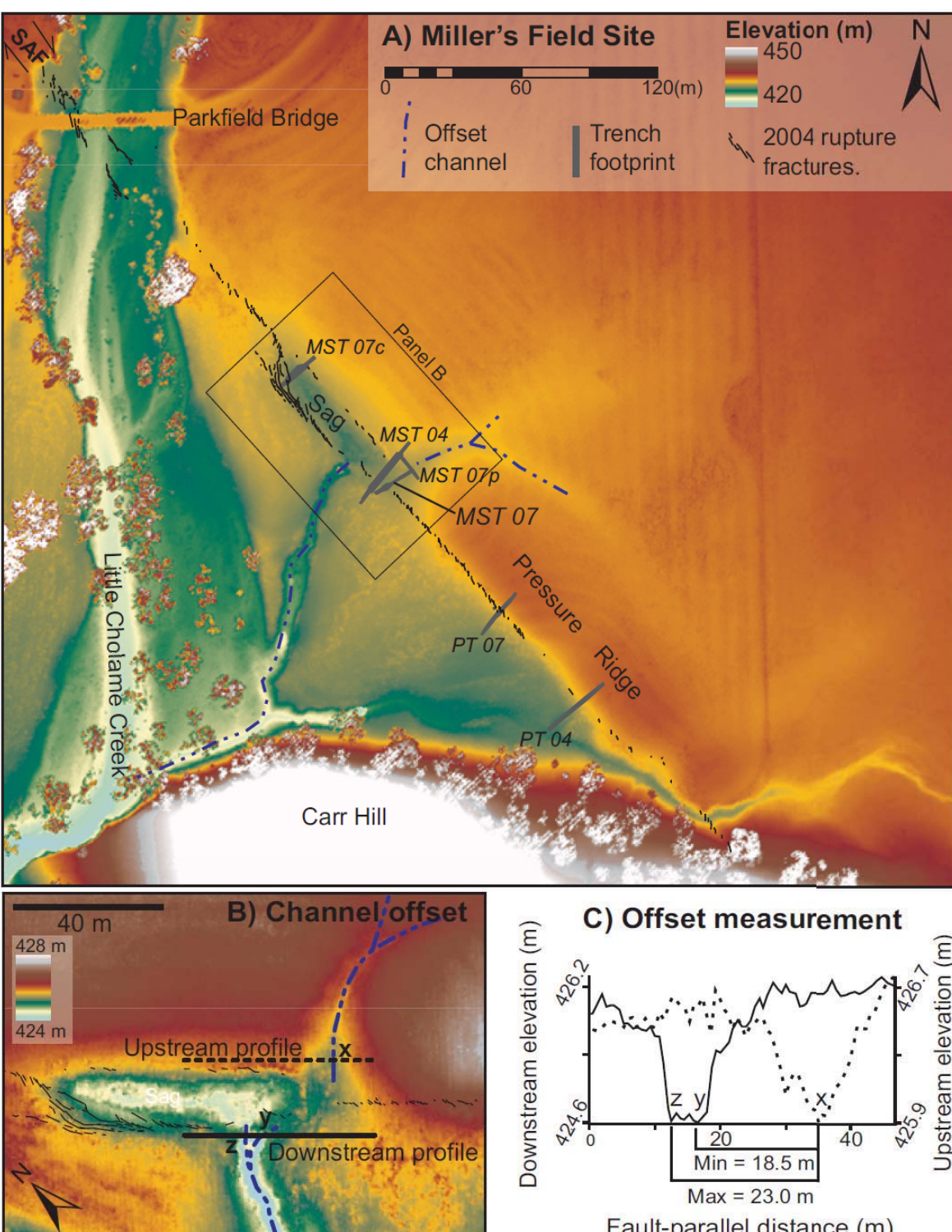
Carrizo Plain: Large Magnitude Ruptures, Fast Slip Rate

Van Matre Ranch (VMR) Slip Rates

Mode (*Most Probable Rate*):	**30.5 mm/yr**
Median (*50th percentile*):	**31.6 mm/yr**
Midpoint (*Most Reported*):	**31.8 mm/yr**
Percent skewed	*3%*
Minimum SR:	**28.2 mm/yr**
Maximum SR:	**35.4 mm/yr**

VMR Displacement of Feature

Preferred Displacement:	**24.8 m**
Symmetrical Uncertainty:	**+/- 1 m**
Minimum Displacement:	**23.8 m**
Maximum Displacement:	**25.8 m**

VMR Age of Displaced Feature

Preferred Age:	**787 yrs BP**
Symmetrical Uncertainty:	**+/- 58 yrs**
Maximum Age:	**845 yrs BP**
Minimum Age:	**729 yrs BP**

VMR data obtained from Noriega, et al., 2006

WC data obtained from Sieh and Jahns, 1984
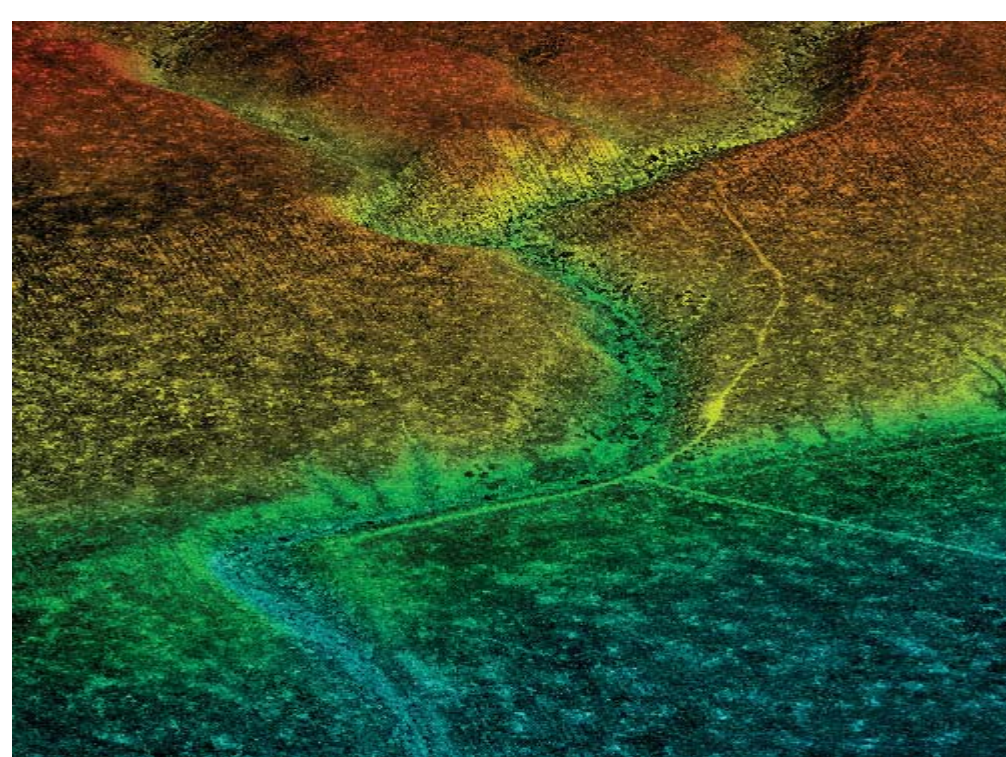
Wallace Creek (WC) Slip Rates

Mode (*Most Probable Rate*):	**33.6 mm/yr**
Median (*50th percentile*):	**34.6 mm/yr**
Midpoint (*Most Reported*):	**34.7 mm/yr**
Percent skewed	*3%*
Minimum SR:	**33.1 mm/yr**
Maximum SR:	**36.3 mm/yr**

WC Displacement of Feature

Preferred Displacement:	**128 m**
Symmetrical Uncertainty:	**+/- 1 m**
Minimum Displacement:	**127 m**
Maximum Displacement:	**129 m**

WC Age of Displaced Feature

Preferred Age:	**3695 yrs BP**
Symmetrical Uncertainty:	**+/- 155 yrs**
Maximum Age:	**3840 yrs BP**
Minimum Age:	**3550 yrs BP**

Wasatch: Large Magnitude Ruptures, Modest Slip Rate

Corner Canyon (CC) Slip Rates

Mode (*Most Probable Rate*):	**1.15 mm/yr**
Midpoint (*Most Reported*):	**1.17 mm/yr**
Percent skewed	*2%*
Minimum SR:	**0.7 mm/yr**
Maximum SR:	**1.6 mm/yr**

CC Displacement of Feature

Preferred Displacement:	**20.6 m**
Symmetrical Uncertainty:	**+/- 7.2 m**
Minimum Displacement:	**13.4 m**
Maximum Displacement:	**27.8 m**

CC Age of Displaced Feature

Preferred Age:	**17,950 yrs BP**
Symmetrical Uncertainty:	**+/- 750 yrs**
Maximum Age:	**18,700 yrs BP**
Minimum Age:	**17,200 yrs BP**

CC data obtained from Kellum and Toke, 2013; also see Jewell and Bruhn, 2013.
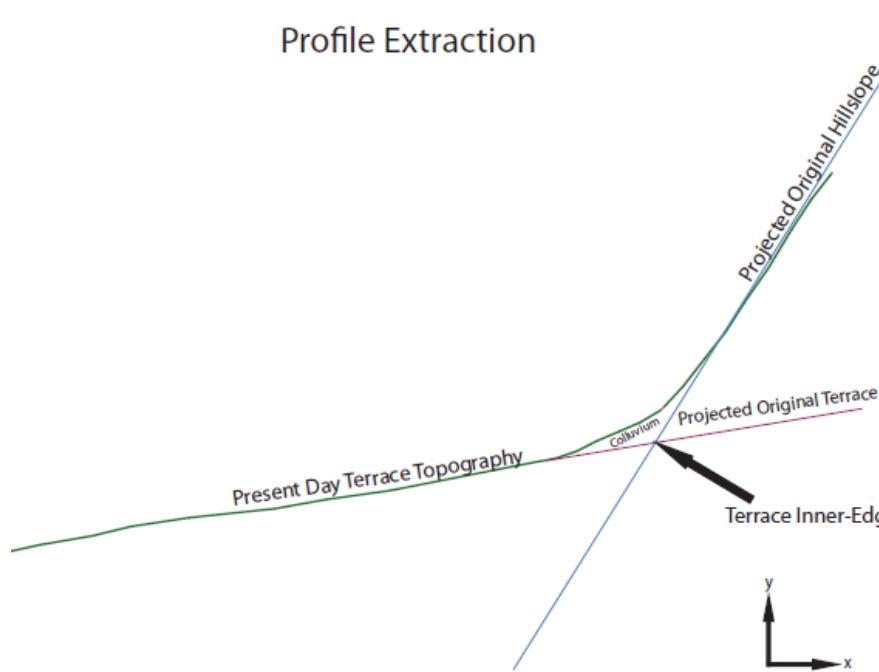
Corner Canyon, Salt Lake City Segment: Wasatch Fault, Utah

Lake Bonneville Terrace Highstand Elevations along the SLC Segment of the Wasatch Fault
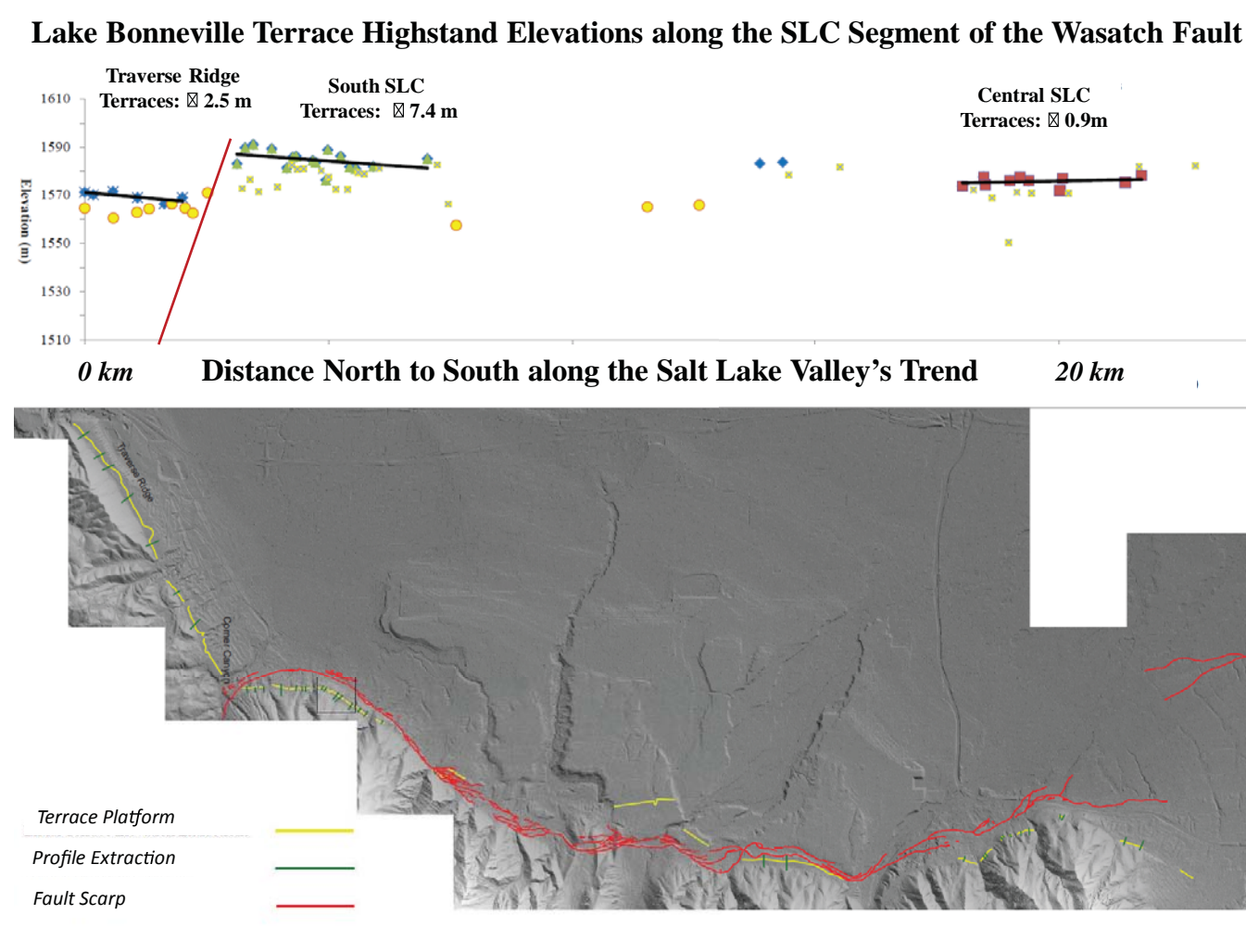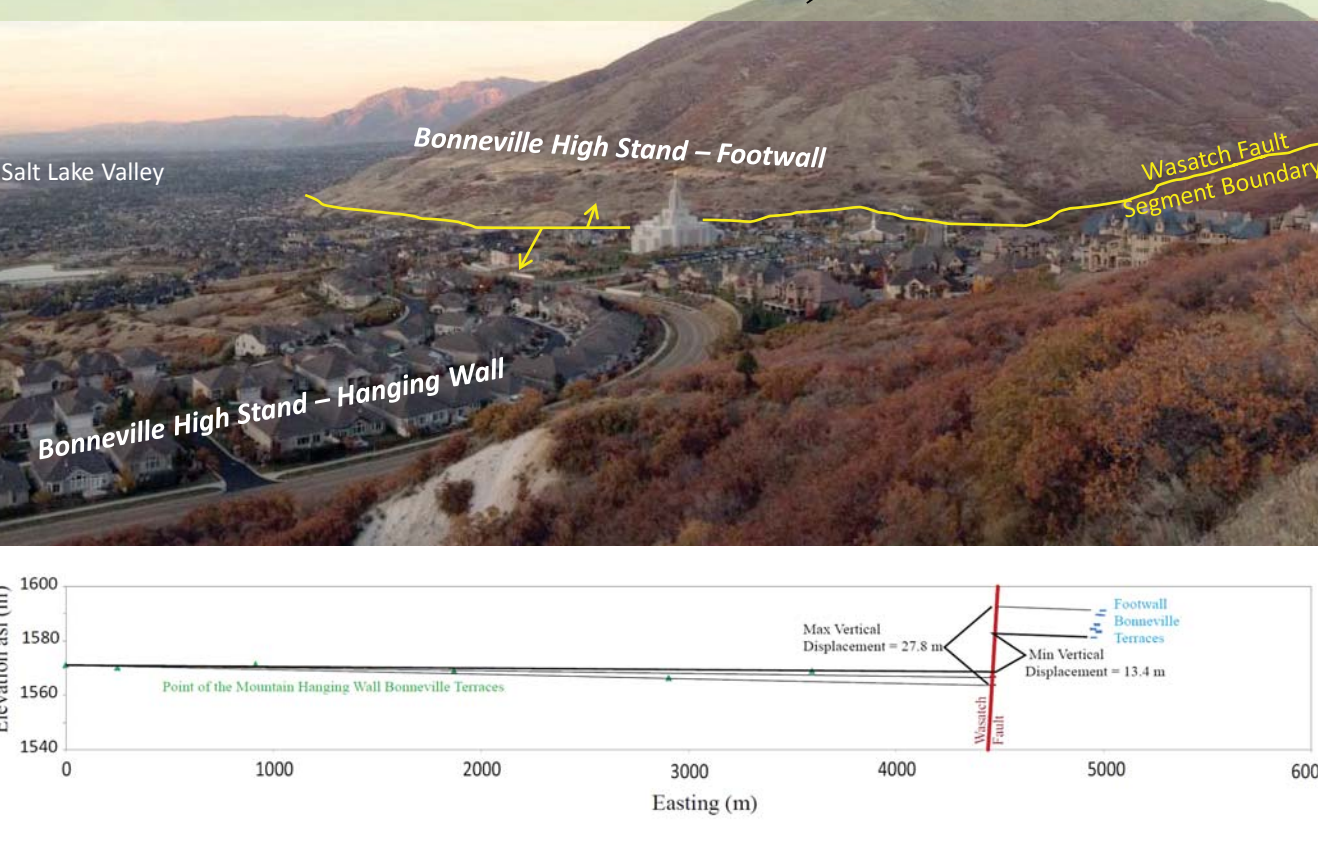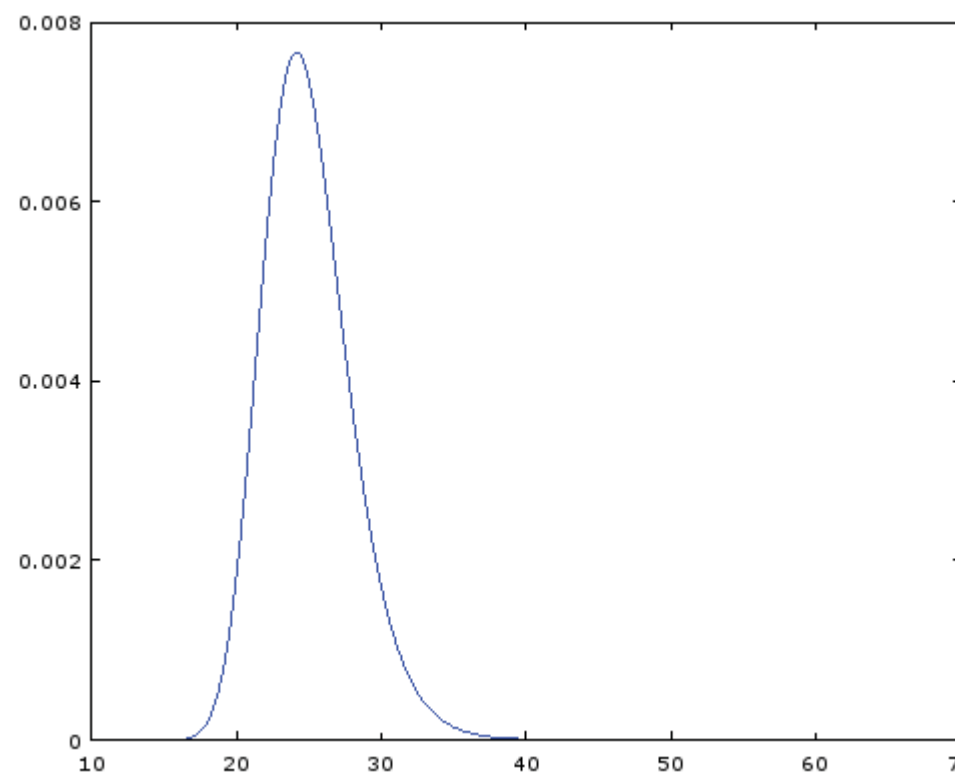
Brief Exploration of Uncertainty Choices, PDFs and Asymmetry for the Parkfield Case

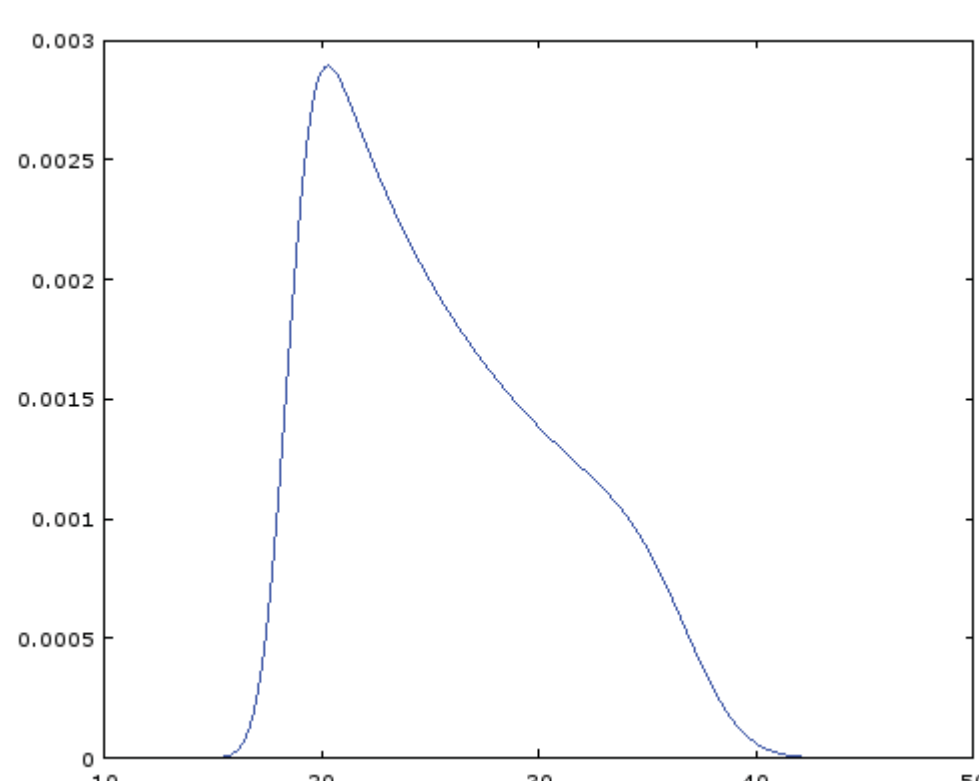### Gaussian (Displacement - U) Gaussian (Age - U)
D = 20.6 +/- 2.25 m
T = 840 +/- 280 yrs
Midpoint = 25.9
Mode = 24.1
Median = 24.7 +7.4/-5.0

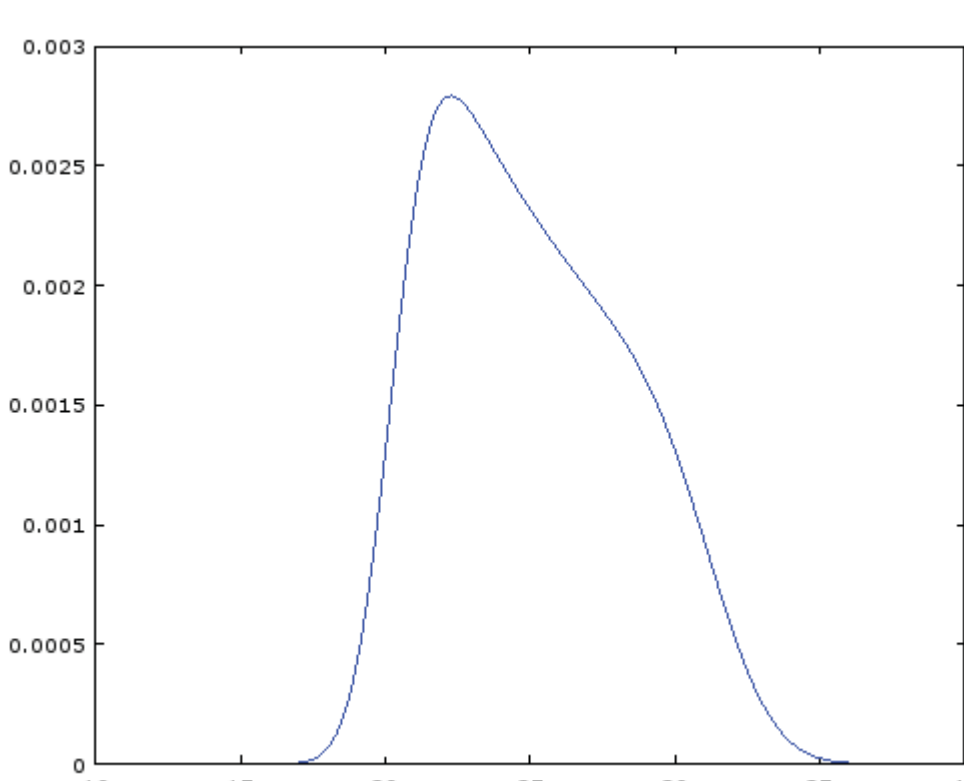### Gaussian (Displacement - U) and Boxcar (Age - U)
D = 20.6 +/- 2.25 m
T = 840 +/- 280 yrs
Midpoint = 27.5
Mode = 20.3
Median = 24.7 +12.3/-6.7

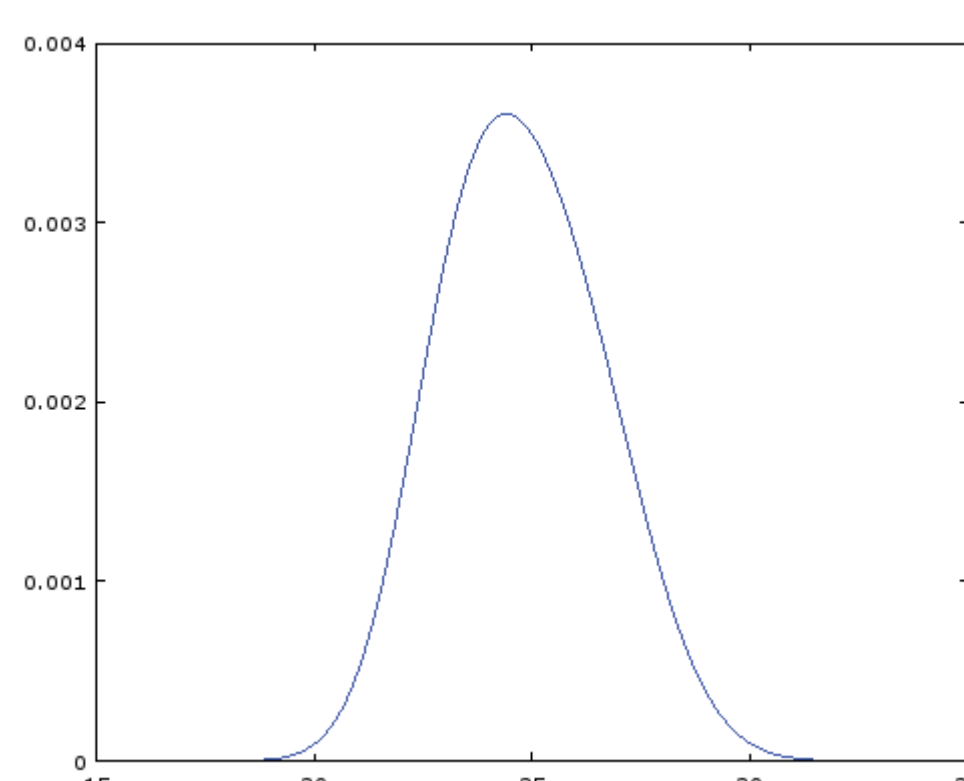### Gaussian (Displacement) and Boxcar (Age)
D = 20.6 +/- 2.25 m
T = 840 +/- 180 yrs
Midpoint = 25.9
Mode = 22.3
Median = 24.7 +7.4/-5.1
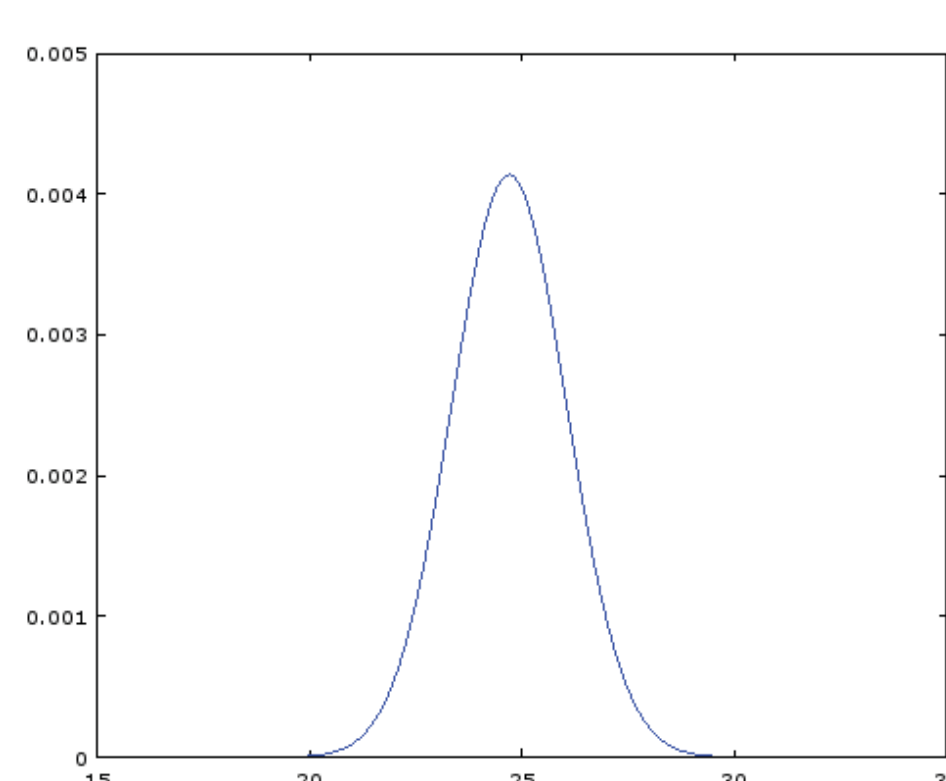
Gaussian (Displacement) and Boxcar (Age)
D = 20.6 +/- 2.25 m
T = 840 +/- 80 yrs
Midpoint = 25.0
Mode = 24.4
Median = 24.7 +4.0/-3.5

### Gaussian (Displacement) and Boxcar (Age)
D = 20.6 +/- 2.25 m
T = 840 +/- 10 yrs
Midpoint = 24.7
Mode = 24.7
Median = 24.7 +2.7/-2.7

Convolved Gaussian (displacement)-Gaussian(age) Uncertainty PDFs Yield Less Asymmetry than Mixed Gaussian (displacement)-Boxcar (age) PDF convolutions.

As Boxcar (age) Uncertainty Range Decreases Asymmetry Decreases.

Slip Rate Asymmetry Gains Importance as Age Uncertainty Increases

% Age Uncertainty and % SR Asymmetry (Difference in Slip Rate Midpoint and Mode)
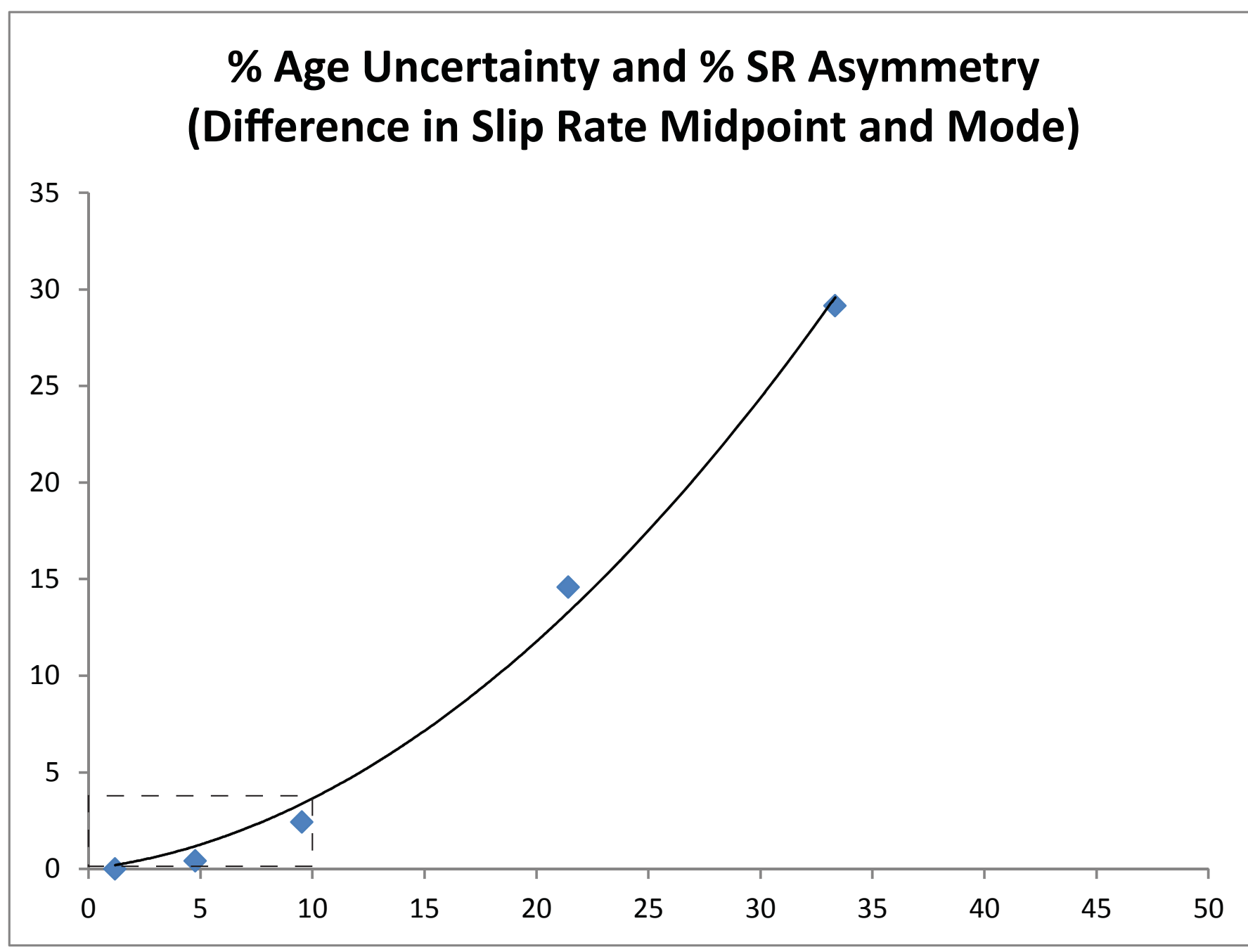
Below 10% age uncertainty (box car case) slip rate asymmetry is less than 4%. Thus, asymmetry is more important to consider for late Holocene offsets, especially if ages are not tightly constrained.

CONCLUSION:
Investigators should strive to report slip rate ranges as well as median or mode values with asymmetrical bounds rather than midpoint values with symmetrical bounds.