FINAL TECHNICAL REPORT

Award Title

Rupture History of the San Andreas Fault in the Carrizo Plain prior to 1300 A.D.

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U.S. Geological Survey
National Earthquake Hazard Reductiction Program
Award No. G10AP00073

06/1/2010 - 05/30/2012

ABSTRACT:

It is important to determine variability in time between earthquakes to constrain uncertainty in probabilistic calculations of rupture potential. Results from our field work since 2005 at the Bidart site in the Carrizo Plain and new radiocarbon dates from archival samples collected for Grant's 1993 dissertation reveal evidence of six ruptures of the San Andreas fault (SAF) between 1345 and 1857 AD (Akciz et al., 2009; 2010). This short recurrence time (approx 100 years or less) motivates re-evaluation of recurrence models such as the characteristic earthquake model (Schwartz and Coppersmith, 1984). The most recent rupture occurred in 1857, suggesting that the SAF in the Carrizo Plain has a high probability of rupture in the next few decades. Additional research is needed to find out if the short recurrence time holds for a longer time interval (i.e. prior to 1300 AD) or if the model of clustered earthquakes proposed by Grant and Sieh (1994) still holds for the Carrizo.

To reveal evidence and determine ages of the last six SAF surface ruptures at the Bidart site required excavation of trenches that were up to 17 feet deep. Deeper trenches will be required to extend the chronology further, but we were able to begin by examining evidence from the oldest part of the section in existing trenches. For this project, we completed logging and tried to date organic samples from the western end of trenches that recorded evidence for older earthquakes. Several samples from different stratigraphic units within trench BDT11 yielded the following age intervals for three older earthquakes, based on the dating of detrital charcoal samples: 666 - 430 BC, 817- 636 BC and 2,353 - 990 BC. Age of the oldest earthquake is constrained by the age of a sample from a bioturbated zone which is faulted and the age of an organic sample from the oldest stratigraphic unit that capped the earthquake evidence. We therefore speculate the age of this earthquake was closer to 990 BC and not the 2,353 BC. Based on this assumption, data from trench BDT 11 indicate that three of the older earthquakes that ruptured the Carrizo Plain are separated roughly by >200 years. If true, recurrence intervals between large surface rupturing earthquakes along the southern SAF in the Carrizo Plain vary through time, as proposed by Grant and Sieh (1994).

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1.0 INTRODUCTION

The Carrizo Plain (Figure 1) has been one of the most productive sections of the San Andreas fault for paleoseismic research, yielding multiple slip rates from different time intervals at Wallace Creek (Sieh and Jahns, 1984) and Van Matre Ranch (Noriega et al., 2006) in agreement with geodetic measurements (Schmalzle, 2006); measurements of slip for several ruptures (Zielke et al., 2010; Grant Ludwig et al., 2010; Liu et al, 2004 and 2006; Grant and Sieh, 1993; Grant and Donnellan, 1994); and dates of surface ruptures at the Bidart Fan (Akciz et al., 2009, 2010; Grant and Sieh, 1994).

Results from our field work since 2005 and new radiocarbon dates from archival samples collected for Grant's 1993 dissertation reveal evidence of six ruptures between 1345 and 1857 AD. (Akciz et al.,2009; 2010). This yields a short recurrence time (approx 100 years or less) for ruptures of the San Andreas fault, and motivates re-evaluation of recurrence models such as the characteristic earthquake model (Schwartz and Coppersmith, 1984). The most recent rupture occurred in 1857, suggesting that the SAF in the Carrizo Plain has a high probability of rupture in the next few decades. Additional research is needed to find out if the short recurrence time holds for a longer time interval (i.e. prior to 1300 AD) or if the model of clustered earthquakes proposed by Grant and Sieh (1994) still holds for the Carrizo. It is important to determine the variability in time between ruptures to constrain uncertainty in probabilistic calculations of rupture potential.

In an effort to glimpse the older history of the earthquakes that ruptured the Carrizo section of the SAF, we investigated an older section of deposits exposed in the western 1/3 of the trenches we have already opened within the Bidart Fan (Figure 1). Following is the summary of the paleoseismic and radiocarbon dating results of our investigation.

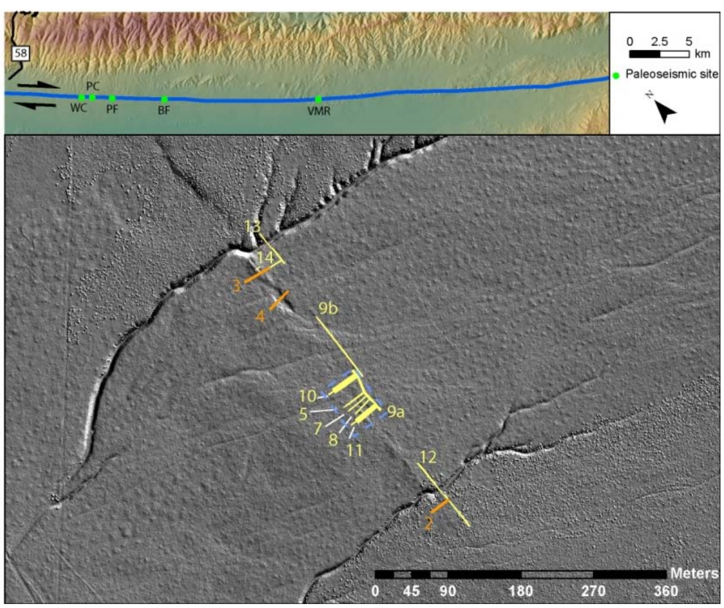

Figure 1. Locations of trenches at the Bidart Fan paleoseismic site along the Carrizo section of the southern SAF. Orange trenches (2-4) were excavated and published by Grant and Sieh (1994) and Akciz et al. (2009; 2010). Yellow trenches (5, 7-14) were excavated between 2005 and 2008. Trench BDT4 revealed a longer record of earthquakes than trench BDT3, as the structural push-up uplifted a deeper stratigraphic section Excavations at the blue boxed area exposed a similar, but buried sag pond-push up pair (See figure 2). Paleoseismic site acronyms are: WC = Wallace Creek, PC = Phelan Creeks, PF = Phealn Fan, BF = Bidart Fan, VMR = Van Matre Ranch

2.0 PALEOSEISMIC DATA

The most recent seven earthquakes that ruptured the Carrizo Plain section of the SAF are summarized by Akciz et al. (2010). An observation common to almost all of the fault-parallel trenches we have opened at the Bidart Fan site is that stratigraphic units exposed west of the western-most main fault splay ~ 2 m below the surface are different from the stratigraphic units found within and east of the main fault zone, indicating that they have been brought to their current location from a different location along the SAF. Radiocarbon ages of detrital charcoal samples collected from various stratigraphic units within these allochthonous units are consistently older than the in-situ stratigraphic units.

While many of our trenches were not deep enough to see the earthquake evidence preserved within these allochtonous units, trenches BDT10 and BDT11 were deep enough to expose some of these older earthquakes. Trench BDT10 was bioturbated extensively and no clear earthquake evidences were deduced convincingly. We have therefore concentrated our efforts at BDT11.
(Figure 2).

The oldest earthquake (Eold3) is observed at the bottom of BDT11 (and others) where a series of fractures within the lowermost bioturbated zone terminate upwards by the oldest preserved stratigraphic unit (unit 1230), which is a fine sand unit with silty sand laminations. Since the terminations are within a bioturbated zone with no internal structure, no additional evidence besides upward terminations is observed.

Earthquake Eold 2 occurred following the deposition of unit 1220 (an upward fining coarse sand to sand) and unit 1210 (laminated silt). This earthquake has caused apparent vertical displacements, unit thickness changes across the ruptured fault surfaces. A clast supported gravel unit with sandy interbeds has capped the event horizon, filling the depressions created by this earthquake.

Series of coarse clastics, consisting of matrix supported gravel (unit 1150), clast supported gravel (unit 1140), sand (unit 1130), clay (unit 1120), sand (unit 110) and upward fining coarse sand to sand (unit 1100) were deposited until the next earthquake, Eold1, occurred.

Evidence for Eold1 is best observed on the northwest wall of the trench between 22 and 23 m grids. Units 1100 and older are displaced, and covered by a laminated silt unit (unit 1060). The only evidence on the southeast wall is an upward terminating fault, which does not seem to affect any of the stratigraphic layers.

After the deposition of unit 1060, another series of coarse clastics, consisting mostly of coarse sand and gravel units have deposited. All these units have been deformed by a series of faults, however, all of these faults upward terminate within another bioturbated zone. A fissure terminates below the lower boundary of this upper bioturbated zone, but it affects and terminates different stratigraphic layers on either side of the trench wall. No additional cuts have been made to expose the full 3D geometry of this fissure. Therefore, for the time being, evidence is not used to propose an earthquake.

3.0 RADIOCARBON DATA

A distinct advantage of the Bidart Fan paleoseismic site compared to other sites along the SAF in the Carrizo Plain is the abundance of organic material found in the trenches. Trench BDT11 was not an exception, however most samples collected from within this older section were very small. Many of the samples collected from critical stratigraphic units dissolved during the Acid-base-acid wash of the pretreatment process.

Locations of all samples successfully dated are shown with red stars in Figure 2. The sample numbers (i.e. 144) next to the star correspond to the sample name (i.e. 07BDT11-144) in Table 1.

Table 1. Radiocarbon analysis results.

UCIAMS #	**Sample name**	**fraction Modern**	**±**	**$D^{14}C$ (‰)**	**±**	**^{14}C age (BP)**	**±**
79778	07-bdt11-129 .025mgC	0.7212	0.0065	-278.8	6.5	2630	80
79774	07-bdt11-135 .015mgC	0.7095	0.0094	-290.5	9.4	2760	110
79775	07-bdt11-136	0.7279	0.0012	-272.1	1.2	2550	15
79779	07-bdt11-137	0.7328	0.0013	-267.2	1.3	2500	15
41080	07BDT11-141	0.7176	0.0025	-282.4	2.5	2665	30
79776	07-bdt11-142 .015mgC	0.7408	0.0099	-259.2	9.9	2410	110
41081	07BDT11-144	0.6151	0.0013	-384.9	1.3	3905	20
41082	07BDT11-145	0.7048	0.0013	-295.2	1.3	2810	20
79780	07-bdt11-147	0.7336	0.0015	-266.4	1.5	2490	20
41090	07BDT11-180	0.9150	0.0017	-85.0	1.7	715	15

Radiocarbon concentrations are given as fractions of the Modern standard, $D^{14}C$, and conventional radiocarbon age, following the conventions of Stuiver and Polach (Radiocarbon, v. 19, p.355, 1977).

Sample preparation backgrounds have been subtracted, based on measurements of ^{14}C-free wood.

All results have been corrected for isotopic fractionation according to the conventions of Stuiver and Polach (1977), with $d^{13}C$ values measured on prepared graphite using the AMS spectrometer. These can differ from $d^{13}C$ of the original material, if fractionation ocurred during sample graphitization or the AMS measurement, and are not shown.

The large uncertainties for some of these results are due to the very small sample sizes

We used 10 charcoal samples to constrain the ages of the three old earthquakes (Eold1, Eold2 and Eold3) that ruptured the southern San Andreas Fault in the Carrizo Plain. The radiocarbon ages were calibrated to calendar ages using OxCal software (Ramsey, 2005). The OxCal-modeled 95 percentile ranges (Figure 3) accounting for stratigraphic constraints for the events and the intervening layers of these three old earthquakes are:

Eold1 = 666 - 430 BC

Eold2 = 817 - 636 BC

Eold3 = 2353 - 990 BC

Of the three earthquakes, Eold3 is least well constrained, as we had to rely on the age of a sample from the lower bioturbated zone. Ages of samples 135 and 145 (from unit 1230) are likely much closer to the age of Eold3.

4.0 DISCUSSION

There are several limitations to this data, two of which are: (1) Even though the sedimentation within this allocthonous unit seems to be complete, it is not possible to know whether it represents an entire width of a fault zone from that period. In other words, we don't know if the evidences of some other earthquakes within the same depositional period have occurred east of the allochtonous section or not. It is probably safe to assume that these were some of the larger earthquakes which deformed a broad zone. (2) Even though many charcoal samples were collected, they are all detrital and many were too small to date or process in the lab, limiting the accurate age determination of stratigraphic units immensely.

Given these limitations, our data suggest that three surface rupturing earthquakes have occurred in the area between 990 B.C. and 430 B.C., indicating a recurrence interval of ~>200 years between these earthquakes in that time period. This is more than 100 years longer than the recurrence intervals observed within the younger, autochthonous section. Although the spatial and temporal correlations between the younger stratigraphic section of the Bidart Fan and this older section is impossible to make, available data suggest that recurrence intervals along the Carrizo section of the SAF might have varied through time.

5.0 CONCLUSIONS

New earthquake evidence preserved at an older (>1000 yrs) stratigraphic section within the Bidart Fan area in the Carrizo Plain indicate that three surface rupturing earthquakes have occurred in the area between 990 B.C. and 430 B.C.. This suggest a recurrence interval of ~200 yrs. during that time period, compared to <100 years for the time period between 1345 A.D. and 1857 A.D. With such few data points, it is difficult to determine whether recent, shorter recurrence intervals represent a cluster of earthquakes, or if the Carrizo section experiences periods of abnormally long quiescence, perhaps similar to the current behavior of the very southern SAF which has not experienced a large earthquake for over 300 years.

While this was a first attempt to determine the age of older earthquakes that ruptured the southern SAF in the Carrizo Plain, additional trench exposures, possibly from deeper trenches are required to confirm these findings and draw conclusions.

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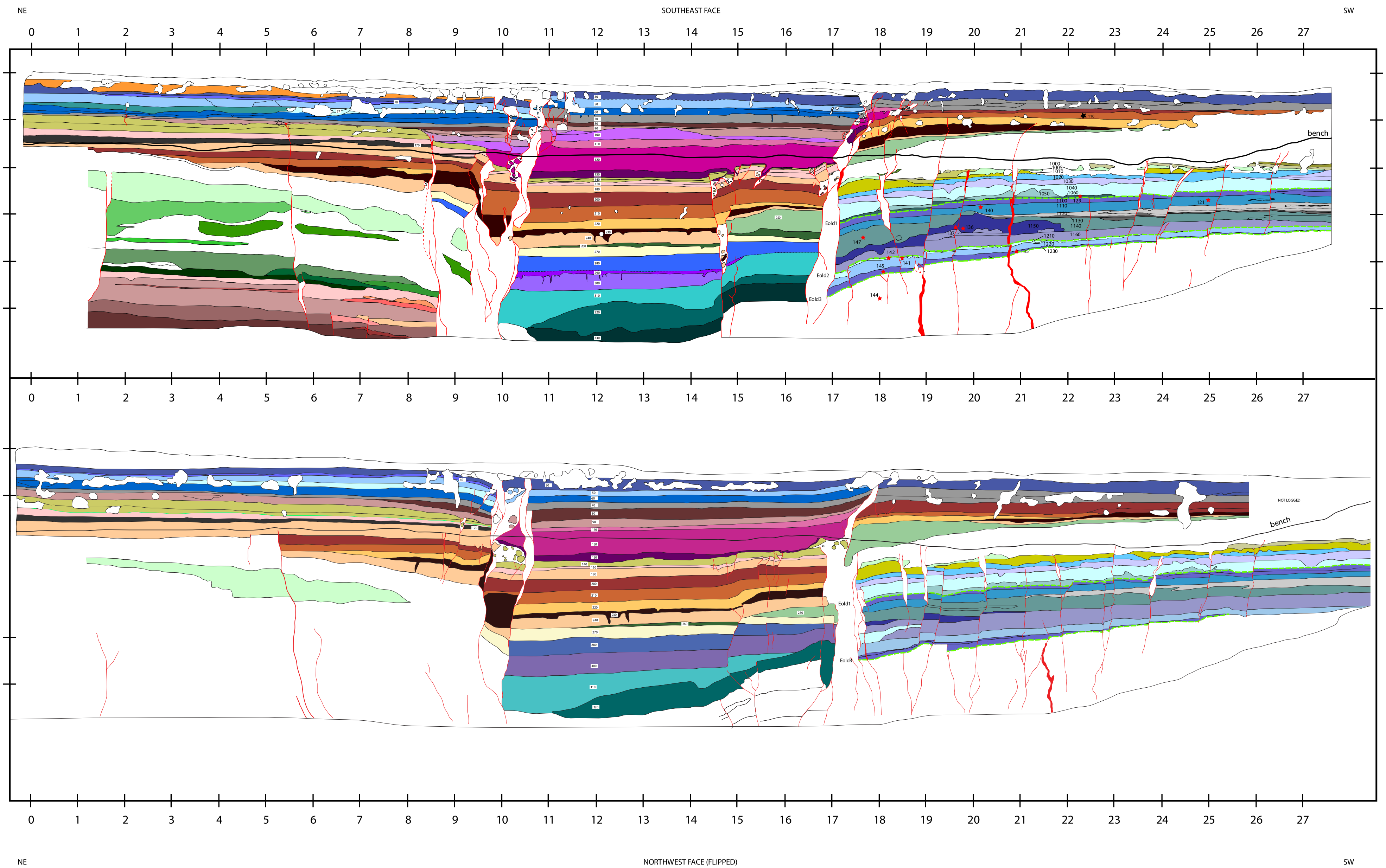
7.0 Bibliography of all publications resulting from this award

At the date of report submission, there are no publications from this work. Future publication is expected.

FIGURE 2 - BDT11 TRENCH LOGS



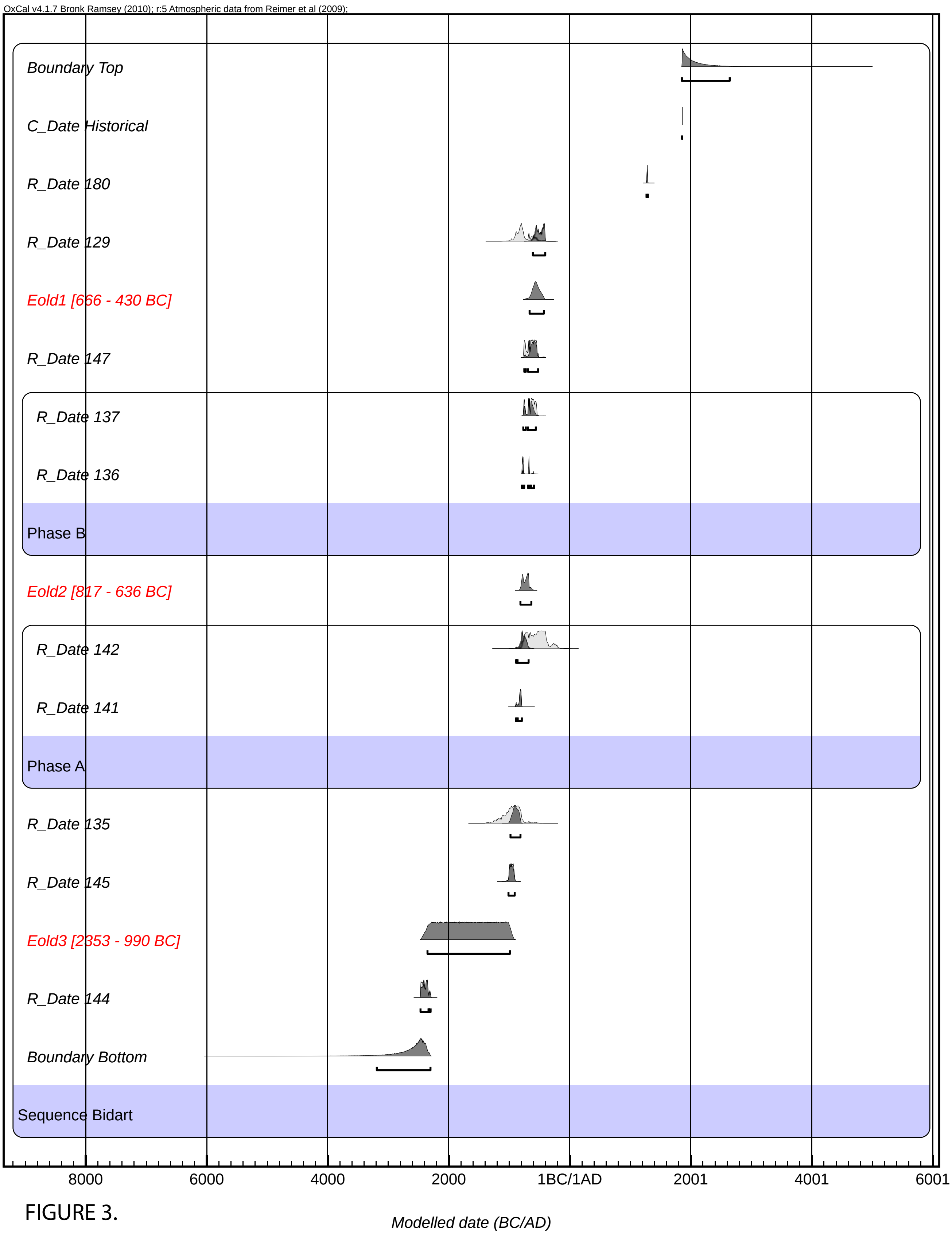

OxCal v4.1.7 Bronk Ramsey (2010); r:5 Atmospheric data from Reimer et al (2009);
Boundary Top
C_Date Historical
R_Date 180
R_Date 129
Eold1 [666 - 430 BC]
R_Date 147
R_Date 137
R_Date 136
Phase B
Eold2 [817 - 636 BC]
R_Date 142
R_Date 141
Phase A
R_Date 135
R_Date 145
Eold3 [2353 - 990 BC]
R_Date 144
Boundary Bottom
Sequence Bidart
8000
6000
4000
2000
1BC/1AD
2001
4001
6001
Modelled date (BC/AD)

FIGURE 3.