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Reply to a comment by Carol S. Prentice, Paul Mann, and Luis R. Peña on: "Historical perspective on seismic hazard to Hispaniola and the northeast Caribbean region" by U. ten Brink et al. (2011)

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[1] The works of *Prentice et al*. [1993; 2003] (henceforth, P1993 and P2003, respectively) and *ten Brink et al*., [2011] (henceforth, TB2011) both characterize the Septentrional Fault (SF) in northern Hispaniola as posing significant seismic hazard to much of the Dominican Republic and Haiti. In particular, TB2011 present an earthquake recurrence model with a ~300 yr-long recurrence interval of M7 1/2 earthquakes on the SF with the last event in 1842. (Prentice et al.'s (Comment) misinterpreted TB2011's Figure 7: TB2011 did not infer rupture of the SF across the entire island of Hispaniola in CE 1200, 1542, or 1842.) P2003 present a different model, wherein the last large SF earthquake occurred more than 800 years ago, and the accumulated strain is sufficient to generate ~10 m of slip in the next earthquake. We note that in their comment, Prentice et al. qualify their P1993 and P2003 interpretation, by saying that "no large earthquake is associated with surface rupture along the SF east of Santiago." Prentice et al. (Comment) offer no criticism of the methodology used by TB2011, except to say that it cannot link a specific fault with a particular earthquake. They challenge our interpretation because it is inconsistent with their interpretation of the paleoseismic data published in P1993 and P2003. While paleoseismic data provide unique on-fault rupture histories, their interpretation is also uncertain. P1993, P2003, and Prentice et al. (Comment) do not discuss the uncertainties in their interpretations of the paleoseismic data. Our reply, therefore, will highlight some of the uncertainties. We contend that P2003's interpretation of the paleoseismic and TB2011's interpretation of the historical data are both plausible, but each has uncertainties. The relative uncertainty and plausibility of the two interpretations need to be evaluated objectively, because the different recurrence models will affect the seismic hazard analyses for these countries, and focus differently the ongoing seismic risk mitigation efforts throughout Hispaniola.

[2] The preservation of paleoseismic evidence depends on the local stratigraphy and fault structure. There may be gaps (unconformities) in the depositional record and contamination by bioturbation of the soil. Furthermore, the near-surface expression of faults can be complex (e.g., flower structures), and repeated ruptures at depth commonly, but not always, occur on the same near-surface strand of fault. Trenching may not always capture the entire width of faulting. Moreover, the dating of paleoseismic events has inherent uncertainties and their interpretations are not unique. The well-known history of paleoseismic research on the San Andreas Fault northeast of Los Angeles, illustrates the uncertainty in the interpretation of paleoseismic data. Although *Sieh's* [1978] initial interpretation at Pallett Creek was widely accepted, he revised his interpretation and dates in 1983 [*Sieh*, 1984], and again in 1989 [*Sieh et al*., 1989]. The nearby Wrightwood trenches then put a different interpretation to the sequence of pre-historic San Andreas fault events [*Scharer et al*., 2010], and now *Scharer et al*., 2011 have again revised the interpretation of the rupture history on this fault segment. Paleoseismic interpretations, even those in nearly ideal circumstances, are never certain.

[3] P1993 and P2003 trenched in four locales (from west to east)—Rio Licey, Rio Juan Lopez, Rio Cenovi and Rio Tenares. All four sites are located 8–30 km east of Santiago, DR, and say little about SF rupture west of Santiago. We briefly discuss the paleoseismic data from the Rio Licey, Rio Cenovi and Rio Tenares sites.

[4] *Rio Licey Trench 2*. P2003's figure 10 shows unit 10 faulted in two places by fault F3. Unit 10 is dated as young as 1930 AD. There is no compelling reason to assume that this faulting did not occur during the historic 1562 or 1842 earthquakes. Ambiguous upward termination extending into unit 110 suggests the possibility of younger faulting. Prentice et al. (Comment) (Lines 67–69) however discard the youngest ages, stating that "unit 10/110 is not depositional but is a soil that has been actively forming for at least 2000 years, and that young material is constantly being bioturbated into the unit as the soil evolves". It remains unclear which dated samples in the bioturbated units represent the depositional age. Moreover, because the top of the underlying unit is dated at 2890–3360 BP, it is unclear how much stratigraphy is missing in the section.

[5] *Rio Licey Trench 3*.The deformation and dating suggest an incomplete stratigraphic record. Stratigraphy shown in P2003's Figure 5 indicates a fold eroded at its crest and a single folding event, not growth through time from repeated

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ruptures. It is unclear how this evidence is used to determine with certainty that the last earthquake ruptured 800 years ago and that no erosion took place either before or after that event. In particular, there is no compelling evidence to exclude faulting during the 1562 earthquake.

[6] *Rio Cenovi West*. Reworking of detrital charcoal clearly exists, evidenced by the spread in ages (see P1993's Figure 4), but the degree of reworked "old" charcoal is not described. The most common and reasonable interpretation of the radiocarbon dates in trenches is that the youngest samples represent the age of the sediment layer. An abundance of old dates in layers may simply indicate significant reworking of detrital charcoal. Averaging old samples may not improve the accuracy of dating layers, and may introduce errors. P1993 use the trench stratigraphy to discuss the possibility that layer 40 was deformed during the 1564 (1562 according to TB2011) earthquake. P1993 dismiss, without discussion, the sample in layer 40 dated 1519–1955. If this sample is interpreted as the most representative depositional age, a common practice in paleoseismology, then the ages of the overlying older samples should not be included [e.g., *Lienkaemper et al*., 2002].

[7] *Rio Tenares*. Unit 10 is interpreted as a post-earthquake soil with dates ranging between 1320–1950 AD (P2003's Figure 12). P2003's Figures 11 and 12, however, show this layer to be faulted. The underlying layer, Unit 40, is dated at 3480–4530 BP, suggesting a gap in the stratigraphy. Faults on the left side of the figure terminate at the top of this layer. P2003's Figure 11 shows that faults F1 and F2 cut into the soil (Unit 10) and the overlying surface may be deformed, suggesting younger faulting. This is consistent with the occurrence of at least one of the historical events on the SF.

[8] Prentice et al. (Comment) introduce several ancillary issues. First, they use the TB2011 analysis of the 1946 earthquake to demonstrate the uncertainty in locations obtained from intensity data. We have acknowledged that intensity data are not sufficient to resolve the causative fault in complex tectonic regions with multiple seismically active, closely spaced faults. The interpretation of the 1946 event is, however, more nuanced than suggested by Prentice et al. (Comment). The intensity center, which corresponds more to the moment centroid than to the epicenter [*Bakun et al*., 2012], is located about 30 km north of the SF, near Nagua, Dominican Republic, where a devastating tsunami associated with the earthquake occurred. We note that the spatial pattern of damage reports from the 1946 earthquake is very different from the smaller 1842 earthquake (compare TB2011 Figures 3b and 4c). That is, if the 1946 event is a representative large Puerto Rico Trench earthquake, then the 1842 earthquake did not occur on the Puerto Rico Trench.

[9] Second, Prentice et al. (Comment), misinterpret TB2011 Figure 7 as showing rupture of the SF across the entire island of Hispaniola in ~1200, 1542, and 1842. The red lines in TB2011 Figure 7 mark our estimated recurrence of stress release along different tectonic elements in the NE Caribbean, not a rupture of a single earthquake. For example, convergence along the Puerto Rico Trench north of Hispaniola is marked as a single line on Figure 7, but has been taken by many earthquakes. Arc-type earthquakes occur in the northern Lesser Antilles every 75–100 years, but they do not rupture along a fault stretching from Guadeloupe to the Virgin Islands (red line in Figure 7). TB2011 noted in their discussion of the 1842 earthquake, a distance of 290 km between the two most severe damage reports (intensity IX), Mole St. Nicolas in Haiti and Santiago in the Dominican Republic—the 1842 rupture was probably of that dimension, about 300 kilometers.

[10] Third, Prentice et al. (Comment) provided examples of historical earthquakes with large slip to counter TB2011's suggestion that the expected slip on the Septentrional Fault after than 800–1000 years without rupture would be much higher than the average slip in strike-slip faults from global survey [*Wesnousky*, 2008]. However, only slip during the Mongolia 1905 and the Haiyuan 1920 earthquakes approached that inferred from P2003's paleoseismic interpretation. The Mongolia 1905 and the Haiyuan 1920 earthquakes were the largest (M8.4–8.5) and second largest (M8.3) continental strike-slip fault ruptures ever recorded [*Engdahl and Villaseñor*, 2002]. Neither occurred within an arc environment, over a subduction zone. Therefore, the only strike-slip earthquakes with slip approaching that inferred for the next SF event by P2003 do not appear to be good tectonic analogues for earthquakes on the SF.

[11] Finally, Prentice et al. (Comment) note that large earthquakes produce natural offsets along the fault trace. Offset stream gullies are prominent features along the San Andreas Fault in arid southern California. Comparable offset gullies on the San Andreas Fault are rare in the wetter San Francisco Bay region. In fact, Lawson (1908) shows no offset of stream gullies or other natural features during the 1906 earthquake. Environmental or climatic conditions apparently control the visibility of slip offsets. In particular, natural offsets on faults with infrequent larger earthquakes may be rare in wet climates.

[12] In summary, paleoseismic investigations are an important tool in the study of earthquake recurrence, but their interpretations are subject to uncertainties, which should be acknowledged and if possible, quantified. The interpretations of the paleoseismic and historical data for the SF are both plausible, but each is uncertain. The relative uncertainty and plausibility of the two interpretations need to be evaluated objectively.

[13] **Acknowledgments.** We thank Prentice et al. (Comment) for pointing out an error in TB2011's FigURE 4c. The locations of the intensity center and the damage reports were displaced northward during final figure production. The correct locations can be found in Bakun et al., 2012, Figure 4.

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