Chapter 5

Persistent segmentation at the boundary of the 2004 and 2005 Sunda megathrust ruptures

1. Introduction

Simeulue island, off the west coast of northern Sumatra, straddles the boundary of the 2004 (M_W 9.2) and 2005 (M_W 8.6) Sunda megathrust ruptures. The 26 December 2004 earthquake nucleated north of the northern tip of Simeulue island and propagated bilaterally into the 100-km-long island. Three months later, the 28 March 2005 event began southeast of Simeulue and also propagated bilaterally into the island. Both ruptures were arrested under central Simeulue, and only small amounts of slip occurred there: cumulative uplift was 1.5 m at both the northwestern and southeastern tips of the island but diminished toward the island's center, where uplift was 0.5 m or less [*Briggs et al.*, 2006] (Fig. S1). Hence, although the 2004 and 2005 uplifts overlapped, there was an uplift deficit on central Simeulue. Contours of 2004–2005 cumulative uplift on Simeulue resemble a saddle, which led *Briggs et al.* [2006] to refer to central Simeulue as the Simeulue Saddle.

The question arises as to whether the 2004–2005 rupture boundary is a transient or persistent feature. Elsewhere along strike on the Sunda megathrust, studies have documented evidence for both: the Batu Islands patch at the southern end of the 2005 rupture has repeatedly behaved as a barrier to rupture [*Natawidjaja et al.*, 2006; *Sieh*, 2007], whereas along the Mentawai patch farther south, the boundaries of the 2007 sequence appear to be transient features that do not coincide with rupture boundaries during the previous sequence [*Konca et al.*, 2008].

In this study, we present observations and analysis from the Bunon site on southern central Simeulue, above the northern limit of the March 2005 rupture. In conjunction with our results from northern Simeulue sites above the southern end of the 2004 rupture (see previous chapters), our findings provide evidence that the 2004–2005 rupture boundary—the "Simeulue Saddle" of Briggs et al.—has been a persistent barrier to rupture in past megathrust earthquakes.

2. Description of the Bunon (BUN) Site

The Bunon site sits along the southwest coast of Simeulue, ~10 km south of the center of the island, near Bunon village (Fig. S1). As we will discuss, the site was uplifted 60–70 cm in the 2005 earthquake but experienced little vertical change in 2004. Thus, at least for the 2004–2005 sequence, Bunon has acted as part of the southern Simeulue patch and has been independent of northern Simeulue. In addition, Bunon rose 15–20 cm in the M_W 7.2 earthquake of 2 November 2002, which had a locus of deformation centered ~15 km to the west-northwest in central Simeulue.

The Bunon site consists of two subsites: BUN-A is the primary site, and BUN-B is a subsidiary site ~ 1.8 km to the west-northwest. Both subsites have abundant modern heads (i.e., coral heads that were living at the time of the 2004 and 2005 earthquakes), although none of the modern heads had records of relative sea level extending back more than ~25 years. In addition, the BUN-A site has multiple generations of large fossil microatolls (i.e., microatolls that died long before 2004, possibly in prior uplift events) from the 9th–11th and 14th–17th centuries AD. A total of three modern and seven fossil corals were sampled from the BUN sites; all but one modern head originated from site BUN-A (Table S1).

Of the sampled fossil microatolls from Bunon, six are from overlapping generations that combine to provide a continuous history of relative sea level at the site from the early 14th to the early 17th century. This time period encompasses the 14th–15th century continuous record from sites on northern Simeulue (see earlier chapters), allowing us to compare the behavior of the two sections of the megathrust for the duration of the overlap. The seventh fossil head from Bunon provides a discrete, older record that ends in the early 11th century. This, too, overlaps with observations on northern Simeulue, providing another window to examine the simultaneous behavior of the two portions of the fault. The joint analysis of the Bunon and northern Simeulue records reveals strikingly disparate relative sea level histories for the two parts of the island:

during those parts of the record that overlap, all ruptures observed as significant uplifts at one end of the island had little effect at the other end.

The two modern microatolls and the six 14th–17th century fossil heads from BUN-A will be described in detail in this chapter. The older fossil head will be discussed briefly, but a detailed description will be deferred to a subsequent publication. In addition, the modern head from BUN-B confirms certain ambiguous interpretations on the modern heads at BUN-A but does not otherwise add unique information; discussion of this head will also be deferred to a subsequent publication.

3. Changes since 2004 at the Bunon (BUN) Sites

Field observations by K. Sieh in mid-January 2005, observations by R. Briggs of freshly uplifted microatolls in early June 2005, and conversations with local villagers and fishermen in 2005 and 2006 all suggest there was little if any vertical change at Bunon in the 2004 earthquake. Perhaps as much as a decimeter or two of coseismic subsidence in December 2004 might have gone unrecognized, but our own coral microatoll cross-sections (e.g., Figs. S2–S3) preclude uplift in late 2004.

Briggs et al. [2006] reported 47 ± 16 cm (2σ) of uplift in 2005 at their site RDD05-L, which corresponds to our site BUN-B. This value was determined by comparing the pre-uplift HLS on several consistent *Porites* microatolls with ELW, but (as discussed in previous chapters) the calculation did not consider SLAs. Redoing the calculation with the original field measurements, an updated tide model, documented SLAs, the revised correction for the difference between HLS and ELW, and an appropriate inverted barometer correction results in a higher estimate of 60 ± 9 cm. This value represents the net vertical change that occurred between late 2004 and 2 June 2005.

In June 2006, we measured the net uplift at site BUN-A by surveying the water level relative to pre-uplift HLS and tying the water level to ELW. The net uplift as of June 2006 at that more southeasterly site was 68 ± 9 cm. The slightly larger value at BUN-A in June 2006 than at BUN-B in June 2005 was probably mostly or entirely due to the difference in location, although we cannot preclude additional minor postseismic uplift between June 2005 and June 2006; in any case, the two values are statistically indistinguishable.

In July 2007, we re-measured the net uplift at site BUN-A in a similar manner and obtained a result of 78 ± 9 cm. The difference between this value and that measured in 2006 suggests a small amount of uplift (10 ± 13 cm) between June 2006 and July 2007, although we note that this difference is not statistically significant.

In January 2009, nearly a year after the 20 February 2008 M_W 7.3 Simeulue earthquake, we independently re-measured the net uplift (since 2004) at both BUN-A and BUN-B, again by comparing the pre-uplift HLS with ELW at both sites. At BUN-A, we estimated the net uplift to be 75 ± 9 cm, indistinguishable from the July 2007 estimate; this suggests there was little if any change there during the 2008 earthquake. At BUN-B, we estimated the net uplift to be 66 ± 9 cm, consistent with the spatial trend of decreasing uplift to the northwest, and slightly larger than but statistically indistinguishable from the uplift measured there in June 2005.

4. Modern Paleogeodetic Record at BUN-A

At the BUN-A site, the BUN-1 *Porites* microatoll was selected for slabbing because of its nearly perfect radial symmetry and pristine condition, and the BUN-2 *Porites* microatoll was selected because it appeared to have a longer record. As with other heads in this study, we followed the methodology for slab extraction and analysis described in earlier chapters. Figures S2 and S3 show the interpreted x-ray mosaics of slabs BUN-1 and BUN-2, respectively.

BUN-1 began growing in the early 1980s and first recorded an HLS "hit" in late 1997. BUN-2 probably began growing in the 1960s and recorded its first "hit" in late 1982. BUN-2 recorded additional HLS diedowns in late 1986, late 1989, and late 1991. Both heads recorded the late 1997 diedown, as well as subsequent diedowns in late 2002, late 2003, and ultimately early 2005, when the diedown was sufficient that the entirety of both corals died. Except for the diedowns in late 1989, late 2002, and early 2005, all of these are seen repeatedly on northern Simeulue. The 2002 and 2005 diedowns are attributed to tectonic uplifts that were spatially restricted to areas south of northern Simeulue. At both BUN-A and BUN-B, the 2002 diedown was in the range 15–20 cm. The cause of the 1989 diedown on BUN-2 is unclear, but it was very minor, affecting only the uppermost few millimeters of the head.

We can also use the coral microatoll cross-sections to constrain interseismic subsidence rates. A time series of HLG and HLS is plotted on Figures S2 and S3 for BUN-1 and BUN-2, respectively. As outlined in previous chapters, we attempt a linear fit to the data, using the head's HLG in the years prior to each diedown, and omitting data prior to the head's initial diedown. For all sites, we treat post-1997 elevations with caution, because it is not always clear whether heads had grown up to near their theoretical HLS prior to tectonic uplift; for sites in central Simeulue, we explicitly exclude data following the November 2002 earthquake, because we know those elevations are affected by coseismic uplift, and we are interested in the longer-term interseismic signal averaged over the years to decades prior to that uplift.

The linear least squares fit for BUN-2 suggests an average interseismic submergence rate of 5.6 mm/yr over the period 1986–2002 (Fig. S3). Considering only 1986–1995, the average submergence rate is 7.3 mm/yr (not shown). Correcting for eustatic sea level rise as discussed in previous chapters, these correspond to tectonic subsidence rates of 3.6 and 5.3 mm/yr, respectively, for 1986–2002 and 1986–1995. It is noteworthy that these rates are lower than at Lhok Dalam and Ujung Salang (see sites LDL-A and USL-A, Chapter 3, figure 19), sites approximately equidistant from the trench along the southwest coast of northern Simeulue. Unfortunately, the limitations on this method preclude a fit to the data from BUN-1, which has only a single usable datum prior to the 2002 uplift.

5. Fossil Paleogeodetic Record at BUN-A

Not including the oldest sampled microatoll at the site (BUN-9) and several severely eroded microatolls that may be even older, most of the fossil microatolls at BUN-A can be divided into two populations based on their morphologies. One sizable population consists of large cowboy hat or sombrero-shaped microatolls (e.g., Figs. S4–S7). The centers of these heads are either hemispheres or cup-shaped microatolls in their own right, with upper surfaces rising toward the outer rims of the inner heads. As these heads grew, their HLS suddenly dropped to lower levels: the inner heads are surrounded by much lower brims, which themselves rise very gradually (with gradients lower than on the inner parts of these heads) toward their outer perimeters. For clarity, we will refer to the initial large diedown as the inner diedown, and the final death of these sombrero-shaped heads as the outer diedown. The second population of fossil microatolls at BUN-A has more conventional cup-shaped morphologies, except for an exceptionally pronounced upward step in their outward growth (e.g., Figs. S8–S9), suggesting a burst of rapid interseismic subsidence or sea level rise amidst a longer period of steady, slower relative sea level rise.

5.1. 14th–15th century record at BUN-A

5.1.1. Sampled heads

In the field, we decided to take slabs from three of the sombrero-shaped microatolls. We chose to sample BUN-7 (Fig. S4) because it had a beautifully preserved inner head with stairstepping concentric rings that record a century of steady relative sea level rise. The uppermost part of the crown of this inner head had sustained significant erosion, and in places it appeared as though parts of the upper crown had been chiseled off prior to our visit, but this head was still in better condition than most in the population. The main problem with BUN-7 was that its outer brim had broken off and settled relative to the inner head. It was not clear in the field how the broken-off outer brim fit back onto the inner part of the head, and we feared it would have been impossible to confidently reconstruct the elevation of points on the outer brim.

Fortunately, the outer brim of a nearby head with a similar morphology had remained intact. The inner part of this nearby head (BUN-8) and its uppermost crown were much more extensively eroded than the corresponding portions of BUN-7, but the similarity of the two heads suggested that the outer brim of head BUN-8 could serve as a proxy for the broken-off outer brim of BUN-7. The slab of BUN-7 is an entire radius through the inner head of microatoll BUN-7 (including what remains of its uppermost crown), and the slab of BUN-8 (Fig. S5) is a radius through the outer edge of its uppermost crown and the low brim outboard of its upper crown. Even prior to confirmation by U-Th dating analyses, we anticipated that these two slabs could be combined to form a single continuous record of relative sea level.

The third sombrero microatoll (BUN-6; Fig. S6) had a hemispherical center and was much more eroded than BUN-7 or BUN-8, but its outer brim was considerably wider (and taller) than those of BUN-7, BUN-8, and most other heads in the population. The taller nature of the BUN-6 outer brim is consistent with a deeper substrate in that vicinity, and it could have allowed BUN-6 to survive a small diedown that completely killed shallower heads, including BUN-7 and BUN-8. This interpretation implied to us in the field that BUN-6 contains a part of the sea level record beyond that recorded by BUN-7 or BUN-8.

A fourth head, BUN-5 (Fig. S7), also belongs to the sombrero generation, although this association was not evident until revealed by U-Th dating analyses. BUN-5, which was mostly buried in the pre-2005 beach berm until we dug it out, captures the last few decades of growth of the inner, higher parts of the sombrero heads, just prior to the inner diedown. BUN-5 started growing decades (to nearly a century) after the more recognizable sombrero-shaped microatolls in the population, so its record is much more brief; furthermore, it was not tall enough to survive the inner diedown, so BUN-5 has no outer brim. BUN-5 is very well preserved, however, and its record spans the time period of the eroded crowns of BUN-7, BUN-8, and the other sombrero heads; BUN-5 thus adds critical data to that portion of the HLS record.

5.1.2. Dating results and preferred interpretation

One sample from BUN-5, two from BUN-6, three from BUN-7, and two from BUN-8 were dated by U-Th analysis (Tables S2–S3). Most of the dates agree and indicate these four heads span the 14th–15th centuries AD. The weighted-mean dates for the inner diedown (assuming it was a single diedown; see also Section 5.1.4) on the sombrero heads are late 1437 ± 23, early 1425 ± 11, and late 1434 ± 13, from BUN-5, BUN-7, and BUN-8, respectively (Table S4), which combine to yield an overall weighted average of AD 1430.4 ± 7.9. This date is indistinguishable from and may be correlative with the AD 1430 ± 3 minor diedown seen on northern Simeulue; we adopt AD 1430 as our preferred timing of the sombrero heads' inner diedown (again assuming it was a single diedown). Counting outward from the inferred 1430 diedown on BUN-8, the date of that head's outer preserved band is AD 1474.

Interpretation of the two dates from BUN-6 is less straightforward. The two dates are mutually exclusive, as they are only compatible when the error of each is simultaneously considered at 4σ (Table S3; Fig. S6). Indeed, the morphology of BUN-6 is incompatible with any of the other sombrero heads at the site if the date from BUN-6-A1 is valid. If the date obtained on BUN-6-A1 is thrown out and we instead rely on only BUN-6-B1, the apparent age of head BUN-6 makes much more sense: in that case, the inner diedown on BUN-6 would date to within a few years of AD 1430 (the date estimated from BUN-5, BUN-7, and BUN-8), well within the stated 2σ uncertainty of ±21 years on BUN-6-B1. Using the preferred date of AD 1430 for the inner diedown on BUN-6 and counting outward, we estimate the date of the outer preserved band on BUN-6 to be AD 1511.

As we had interpreted in the field, BUN-6 appears to contain a part of the sea level record beyond that recorded by BUN-7 or BUN-8. Possible explanations for this are (*a*) that the thin outer brims of BUN-7 and BUN-8 were killed entirely by a very small diedown shortly after AD 1474, but the taller nature of the BUN-6 outer brim, and the deeper substrate nearby, allowed BUN-6 to continue growing after this small diedown; or (*b*) that BUN-7 and BUN-8 originally had much wider brims, but the outermost parts of those brims subsequently broke off and were transported away. Unfortunately, because of extensive erosion of BUN-6, that head is not useful for distinguishing among these possible explanations. Indeed, we cannot preclude the possibility that BUN-6 is also missing many outer bands: as wide as the preserved outer brim is on BUN-6, it may have originally been much wider. The apparent outer diedown on BUN-6 might not signal an event at that time, especially given the lack of corroborating heads with morphologically similar outer perimeters.

Time series of relative sea level determined from the 14th–15th century microatolls are plotted individually on Figures S4–S7 and together on Figure S10a. From Figure S10a, it is evident how BUN-5 fills in the part of the BUN-7 record lost by erosion of its upper crown. Although BUN-7 provides an excellent record of relative sea level from AD 1311 to 1411, BUN-5 provides the best record from 1412 until shortly before the 1430 uplift.

5.1.3. ~1430 uplift (preferred interpretation)

To quantify the 1430 uplift (assuming it was a single event; see also Section 5.1.4), we measure down from the HLG on BUN-5 in the years before 1430 to the post-diedown HLS in 1430 on BUN-8. We estimate that uplift to be 82–86 cm (Fig. S10a). After the 1430 diedown, BUN-8 experienced unrestricted upward growth of at least 11 cm in ~11 years, suggesting the coseismic uplift was followed by a decimeter of postseismic subsidence.

5.1.4. Dating results and ~1430 uplift (alternative interpretation)

Although the observations at site BUN-A are for the most part consistent with the interpretation presented in Sections 5.1.2 and 5.1.3, the morphology of BUN-8 suggests an alternative interpretation: that there were two diedowns less than 10 years apart around 1430. The simpler interpretation—that there was a single diedown around that time—requires that 10 bands have been completely eroded from the upper part of BUN-8, as shown on Figure S5a. While such erosion is possible, it would be a little surprising, given the comparatively good preservation of the head's outer brim. Moreover, the upper part of the head appeared in the field to be radially symmetric, requiring any inward erosion to have been uniform from all directions and hence suggesting (by Occam's razor) that the total inward erosion was not substantial. These concerns lead us to consider an alternative (dual diedown) hypothesis.

In this alternative scenario, the majority of the diedown on BUN-8 would have occurred about 7–9 years prior to the band labeled "1430" on Figure S5a; following this first diedown, HLS would have been about 10–15 cm higher than after the second diedown (labeled "1430"). In this scenario, although the second diedown is the more obvious of the two on the slab, it would have been the smaller one. The slabs from BUN-7, BUN-5, and BUN-6 are not inconsistent with dual diedowns around 1430, but in that case BUN-7 and BUN-5 record only the first, and BUN-6 is sufficiently eroded that the two diedowns are indistinguishable.

In the alternative interpretation, the weighted-mean ages are calculated differently. The dates for the first (and larger) of the successive inner diedowns are still late 1437 ± 23 and early 1425 ± 11 from BUN-5 and BUN-7 (Table S4), but the appropriate date from BUN-8 is ~8 years earlier, or late 1426 ± 13; these combine to yield an overall weighted average of AD 1427.2 ± 8.0. The second (smaller) diedown would have occurred 8 ± 2 years later.

While this alternative hypothesis proposes two diedowns in rapid succession and the first diedown is so large that it must reflect uplift, the second diedown is not necessarily tectonic. If the alternative hypothesis is taken to be true, we still consider it equally plausible for (*a*) the first diedown to have been followed by a second uplift of 10–15 cm and then ~11 cm of postseismic subsidence, or (*b*) the first tectonic diedown to have been followed by a non-tectonic diedown similar to the 1997–98 IOD event. If two uplifts occurred around 1430, the uplift calculated in Section 5.1.3 (82–86 cm) represents the cumulative uplift in those events. From the morphology of BUN-8, we estimate the uplift in the first event to be roughly 70–75 cm, with 10–15 cm of uplift in the second. If in this scenario only the first diedown was tectonic, then only 70–75 cm of uplift occurred.

5.1.5. Maximum uplift at Bunon in 1394 and 1450

Two large uplift events on northern Simeulue dated to AD 1394 ± 2 and 1450 ± 3 do not show up as significant events at Bunon. A small diedown is seen on BUN-7 some time around 1394, but even if it corresponds to the northern Simeulue uplift, that diedown on BUN-7 was not more than ~4 cm. No diedown is evident around 1450 on BUN-8, although evidence for a small diedown (a few centimeters or less) could have been eroded away. Even if the alternative hypothesis discussed in Section 5.1.4 is correct, no large diedowns (of more than a few centimeters) appear on BUN-5, BUN-7, or BUN-8 that could date to around AD 1394 or 1450.

5.1.6. Interseismic submergence

We estimate the average interseismic submergence rate for AD 1311–1430 from BUN-7 and BUN-5 to be 5.5 mm/yr, although a closer examination of BUN-7 reveals the rate was faster than that average prior to 1319, slowed to ~2.2 mm/yr between 1319 and 1348, was interrupted by rapid submergence for an unknown duration at some time between 1348 and 1360, and ultimately settled to ~6.6 mm/yr from 1361 possibly until 1430 (Fig. S10a). We estimate the rate for 1441–1474 to be a much lower 0.3 mm/yr, based on BUN-8. Based on the limited evidence discussed in earlier chapters, we assume that eustatic sea level change was negligible in the millennium preceding the 20th century AD, which would imply that tectonic subsidence rates prior to the 20th century roughly equal the submergence rates determined from our fossil microatolls.

5.1.7. Settling of BUN-6

It is evident from Figure S10a that head BUN-6 has settled relative to coeval heads at the site, by as much as 10 cm. This is not surprising, as BUN-6 is farther out on the reef than any of the coeval heads (Fig. S1), and observations at other sites have suggested that the outer parts of the reef tend to be more susceptible to settling and slumping. If any of the settling of BUN-6 occurred during the recent earthquakes, it would imply that the modern heads at the site—all of which are located nearby (Fig. S1)—may have settled by several centimeters as well.

5.2. 16th–17th century record at BUN-A

5.2.1. Sampled heads

We collected two slabs from the population of cup-shaped fossil microatolls with a pronounced upward step. BUN-3 (Fig. S8) was the most well preserved of a cluster of similar tilted heads growing ~200 m northeast of the other slabbed heads at the site. BUN-4 (Fig. S9) grew apart from the main BUN-3 population and was mostly buried in the pre-2005 beach berm (along with BUN-5) when we found it. The morphology of BUN-4 was similar but not identical to that of BUN-3, so it was not obvious in the field that they belonged to the same generation.

5.2.2. Dating results and preferred interpretation

One sample was dated from each head (Tables S2–S3). The dates are close enough, and the records on each head are long enough and similar enough, that they must overlap. Indeed, starting with the diedown labeled "1511" on both BUN-3 and BUN-4 (Figs. S8–S9), both heads experienced additional diedowns 23, 26, 33, 43, and ~55 years later—and both heads experienced faster-than-average upward growth beginning ~26 years later—strongly suggesting those portions of the two heads are coeval. If that is the case, however, BUN-4 must be missing 36.5 outer bands that are preserved on BUN-3. That so many bands are missing from BUN-4 is surprising, considering that the head appears to be in good condition with minimal erosion, but we find the similarities in BUN-3 and BUN-4 to be compelling evidence that is difficult to refute.

Assuming BUN-3 is missing 2.0 ± 2.0 bands and BUN-4 is missing exactly 36.5 bands more (38.5 ± 2.0), the U-Th analyses for these heads yield dates of death of mid-1570 ± 42 and mid-1613 ± 38 for BUN-3 and BUN-4, respectively (Table S3); the weighted average of these two dates is early 1594 ± 28 (Table S4). If we were to use this date as the actual date of the event that killed BUN-3 and BUN-4, then the earliest diedown recorded on BUN-3, 106 years prior to its outer preserved edge, would have occurred in 1486 ± 28.

BUN-6 also bears on this matter. Comparing the records of BUN-3 and BUN-4 to that of BUN-6, with the assumption that BUN-6 is dated correctly, suggests that the earliest possible date of the initial diedown on BUN-3 is AD 1500. We assume 1500 as our preferred date for that initial diedown, which corresponds to a preferred date of 1605 for the outer preserved band on BUN-3. The estimated date of the diedown that killed BUN-3 and BUN-4 would then be AD 1607, but the true date of that final diedown could be later, if either (*a*) the date of the initial diedown is later than assumed, or (*b*) we are underestimating the number of missing bands.

5.2.3. Dating results: alternative interpretation

Unfortunately, the considerable erosion of BUN-6 and the problematic dates from that head make interpretation of its history challenging. If we discard all information from BUN-6 based on the contention that this information is less reliable, then the dates from BUN-3 and BUN-4 alone suggest those heads may be slightly older than indicated on Figure S10.

5.2.4. BUN-3: original elevation

BUN-3, and all the other heads within tens of meters, were clearly tilted and had settled relative to one another. By carefully surveying the most well preserved concentric ring of BUN-3, we were able to restore the head's original horizontality, but its original elevation was still unknown. Assuming BUN-4 was in place and that the HLS following each diedown was the same on the two heads (to within a small error), we determined the original elevation of BUN-3 by comparing the 1511, 1537, 1544, and 1554 post-diedown HLS on the two heads. The calculated original elevation of BUN-3 is reflected in the time series plots in Figures S8 and S10.

5.2.5. Interseismic submergence

The long-term (AD 1509–1604) average submergence (and subsidence) rate recorded by BUN-3 is 6.0 mm/yr. As suggested by the morphology of the head, however, this rate does not appear to be constant over time. The average rate was 5.8 mm/yr from 1509 to 1544, increased to 11.7 mm/yr from 1544 to at least 1555, was below the long-term average (but is poorly resolved) until ~ 1573, and then returned to 5.6 mm/yr from 1573 until at least 1604. Similarly, BUN-4 records an average rate of 5.9 mm/yr from 1508 to 1544, followed by an average rate of 10.1 mm/yr from 1544 until at least 1566. The faster submergence rate beginning around or just prior to 1544 probably reflects a period of faster interseismic subsidence, but we should not preclude an extended period (2-3 decades) of persistently higher-than-average sea levels, as the early and late parts of the HLS record on BUN-3 can essentially be fit by a single straight line. The cause of the exceptionally pronounced upward step in the morphology of the BUN-3 and BUN-4 microatolls was clearly not a sudden (effectively instantaneous) subsidence "event"; during the decades of rapid upward growth, both BUN-3 and BUN-4 repeatedly experienced HLS "hits," an indication that the corals' HLG was close to their theoretical HLS for most, if not all, of that time.

5.3. 9th–11th century record at BUN-A

In addition to the abundant fossil microatolls at the BUN-A site belonging to the 14th–17th century populations described above, a solitary 7-m diameter pancake-shaped microatoll was observed at the site (BUN-9; Figs. S1, S11). Four discontinuous slabs were cut from this head: BUN-9A through the outer edge, BUN-9B through the outer ring, BUN-9C through the second ring, and BUN-9D in the center. The number of bands between each slab can be estimated only based on the average thickness of bands in this head and the spacing between the slabs. Nonetheless, U-Th analyses provide a precise estimate for the age of the head's outer preserved band: AD 1017 ± 14 (Table S3). Incidentally, this is ~60 years after the estimated AD 956 ± 16 date for the death of a fossil coral microatoll at the Ujung Salang site of northern Simeulue. Although this head has yet to be fully analyzed, it experienced <20 cm of net upward growth over an estimated ~140 years, suggesting an average submergence rate of <1.4 mm/yr, and more importantly yielded no evidence for any large uplift or subsidence events in the century prior to its outer preserved band. Thus, although information regarding the 10th-century tectonic histories of northern and southern Simeulue is still sketchy, the evidence collectively hints at yet another northern Simeulue uplift that is not seen at the Bunon site.

6. Summary and Implications of Paleogeodetic Observations at Bunon

We have obtained three discrete continuous histories of relative sea level at the BUN-A site, spanning the mid-9th to early 11th centuries AD, the early 14th to early 17th centuries, and AD 1982 to present. A summary of observations and potential inferences of relative sea level at Bunon since AD 1300 is presented in Figure S10b.

The mid-9th to early 11th century record is one of remarkably steady relative sea level, with any tectonic change in land level offset by a similar change in absolute sea level; presumably both were small or zero. The inferred death of BUN-9 around AD 1022 suggests a modest uplift event at around that time.

The record picks up again three centuries later around AD 1311 as the site was rapidly accumulating strain, with an average subsidence rate of 5.5 mm/yr. This subsidence continued until the site rose suddenly around AD 1430, with 70–86 cm of coseismic uplift, possibly followed by postseismic subsidence of ~10 cm. Then, from ~1441 to ~1474, there was little vertical change. By AD 1509, the site was subsiding again at ~6 mm/yr, and that subsidence continued until the early 17th century. Significant and robust variability in the rates, at scales of 15–70 years, are superimposed on the century-scale averages. Another uplift event is inferred in the early part of the 17th century.

Finally, the modern record reveals an interseismic subsidence rate of 5.3 mm/yr from 1986 to 1995, followed by 15–20 cm of coseismic uplift in 2002 and 60–70 cm of coseismic uplift in 2005, with little vertical change in 2004. We infer from observations elsewhere on southern Simeulue [*Meltzner et al.*, 2009] that Bunon was uplifted during the 1861 southern Simeulue–Nias earthquake, but no evidence was documented at Bunon to either confirm or refute such a proposition.

The records from the BUN-A site provide robust positive evidence that none of the major uplifts known or inferred on northern Simeulue in the past 1100 years involved significant uplift or subsidence at Bunon. Specifically, significant land-level changes did not occur at Bunon in AD 956 ± 16, AD 1394 ± 2, AD 1450 ± 3, or AD 2004. In addition, the largest uplifts at Bunon in the modern or paleogeodetic record—the 70–86-cm uplift around AD 1430 and the 60–70-cm uplift in 2005—had little or no effect on northern Simeulue. Around 1430, there was ~12 cm of uplift at Lhok Pauh on northern Simeulue (Fig. S12); even if this and the similarly dated uplift at Bunon correspond to the same event, the uplift at Lhok Pauh is small compared to the 100 cm of uplift there in 2004 and could be consistent with a megathrust rupture petering out to the north.

Alternatively, it is entirely possible that the 12-cm uplift at Lhok Pauh in 1430 ± 3 did not coincide with the 70–86 cm of uplift at Bunon—those two uplifts could have been separated by months, as in 2004 and 2005, or even a few years—and if that were the case, the argument would be even stronger for strict segmentation of the megathrust between Bunon and northern Simeulue. Regardless of the details of the ~1430 event or events, central Simeulue—somewhere between Bunon and Lhok Pauh—has behaved as a persistent barrier to rupture over at least the past 1100 years.

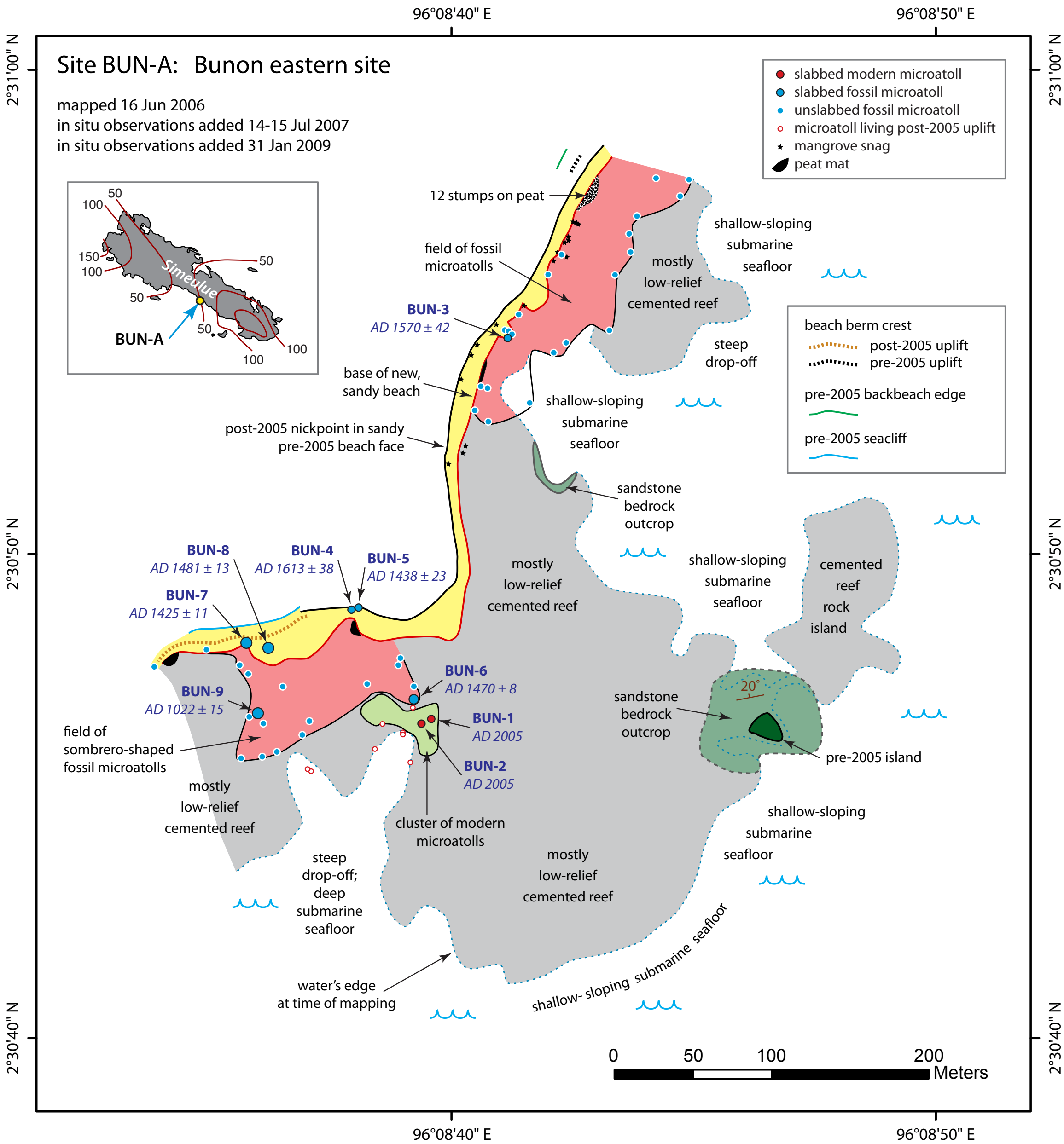


Figure S1. Map of site BUN-A, southwest coast of Simeulue, showing sampled microatolls and their dates of death. Inset shows the relative location of the BUN-A site on Simeulue, along with contours of cumulative uplift (in centimeters) in 2004 and 2005, modified from *Briggs et al.* [2006]. The locus of uplift on the northwestern part of the island is attributed to the 2004 earthquake, while the southeastern locus of uplift occurred in 2005.

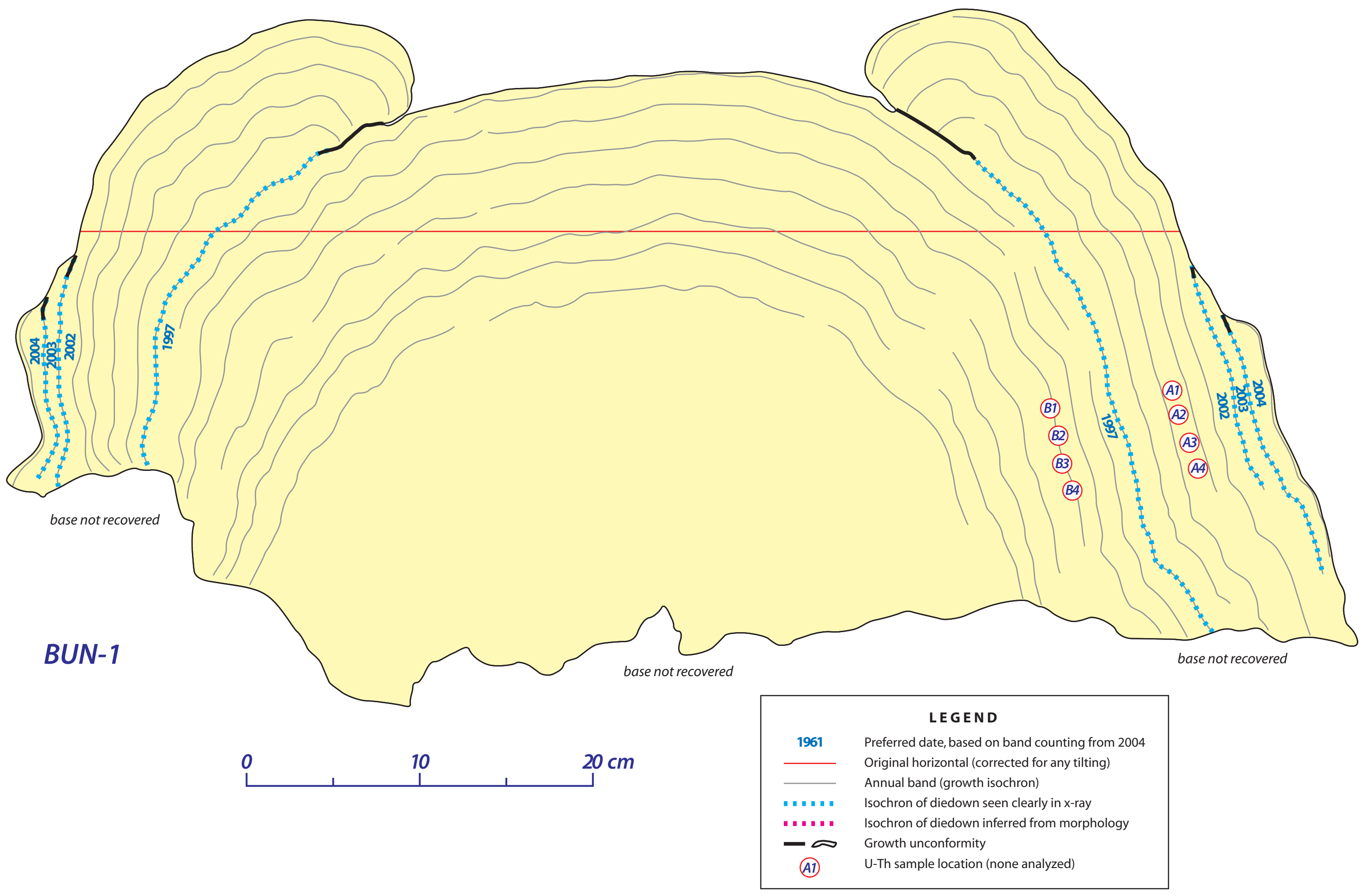


Figure S2a. Cross-section of slab BUN-1, from site BUN-A.

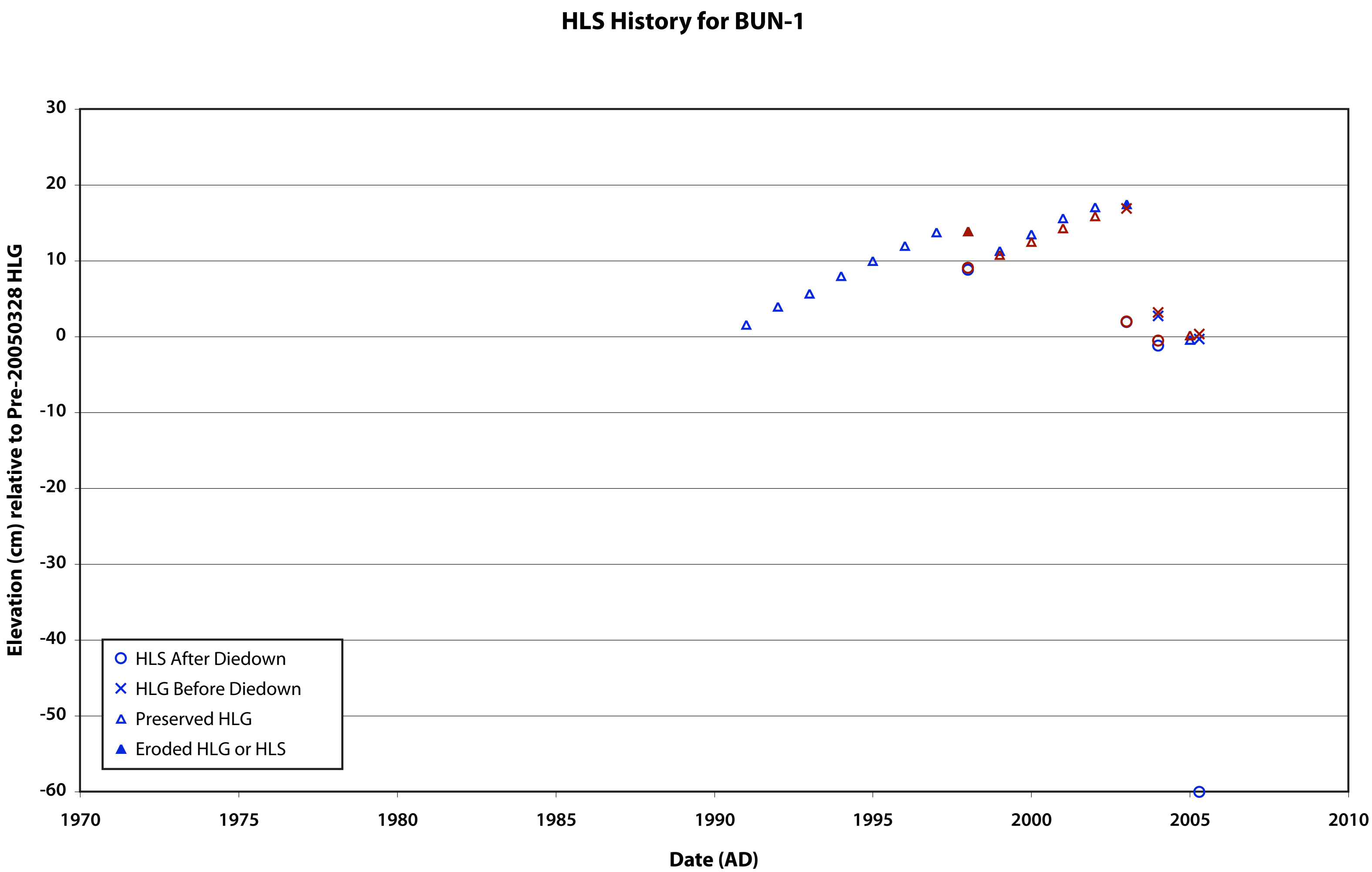


Figure S2b. Graph of relative sea level history derived from slab BUN-1.

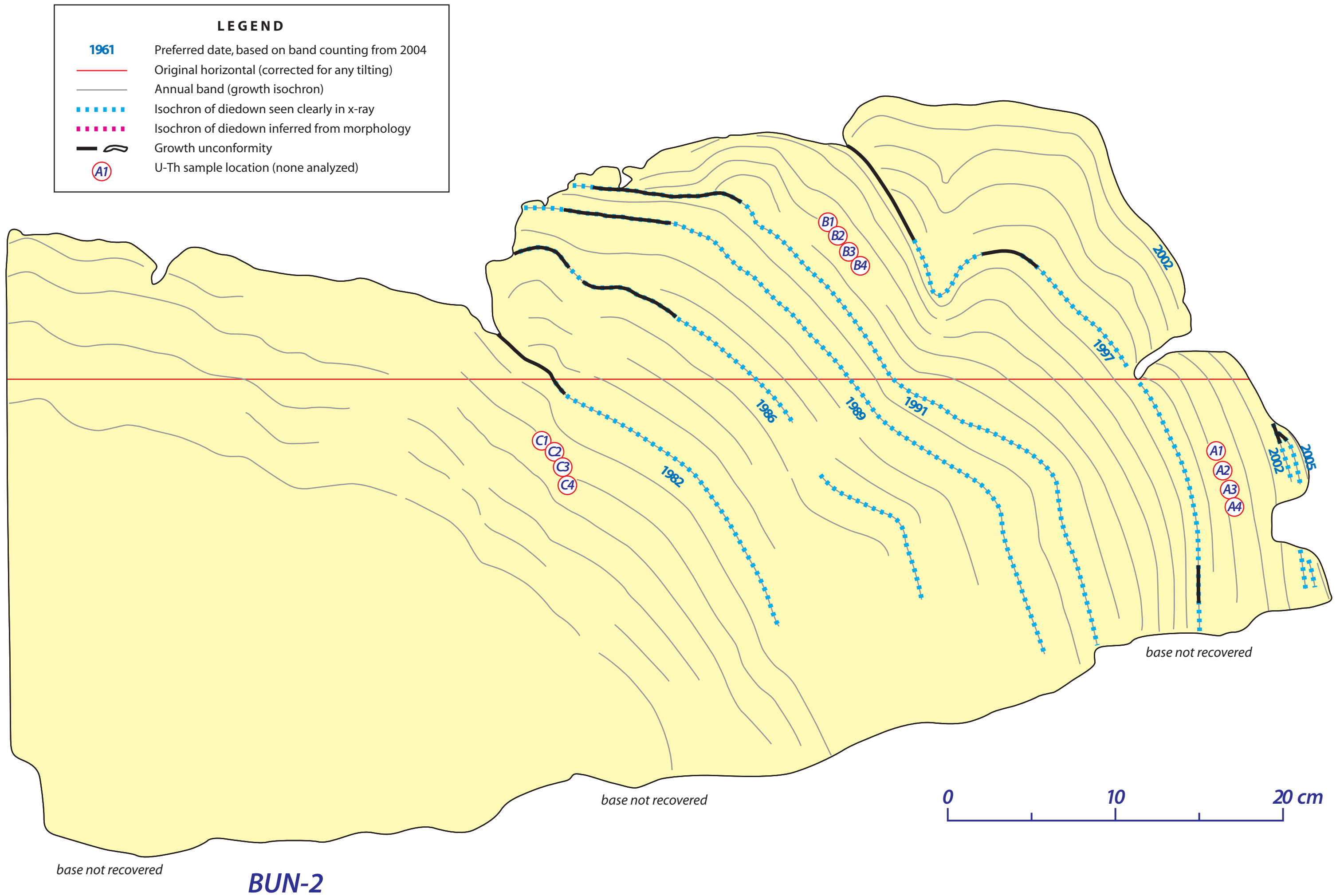


Figure S3a. Cross-section of slab BUN-2, from site BUN-A.

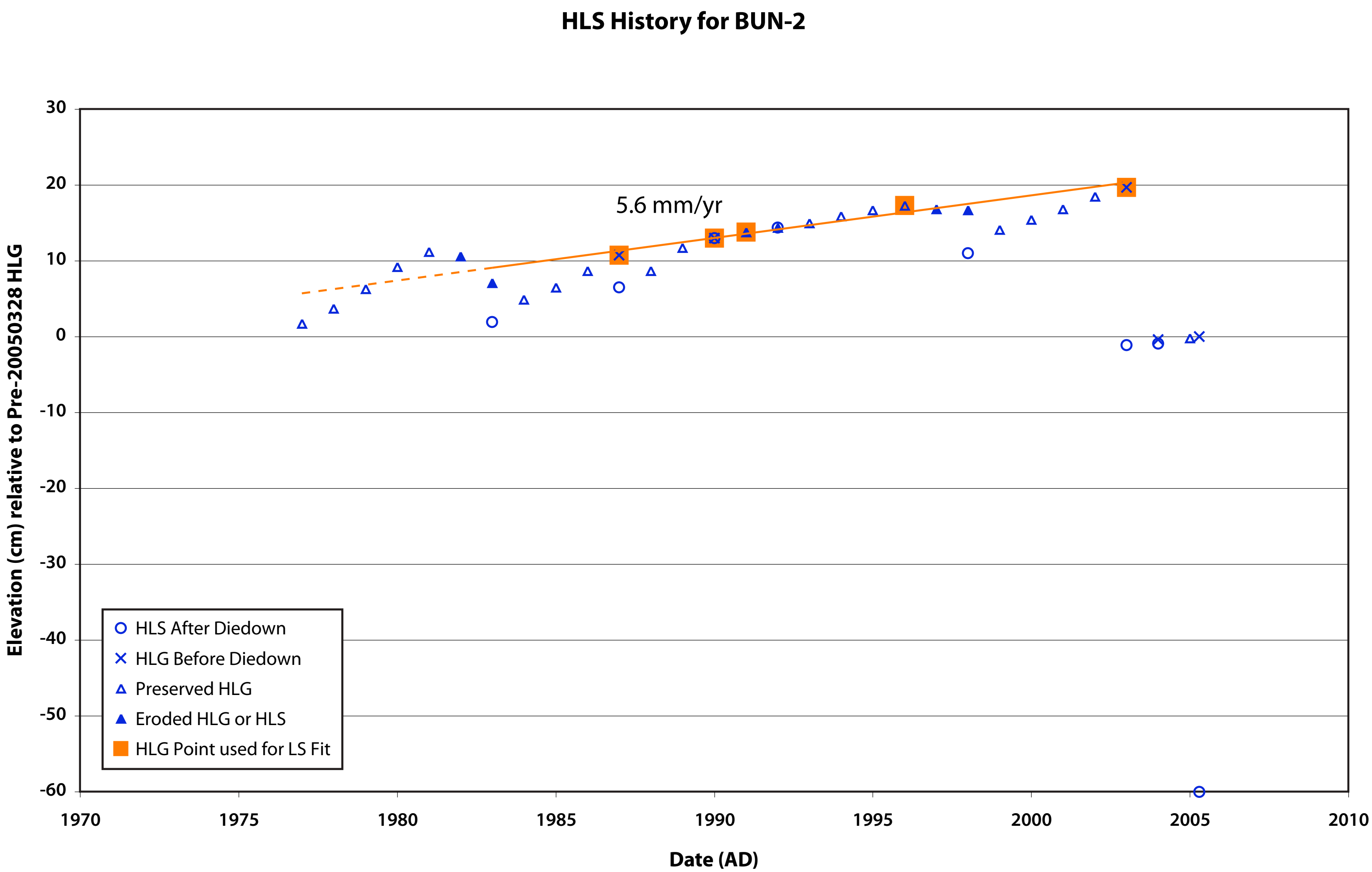


Figure S3b. Graph of relative sea level history derived from slab BUN-2.

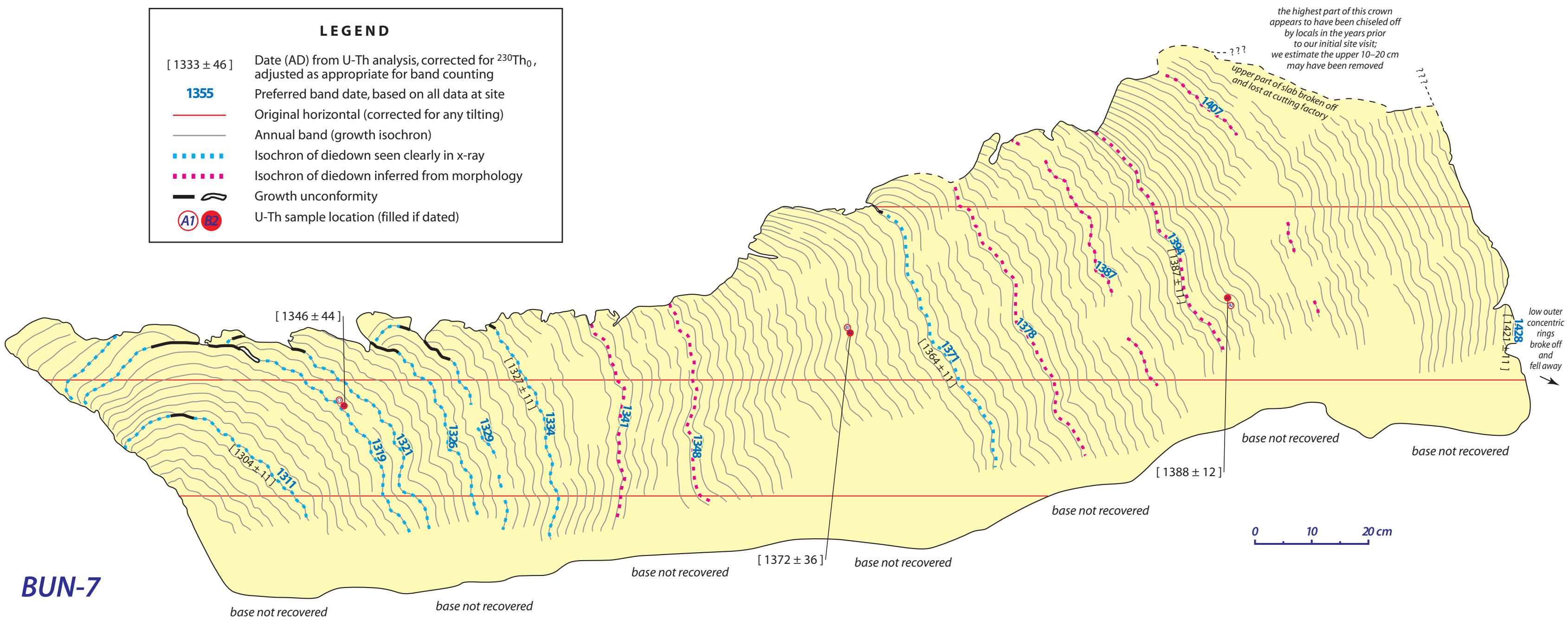


Figure S4a. Cross-section of slab BUN-7, from site BUN-A.

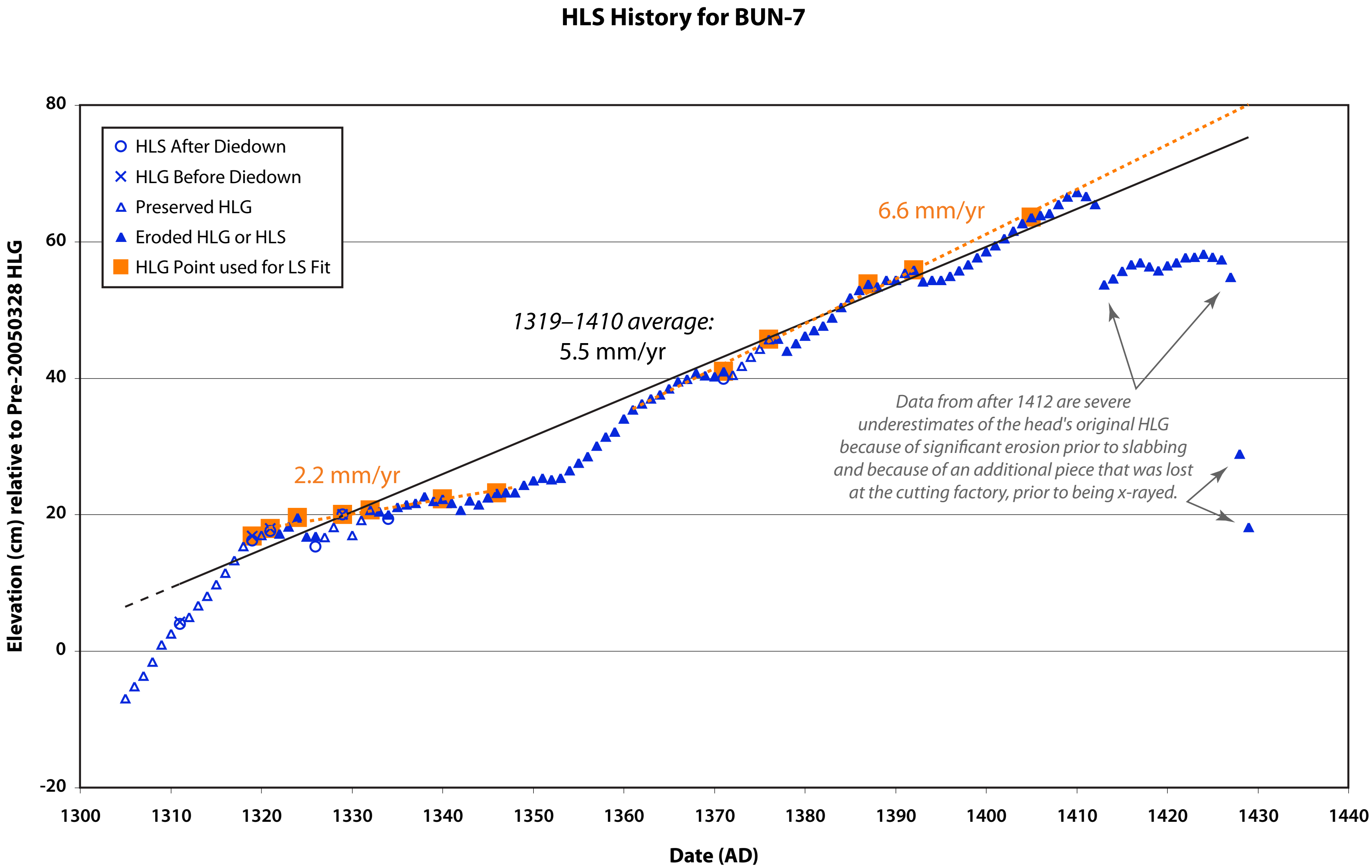


Figure S4b. Graph of relative sea level history derived from slab BUN-7.

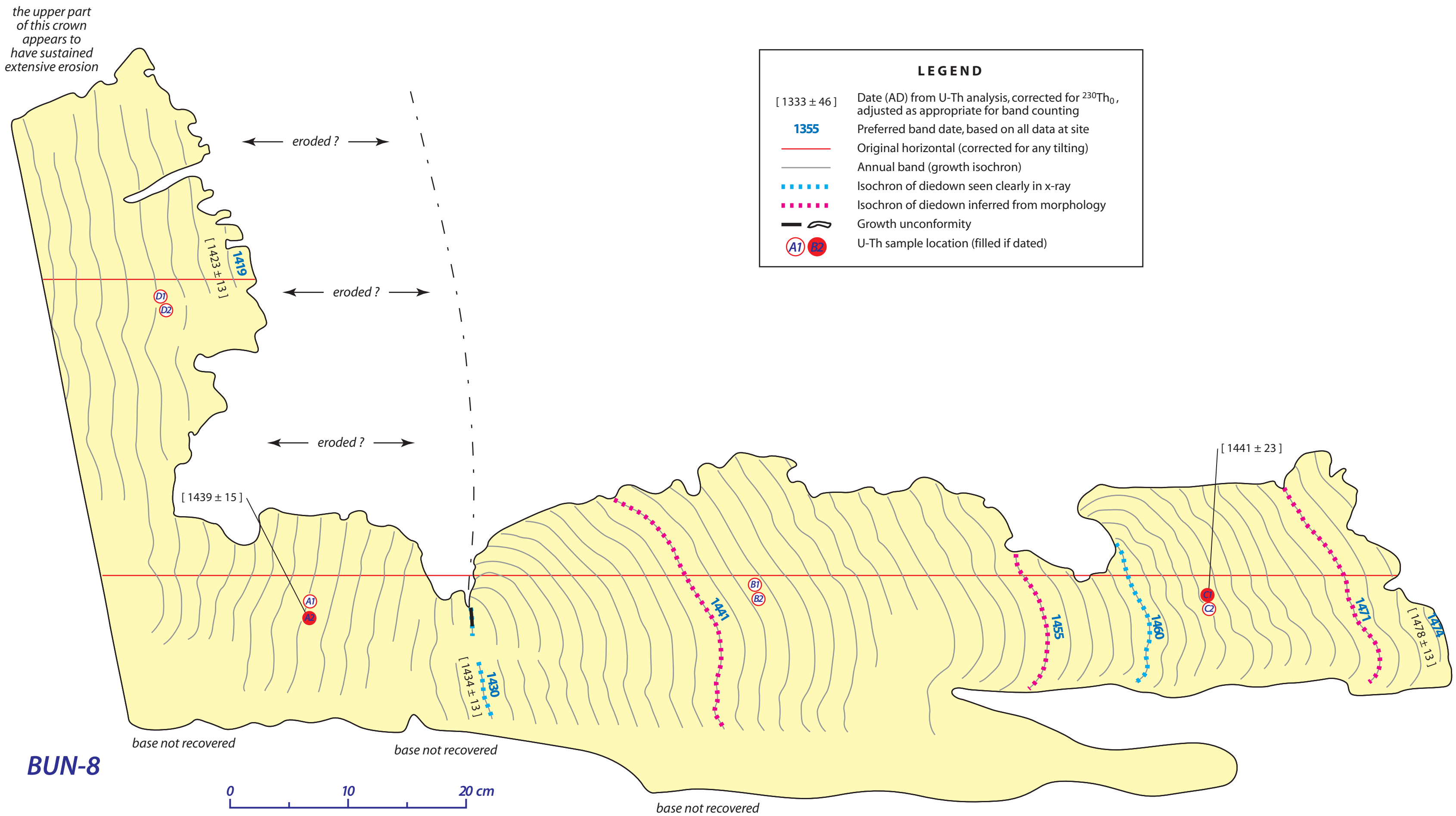


Figure S5a. Cross-section of slab BUN-8, from site BUN-A.

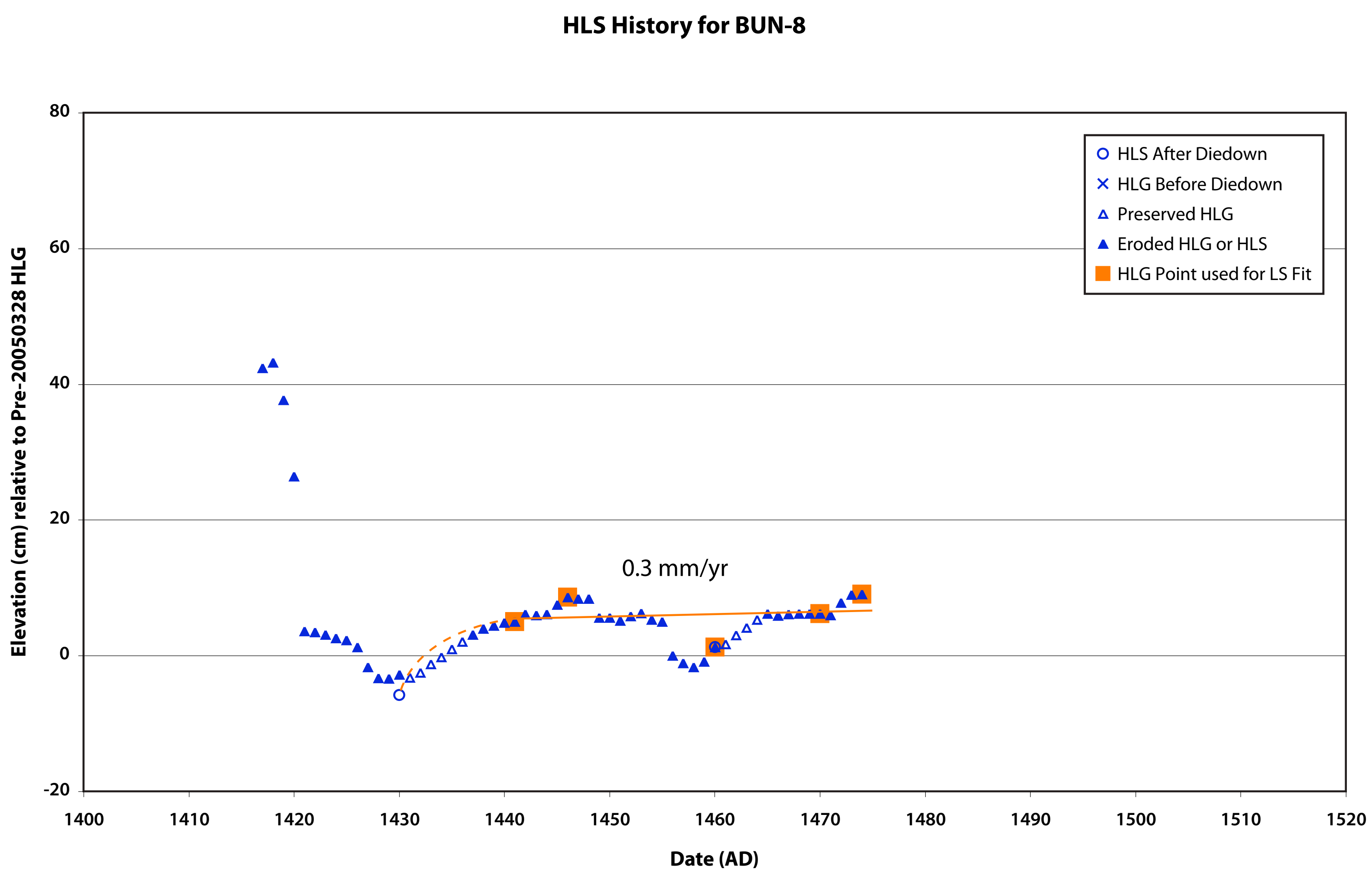


Figure S5b. Graph of relative sea level history derived from slab BUN-8.

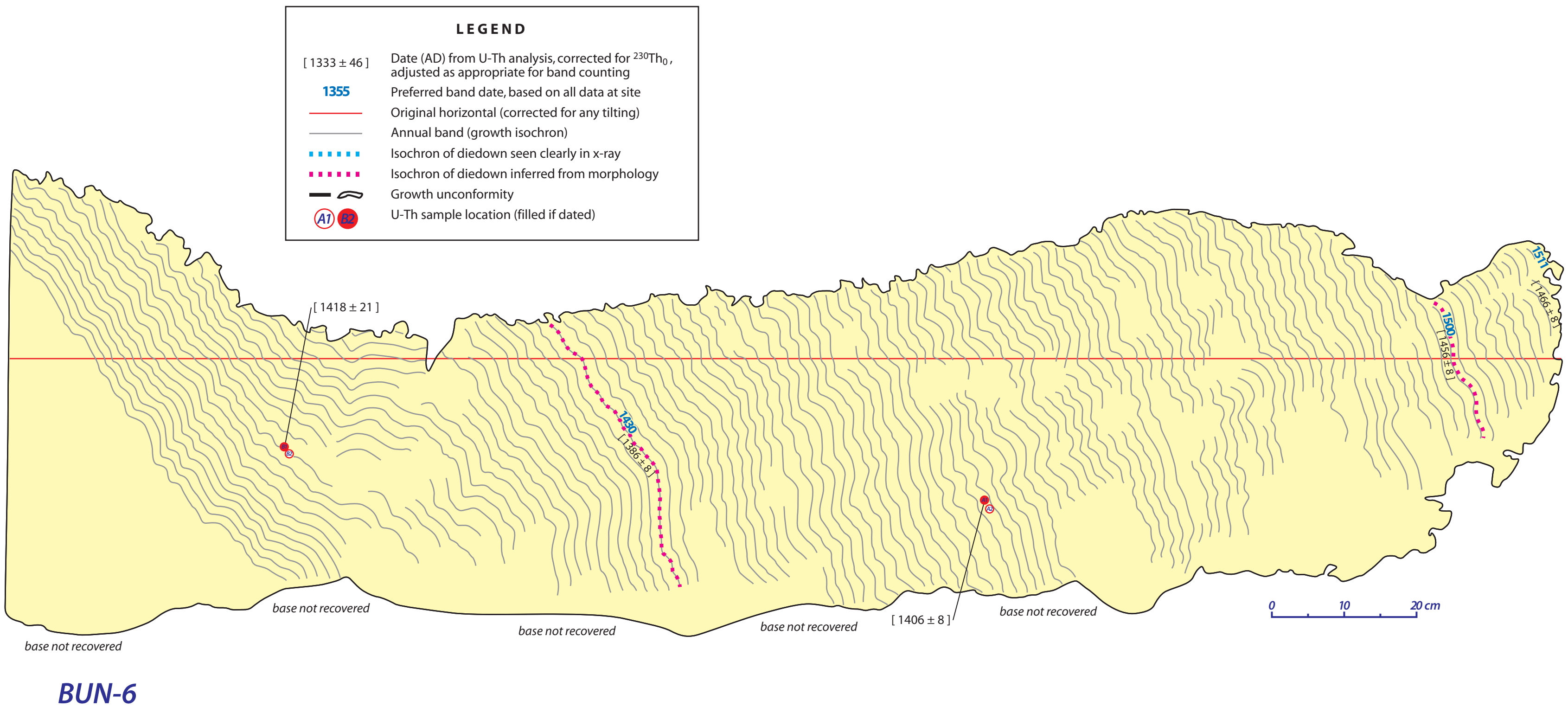


Figure S6a. Cross-section of slab BUN-6, from site BUN-A.

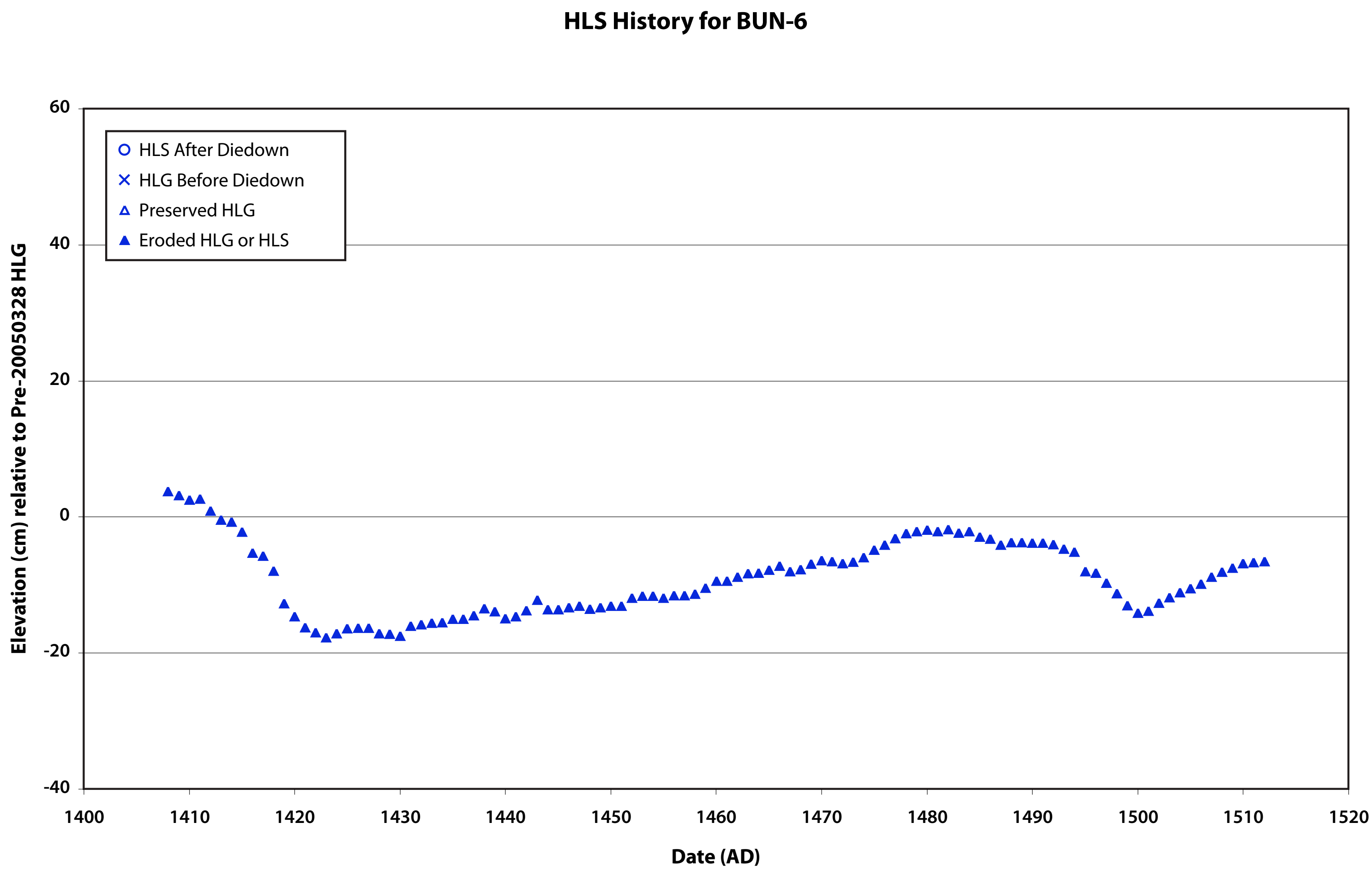


Figure S6b. Graph of relative sea level history derived from slab BUN-6.

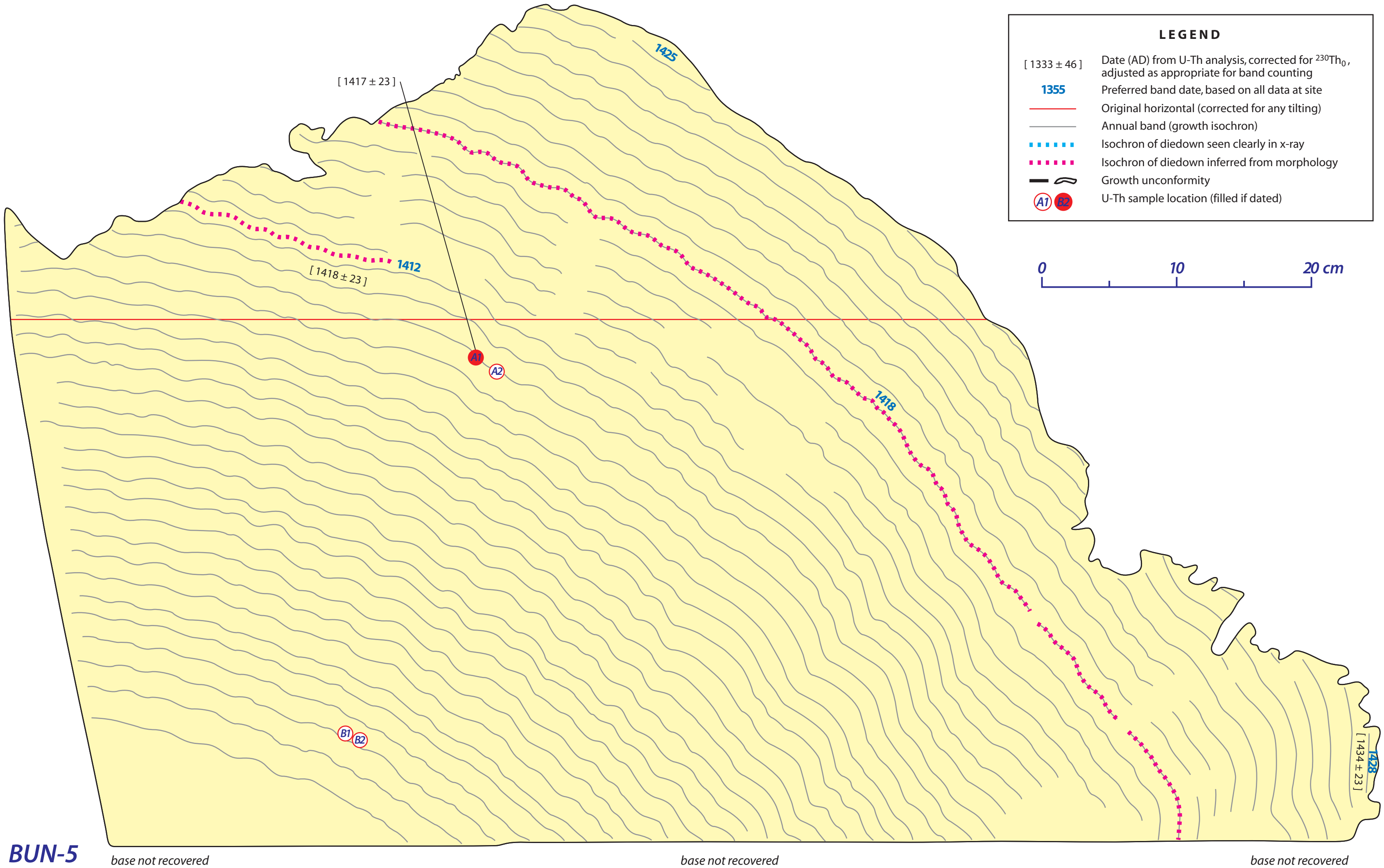


Figure S7a. Cross-section of slab BUN-5, from site BUN-A.

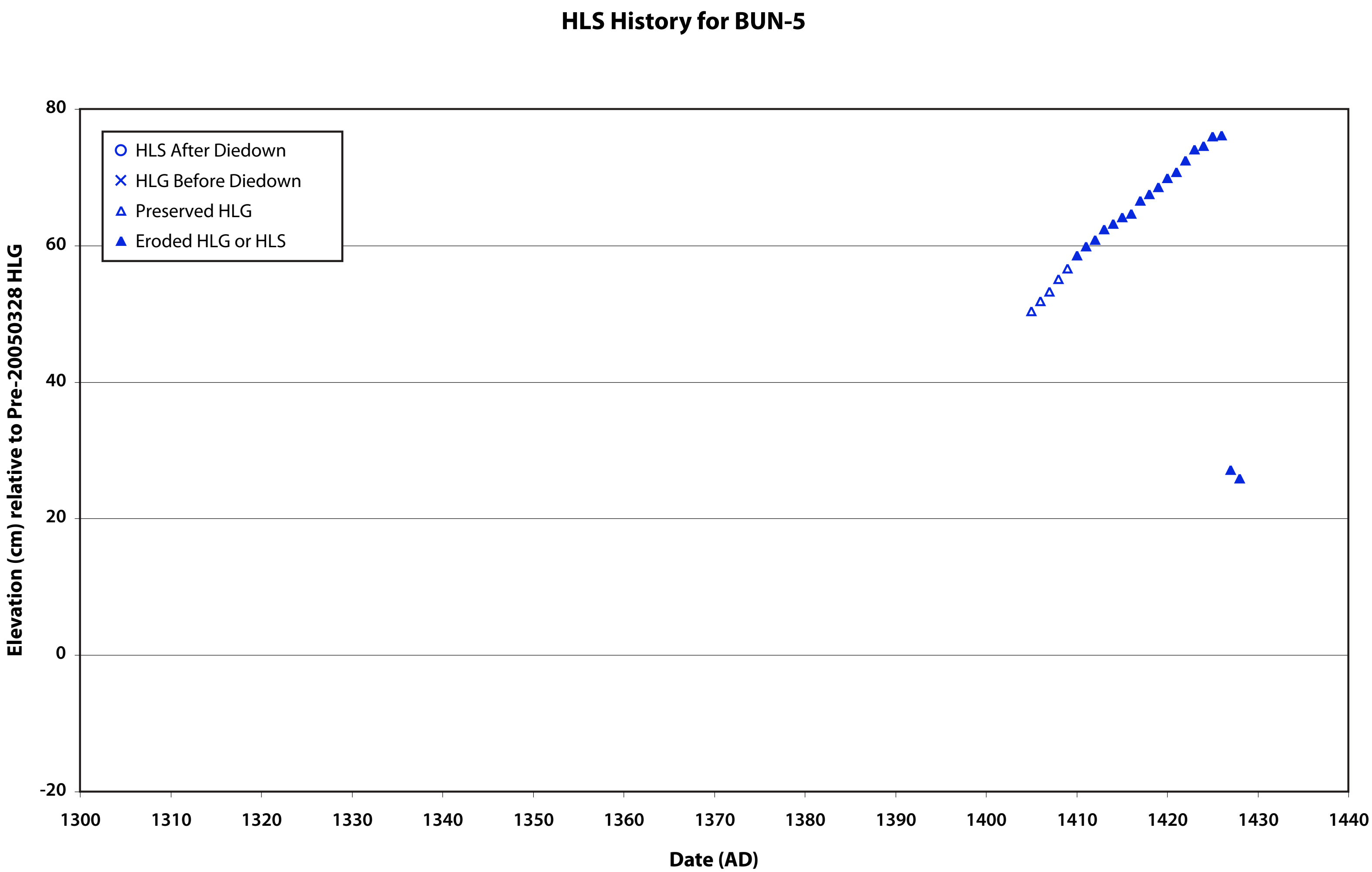


Figure S7b. Graph of relative sea level history derived from slab BUN-5.

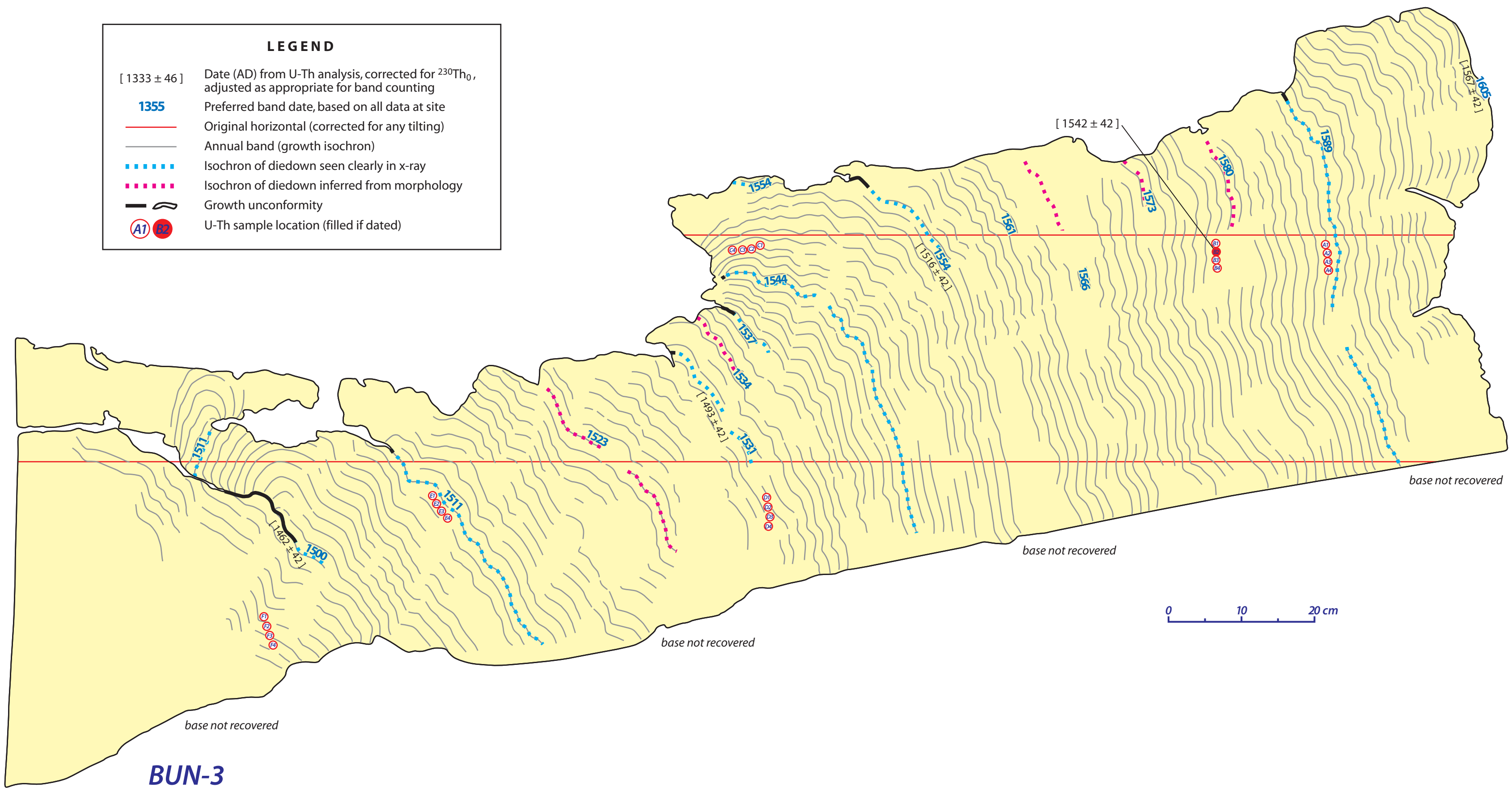


Figure S8a. Cross-section of slab BUN-3, from site BUN-A.

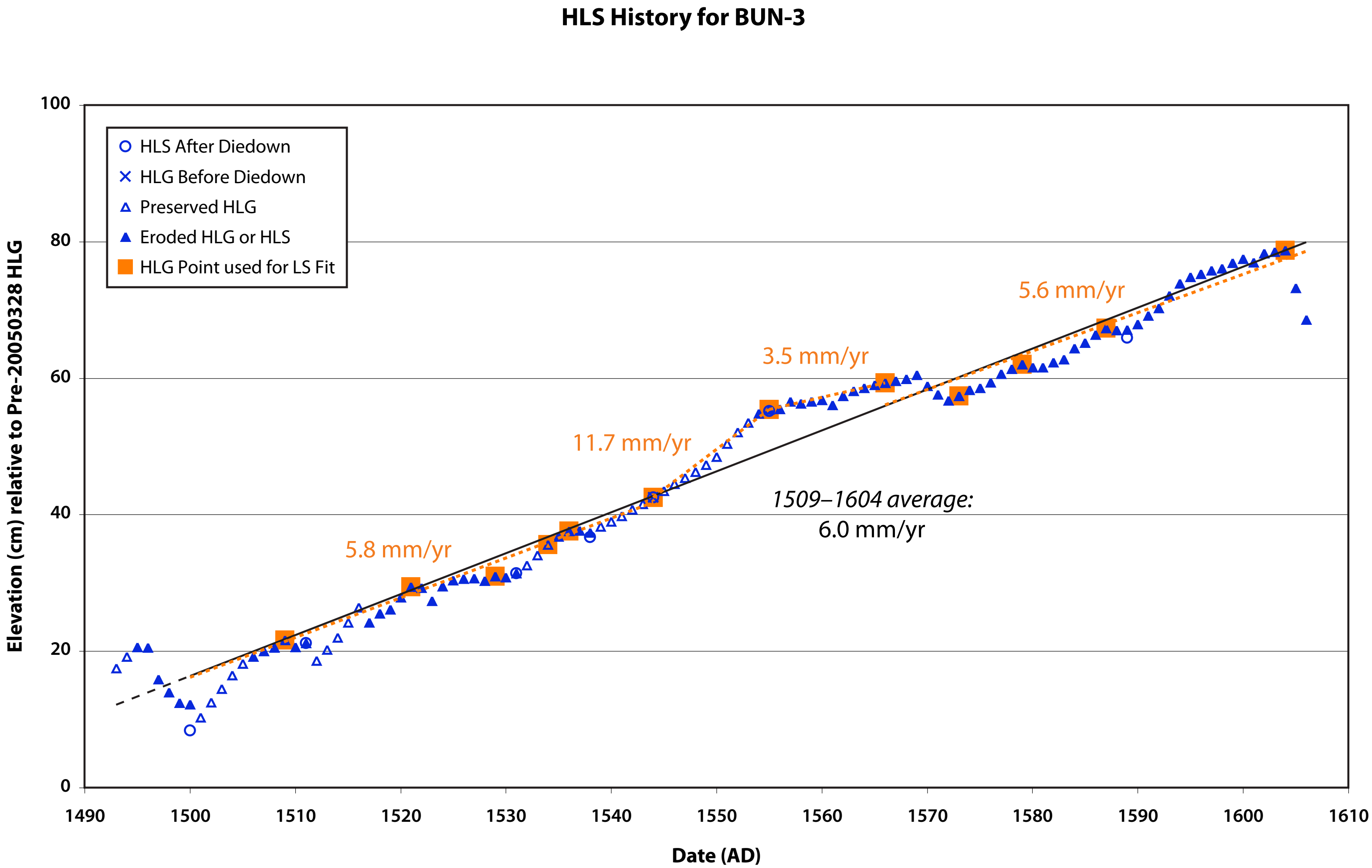


Figure S8b. Graph of relative sea level history derived from slab BUN-3.

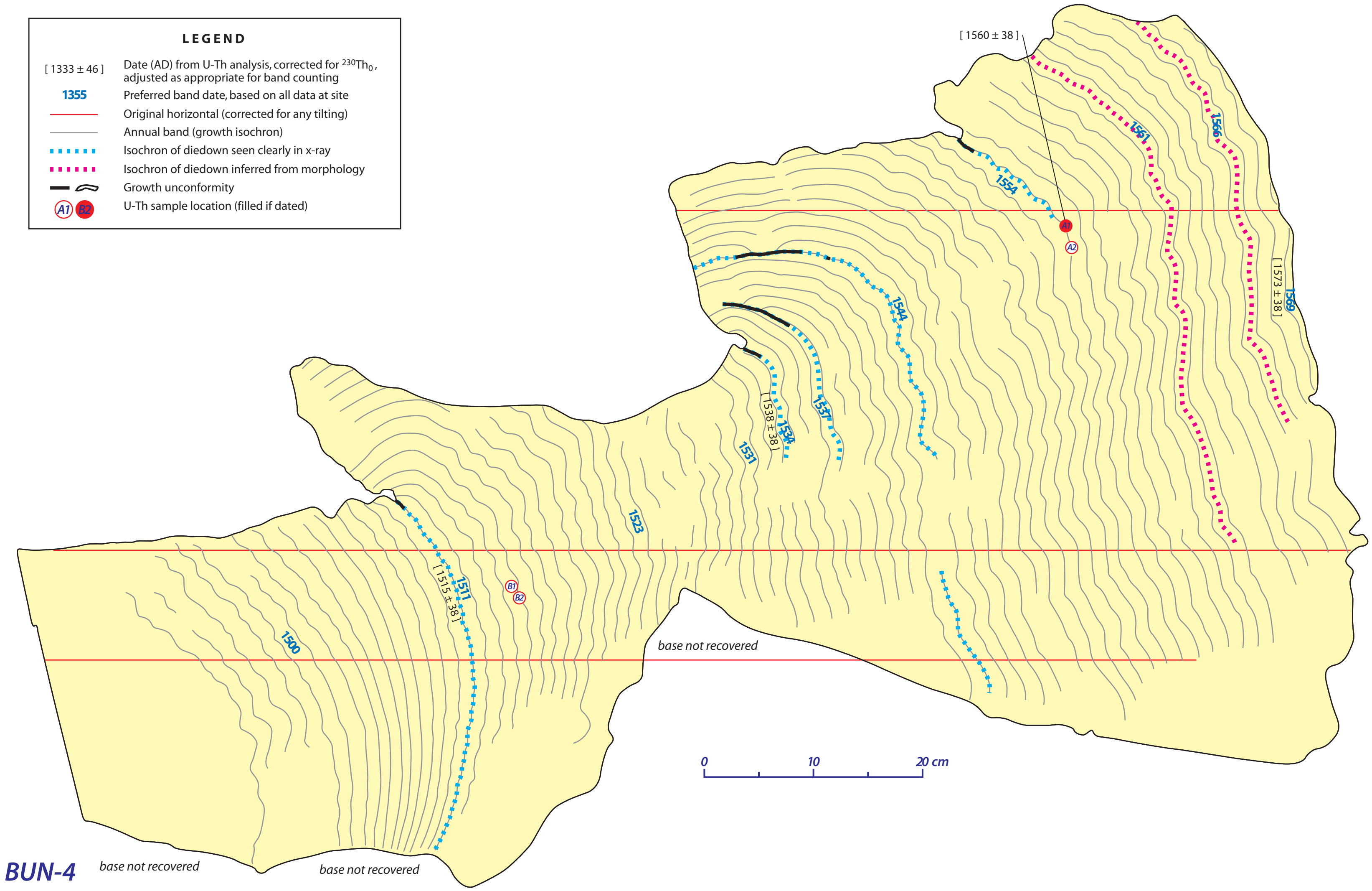


Figure S9a. Cross-section of slab BUN-4, from site BUN-A.

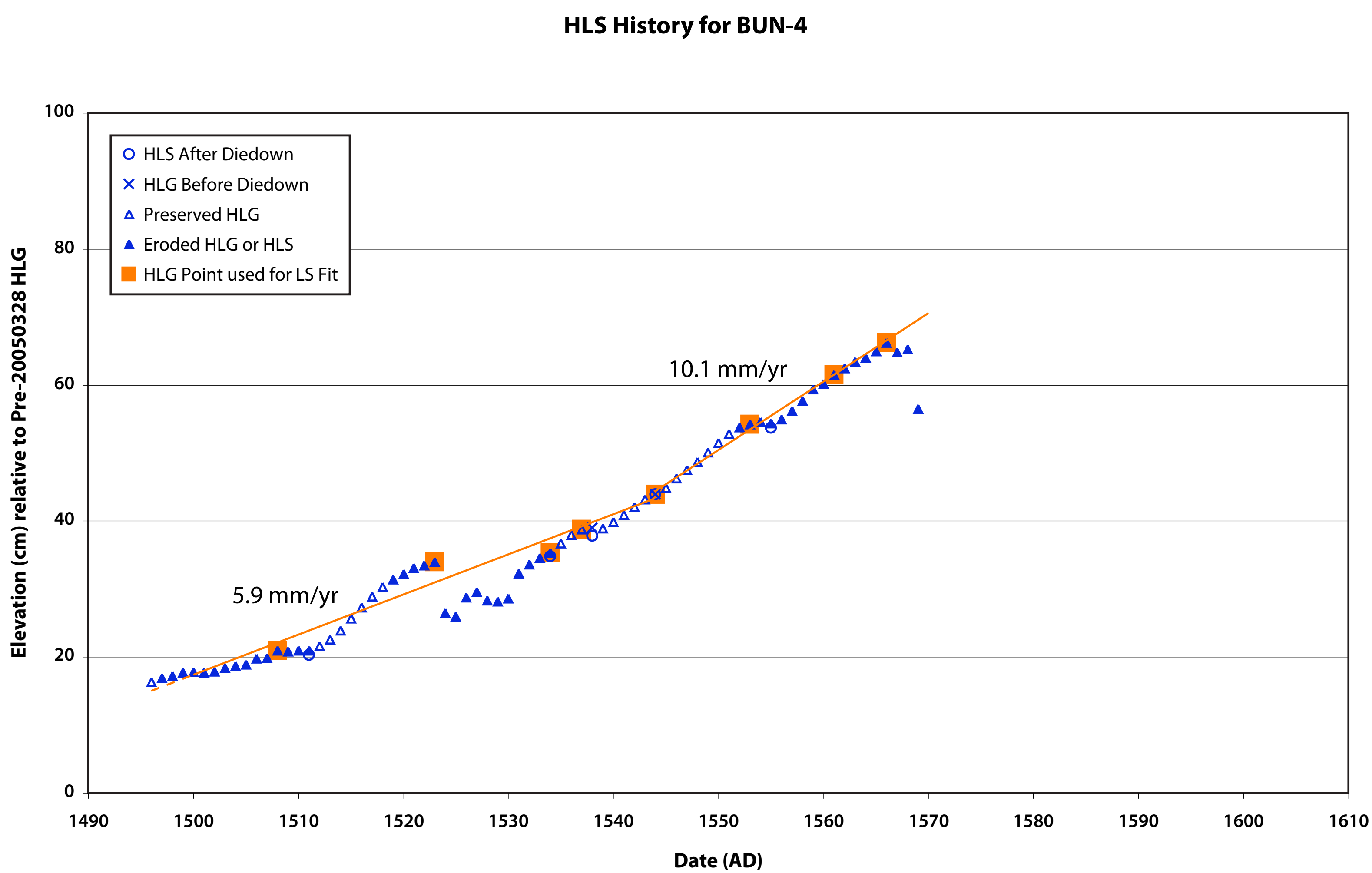


Figure S9b. Graph of relative sea level history derived from slab BUN-4.

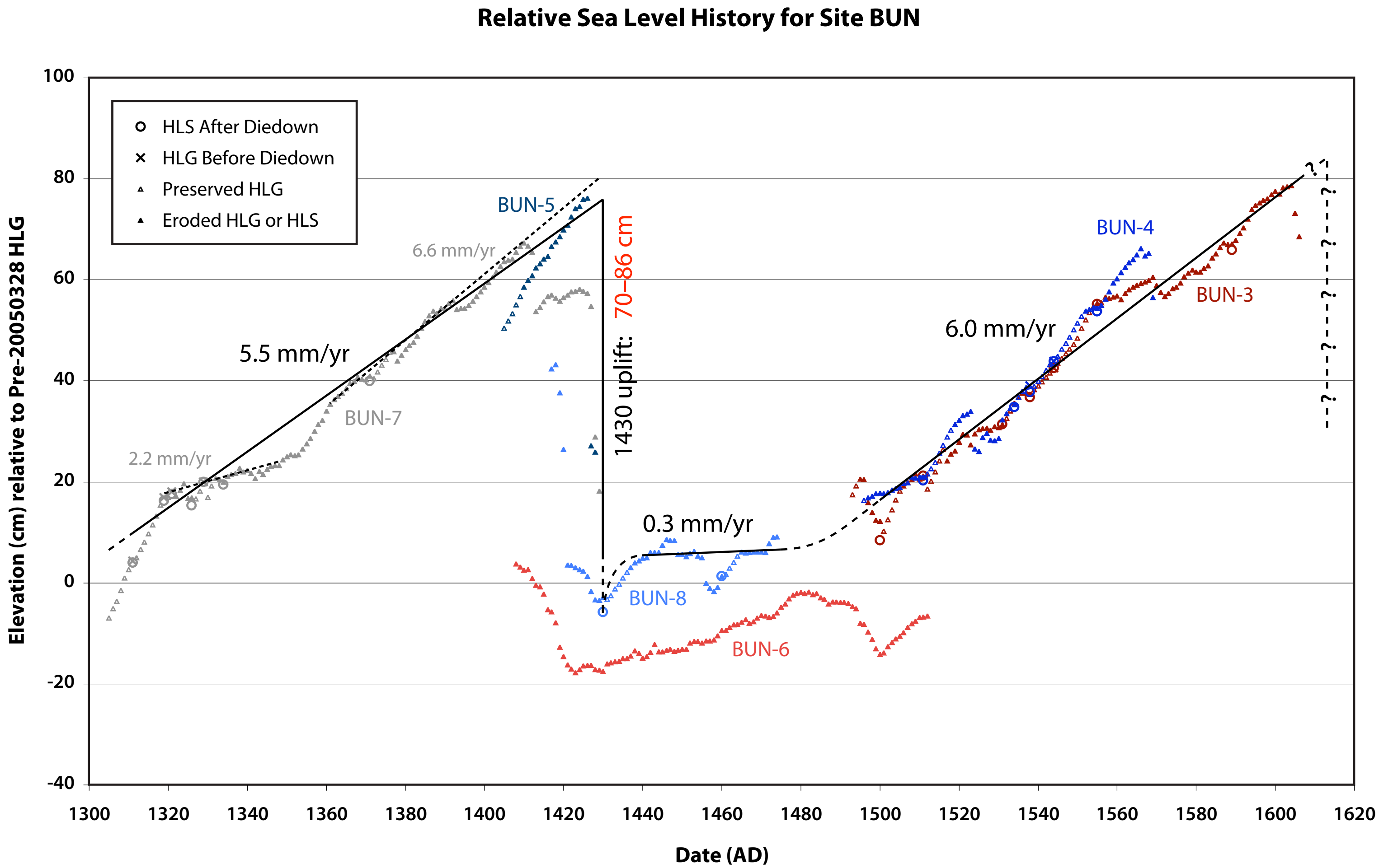


Figure S10a. Relative sea level history for the 14th–17th centuries at site BUN-A. The sea level curve (black) is solid where well constrained by data, dashed where inferred, and queried where conjectural; dotted lines depict short-term deviations of the interseismic rates.

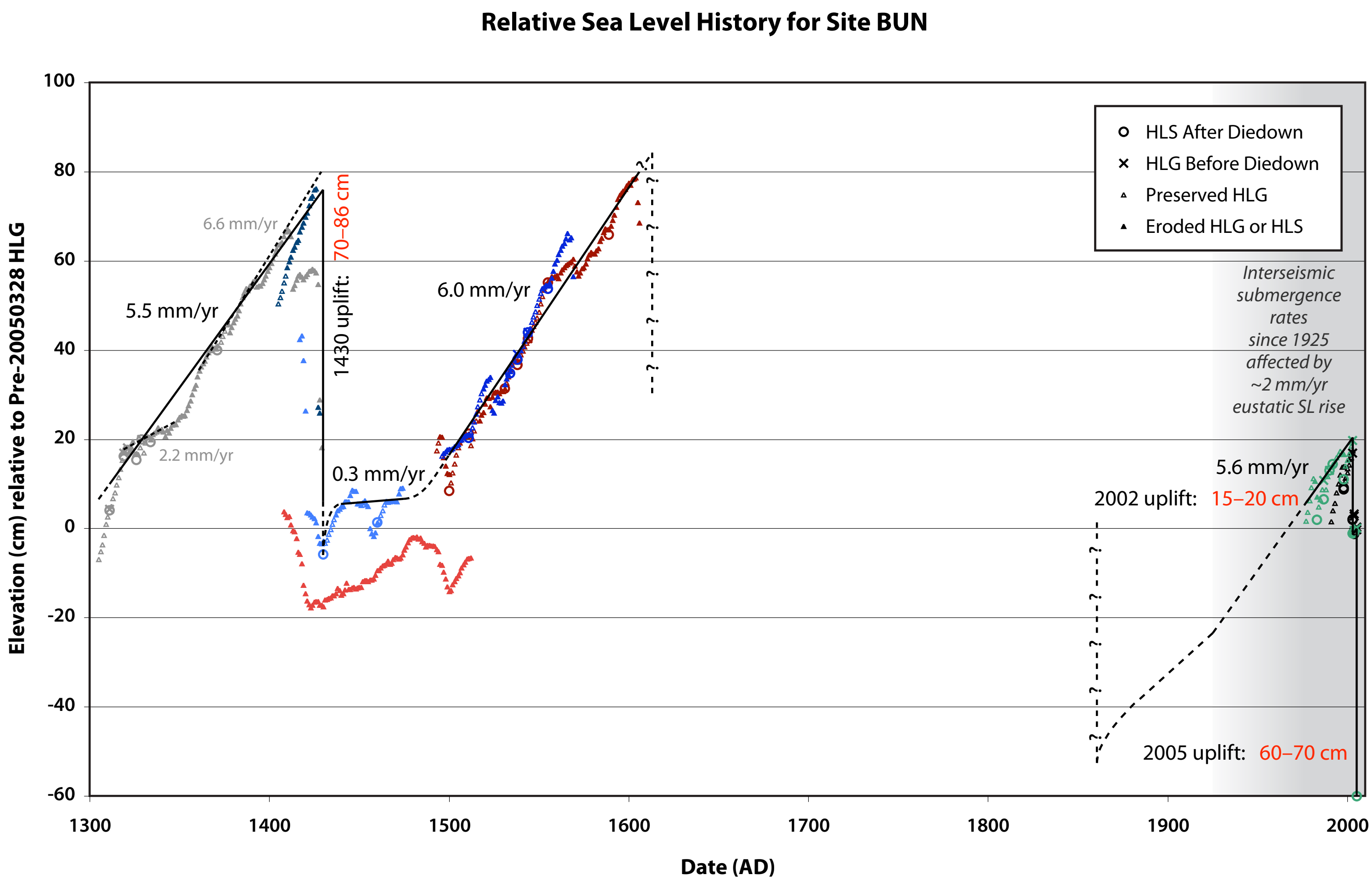


Figure S10b. BUN-A relative sea level history from the 14th century through the present. Note that the rates and elevations measured are influenced by time-varying eustatic sea level change and hydroisostasy; such signals must be removed before long-term tectonic uplift and subsidence are determined.

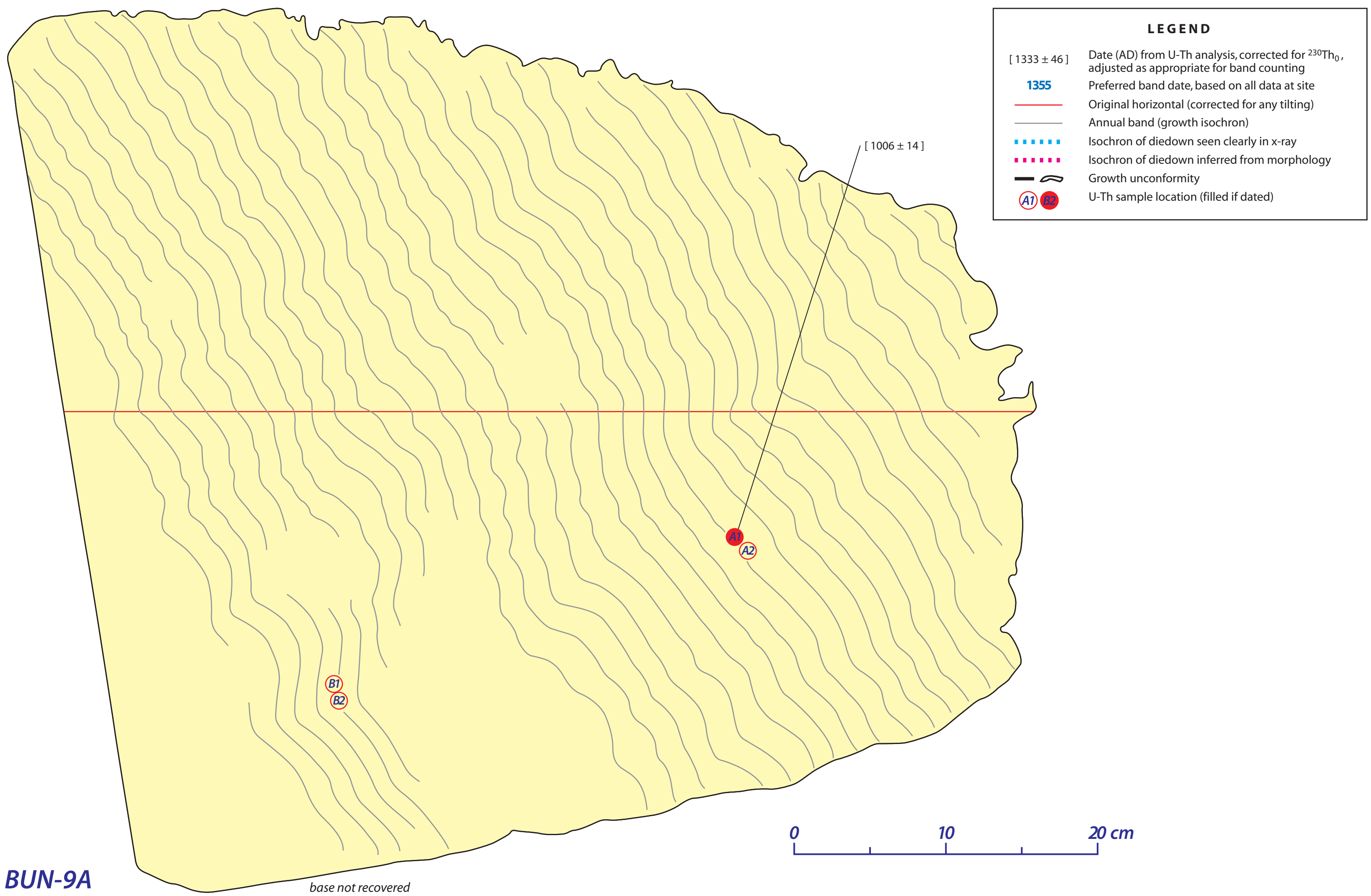


Figure S11a. Cross-section of slab BUN-9A, from site BUN-A.

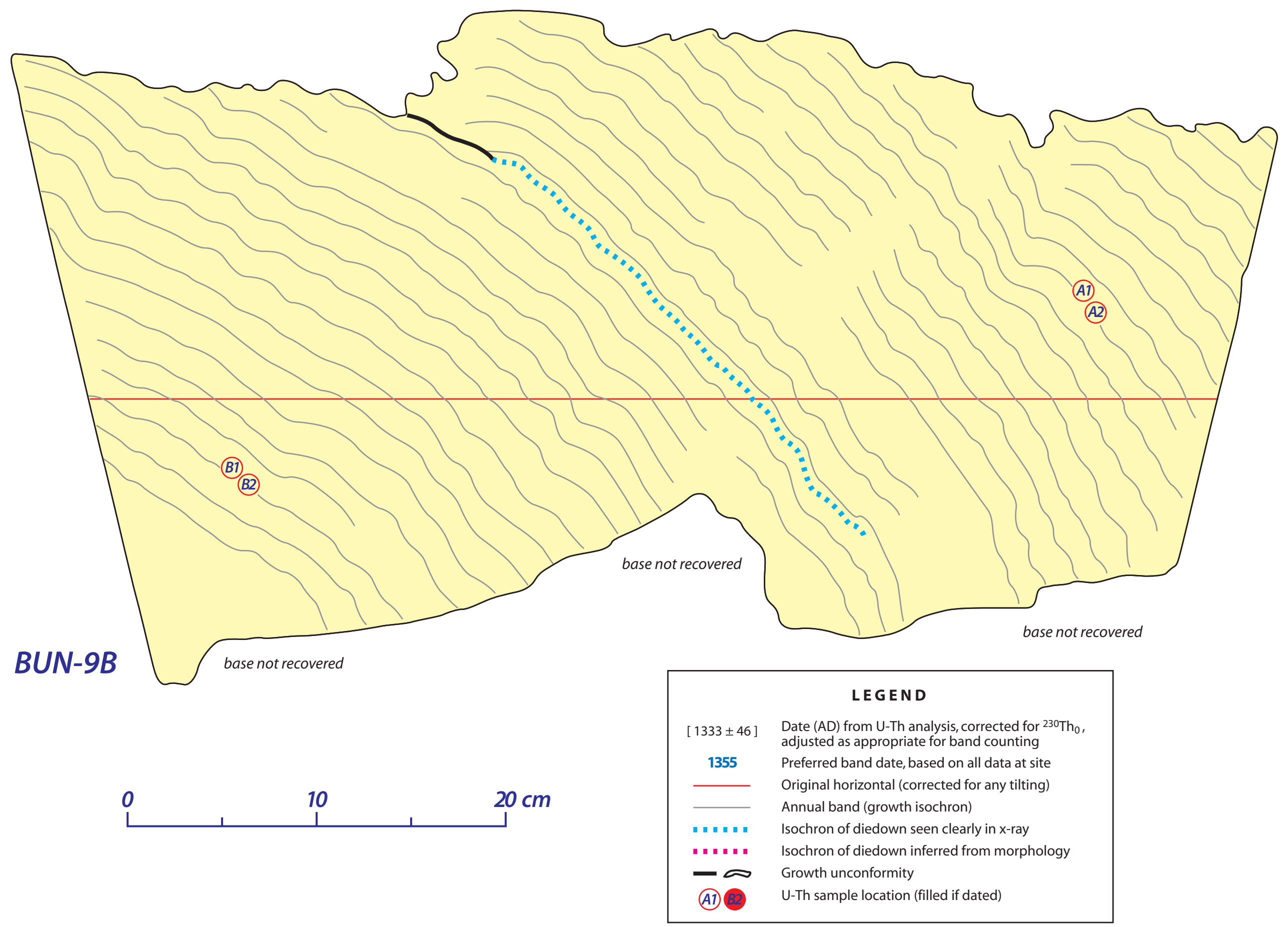


Figure S11b. Cross-section of slab BUN-9B, from site BUN-A.

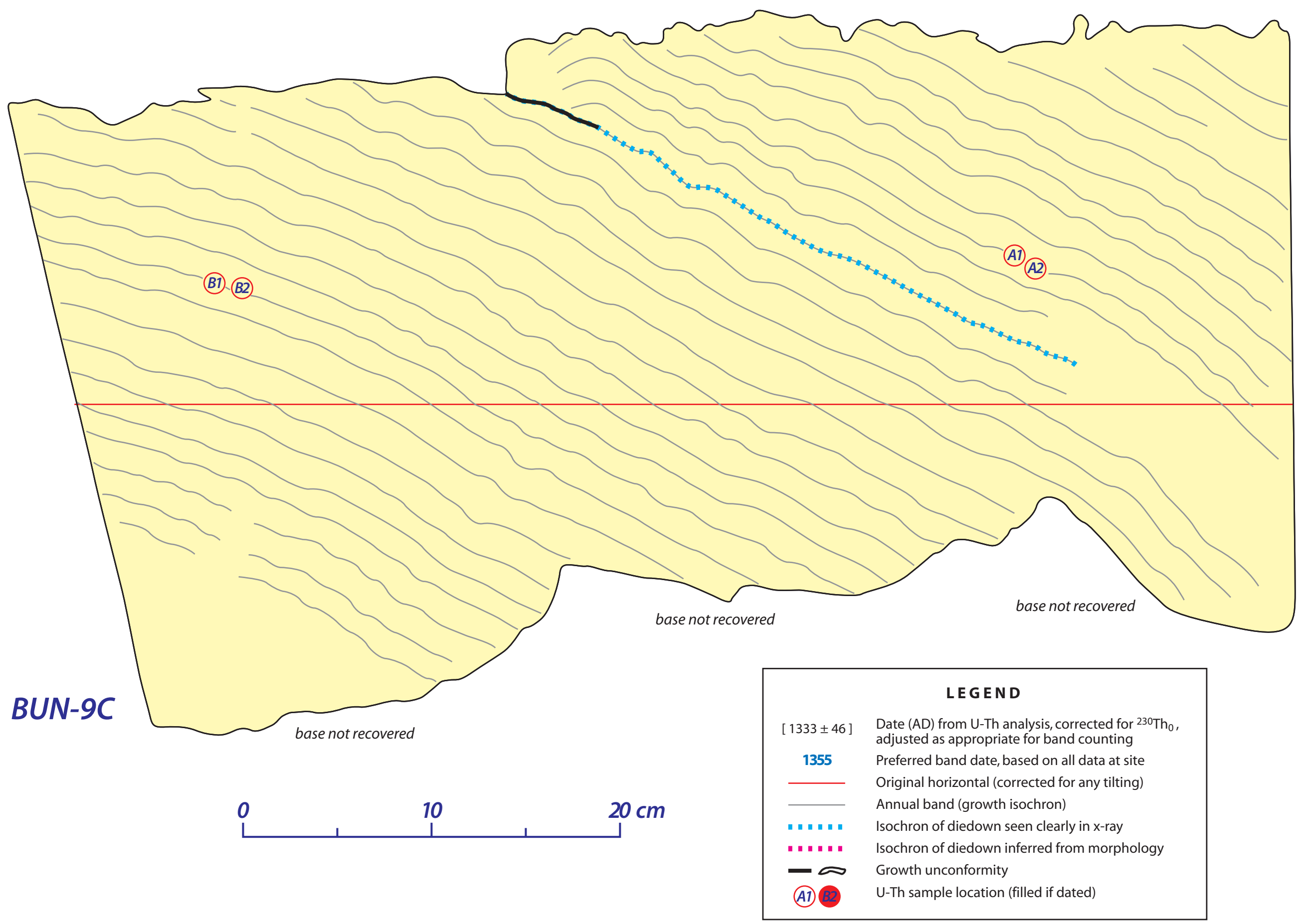


Figure S11c. Cross-section of slab BUN-9C, from site BUN-A.

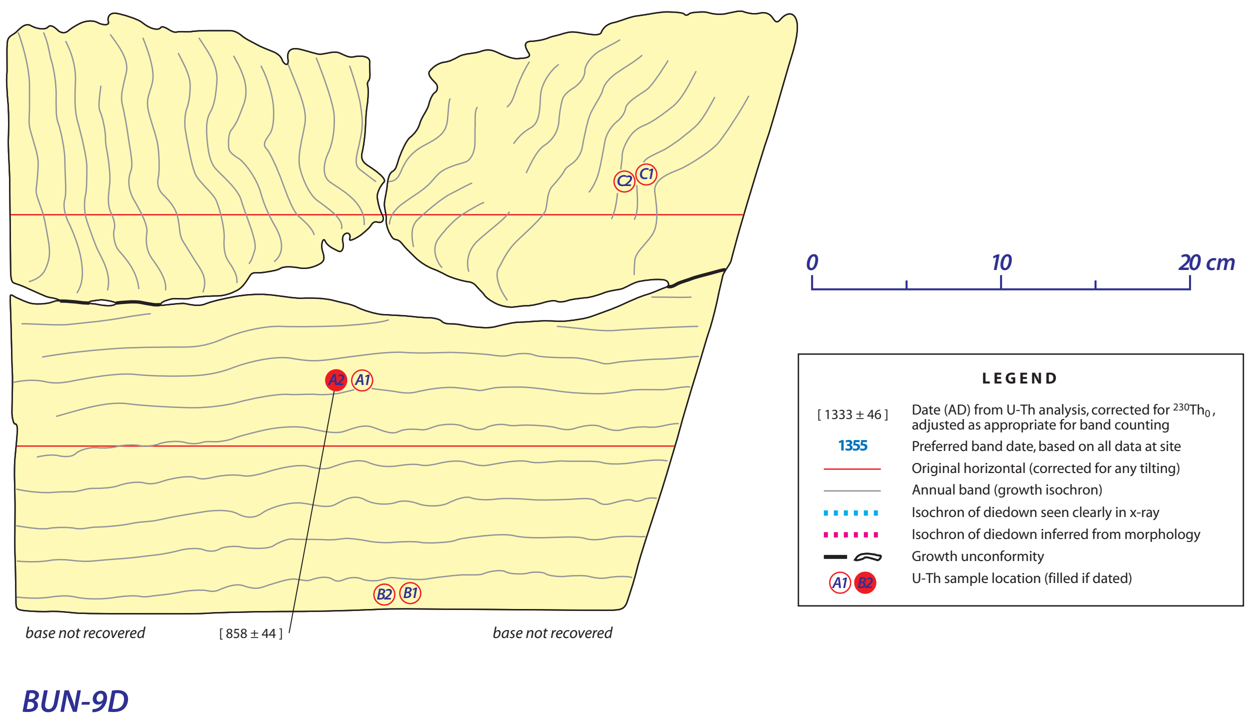
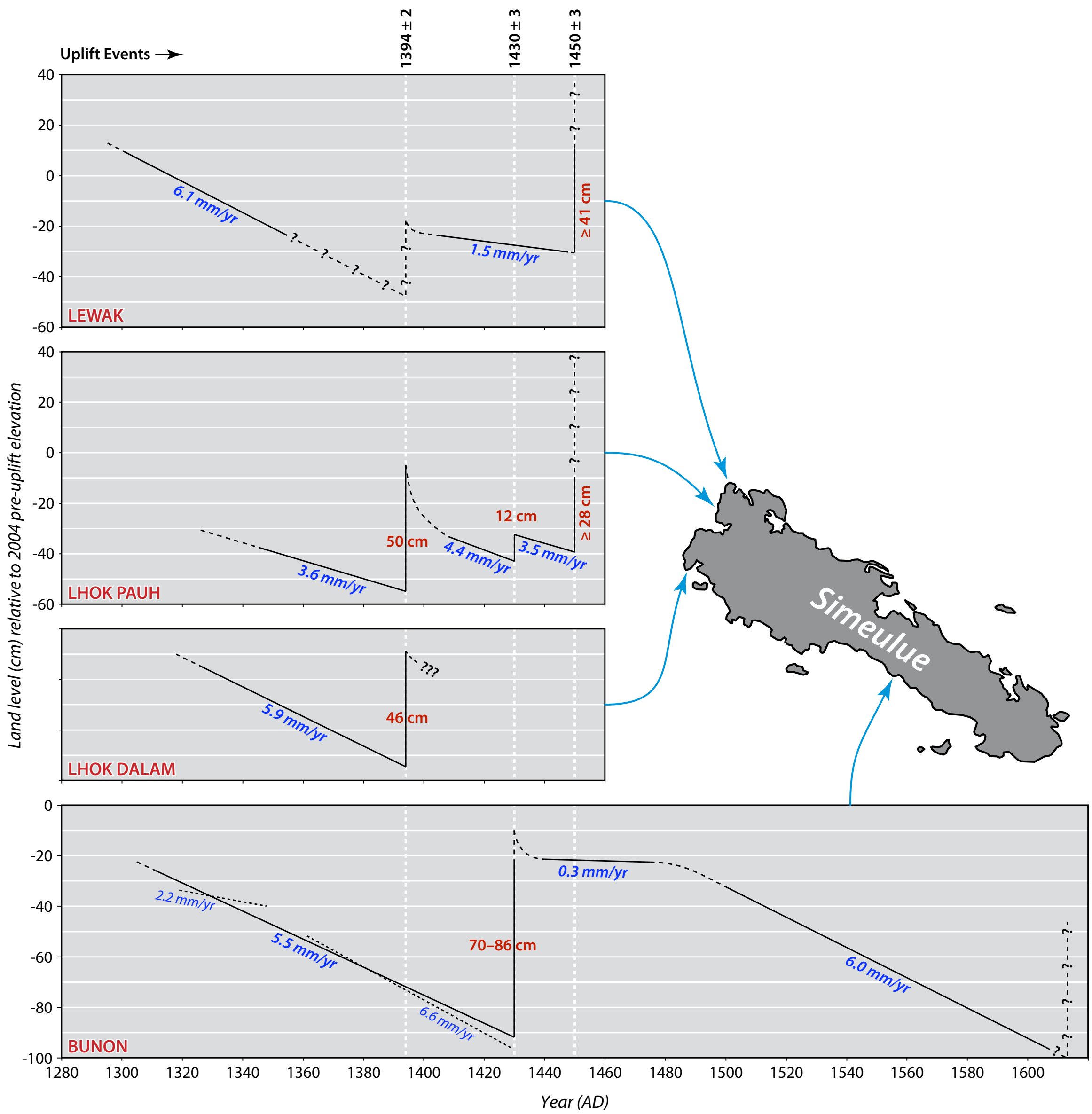


Figure S11d. Cross-section of slab BUN-9D, from site BUN-A.

Figure S12. Histories of interseismic subsidence and coseismic uplift through the 14th–15th centuries at Lewak, Lhok Pauh, and Lhok Dalam on northern Simeulue, compared to the 14th–17th century history at the southern Simeulue site of Bunon. Data constrain solid parts of the curves well; dashed portions are inferred, and queried portions are conjectural. Dotted black lines depict significant short-term deviations of the interseismic rates from longer-term averages. Uplift amounts (in centimeters) are red. Interseismic subsidence rates (in millimeters per year) are blue. Vertical dotted white lines mark dates of uplifts. The zero elevation datum at each site is the site's elevation immediately prior to the 2004 uplift (Lewak and Lhok Pauh) or immediately prior to the 2005 uplift (Bunon), corrected as described in previous chapters for eustatic sea level rise since the 20th century. 14th-century elevations at Lhok Dalam are not known relative to 2004 elevations because none of the 14th-century heads at the site were in place.



Uplift Events
1394 ± 2
1430 ± 3
1450 ± 3
LEWAK
6.1 mm/yr
1.5 mm/yr
≥ 41 cm
LHOK PAUH
3.6 mm/yr
50 cm
4.4 mm/yr
12 cm
3.5 mm/yr
≥ 28 cm
LHOK DALAM
5.9 mm/yr
46 cm
???
BUNON
2.2 mm/yr
5.5 mm/yr
6.6 mm/yr
70–86 cm
0.3 mm/yr
6.0 mm/yr
Land level (cm) relative to 2004 pre-uplift elevation
Year (AD)
Simeulue

Figure S12.

Sampled Coral Microatolls: Location and Information **Table S1**

Head Name	Site Name	Collected	Latitude	Longitude	Mod/Fsl	Genus
BUN-1	BUN-A	Jun 2006	2.51294	96.14433	Modern	*Porites*
BUN-2	BUN-A	Jun 2006	2.51291	96.14427	Modern	*Porites*
BUN-3	BUN-A	Jun 2006	2.51513	96.14477	Fossil	*Porites*
BUN-4	BUN-A	Jul 2007	2.51357	96.14387	Fossil	*Porites*
BUN-5	BUN-A	Jul 2007	2.51358	96.14391	Fossil	*Porites*
BUN-6	BUN-A	Jul 2007	2.51305	96.14423	Fossil	*Porites*
BUN-7	BUN-A	Jul 2007	2.51338	96.14327	Fossil	*Porites*
BUN-8	BUN-A	Jul 2007	2.51335	96.14339	Fossil	*Porites*
BUN-9	BUN-A	Jul 2007	2.51297	96.14333	Fossil	*Porites*
BUN-10	BUN-B	Jan 2009	2.51870	96.12891	Modern	*Porites*

Uranium and Thorium isotopic compositions and ^{230}Th ages for Sumatran coral samples by ICP-MS **Table S2**

Sample ID	Weight g	^{238}U ppb	^{232}Th ppt	δ^{234}U measured [a]	[^{230}Th/^{238}U] activity [c]	[^{230}Th/^{232}Th] (x 10^{-6}) [d]	$\delta^{234}U_{initial}$ corrected [b]	^{230}Th Age uncorrected	^{230}Th Age corrected [c,e]	Chemistry Date (AD)	Chemistry Date (AD)	Date (AD) of Sample Growth	[^{230}Th/^{232}Th]$_0$ (x 10^{-6}) [e]
BUN-3-B2 (1)	0.641	1821 ± 3	1529 ± 3	142.9 ± 2.1	0.00547 ± 0.00008	107.7 ± 1.6	143.1 ± 2.1	524.2 ± 7.8	465 ± 42	2006/12/21	2007.0	**1542.0 ± 42.0**	10.8 ± 11.9
BUN-3-B2 (2)	0.810	2075 ± 5	813 ± 3	142.1 ± 2.9	0.00525 ± 0.00010	221.3 ± 4.4	142.3 ± 2.9	503 ± 10	*sample age and initial thorium ratio determined by 3-D isochron method*				
BUN-3-B2 (3)	0.571	1999 ± 3	912 ± 2	145.8 ± 1.9	0.00517 ± 0.00008	186.9 ± 2.9	146.0 ± 1.9	493.3 ± 7.7					
BUN-3-B2 (4)	0.434	2179 ± 3	1241 ± 3	145.8 ± 2.0	0.00519 ± 0.00007	150.3 ± 1.9	146.0 ± 2.0	495.3 ± 6.4					
BUN-4-A1	0.102	1857 ± 2	1842 ± 8	144.8 ± 1.5	0.00507 ± 0.00008	84.4 ± 1.4	145.0 ± 1.5	484.6 ± 7.8	447 ± 38	2007/10/24	2007.8	**1560.5 ± 38.1**	6.5 ± 6.5
BUN-5-A1	0.101	2513 ± 2	1511 ± 8	145.4 ± 1.5	0.00641 ± 0.00006	176.2 ± 1.9	145.7 ± 1.5	613.1 ± 5.9	591 ± 23	2007/10/24	2007.8	**1417.2 ± 23.3**	6.5 ± 6.5
BUN-6-A1	0.119	2183 ± 2	359 ± 6	144.4 ± 1.5	0.00636 ± 0.00006	638 ± 12	144.6 ± 1.5	608.2 ± 5.5	602.0 ± 8.3	2007/10/24	2007.8	**1405.8 ± 8.3**	6.5 ± 6.5
BUN-6-B1	0.100	2352 ± 4	1301 ± 4	145.5 ± 2.6	0.00640 ± 0.00005	190.8 ± 1.4	145.7 ± 2.6	611.3 ± 4.6	591 ± 21	2008/10/13	2008.8	**1418.2 ± 21.3**	6.5 ± 6.5
BUN-7-A1	0.100	2418 ± 2	664 ± 7	143.9 ± 1.2	0.00658 ± 0.00007	395.7 ± 5.9	144.1 ± 1.2	630.1 ± 6.4	620 ± 12	2007/10/24	2007.8	**1388.0 ± 12.1**	6.5 ± 6.5
BUN-7-B2	0.115	2090 ± 3	1962 ± 5	145.4 ± 2.2	0.00703 ± 0.00006	123.7 ± 1.1	145.7 ± 2.2	672.3 ± 5.9	637 ± 36	2008/10/13	2008.8	**1371.7 ± 35.7**	6.5 ± 6.5
BUN-7-C2 (1)	0.094	2460 ± 4	5328 ± 14	147.0 ± 2.2	0.00779 ± 0.00009	59.4 ± 0.7	147.3 ± 2.2	744.5 ± 8.7	663 ± 82	2008/10/13	2008.8	1345.5 ± 81.7	6.5 ± 6.5
BUN-7-C2 (2)	0.101	2406 ± 4	5625 ± 15	143.1 ± 2.3	0.00784 ± 0.00009	55.4 ± 0.7	143.3 ± 2.3	751.2 ± 9.1	663 ± 88	2008/10/13	2008.8	1345.5 ± 88.4	6.5 ± 6.5
BUN-7-C2 (3)	0.102	2469 ± 3	5925 ± 14	143.1 ± 2.3	0.00789 ± 0.00009	54.3 ± 0.6	143.3 ± 2.3	756.2 ± 8.7	666 ± 91	2008/10/13	2008.8	1342.9 ± 90.7	6.5 ± 6.5
BUN-7-C2 (4)	0.125	2512 ± 6	6154 ± 14	150.5 ± 2.9	0.00786 ± 0.00009	53.0 ± 0.6	150.7 ± 2.9	748.6 ± 8.7	657 ± 92	2008/10/13	2008.8	1351.8 ± 92.0	6.5 ± 6.5
										weight-averaged age		***1346.3 ± 44.0***	
BUN-8-A2 (1)	0.092	3049 ± 3	4082 ± 12	144.9 ± 1.5	0.00629 ± 0.00007	77.6 ± 0.9	145.1 ± 1.5	601.9 ± 7.0	569 ± 15	2007/10/24	2007.8	**1438.8 ± 15.0**	4.2 ± 1.5
BUN-8-A2 (2)	0.090	2925 ± 5	4316 ± 13	144.2 ± 2.5	0.00633 ± 0.00007	70.8 ± 0.8	144.4 ± 2.5	605.7 ± 6.8	*sample age and initial thorium ratio determined by 3-D isochron method*				
BUN-8-A2 (3)	0.102	3098 ± 5	7373 ± 21	144.1 ± 2.4	0.00656 ± 0.00008	45.5 ± 0.5	144.3 ± 2.4	627.7 ± 7.4					
BUN-8-A2 (4)	0.118	2890 ± 5	4742 ± 12	144.7 ± 2.6	0.00638 ± 0.00007	64.2 ± 0.7	145.0 ± 2.6	610.5 ± 6.5					
BUN-8-C1 (1)	0.097	2925 ± 4	10245 ± 26	146.5 ± 2.2	0.00618 ± 0.00010	29.1 ± 0.5	146.7 ± 2.2	589.8 ± 9.4	568 ± 23	2008/10/13	2008.8	**1440.8 ± 23.0**	1.2 ± 1.0
BUN-8-C1 (2)	0.094	2966 ± 3	16767 ± 48	146.5 ± 1.7	0.00634 ± 0.00013	18.5 ± 0.4	146.8 ± 1.7	606 ± 12	*sample age and initial thorium ratio determined by 3-D isochron method*				
BUN-8-C1 (3)	0.123	2850 ± 3	9016 ± 22	147.2 ± 1.7	0.00617 ± 0.00009	32.2 ± 0.5	147.4 ± 1.7	589.0 ± 8.9					
BUN-8-C1 (4)	0.106	2848 ± 4	10800 ± 28	147.9 ± 2.1	0.00625 ± 0.00009	27.2 ± 0.4	148.1 ± 2.1	596.0 ± 8.6					
BUN-9A-A1	0.111	2476 ± 3	833 ± 7	146.2 ± 1.6	0.01060 ± 0.00007	519.7 ± 5.2	146.6 ± 1.6	1,014.2 ± 6.4	1,002 ± 14	2007/10/24	2007.8	**1006.2 ± 14.2**	6.5 ± 6.5
BUN-9D-A2 (1)	0.099	2677 ± 2	22731 ± 93	145.0 ± 1.4	0.01263 ± 0.00024	24.6 ± 0.5	145.3 ± 1.4	1,211 ± 23	1,150 ± 44	2007/10/24	2007.8	**857.8 ± 44.0**	1.6 ± 1.4
BUN-9D-A2 (2)	0.083	2567 ± 4	21109 ± 66	145.9 ± 2.5	0.01292 ± 0.00018	25.9 ± 0.4	146.3 ± 2.6	1,238 ± 17	*sample age and initial thorium ratio determined by 3-D isochron method*				
BUN-9D-A2 (3)	0.097	2449 ± 5	32700 ± 134	147.0 ± 2.7	0.01331 ± 0.00025	16.5 ± 0.3	147.4 ± 2.7	1,274 ± 24					
BUN-9D-A2 (4)	0.126	2636 ± 5	37697 ± 188	144.2 ± 2.5	0.01344 ± 0.00028	15.5 ± 0.3	144.5 ± 2.5	1,290 ± 27					

For a discussion of the ICP-MS method, see *Shen et al.* [2002]. Analytical errors are 2σ of the mean.

[a] $\delta^{234}U = ([^{234}U/^{238}U]_{activity} - 1) \times 1000$.

[b] $\delta^{234}U_{initial}$ corrected was calculated based on ^{230}Th age (T), i.e., $\delta^{234}U_{initial} = \delta^{234}U_{measured}\ X\ e^{\lambda 234 * T}$, and T is corrected age.

[c] $[^{230}Th/^{238}U]_{activity} = 1 - e^{-\lambda 230\, T} + (\delta^{234}U_{measured}/1000)[\lambda_{230}/(\lambda_{230} - \lambda_{234})](1 - e^{-(\lambda 230 - \lambda 234)\, T})$, where T is the age.

Decay constants are 9.1577×10^{-6} yr^{-1} for ^{230}Th, 2.8263×10^{-6} yr^{-1} for ^{234}U, and 1.55125×10^{-10} yr^{-1} for ^{238}U [*Cheng et al.*, 2000].

[d] The degree of detrital ^{230}Th contamination is indicated by the [^{230}Th/^{232}Th] atomic ratio instead of the activity ratio.

[e] Except where isochron techniques were used to determine the ages and initial ^{230}Th/^{232}Th atomic ratios, the initial ^{230}Th/^{232}Th atomic ratio is assumed to be 6.5 ± 6.5 x10^{-6} [*Zachariasen et al.*, 1999].

Dates of Presumed Uplift of Individual Coral Heads **Table S3**

Sample ID	Date of Sample (AD)	Preserved Bands after Sample	Date of Outer Band (AD)	Slab Weighted Mean Date of Outer Band	Inferred Number of Missing Bands	Slab Weighted Mean Date of Coral Death	Outer Rim Elevation (cm) above Pre-20050328 HLG	
BUN-3-B2	1542.0 ± 42.0	26.5 ± 0.5	1568.5 ± 42.0	**1568.5 ± 42.0**	2.0 ± 2.0	**1570.5 ± 42.1**	56.7	tilted and settled **
BUN-4-A1	1560.5 ± 38.1	14.5 ± 0.5	1575.0 ± 38.1	**1575.0 ± 38.1**	38.5 ± 2.0	**1613.5 ± 38.1**	66.4	inner of double rim
BUN-5-A1	1417.2 ± 23.3	18.5 ± 0.5	1435.7 ± 23.3	**1435.7 ± 23.3**	2.0 ± 2.0	**1437.7 ± 23.4**	76.3	where less eroded
BUN-6-A1	1405.8 ± 8.3	55.0 ± 0.5	1460.8 ± 8.3	**1468.3 ± 7.7**	2.0 ± 2.0 *	**1470.3 ± 8.0 ***	-5.8	fairly eroded
BUN-6-B1	1418.2 ± 21.3	99.5 ± 0.5	1517.7 ± 21.3					
BUN-7-A1	1388.0 ± 12.1	31.0 ± 0.5	1419.0 ± 12.2	**1423.0 ± 11.1**	2.0 ± 2.0	**1425.0 ± 11.3**	76.0	crown of outer rim has sustained substantial erosion, esp. near slab
BUN-7-B2	1371.7 ± 35.7	64.5 ± 0.5	1436.2 ± 35.7					
BUN-7-C2	1346.3 ± 44.0	109.0 ± 0.5	1455.3 ± 44.0					
BUN-8-A2	1438.8 ± 15.0	52.5 ± 0.5	1491.3 ± 15.0	**1479.4 ± 12.6**	2.0 ± 2.0 *	**1481.4 ± 12.7 ***	9.1	outer preserved rim
BUN-8-C1	1440.8 ± 23.0	10.5 ± 0.5	1451.3 ± 23.0					
BUN-9A-A1	1006.2 ± 14.2	12.0 ± 0.5	1018.2 ± 14.2	**1017.0 ± 13.7**	5.0 ± 5.0	**1022.0 ± 14.6**	-11.6	fairly eroded
BUN-9D-A2	857.8 ± 44.0	140.0 ± 35.0	997.8 ± 56.2					

* *Although BUN-6 and BUN-8 are each listed as missing 2 ± 2 outer bands, the real number may be much higher. The outer part of each of those heads was very thin; it is possible that tens of bands or even >100 additional bands originally grew, but broke off and were subsequently transported away. Also, either of those heads may have plausibly died for reasons other than a tectonic diedown, considering their thin perimeters.*

** *The original pre-tilting elevation of BUN-3 can be determined by comparison with BUN-4; see text for details.*

Weighted Average Dates of Presumed Uplift Events **Table S4**

Pre-Historical Event	Site	Head	Date of Tectonic Diedown (AD)		
			Per Head	Site Avg	All-Site Avg
Central Simeulue: AD 1420s–1430s *(assuming a single diedown)*	BUN BUN BUN	BUN-5 BUN-7 BUN-8	1437.7 ± 23.4 1425.0 ± 11.3 1434.9 ± 12.6 *	1430.4 ± 7.9	**1430.4 ± 7.9**
Central Simeulue: AD 1420s–1430s *(assuming dual diedowns; this is the date of the first and larger of the two)*	BUN BUN BUN	BUN-5 BUN-7 BUN-8	1437.7 ± 23.4 1425.0 ± 11.3 1426.9 ± 12.7 º	1427.2 ± 8.0	**1427.2 ± 8.0**
Central Simeulue: early AD 1600s	BUN BUN	BUN-3 BUN-4	1570.5 ± 42.1 1613.5 ± 38.1	1594.1 ± 28.2	**1594.1 ± 28.2**

* *This date is 44.5 ± 0.5 years prior to the date of the outer edge of slab BUN-8.*
º *This date is 52.5 ± 2.0 years prior to the date of the outer edge of slab BUN-8.*

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