Eastern Denali Fault Slip Rate and Paleoseismic History, Kluane Lake Area, Yukon Territory, Canada

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YUKON GEOLOGICAL SURVEY

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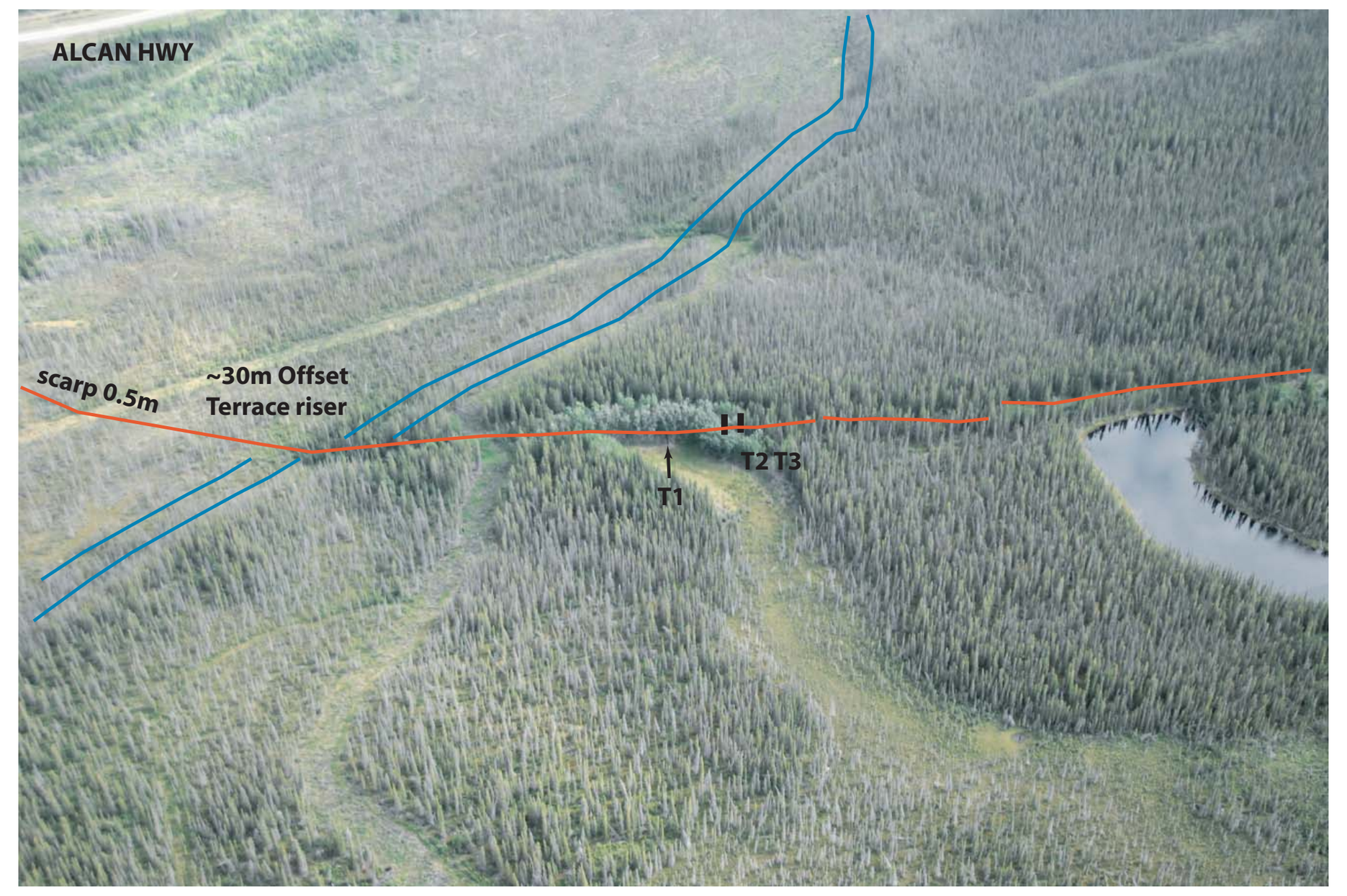
In 2002, the central part of the dextral-slip Denali fault (DF) system generated a M 7.9 earthquake in central Alaska. This rupture included the section of the Denali fault with the highest measured late Pleistocene slip rate, of 12.1±1.7 mm/yr, and the Totschunda fault, with a slip rate of 6.0±1.2 mm/yr. Immediately east of the Denali-Totschunda fault juncture, the slip rate on the eastern Denali fault (EDF) decreases to 8.4±2.2 mm/yr. We present observations of Holocene fault activity on the Yukon part of the EDF (Shakwak segment), which is located about 280 km southeast of the Denali-Totschunda intersection in the vicinity of Kluane Lake.

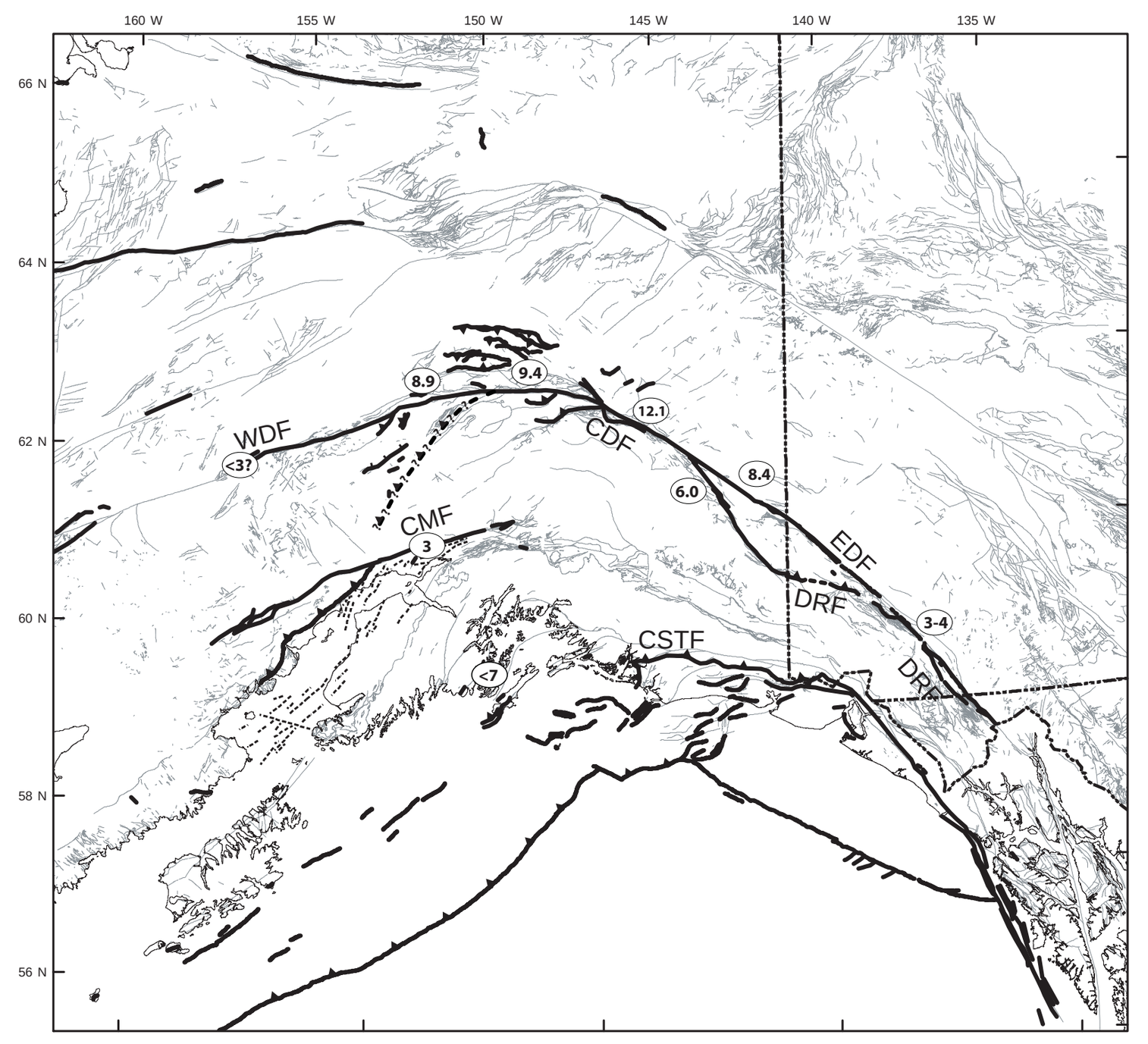
Aerial reconnaissance in 2007, from the Denali-Totschunda fault juncture to the Kluane Lake region revealed a nearly continuously identifiable fault trace, which is occasionally obscured where it is subparallel to glacial landforms. In addition to geomorphic features associated with strike-slip faults, such as shutter ridges and sag ponds, the fault is commonly expressed by a chain of elongate mounds, likely tectonic pushups, 20-70 m in length, 10-50 m wide, and locally up to 10 m high. These appear to have formed by shortening between en echelon left-stepping fault strands that developed in layered glacial sediments. At one location (61degrees 18'30.12" N, 139 degrees 01'02.54"W) we measured on the ground a channel offset of 20-25 m. An aerial view showed that other channels in the vicinity, as well as the margins of two mounds, were offset by similar amounts. These channels likely developed after deglaciation 10-12 ka. Using this age and the offset yields a slip-rate range of 1.7-2.5 mm/yr, a minimum value. *Although there are considerable uncertainties concerning the uplift of these mounds, their dimensions suggest that they accomodate several large magnitude displacements. Combined with the new recurrence interval results which average1 ka, a higher slip rate in the 3-4 mm range appears likely. We attempt to capture the entire range of slip-rate possiblities in a surface deformation fault slip rate model, that includes both the uncertainty in age and offset value., an results in an upper limit of about 6 mm/yr.*

Adjacent to and south of the Duke River, an approximately 2-km-long section of the fault is expressed by an upslope southwest-facing 9-m-high scarp. In 2008 we targeted this location (61degrees 21'54.36"N,139 degrees 07'59.34"W) with three cross-fault excavations that exposed deformed sediments. Evidence for at least 3 paleoearthquakes was recognized in fissure fills, folding, and scarp-derived colluvium. Preliminary age control is provided by the two White River volcanic ashes (1.2 ka and 1.9 ka) exposed in the trenches and by unfaulted paleo-shorelines of Alsek and Kluane Lakes, which others suggest have an age of 0.3-0.5 ka, respectively. The most recent event post-dates the 1.2 ka White River ash and occurred prior to formation of the 0.3 ka and 0.5 ka shorelines. The older events pre-date the 1.9 ka White River ash. *12 AMS radiocarbon dates provide a well constrained record of the most recent 3 earthquakes at: 970 BC, 230 BC and 1050 AD.* Although the ages of the two older events are uncertain, trench and field relations suggest that the most recent event (MRE) occurred close in time to deposition of the 1.2 ka ash. The observations of a lower slip rate on the eastern Denali fault in the Yukon are consistent with previous regional tectonic models. The occurrence of at least three surface-rupturing paleoearthquakes in late Holocene time, and a significant elapsed time since the MRE, emphasizes the need for proper seismic design of proposed natural gas pipelines in this region.

Italics indicate updates from the submitted abstract.



Airphoto of the Trench Site. We selected a site that has a prominent closed depression formed in part by an uphill facing scarp on the order of 8 m in height. We excavated cross-fault trenches. Two trenches presented here show clear evidence for 3 earthquakes, and a possible older 4th event. The underlying sediments are glacial till, and possibly alluvium. West of the site there is an offset terrace riser, which represents a future target for a slip rate determination.



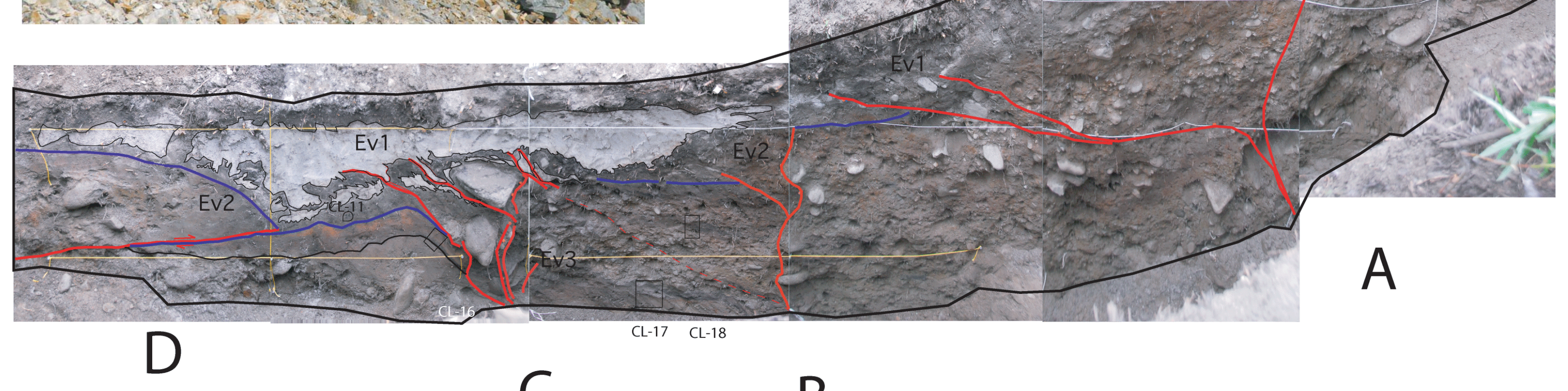
Fault Map of Alaska and the Yukon. The Denali fault has a maximum slip rate in it's central portion. The Eastern Denali fault defined on the west end by the Totshunda fault junction, has it's maximum slip rate at this west end. It appears that the fault slip rate decreases by about 50 % to the east, at the location of Kluane Lake. The 3-4mmestimate is from our investigation presented here. The Denali fault slip rates are largely from Matmon et al. 2006: Geology; August 2006; v. 34; no. 8; p. 645-648.

Events

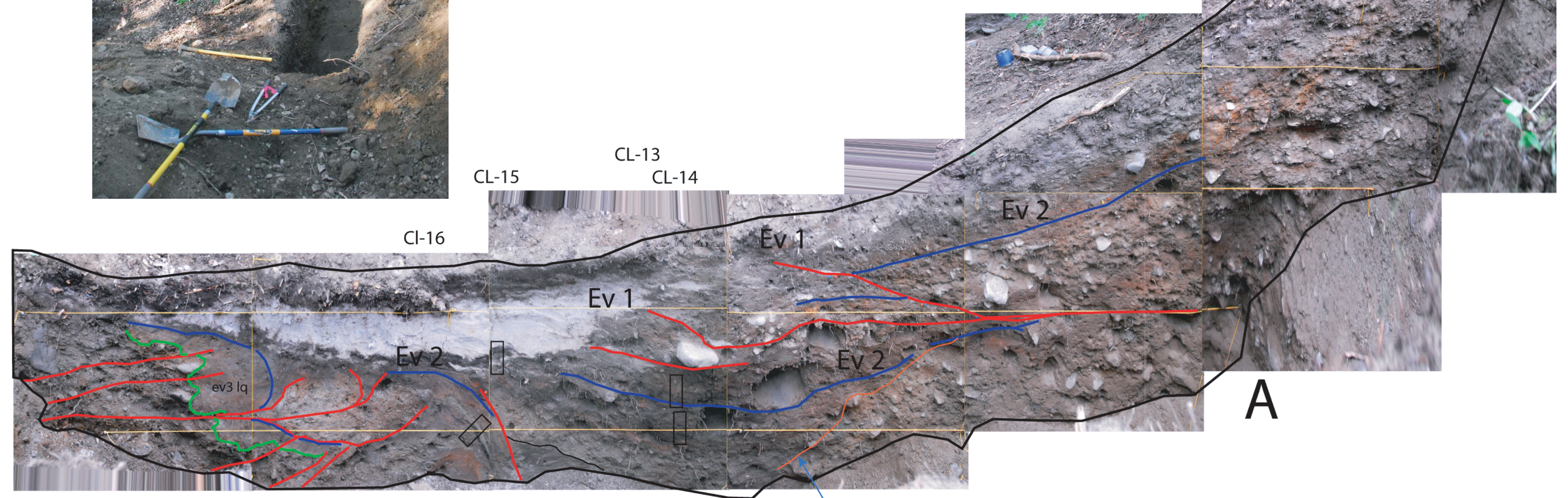
Faut Scarp near T1. View to the west.

Fault Scarp Zone between the site and Crescent Lake

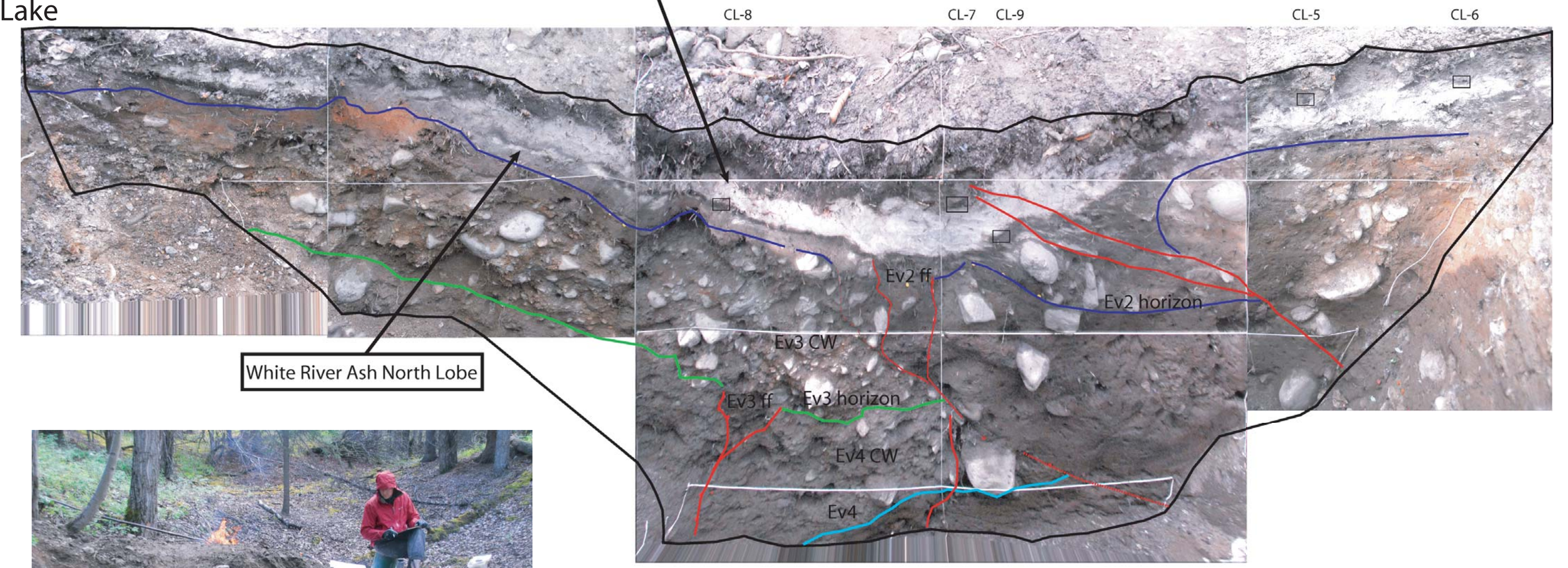
T3 east reversed



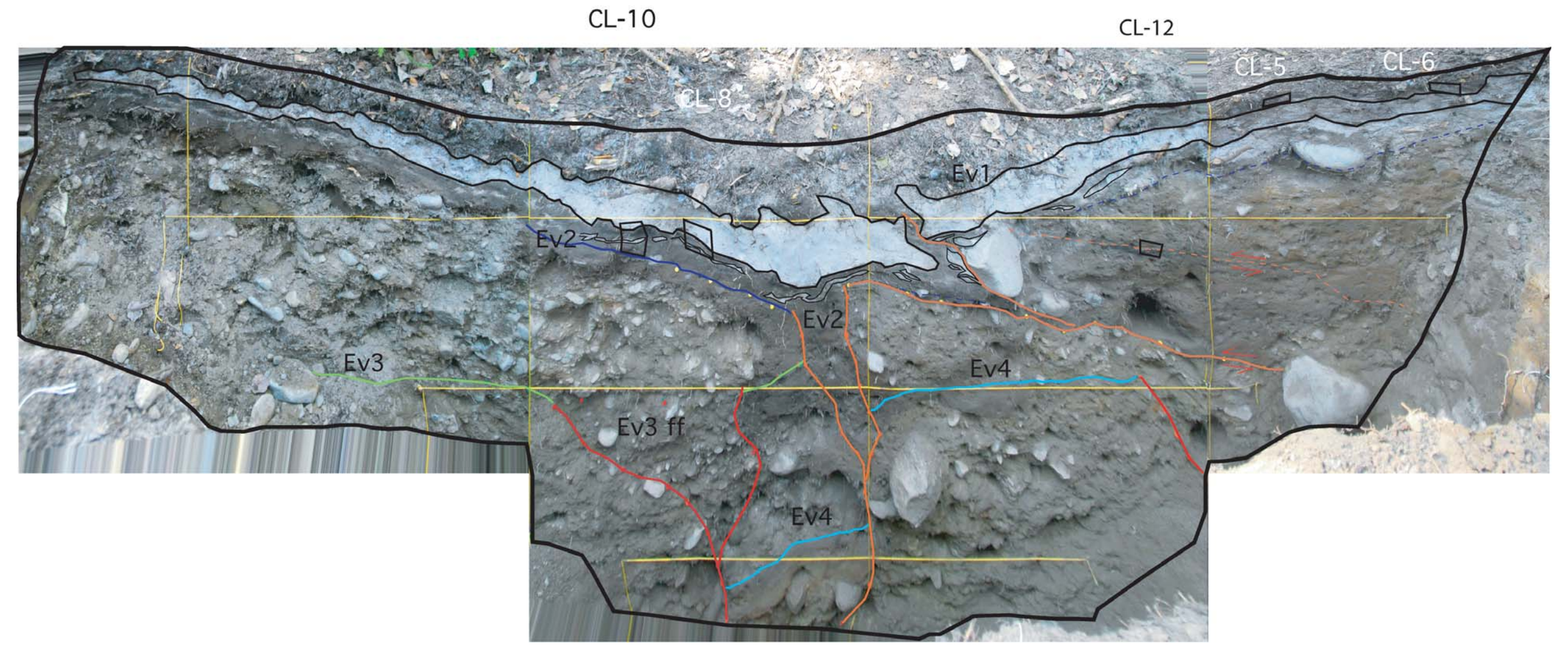
T3 west

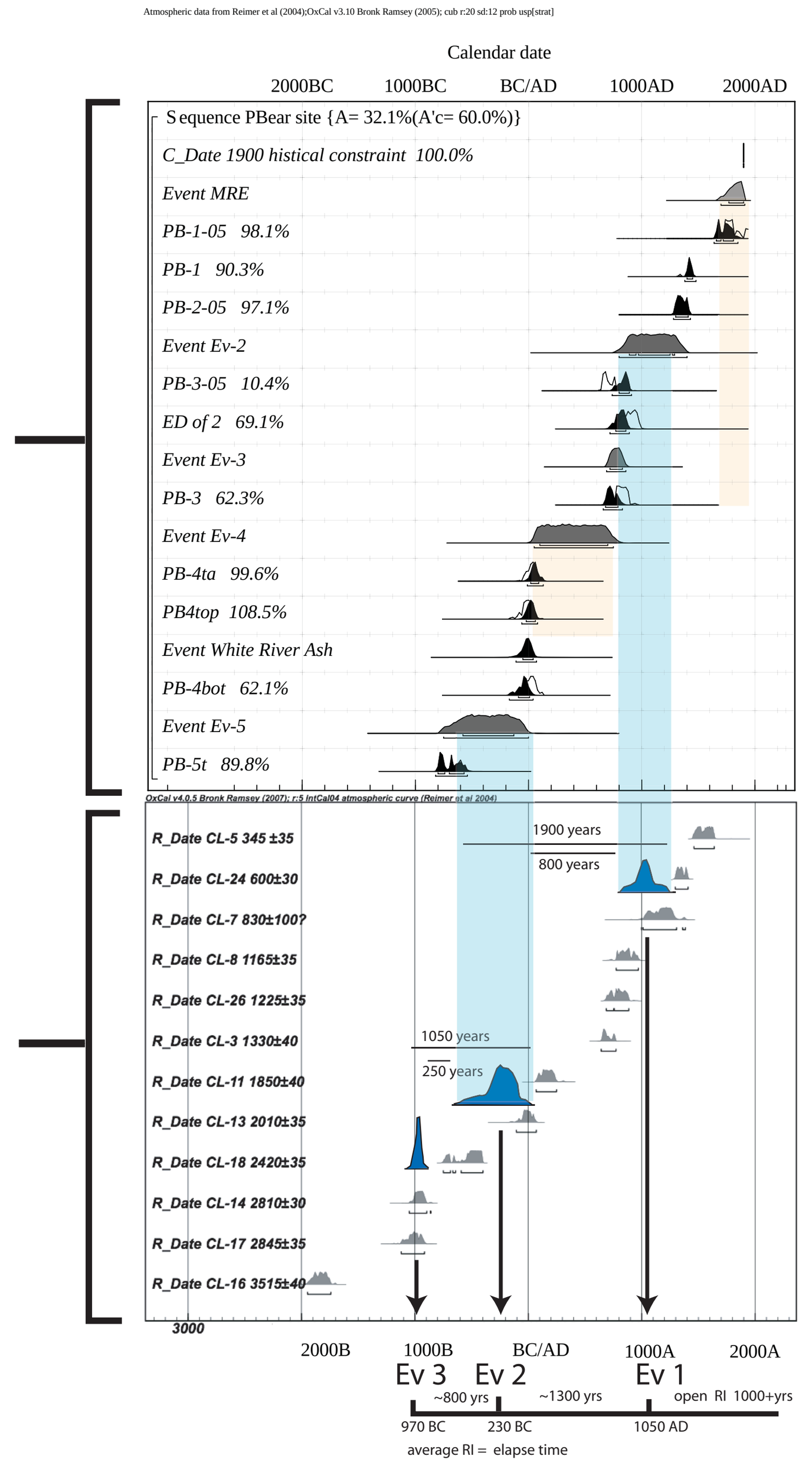


T2 east reversed



T2 west



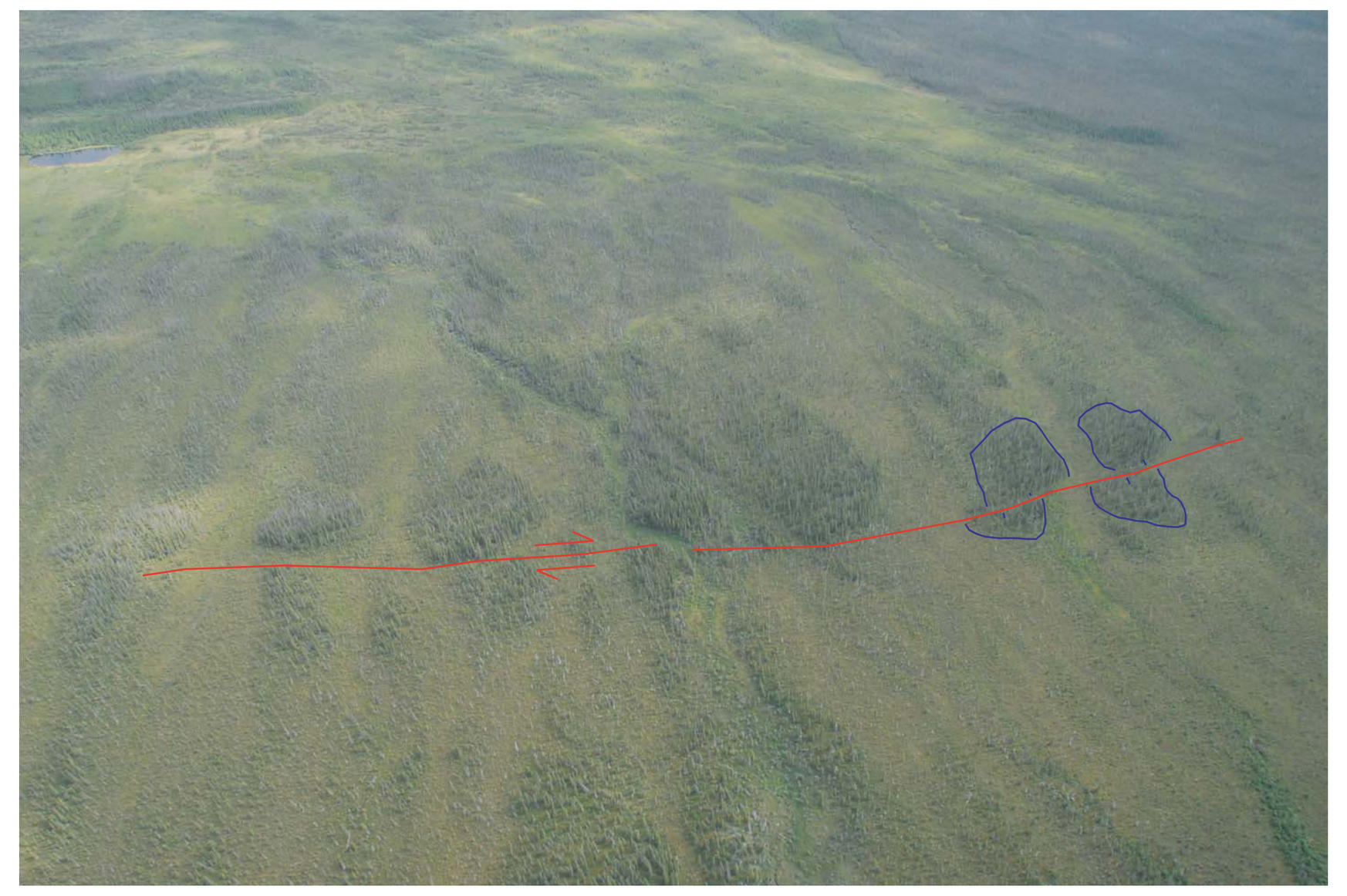


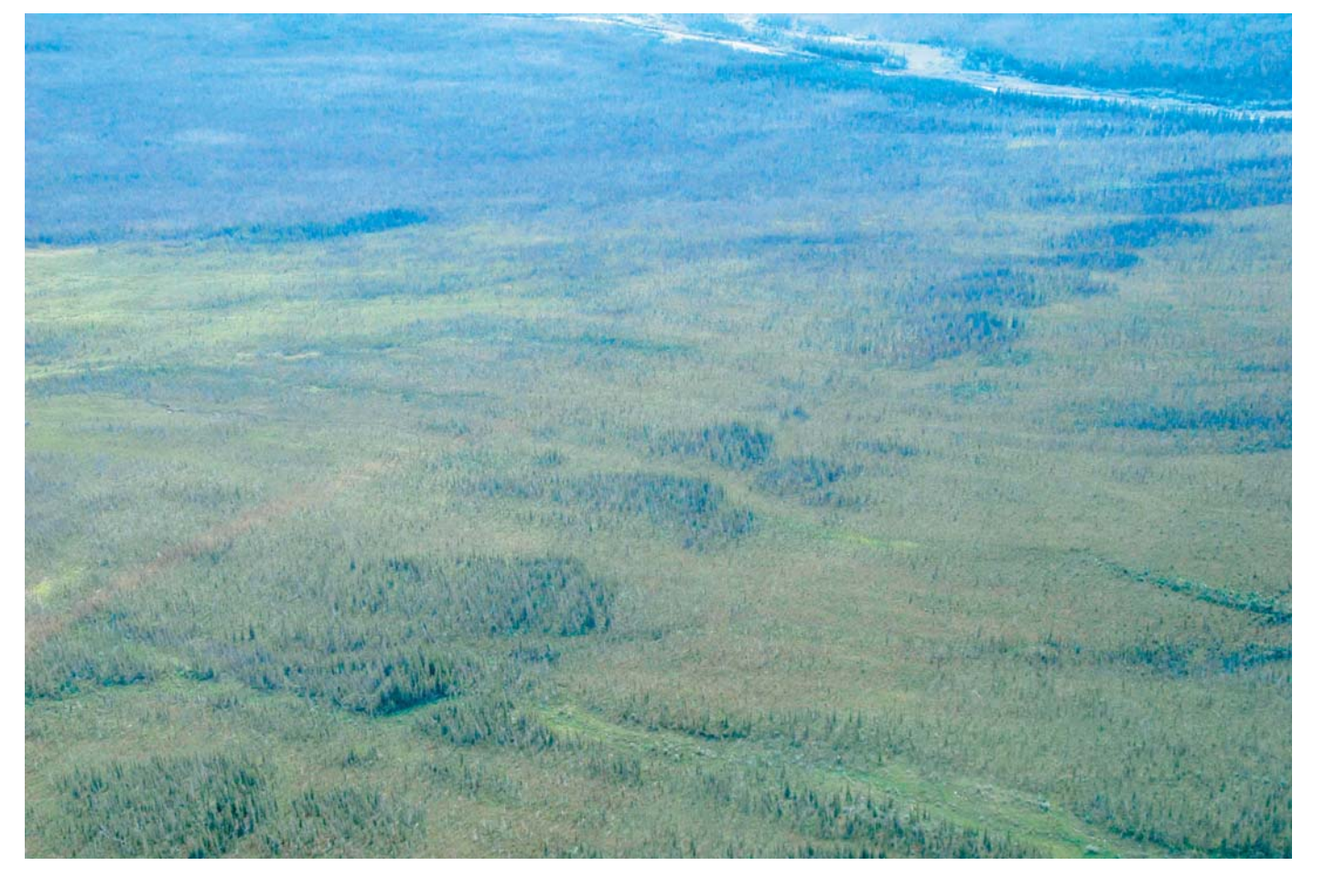
Eastern Denali Fault Paleoseismic Records. Our new Crescent Lake site is shown below, and our previous Pooh Bear site is shown above. The X-axis is calendar age; the Y-axis is a stratigraphically ordered list of radiocarbon dates. To the right of each date are the calibrated age probability density functions. Paleoseismic events are shown as blue or gray probability density functions. The vertical bars indicate potential correlations (light blue) and non-correlations (light orange) of surface ruptures between the westernmost Denali Fault, Alaska and the East Denali Fault, Yukon. These two sites are 260 km apart.

Paleoseismic Evidence

Incremental down-section increase in deformation shows clear evidence for 3 and possibly 4 events. Individual event evidence features consist of fissure fills, folding, scarp-derived colluviums, upward terminations and stratigraphic mismatches. We present the photo logs from two trenches excavated to the permafrost. Each grid is 1 m horizontal by 0.5 m vertical. The view is to the west with east logs reversed. Radiocarbon sample locations used for age control are shown. Near the top of the section two White River Ash deposits provide additional age control. Our new dates are consistent with published ages of these two eruptions at 1.2 ka and 1.9 ka.

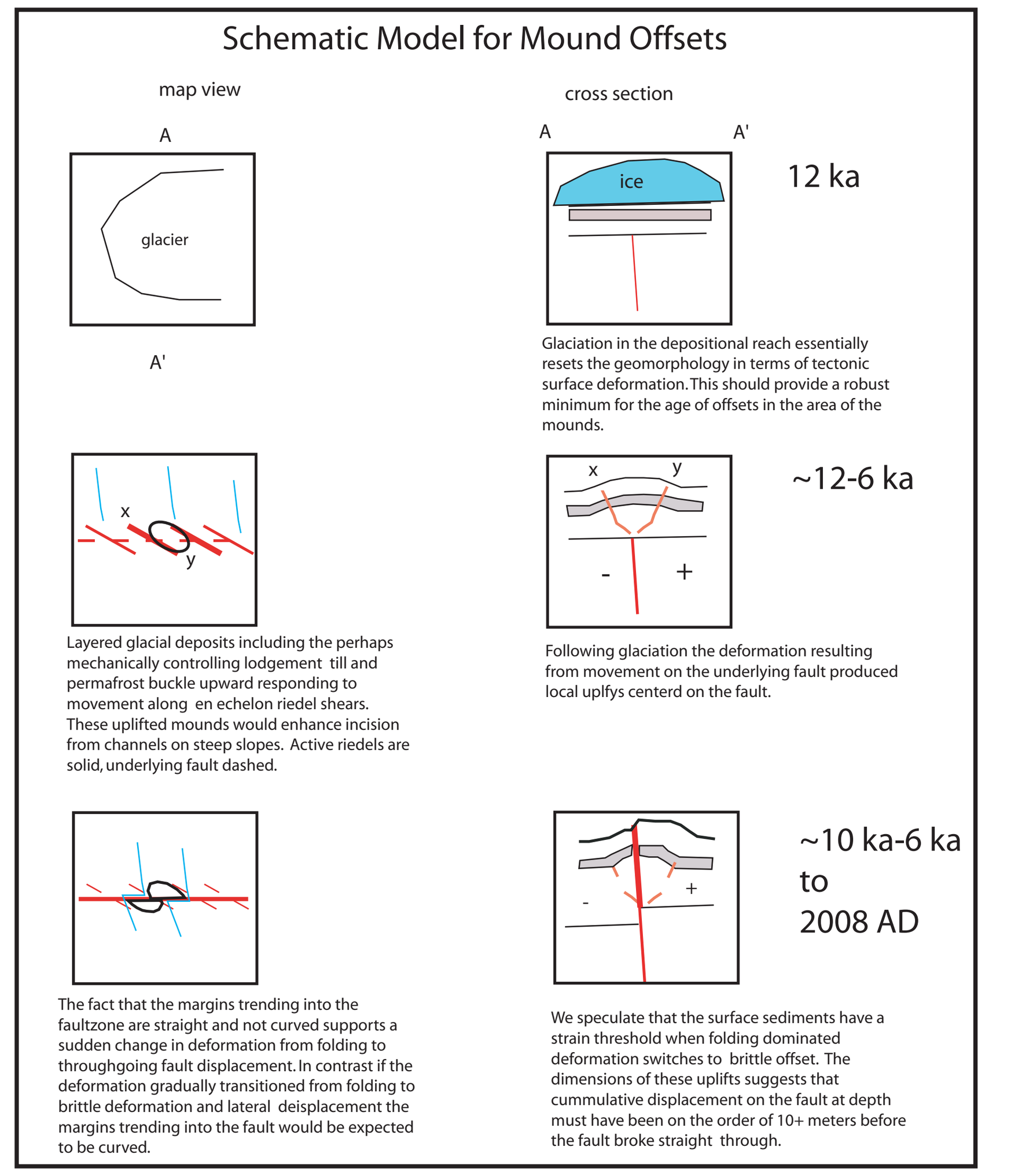
Slip Rate





Along the range front, on this previously glaciated (12 ka) valley floor, the fault is expressed by a series of faultzone uplifts. Although the fault trends semi parallel to the grain of the glacial landforms, the fault can be clearly distinguished by cross cutting these at a low angle. We did not clearly identify offset glacial landforms, however, the tectonic uplifts have been offset. A few km east of the trench site we observed several tectonic mounds that are clearly right-laterally offset. We made field measurements of two of these offsets. The measurement range is indicated on the slip rate model figure.

Schematic Model for Mound Offsets



Glaciation in the depositional reach essentially resets the geomorphology in terms of tectonic surface deformation. This should provide a robust minimum for the age of offsets in the area of the mounds.

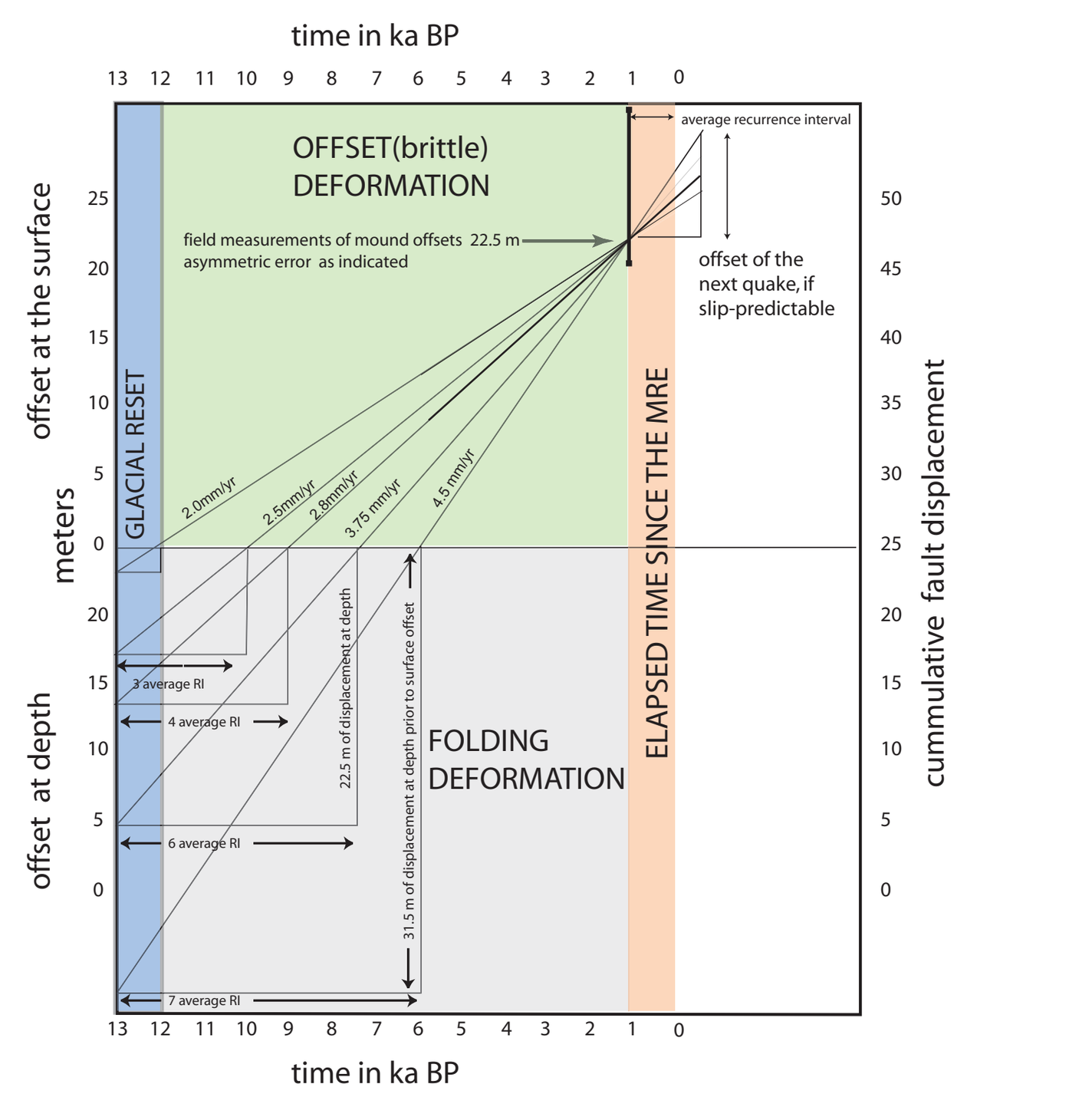
Layered glacial deposits including the perhaps mechanically controlling lodgement till and permafrost buckle upward responding to movement along en echelon riedel shears. These uplifted mounds would enhance incision from channels on steep slopes. Active riedels are solid, underlying fault dashed.

Following glaciation the deformation resulting from movement on the underlying fault produced local uplfys centerd on the fault.

The fact that the margins trending into the faultzone are straight and not curved supports a sudden change in deformation from folding to throughgoing fault displacement. In contrast if the deformation gradually transitioned from folding to brittle deformation and lateral deisplacement the margins trending into the fault would be expected to be curved.

We speculate that the surface sediments have a strain threshold when folding dominated deformation switches to brittle offset. The dimensions of these uplifts suggests that cummulative displacement on the fault at depth must have been on the order of 10+ meters before the fault broke straight through.

Surface Deformation Fault Slip Rate Model



Surface Deformation Fault Slip Rate Model. On this graph we illustrate the range of possible slip rates based on the age of initiating brittle offset. Because this area is in the depositional reach of the 12 ka valley glaciation, the landscape was essentially resShown are offset initiation times from 12 ka to 6 ka. Considering the dimensions of these mounds, we speculate that at least several earthquakes occurred folding the near surface sediments prior their offset. We used a 22.5 m average of the overlap of two field measurements. The actual offset value may be significantly higher as indicated. Until further refinements, given these considerations, a slip rate in the 3-4mm range appears most likely.

Tectonic faultzone uplift example from the Kunlun rupture 2001, Mw 7.8.Fu and Lin (2003).

Field measurements of the offsets shown in the top airphotos. We are in the process of a comprehensive airphoto analysis using higer quality imagery.

Conclusions

Our results clearly show that the East Denali fault is more active than previous publications concluded. The somewhat elusive tectonic geomorphic signature can be largely attributed to the pervasive glacial overprint of the landscape that occurred 12 ka ago, often with trends semi-parallel to the fault.

In the Kluane Lake reach of the East Denali fault we recognized the most recent event at 1050 AD, the 2nd event at 230 BC and a 3rd event at 970 BC. With the open interval to the present this equates to an average recurrence of 1000 years. The elapse time since the most recent event is equal to the average recurrence interval. Events 1 and 2 potentially correlate to events at the westernmost end of the East Denali fault, a distance of 260 km to the west. If these are the same surface ruptures, empirical rupture length to earthquake magnitude relationships indicate the events would be in the 7.5 Mw or greater range. Our slip rate estimate is on the order of 50% of the slip rate at the west end of the fault, where surface rupturing earthquakes are about twice as frequent.