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DATASETS, ADDITIONAL METHODOLOGY, AND OPTICALLY STIMULATED LUMINECESCE DATING

Elevation Datasets and Quaternary Mapping

The ~600 km^2 airborne lidar dataset (0.5-m-resolution) that aided our field mapping and profiling of Quaternary river terraces along the Sacramento River channel was acquired from the California State Department of Water Resources. A standard 10-m-DEM downloaded from the USGS elevation dataset was used for the portions of the study area not covered by the lidar dataset and aided field mapping and construction of the topographic profile traversing the older Quaternary units of the Red Bluff Formation (Fm) and Coleman Forebay basalt (Blake et al., 1999).

The four main river terraces (T1, T2, T3, and T4) mapped along the ~100 km stretch of the Sacramento River channel were differentiated based on prior mapping of Blake et al. (1999), along with relative height, surficial characteristics within the lidar, and soil development observed from natural exposures. The T1 and T2 terraces are the lowest set of terraces. The T1 terraces are cut-and-fill deposits that less than 3 m thick and have soils lacking a pedogenic B horizon. T1 surfaces form the lowest terraces surface, sitting ~3 m above the modern river, exhibits bar and swale topography, and are active during flood stage. The Pliocene bedrock straths of which these deposits lie on can be observed in the modern channel within the interpreted zones of uplift. We considered the T1 deposits to be Holocene in age. The T2 terraces are cut-and-fill deposits that are <5 m thick. T2 surfaces sit 2–4 m above T1 surfaces and are relatively smooth in character where undisturbed, however, the T2 surfaces are commonly disturbed by agriculture activity, covered by various nut and fruit orchards. The T2 deposits have soils that display a weak B-horizon and are considered late Pleistocene to Holocene in age. The T3 and T4 terraces are cut-and-fill deposits that are <10 m-thick and form the highest terrace surfaces within the river channel, sitting >10 m above the modern river. The T3 and T4 deposits lie on Pliocene and Red Bluff strath surfaces within the interpreted zones of uplift and thin to <3 m. We consider them as strath terraces in this zone. Soils developed within these deposits are distinctly red in color, have a Bt-horizon, and locally contain a Bqm (duripan) horizon, an illuvial silica cemented soil horizon (Birkland, 1984; Soil Survey Staff, 1996). Undisturbed T3 and T4 surfaces often have mounded topography and ponded water. The older T4 surfaces sit higher in elevation, have greater incision, sit 2 – 3 m above the the younger T3 surface, can be considered a strath terrace in the interpreted zones of uplift. The duripan soils developed within the T3 and T4 terrace deposits indicate these suggest these are relatively older surface (Flach et al., 1969).

Based on prior mapping of Blake et al. (1999), the T1 and T2 terraces correlate to the upper and lower members of the Modesto Fm (14 –42 ka) and the T3 and T4 correlate to the upper and lower members of the Riverbank Fm (130–450 ka) (Helley et al., 1981; Blake et al., 1999). We note that the nomenclature of these mapped formations is adopted from the San Joaquin river valley in southern CA (Marchand and Allwardt, 1981), where surfaces have been correlated predominately by soil characteristics (Steele, 1980).

Fluvial Terrace Profiling

River terrace profiles were constructed measuring the downstream distance along the center of the river, following a similar method to Merritts et al. (1994); whereby preserved terrace tread elevations were projected toward the center of the river following the general migration path of the river during abandonment (Fig. DR2). This method allows for the projection of terrace surfaces points where large sinuosity occur, and the river channel flows in the opposite general direction; whereas standard plotting of terrace surface points along a linear transect would overlap in this environment. Uncertainty lies within our method in two places. One, where terrace surface points may be incorrectly projected to the exact point on the river that they correspond to. The grade of the river through the study region is relatively low (~0.00077), thus elevation changes are minimal over small (<1 km) distances, decreasing the amount of uncertainty in this method this method. Second, results from unknown thickness changes along the terrace deposits. An additional minor element of uncertainty lies within the fluvial terrace surfaces, as many of the surface are anthropogenically disturbed and are inherently subject to differential erosion and deflation through time. To minimize this systemic uncertainty, we chose elevations to project to the river from terrace surfaces that appeared to be the least modified and deflated. Such surfaces are characterized by relatively finer grain sediments capping the terrace and have smooth continuous surfaces. As a result, this limits the amount of projections per terrace, especially for the older more incised terraces, but allows for more consistency. We estimate the approximate uncertainty is about ± 0.5 m in elevation for our terrace surface projections.

The surface elevations from the older Quaternary units (Qrb and Qcb) are plotted onto the profiles in Fig 3. by projecting their surface elevations along profile A-A' (Fig 2A/B) parallel to structure (Fig. DR2).

Optically Stimulated Luminescence Dating

Deposits from the T3 terrace were dated along the Sacramento River using analysis of optically stimulated luminescence (OSL) small aliquot measurements. Samples were obtained by hammering an opaque ~20 cm long plastic tube horizontally into a freshly cleaned outcrop or pit exposures at locations shown in Fig. 2A. The tube was packed tight, taped, sealed, and later processed and measured in the Luminescence Dating Laboratory at the University of Cincinnati. There, OSL samples were prepared following the methods described in Counts et al. (2015) and in detail below. The tubes were opened in the laboratory under amber light and the sediment was removed in the following way: 1) the sediment present at the extremities of the tubes (~5 cm for each end), was removed, separated, and kept aside for water content estimation and dose-rate measurements while 2) the sediment at the center of the tube was removed and reserved for the OSL. The sample corresponding to the extremities of the tubes, was weighted, fully dried and weighted again, to estimate their water content. An unbiased selection of the sample was crushed with an agate mill and sent to Actlabs for chemical analysis, in order to obtain U, Th, K and Rb concentrations, needed for dose-rate (D_R) determinations. For the equivalent dose (D_E)

measurements, we measured at least 20 aliquots in multi-grain steel disks in an automated Risø TL-DA-20 OSL reader. The single aliquot regeneration (SAR) method of Murray and Wintle (2000) was used to determine the D_E for age estimation. The sediment for OSL was pretreated with 10% HCl and then with 10% H_2O_2 to remove carbonates and organic. The sample was then rinsed with DIW (deionized water), dried at temperatures ≤40°C, and sieved. To etch the quartz surface grains and simultaneously dissolve feldspars and other existent silicates, the 90–150 µm fraction was treated with 48% HF for 60 minutes, rinsed with DIW and treated with 38% HCl for about 40 minutes to remove any fluorides left by the HF dissolution in the sample. Both processes were done in a magnetic stirring plate, so that the sample was constantly stirred. The sample was then rinsed with DIW, dried and subjected to a magnetic separation by a variable magnetic field (Franz isodynamic magnetic separator), to remove heavy minerals (generally magnetic) from the sample and grains with magnetic inclusions. After all referred laboratory treatments, aliquots for each sample were subjected to IRSL and OSL to test for feldspar presence and evaluate quartz quality; when necessary, the etching step was repeated.

The potential for partial bleaching (incomplete resetting) of quartz grains presents a common uncertainty with OSL dating of fluvial sediments using aliquots, resulting in high dispersion amongst the luminescence measurements and artificially older depositional ages (e.g., Rettenour, 2008). To address this issue, we perform statistical analysis of the D_E measurements using *RadialPlotter* (Verneesch, 2009) and apply appropriate age models dependent on the amount of dispersion within the measurements. For samples having >20% dispersion, we apply a 2-mixing model and utilize peak 1 as the representative age of deposition, and a weighted mean age is applied for samples with <20% dispersion. Sample information, measurements, and age results are presented in Table DR1.

OSL Sample Sites and abandonment age of the T3 terrace

Sample IC-WG-01 was collected from a roadcut exposure within the wind gap feature on the Inks Creek anticline structure (Fig 2A and 2C). The roadcut exposes an ~3-m-thick fining upward package of interbedded sands and gravels that overlay a Pliocene bedrock strath surface ~19 m above the modern river (Fig 3 and DR3). A well-developed soil, characterized by a rubified argillic B-horizon and prominent ~10-cm-thick underlying Bqm (duripan) horizon, is developed within the upper ~50 cm of the deposit, suggesting a relatively older surface (Flach et al., 1969). The sampled sediment was collected from a sand lens interbedded within coarse rounded gravels ~1.5 m below the T3 terrace surface (Fig DR3). Luminescence measurements of 32 aliquots yielded relatively high dispersion (46%), thus we apply a mixing age model providing an age of 20.4±2.0 ka (Table 1). This age result generally agrees with the presence of the duripan soil and is representative of deposition and places a maximum to the T3 terrace surface at this location.

Samples IC-BB-b and IC-BB-c were collected from a ~1-m-deep pit excavated into a well vegetated T3 terrace surface at ‘Big Bend’ (Fig 2A), that sits ~30 m above the modern river (Fig. 3). The pit exposes ~0.5 m of fine over bank deposits that overly a well-cemented unit of rounded weathered cobbles and pebbles interpreted to be Red Bluff Fm. (Fig. DR4). The samples were collected just above the Red Bluff Fm. strath, ~0.4 m below the surface. Samples IC-BB-b and IC-BB-c yielded low to moderate dispersion and provide weighted mean ages of 1.7±0.2 ka and 3.7±0.3 ka, respectively (Table DR2). The relatively shallow sampling depth imposed by the shallow strath surface and thus thin terrace deposit, provides low confidence in these Holocene age results. We interpret these young ages to reflect surface mixing due to surficial processes (e.g., burrowing, tree roots, etc.), and thus we do not consider these ages to be representative of deposition and do not consider them in our age assessment of the T3 terrace surface abandonment.

Sample IC-RBF-01 was collected from a vegetated stream cut of a T3 terrace deposit within an access limited neighborhood near the southern end of Iron Canyon within the interpreted zone of uplift (Fig. 3). The surface of the T3 terraces sits ~19 m above the modern river where disturbed surfaces exposed a soil displaying strong rubification and fragments of duripan (Fig. DR5). Excavation of the stream cut exposed a red colored rounded pebble conglomerate that overlays a package of well-sorted laminated very fine sand (Fig. DR5). The sample was collected ~1 m below the surface within the pebble conglomerate and yielded high dispersion (40%). We apply a mixing age model yielding an age of 2.6±0.2 ka (Table DR2). Little confidence is assigned to this age results due to significant dispersion in this sample (Table DR2). Furthermore, a Holocene age for this surface would conflict with the rubified duripan soil observed at the surface (Fig. DR5). On this basis, we interpret this age result not to be representative of deposition and do not consider it age assessment of the T3 terrace surface abandonment.

Sample IC-SRB-01 was collected from a road cut exposure of a T3 terrace deposit south of the city of Red Bluff, CA and outside the interpreted zone of uplift, where the surface sits ~12 meters above the modern river (Fig. 3). The cut exposes a massive small pebble matrix supported conglomerate that fines upward into finer overbank deposits that have a 10-20 cm-thick duripan soil horizon developed ~0.75 m below the surface (Fig. DR6). The sample was collected below the duripan horizon at 1.2 m depth, has low dispersion, and yields a weighted mean age of 34.7±2.9 ka. The low dispersion in this samples provides high confidence in this age result and is interpreted to be representative of deposition and provides a maximum to the surface.

Based on our interpretations above, we use the age range from samples IC-RB-01 (34.7±2.9 ka) and IC-WG-01 (20.4±2.0 ka) as a constraint to the age of surface abandonment of the mapped T3 terrace, yielding an average age of 27.7±9.3 ka. This age is consistent with the characteristic duripan soil in the T3 terraces and provides a maximum age to the T3 terrace surface abandonment. The relatively large uncertainty associated with this abandonment age is likely due to the large fluctuations of water level of the Sacramento River during flood event, such that a recently abandon terrace may progressively accumulate overbank deposits (sand and silt) as the river continues to incise. Thus, a tectonically uplifted terrace will appear to have a younger age as has lifted out of flood water reach quicker than a correlative terrace not being tectonically uplifted, which our age results support.

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Table DR1. OSL measurements and age modeling

Sample number	U	Th	K	Rb	Dose Rate (D_R)	Number of Aliquots	Dispersion	D_E measurements using weighted mean average*	Weighted mean Age $\pm 2\sigma$	D_E measurements using mixing model** for >20% dispersion	Mixing Model Age $\pm 2\sigma$
	(ppm)	(ppm)	(ppm)	(ppm)	(Gy/ka)		(%)	(Gy)	(ka)	(Gy)	(ka)
IC-WG-01	1.5	3.8	1.00	48	1.6 ± 0.1	32	46	44.9 ± 0.4	27.5 ± 1.6	33.2 ± 2.5	20.4 ± 2
IC-BB-b	2.3	5	1.30	55	2.2 ± 0.1	20	12	8.3 ± 0.4	3.7 ± 0.3	9.6 ± 0.2	4.3 ± 0.3
IC-BB-c	2.4	5.3	1.31	55	2.3 ± 0.1	23	19	4 ± 0.3	1.7 ± 0.2	4.6 ± 0.1	2.0 ± 0.1
IC-RBF-02	1.8	5.3	1.16	31	1.9 ± 0.1	20	40	2.6 ± 0.2	2.6 ± 0.2	4.8 ± 0.1	2.5 ± 0.2
IC-sRB-01	2	5.2	0.96	45	1.8 ± 0.1	42	8	62.6 ± 1.6	34.7 ± 2.3	64.4 ± 1.1	35.9 ± 2.2

*Used weighted mean age from statistical analysis using radial plotter (Verneesch, 2009)

**Used statistically determined peak 1 for mixing model

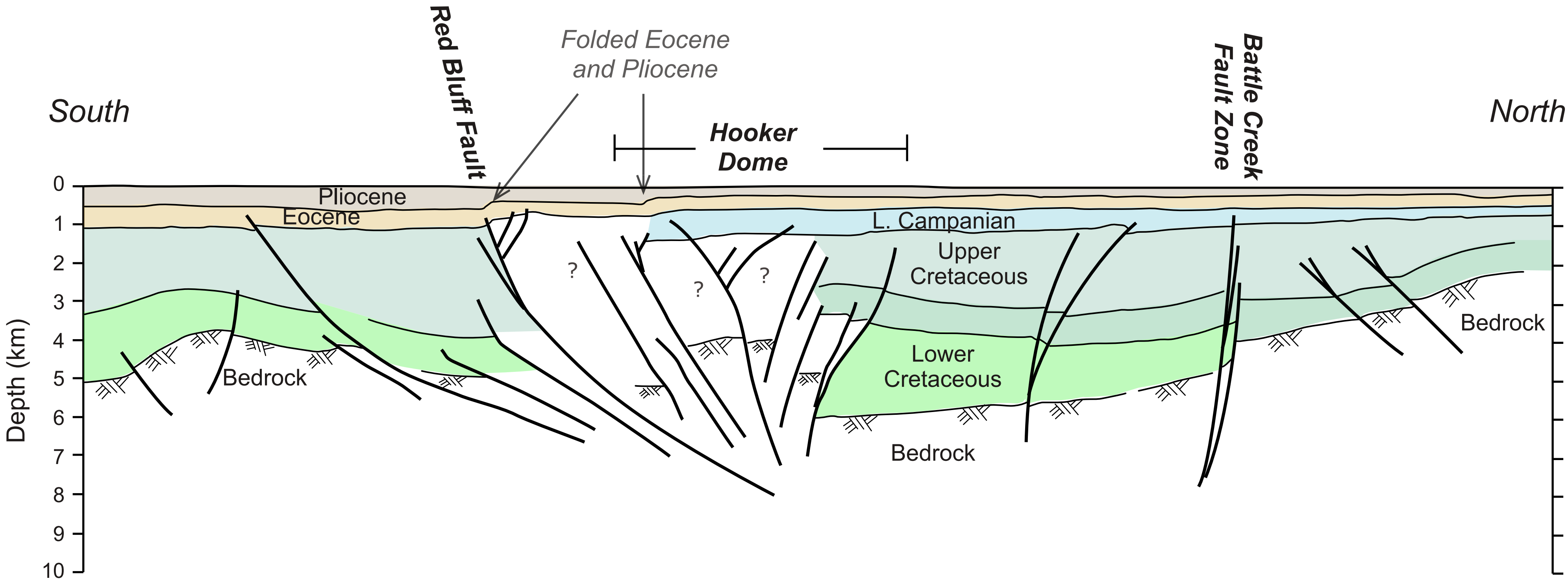


Figure DR1: Generalized cross section across study area, modified from Harlan Miller Tait (1984). The cross section was constructed from interpretations of several proprietary seismic reflection lines presented within the report.

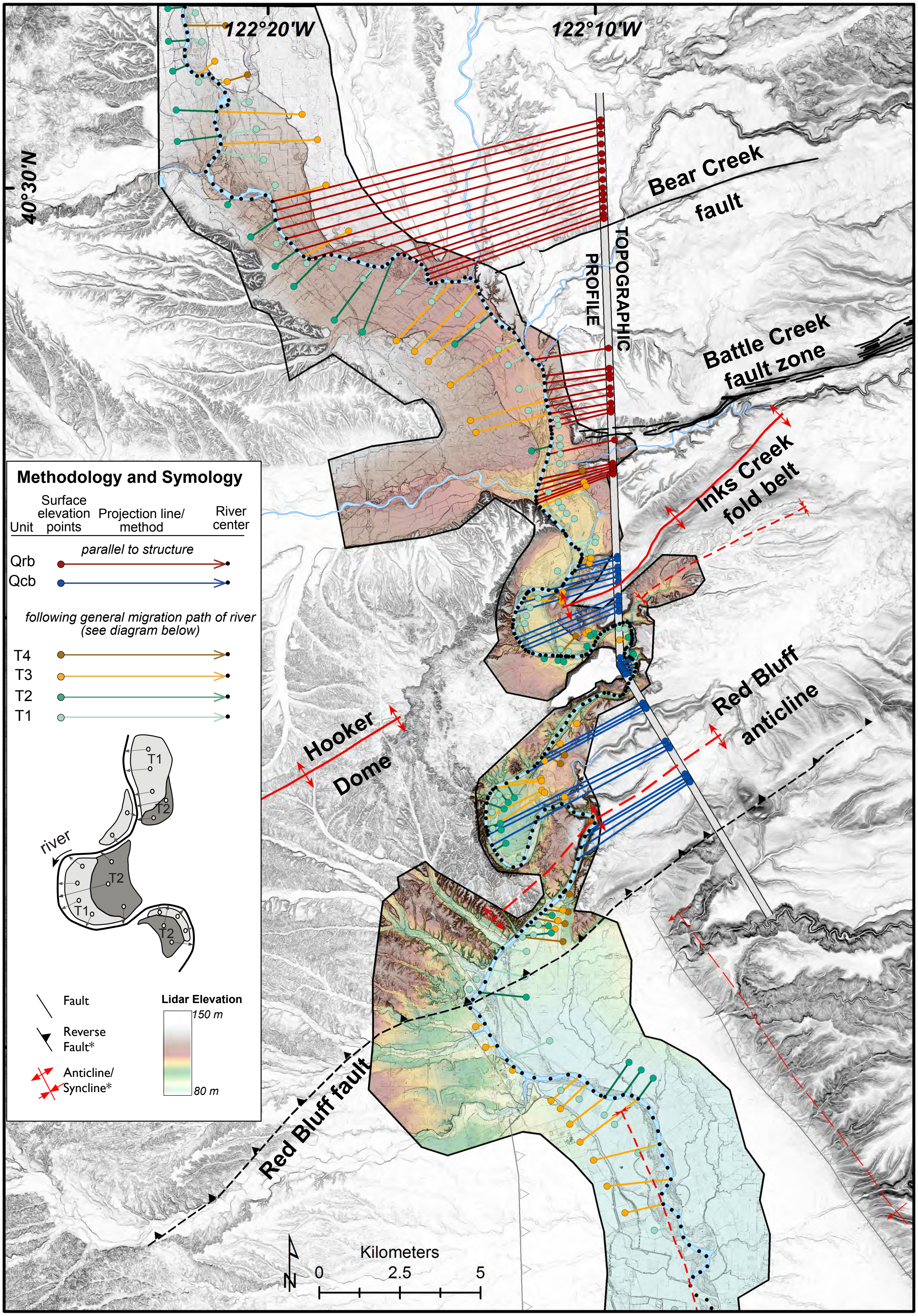


Figure DR2. Methodology and datasets used for construction of topographic and longitudinal terrace profiles. Lidar dataset (0.5 m) colored by elevation used for fluvial terrace profiles unlain by slopeshade image from10-meter DEM from USGS elevation dataset used for topographic profile.

Sample IC-WG_01

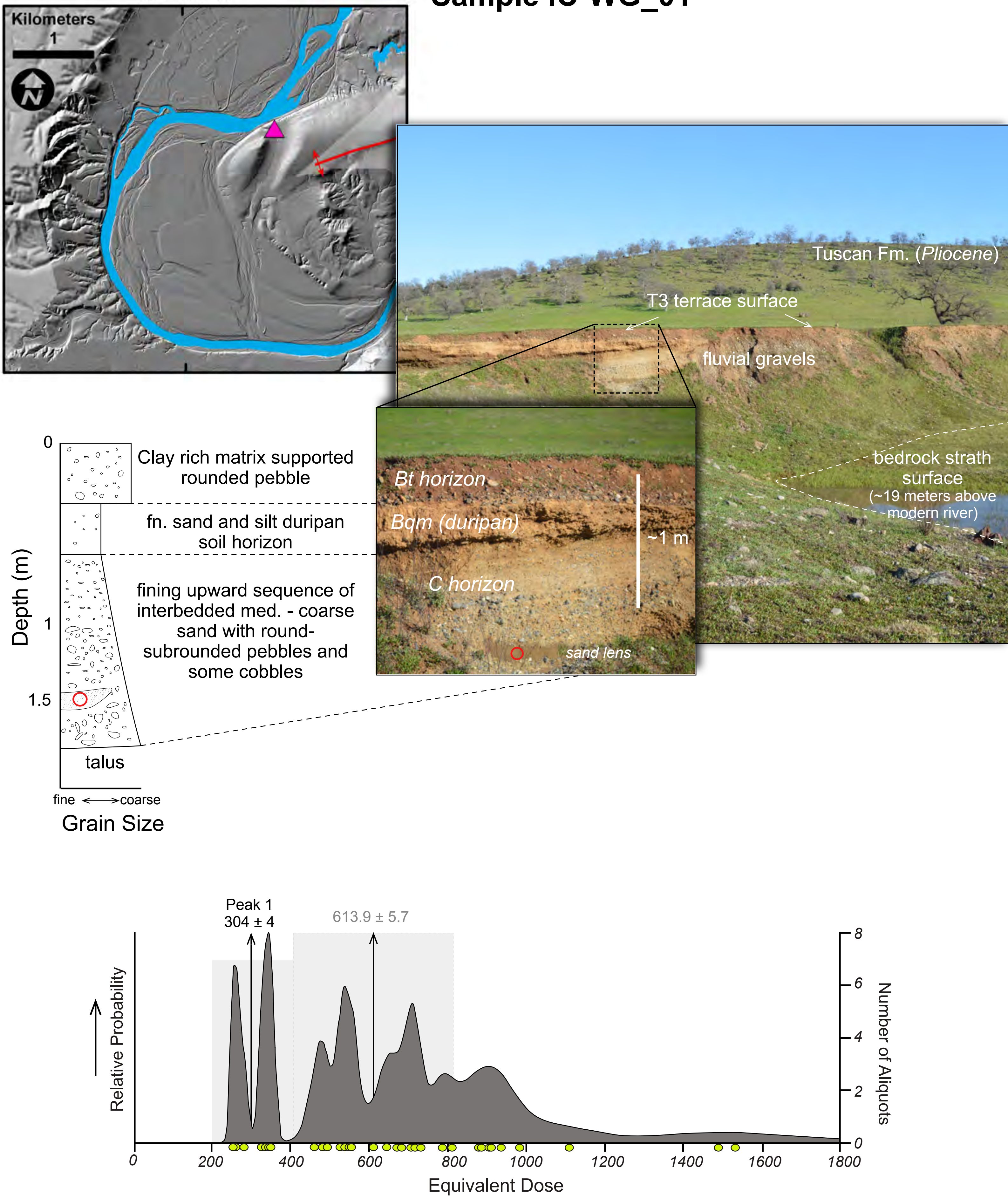
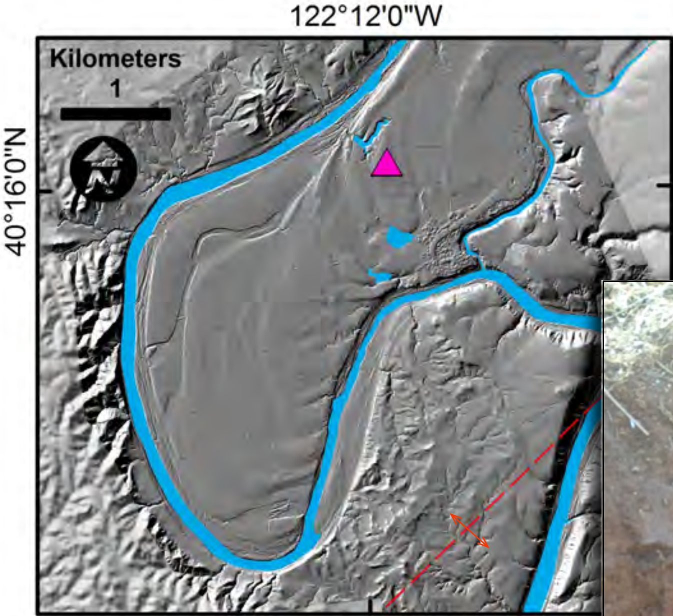
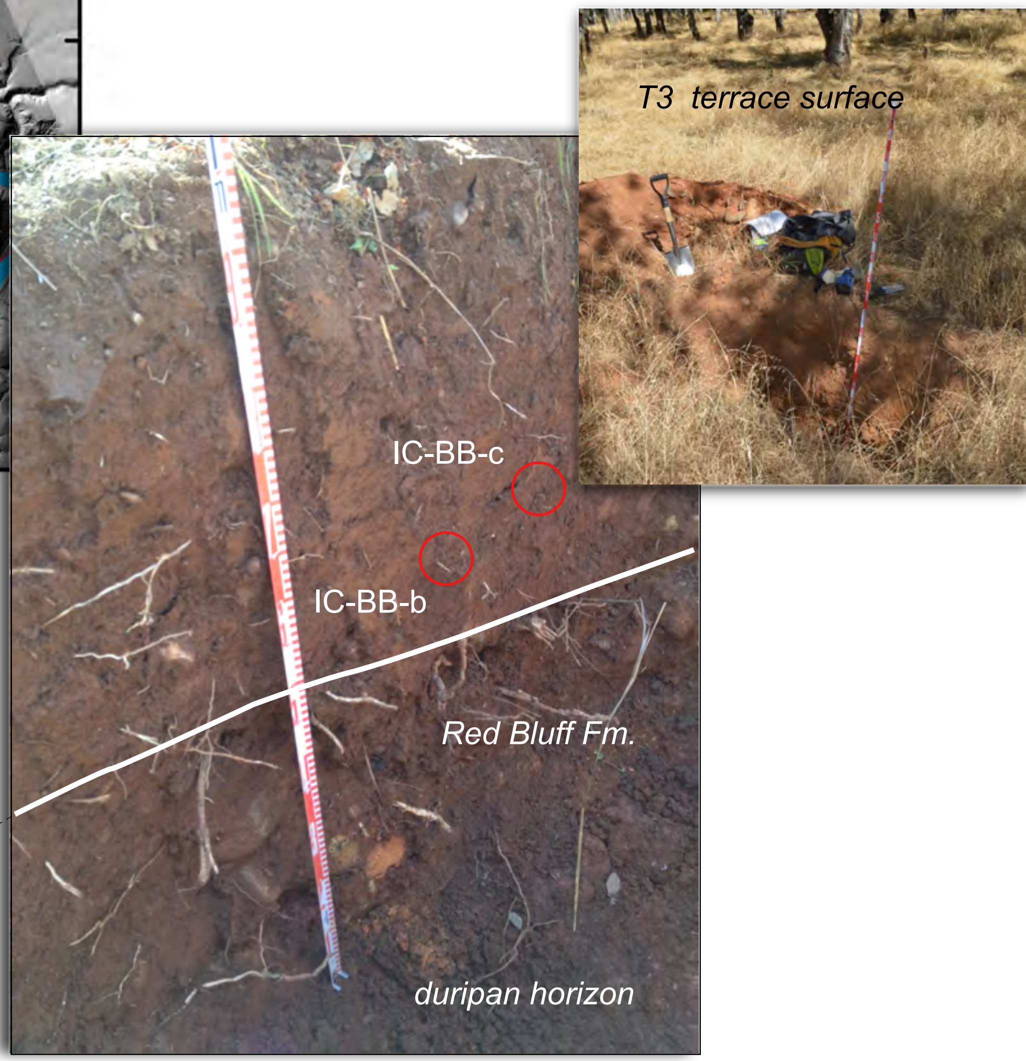
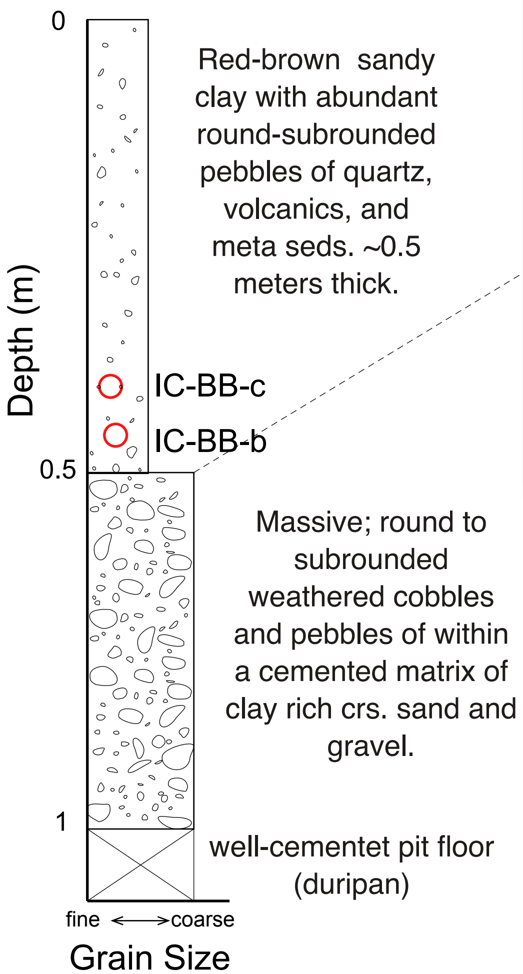


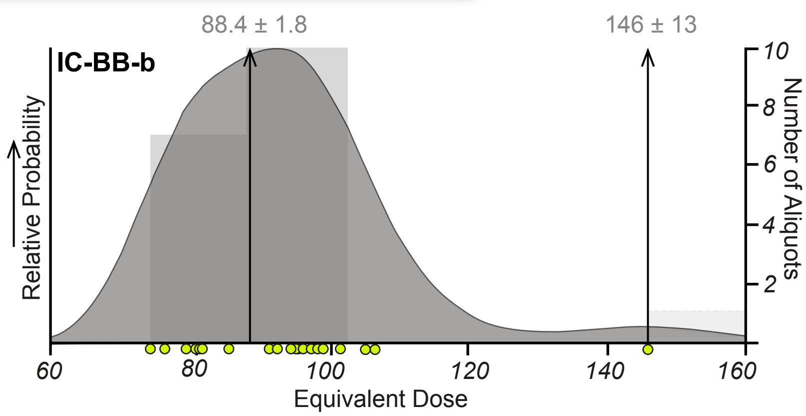
Figure DR2. Stratigraphic column and picture of sample loction. (lower) Relative probability and histogram plot of 32 aliquot measurments (yellow circles) showing equivalent dose distribution of sample. Sample measurments and age results are provided in Table DR1.

Sample IC-BB-b/c









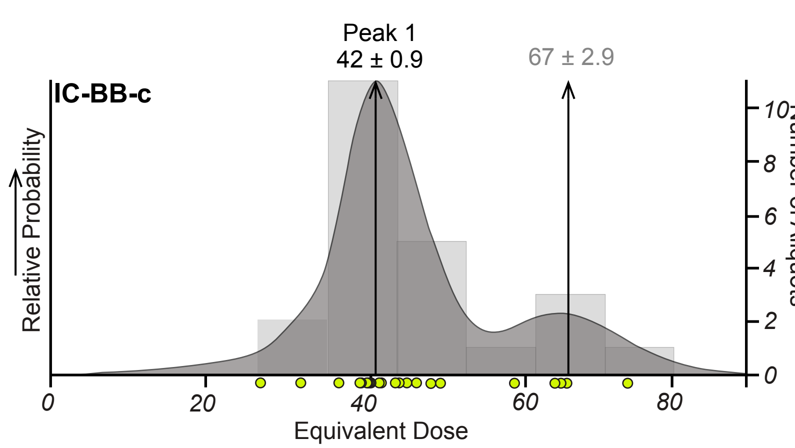


Figure DR3. (above) Stratigraphic column and picture of sample loction. (right) Relative probability and histogram plots of IC-BB-b and IC-BB-c of 20 and 23, respectively, aliquot measurments (yellow circles) showing equivalent dose distrabution of samples.Sample measurments and age results are provided in Table DR1.

Sample IC-RBF_01

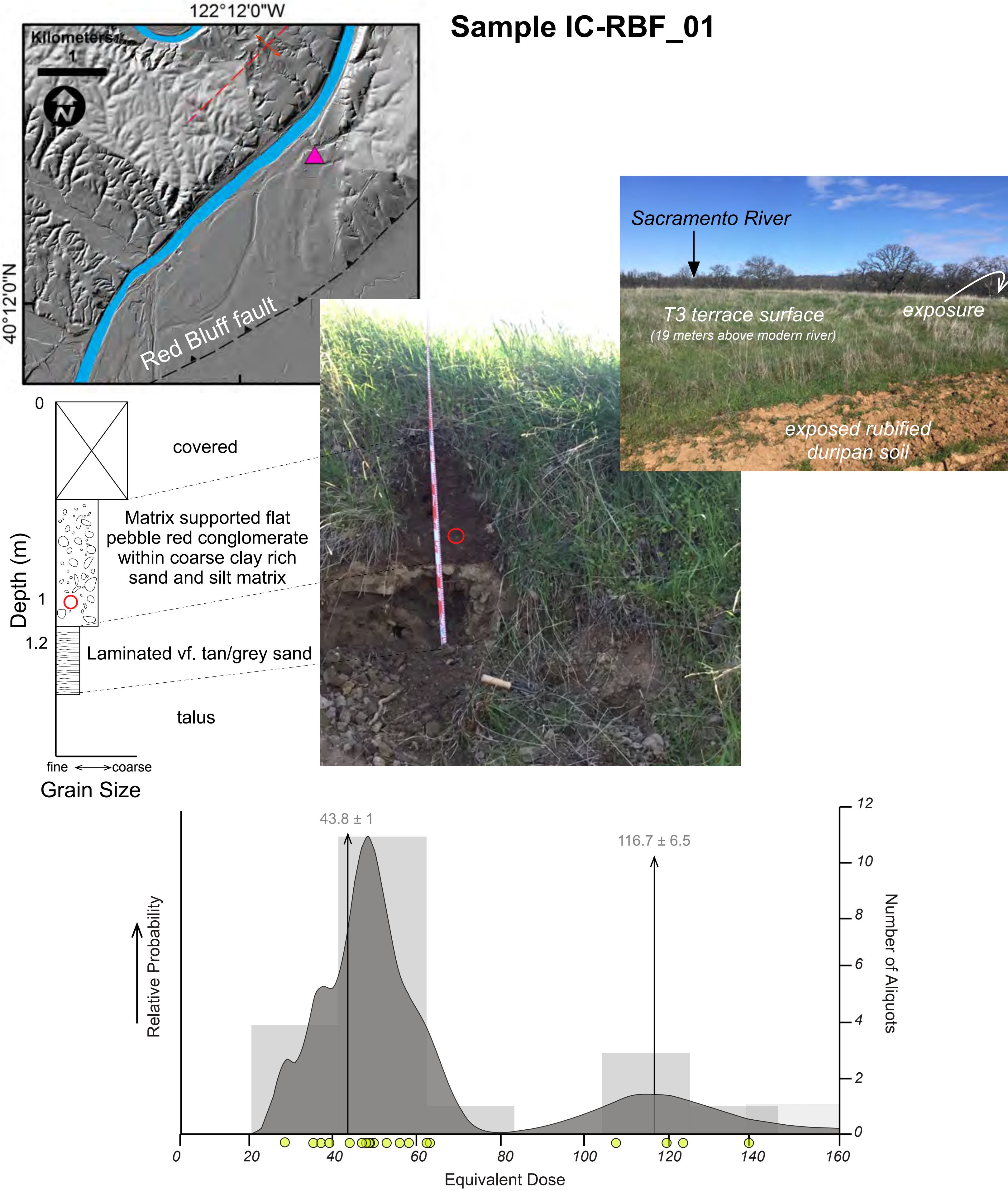
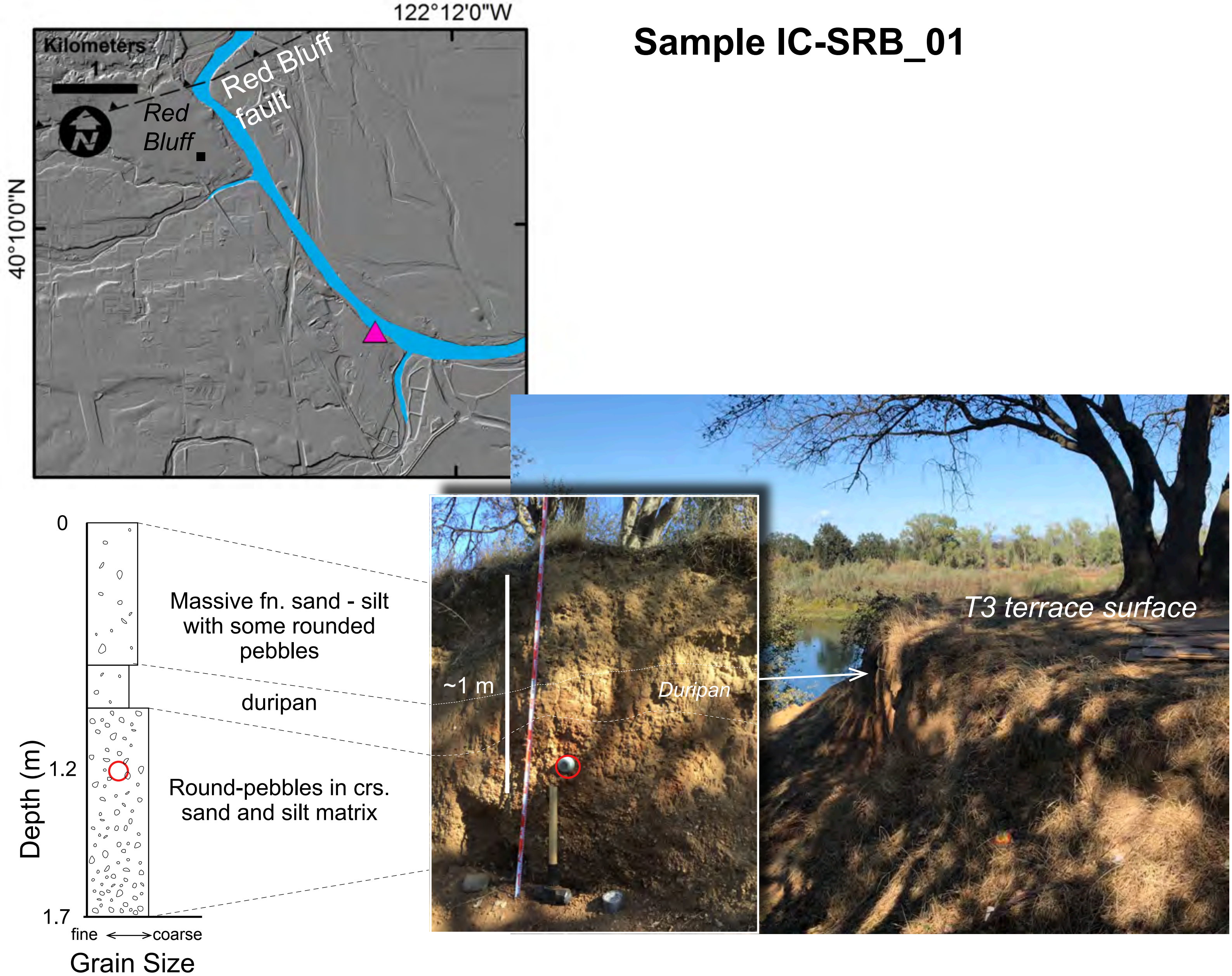


Figure DR4. Stratigraphic column and picture of sample loction (red circle). "X" show location of dispolved sample. Relative probability (left y-axis) and histogram (right y-axis) plot of 20 aliquot measurments (yellow circles) showing equivalent dose distrabution of sample. Sample measurments and age results are provided in Table DR1.

Sample IC-SRB_01



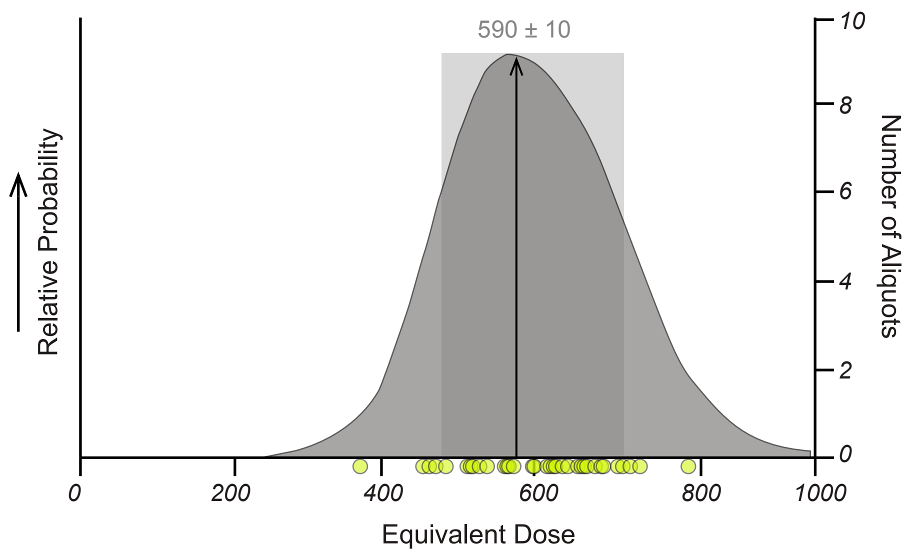


Figure DR5. Stratigraphic column and picture of sample location. Relative probability (left y-axis) and histogram (right y-axis) plot of 42 aliquot measurments (yellow circles) showing equivalent dose distrabution of sample. Sample measurments and age results are provided in Table DR1.