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Scherler, D., Lamb, M.P., Rhodes, E.J., and Avouac, J.-P., 2016, Climate-change versus landslide origin of fill terraces in a rapidly eroding bedrock landscape: San Gabriel River, California: GSA Bulletin, doi:10.1130/B31356.1.

Supplementary Material

In this document we provide additional details on the single-grain post-IR IRSL dating, and a color version of Figure 8B in the original paper.

POST-IR IRSL DATING

Analytical procedures

Grains of less than 2.565 g cm^{-3}, which correspond to the most potassium-rich of the alkali feldspar grains, were isolated by density separation (Rhodes, 2015). Preliminary research indicates that these grains are typically associated with higher post-IR IRSL for signals measured at 225ºC, in comparison to less potassic compositions from the same sediments or bedrock source. We used grains with sizes of 175–200 µm. After sieving and density separation, a 10 min 10% hydrofluoric acid treatment was applied to clean the grains and remove the outer alpha irradiated surface, followed by a second sieving at 180 µm to remove grain fragments. Individual grains were mounted within single grain holders and measured in a Risø TL-DA-20 D automated luminescence reader fitted with a dual laser XY box. IRSL measurements were made using a BG3 and BG39 (blue transmission) filter combination, and using an EMI 9235QB PMT (photo multiplier tube). IRSL stimulation was provided by a 150mW 830 nm IR laser at 90% power for 2.5s passed through a RG-780 filter. Vishay TSFF 5210 870 nm IR diodes were used for a “hot bleach” treatment at the end of each measurement cycle. The measurement protocol followed that described by Rhodes (2015), and is based on a single aliquot regenerative-dose (SAR) approach. This comprises a series of cycles, in which each grain is irradiated, preheated (at 250ºC for 60s), IRSL is measured at 50ºC (2.5s IR laser), followed by a subsequent IRSL measurement at 225ºC for 2.5s. Each grain is then given a standard test dose (c. 9Gy), preheated as above, and IRSL measurements at 50ºC and subsequently at 225ºC (to correct for sensitivity change), and the SAR cycle is completed by a final “hot bleach” at 290ºC while exposed to IR diodes for 40s. In the first cycle, no initial irradiation is used, as this measurement determines the natural burial dose. Seven full cycles are performed for each grain at different regenerative dose values, including a zero dose (to assess thermal transfer), and a repeat of the first added dose, to assess recycling behavior. The second IRSL measurement at 225ºC is used for dating, as this signal has been shown to suffer less from a form of signal loss referred to as “anomalous fading” resulting from quantum mechanical tunneling (Buylaert et al., 2009). While some doubt remains as to the best way to assess the magnitude of fading when using single grains, Rhodes (2015) showed that many Holocene samples with independent age control required no fading correction.

Age estimates

The single grain K-feldspar post-IR IRSL (infrared stimulated luminescence) age estimates presented here were undertaken in preference to the more established approach using a quartz SAR (single aliquot regenerative-dose) protocol owing to the low OSL (optical stimulated luminescence) sensitivity of quartz grains in rapidly eroding landscapes in California (Lawson et al., 2012), and also because we expect severe incomplete zeroing of luminescence signals of some grains when dealing with rapidly deposited high energy depositional environments

(Rhodes, 2011). It was for situations similar to this, that in contexts in which many grains were not exposed to sufficient light prior to deposition to reduce the trapped charge concentration responsible for the measured luminescence signal, that the use of single grain OSL was developed (Roberts et al., 1999).

Where single grain OSL or IRSL sediment dating is undertaken, this is usually applied specifically to overcome one of several problems, primarily the incomplete zeroing by light of some grains (e.g., Rhodes et al., 2010) or the post-depositional mixing of grains by processes such as bioturbation. Although the first studies of single grain quartz OSL dating were undertaken some time ago (Murray and Roberts, 1997; Roberts et al., 1999; Jacobs et al., 2003), this approach has remained less commonly used than conventional, multiple grain OSL, owing to the reduced availability of the expensive equipment required, and also for quartz, the extended time required for measurement, as typically very few grains (usually <5%) provide OSL signals sufficiently intense for age estimation (Duller 2008; Jacobs et al., 2003). However, in the absence of specific information that suggests that grains have been introduced by post-depositional mixing processes, or clear indications of other issues such as signal contamination caused by mineral inclusions within grains, the default interpretation for all OSL dating is that the age estimate provided by the youngest consistent group of grains or aliquots is the best estimate of the depositional age (Rhodes, 2011; Rhodes, 2015; Roberts et al., 1999; Galbraith et al., 1999).

The reason for this default interpretation is that there are many contexts in which it is possible for sediment deposition to occur such that only a sub-set of constituent grains are well zeroed. Perhaps the most common scenario is one in which deposition occurs rapidly at night, or during a period of significantly reduced light intensity as is common during heavy precipitation events, or where grains are transported by media not able to transmit light efficiently such as mudflows or fluvial contexts with very high sediment loads. Under these conditions, most grains that were eroded during the event may retain their original burial doses, and only grains that were already in the channel or lying on the land surface may have had their relevant trapped charge population reduced to a low level. The degree of internal and external consistency, that is between grains of the same sample, between results from different samples of related contexts, and with independent age estimates is important in providing support for this interpretation.

In contrast, one way in which younger apparent age estimates might be introduced is the post-depositional movement of grains within the sediment body by processes such as bioturbation involving burrows, root activity, cryoturbation, or other processes from younger horizons or the surface. The likelihood of these processes must be determined based on the stratigraphic and sedimentary context. Alternatively, where the luminescence technique is not robust and fails for some grains, measurement artifacts might introduce low values occasionally. In this case, it is unlikely that spurious results are reproducible, so assessment of the degree of consistency (a routine feature of the approach used here) between results is important in assessing whether low values do indeed represent the depositional age, or whether they represent a rare measurement artifact.

In this case, we note several features pertinent to our preferred interpretation. Firstly, although higher values appear well grouped, this is in part caused by their degree of full IRSL signal saturation, and the relatively large uncertainties caused by this condition. In fact, we consider that for these grains, the signal is probably indistinguishable to that of grains extracted directly from bedrock, although we have not had the opportunity to test this assertion. The post-IR IRSL signals of these grains may not be fully saturated either because of rapid recent exhumation from deep and warm locations (Herman et al., 2010; Guralnik et al., 2015), or owing to the relatively less well constrained nature of signal growth at high dose values (in comparison to doses corresponding to Holocene sample ages).

In summary, in deriving our age estimates we follow regular luminescence dating procedure. Where we observed no indications of post-depositional sediment disturbance, we rigorously use the minimum dose values to estimate age. For one sample (SG13–03) taken from a sand lens that included a modern bird burrow, we rejected a modern value from a single grain, as we consider this value likely to have been caused by mixing with a recently exposed grain within this or previous burrows at this location. In assessing the consistency of our age estimates produced in this manner, we consider the degree of apparent stratigraphic and morphostratigraphic consistency, besides the relationship of these age estimates to independent chronological control. We have had the opportunity to test this approach using independent age estimates based on ^{14}C and ^{10}Be from a wide range of high energy fluvial deposits in California, Mexico, and Tibet (Rhodes, 2015), and find that it provides highly robust dating of depositional events.

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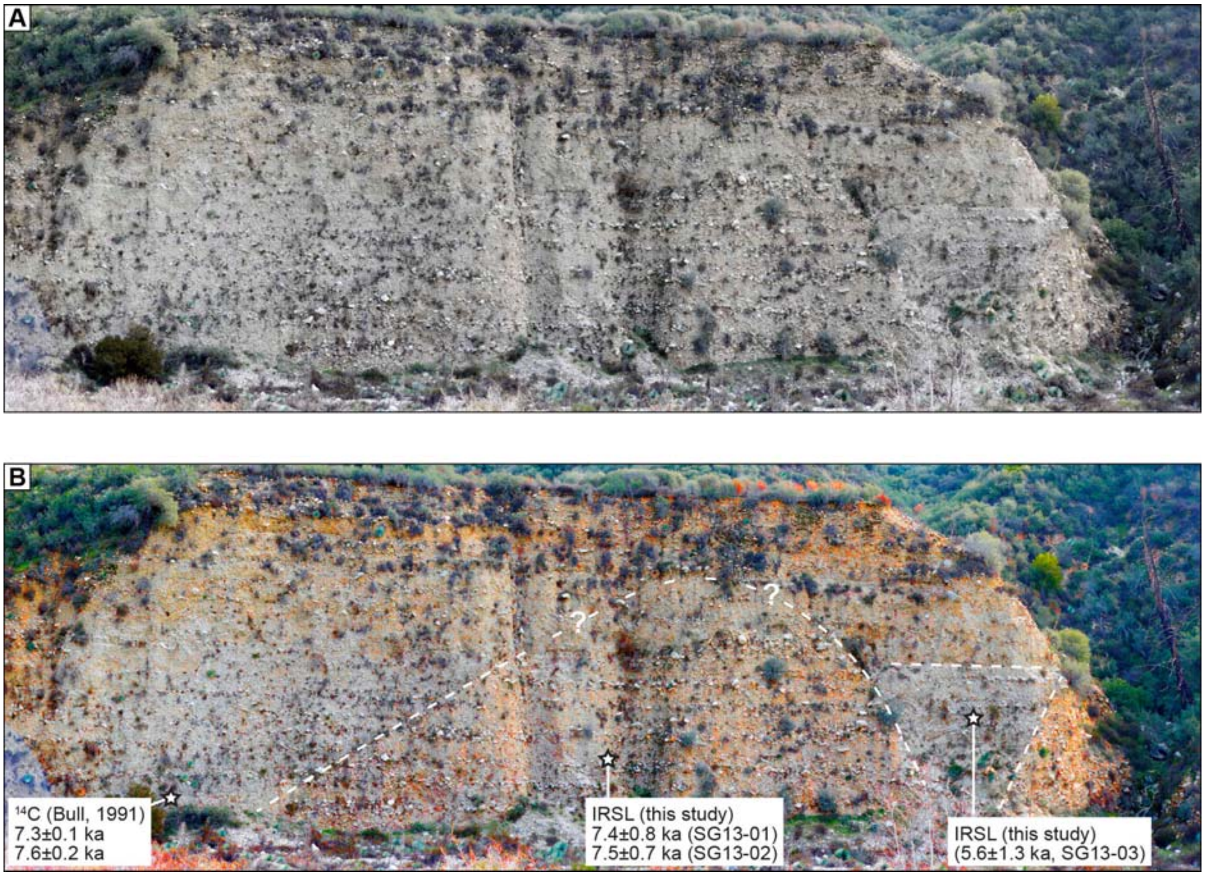

Figure S1: (A) Color photograph of the fill terrace at Tecolote Flat that is shown in Figure 8B of the original paper. (B) Same photograph as in A, but with saturation values pushed to the maximum and red values enhanced to highlight differences in color, which suggest different depositional units within this terrace. The upward convex dashed white line marks boundary that was proposed by Bull (1991), between a stratigraphically older (T3) and younger valley fill (T7). Based on pronounced color contrasts, we added the other dashed lines. However, based on our new ages, the stratigraphic context of these units is not clear. See text for details.

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