Quaternary Geochronology 10 (2012) 314–319

Contents lists available at SciVerse ScienceDirect

Quaternary Geochronology

journal homepage: www.elsevier.com/locate/quageo

Research paper

Assessing soil mixing processes and rates using a portable OSL-IRSL reader: Preliminary determinations

D.M. Stang[a,*], E.J. Rhodes[a], A.M. Heimsath[b]

[a] Department of Earth and Space Sciences, University of California, 595 Charles Young Drive East, Box 951567, Los Angeles, CA 90095-1567, USA
[b] ASU School of Earth and Space Exploration, PO Box 871404, Tempe, AZ 85287-1404, USA

ARTICLE INFO

Article history:
Received 17 October 2011
Received in revised form
18 April 2012
Accepted 20 April 2012
Available online 3 May 2012

Keywords:
San Gabriel mountains
Soil turn-over
Soil production
Grain diffusion
Portable reader

ABSTRACT

Employing a portable luminescence reader in a novel approach for studying soil mantles can help to both better our understanding of and determine the relative importance of the different erosional processes operating on a given landscape. By measuring bulk IRSL signal intensity of unprepared regolith samples as a function of depth, a portable reader has been used to rapidly explore patterns and rates of soil mixing within the actively uplifting San Gabriel Mountains, southern California, USA. Both IRSL and OSL measurements were taken from three different hillslope soil profiles collected within a 100 m radius, as well as a number of bedrock samples. To gauge the rates of grain mixing, bulk IRSL signals are converted to dose values by measuring IRSL growth as a function of dose in a conventional luminescence reader using smaller subsamples from key locations. These data are combined with dose rate determinations based on both in-situ NaI gamma spectrometer measurements and chemical determinations of U, Th and K, in order to convert dose values into “effective age” estimates; these values represent mixed regolith and soil, and not age of sediment deposition. This approach has generated soil turn-over histories much more complex than our simple, signal saturation-with-depth model predicts.

1. Introduction

1.1. Motivation

Landscapes undergo surface lowering by weathering and erosion, which can be controlled by a complex range of processes. Both the chemical conditions that play a key role in breakdown of soil and bedrock, and the physical translocation of regolith are important processes in controlling the rates of weathering and erosion. Physical processes that move lithic fragments and individual grains include creep and surface flow, and may be described by the concept of “soil diffusion” (as described in Heimsath et al., 2002; Braun et al., 2001). While this approach is highly valuable at the landscape scale, it can be difficult in some cases to relate the landscape diffusion coefficient, K (Heimsath et al., 1997) to particular processes; compartmentalization of erosional factors is necessary to assess both the relative importance of different mechanisms and their rates. The new approach presented below aims to provide a method of filling the information gap that we perceive to exist between studies conducted on the landscape scale (10^3 m to 10^6 m), based on methods such as terrestrial cosmogenic nuclide (TCN) or low temperature thermochronologic determinations, and those executed with a much finer scale, such as soil test pit studies or the use of micromorphology (10^{-6} m to 1 m). Our approach complements the use of dense networks of soil pits and multiple TCN determinations, and has the significant advantages of being relatively rapid and inexpensive. We aim to illustrate the scope of this approach and assess its performance at a key site with existing information from previous research (Dibiase et al., 2010; Heimsath et al., 2005).

As grains within soil and regolith profiles are translocated by biologic processes such as animal burrowing or tree throw, they have a finite probability of being transported up to the ground surface. Both daylight exposure and heating during wildfire events have the potential to reset luminescence signals within mineral grains, providing the potential to determine the time since grains were “zeroed” by applying luminescence dating methods. Such an approach was developed by Heimsath et al. (2002) using single quartz grains to determine soil mixing and translocation rates in southeast Australia. Although providing highly valuable data in this key location where extensive soil chemistry and TCN data were also collected, this approach has not been replicated elsewhere, perhaps a reflection of the time-consuming OSL measurements required.

* Corresponding author. Tel.: +1 831 915 2683; fax: +1 310 825 2779.
E-mail address: dallonstang@ucla.edu (D.M. Stang).

1871-1014/$ – see front matter © 2012 Elsevier B.V. All rights reserved.
doi:10.1016/j.quageo.2012.04.021

In the present study, we attempt to complement the quartz single grain approach of Heimsath et al. (2002) with a method to rapidly and inexpensively assess the main features of soil mixing processes and rates, based on the same principles, but using simpler measurements of luminescence (IRSL and OSL) performed on unprepared bulk soil samples as a function of depth within the soil/regolith profile. We have taken advantage of a portable IRSL/OSL reader recently developed by SUERC (Scottish Universities Environment Research Centre, East Kilbride, UK), coupled with sample collection techniques widely used in paleoecological studies (e.g. Tyler et al., 1996). We compare our results to simple numerical simulations of soil diffusion and mixing, to help interpret our observations and to gain insight into the types and rates of processes operating at our sampling location.

1.2. Principles and previous work

This study and future work developing the technique, hopes to differentiate mechanisms that moderate erosion and transport can be studied by measuring contemporary sediment transport rates; besides quantifying rates on extended timescales by measuring TCN inventories, both in vertical profiles from soil test pits (e.g. Kaste et al., 2007), and by measuring sediment eroded from single catchments (DiBiase et al., 2010). TCN profiles can provide rates of erosion and soil production, but a degree of variability is introduced into these measurements by processes operating within the soil profiles being sampled. These processes operate at the cm scale or greater, and can include tree throw, bioturbation and surface transport mechanisms such as slope wash and small scale landslides or debris flows.

Luminescence dating has the potential to contribute to the study of these processes, making use of signal zeroing that occurs when sediment grains are exposed to daylight or high temperature. The techniques of OSL (Optically-Stimulated Luminescence), IRSL (Infrared-Stimulated Luminescence), and TL (Thermoluminescence) have been used widely to estimate the time since sediment samples were last exposed to sunlight (e.g. Murray and Olley, 2002; Rhodes, 2011). Conventional procedures for luminescence sample collection, preparation and measurement (e.g. Rhodes, 1988; Murray and Wintle, 2000, 2003) are relatively time-consuming and expensive, limiting the number of samples that can be measured. The physical dimensions of sample collection tubes often employed (lengths of 10–20 cm, diameters of 3–6 cm, typically) reduce the potential of conventional dating campaigns to recognize discrete events represented within regolith profiles by only thin horizons or lenses.

The objective of this work was to obtain detailed luminescence signal intensity profiles with respect to depth in vertical soil profiles to ascertain soil-mixing processes and rates in the San Gabriel Mountains of Southern California. A location map of the study area can be seen in Fig. 1. These luminescence measurements can be used to help identify processes that are operating at sampled profile locations, and also to assist in constraining the rate of these processes. The portable luminescence reader was used to measure poorly-sorted soils of mixed compositions, untreated and in their natural state; soil samples were collected in “monoliths” and measurements were made in the laboratory at regular intervals down vertical profiles, typically at increments of one to two cm. By employing a SUERC PPSL portable reader as described in Sanderson and Murphy (2010), luminescence signals and characteristics of samples can be measured rapidly and accurately. This research builds on work conducted in the San Gabriel mountains determining erosion using cosmogenic nuclides (Heimsath et al., 2002; DiBiase et al., 2010), and more general slope development studies elsewhere (e.g. Niemi at al., 2005).

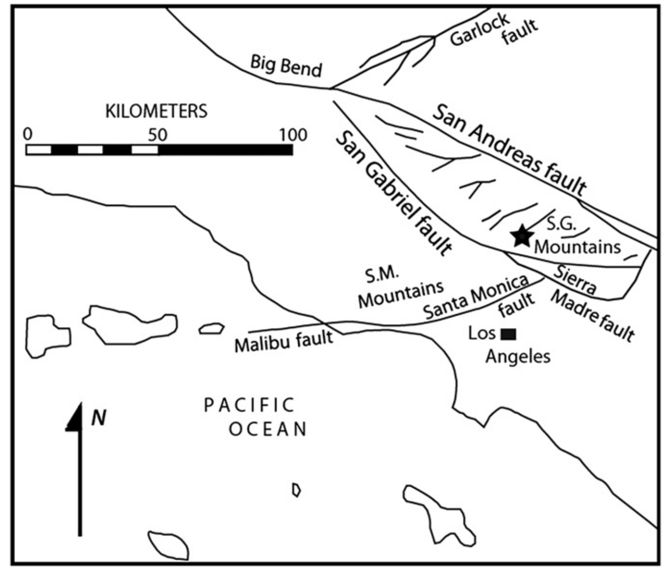

Fig. 1. Area map of Southern California with simplified structural geometry. Study area indicated by star.

While the initial aims of this study were focused on complimenting TCN work done in the area in soil studies, the long term goal of this work is to independently study soil diffusivity rates to find a meaningful soil diffusion constant. Once determined, this may contribute to our understanding and quantification of erosive processes and variations within individual catchments and over broader regions. Once these processes are better understood and quantified, they can be used to support geomorphic transport laws and in the prediction of future landscape development via modeling, as described by Dietrich et al. (2003).

1.3. Regional setting

The San Gabriel Mountains, part of the Western Transverse Range complex within Southern California, represent the current transpressional tectonic regime shaping the Los Angeles basin (Ingersoll, 1999, 2008); a series of thrust faults accommodating the stress of the major restraining bend of the San Andreas fault that bounds the mountains to the northeast (See Fig. 1) has caused rapid uplift of crystalline basement rock. The lithology of the San Gabriel Mountains is comprised primarily of Proterozoic to Mesozoic granitic-to-granodioritic plutonic and gneissic-to-schistose metamorphic rocks (Critelli et al., 1997). Uplift rates throughout the San Gabriels have been estimated to be to be 0.5–5 m year^{-3} (Lifton and Chase, 1992), which surpasses late Quaternary denudation rates quantified for the area (Schumm, 1963; Dibiase et al., 2010). Recent cosmogenic nuclide basin analysis has found erosion rates in the San Gabriels to range from 35 to 1106 m/Ma (Dibiase et al., 2010). These high rates are important as soil must be replenished at a rate equal to or greater than erosion for it to persist and not be removed from a particular environment (Heimsath et al., 1997).

While some research has tried to isolate the effects of climate, tectonism or rock type in landscape evolution within the San Gabriels (Lifton and Chase, 1992), the total result of the combined processes must be known before deconstruction into constituent variables is attempted. While basin catchment analysis can quantify general, large-scale erosion rates and geomorphic activity within an area, luminescence provides the potential to quantify the rates of surficial processes at the local hillslope scale. This detailed analysis can provide a further approach in determining whether or not a landscape is in geomorphic equilibrium (Heimsath et al., 1997). Because of recent fires in the mountains and their zeroing capability, samples were collected outside and upslope of burn-zones to avoid additional variables affecting measured intensities. Potential future work includes the study of zeroing effects of these regularly occurring fires of semi-arid southern California.

2. Materials and methods

2.1. Collection and gamma measurements

Samples were collected by excavating small test pits and removing vertical columns termed "monoliths" in square, three-sided polyvinyl carbonate tubes. Several pits were excavated, though samples were collected only from those with soil profiles which exceeded 20 cm in depth, extending to bedrock. The monoliths measured 10 cm wide by 10 cm deep, with height varying on the soil depth to bedrock. Sample collection of the monolith variety was limited only by the presence of large roots, and made more difficult when soil was dry. Excavated pits are shown in Fig. 2.

Samples were sealed from light exposure and transported back to the lab to be processed under safe light conditions. This was done for convenience and because of the proximity between the research area and laboratory. After removing the outer ~2 cm of potentially light exposed soil, samples were dissected and subdivided every 1–2 cm to depth from each monolith. The project was designed to test soil samples in their natural state to increase rapidity of measurements, so no sieving or acid treatments took place prior to readings being made. Standard sample collecting tubes were collected from each pit also, for future work.

2.2. OSL/IRSL measurement conditions

Two sets of measurements were made for every subsample of each monolith. The first set included alternating 2s IRSL and 2s OSL measurements to assess respective intensities. The relatively short exposure durations (typical values of 10–16% depletion per cycle) causes very little signal depletion. This cycle was undertaken 8 times in total to monitor signal decay rate. These measurements were made using pulsed IRSL and OSL, for two full seconds at full intensity with 15 μs on and 15 μs off time. The signal output represents the on-time integral minus the off time integral, effectively subtracting any background.

Fig. 2. Sample pit after collection of a monolith (right) and sample tubes (left).

The second measurement set included pulsed signals, where on and off times of each measurement were kept the same, and varied in duration from 1 up to 85 μs; specific values used were 1, 3, 8, 15, 30 and 85 μs. These measurements were conducted in order to determine whether there were any significant or systematic changes in the pulsed OSL or IRSL response shape with depth, which there was not.

2.3. Laboratory IRSL measurements

In order to study the form of signal growth with dose, IRSL measurements of standard sample discs of untreated sediment were made in the laboratory using a Risø TL-DA-20 reader fitted with a standard UV transmitting U340 filter, similar in transmission to the UG11 filter in the portable reader. For each monolith, two discs from each of two samples were measured, using a SAR post-IR IR_{225} protocol, incorporating a preheat treatment of 60 s at 250 °C before each IRSL measurement (Buylaert et al., 2009). In the profile measurements made with portable reader, both the IRSL and OSL signals were close in intensity for every sample, strongly suggesting a similar source for both signals. For this reason, only IRSL signal growth was studied, and interpretation of the profile intensities was focused on the IRSL signals.

3. Results

3.1. IRSL signal growth

An IRSL growth curves measured in the laboratory Risø set using the initial 2s of each measurement are shown in Fig. 3. This growth curve was fitted with an exponential-plus-linear function. The curve shown in Fig. 3 is typical of those measured, and has a D_0 value of 135.7 Gy for the exponential part. This growth curve, coupled with U, Th and K concentrations, was used to convert portable reader measurements into effective age.

3.2. Conversion of signal intensity to apparent age

As the aliquots used in the Risø set measurements were much smaller in surface area than those used in the portable reader (c. 2.5 cm diameter), the corresponding IRSL intensities were much lower. For comparison between the two instruments, intensities measured on the Risø set were converted to equivalent intensities for the portable reader, using the average ratio of intensity of the natural signals measured in both machines, allowing the construction of a scaled growth curve, using average parameter

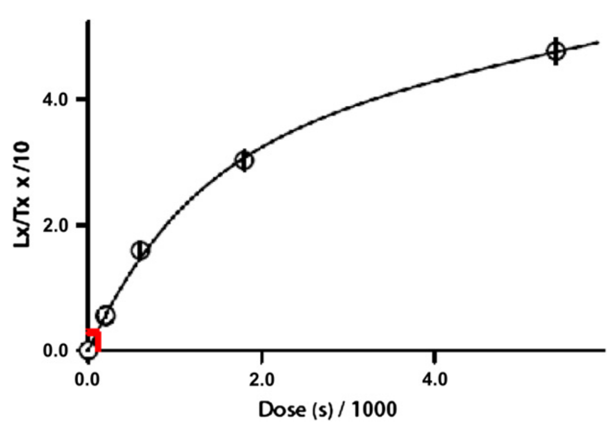

Fig. 3. Growth curve measured in Post-IR $IRSL_{225}$ SAR cycle, characteristic of all measured in this project.

values. This synthetic growth curve, constructed in intensity units applicable to the portable reader, was used to determine a dose value for each portable reader IRSL intensity reading.

At several points within the sampling area, NaI gamma spectrometer determinations were made in order to determine the total gamma dose rate and the concentrations of U, Th and K. Measurements were made using an EG&G MicroNomad portable NaI gamma spectrometer with a diameter of 3 in. The mean of each of these values, which did not vary strongly, was used to estimate an approximate representative sediment dose rate, used to covert dose estimates into age estimates. We fully acknowledge that this dose rate value represents only an approximate estimate, but as the grains are moving within each profile, a more precise or localized estimate will contribute little to our understanding of grain translocation processes and rates. Both the gamma spectrometer values and ICPMS concentrations can be seen in Table 1.

3.3. Zeroing

When grains move close to the surface, their OSL and IRSL signals have a chance of being reset by daylight exposure or by burning in wildfires. The uppermost samples from the measured profiles provide a good opportunity to assess the degree to which this zeroing has taken place at the locations sampled (Fig. 4). For Monolith B, the topmost sample does not have the lowest apparent age, and effect discussed below, and for this profile, we assess zeroing using the lowest value from 8.75 cm depth. For the three profiles, the lowest apparent age estimates are 1,100, 700 and 1000 years (rounded to the nearest 100 years).

3.4. Profile intensities and apparent age

As mentioned above, as the OSL signals track the IRSL values closely, but run the risk of "contamination" from quartz OSL components, only IRSL intensities and age estimates calculated from these are considered in detail. The brightest IRSL signals, which converted to oldest effective ages, came from monolith A (Fig. 4a). In this profile, the natural intensity increases overall with depth, except for two discontinuities, one occurring gradually from 3 to 6 cm below the surface, and a sharp reduction in intensity from 14 to 16 cm below the surface.

The second profile plotted (Monolith B; Fig. 4b) displayed much lower intensity values in comparison to Monolith A; it also expresses a number of low-to-high intensity changes with depth. It is of interest to note that many samples from this profile displayed higher readings for OSL than IRSL. The main feature of note is the inversion in apparent age in the upper 9 cm of the profile.

The third and final profile, Monolith C (Fig. 4c), was of intermediate brightness with respect to the other two and showed very little variation in intensity for a full 12 cm directly below the surface, followed by an intensity increase with two slight inversions at depths of 15 and 22 cm.

One must be careful however to avoid taking intensities as a direct age proxy. The apparent age in each profile represents the combined natural signals of many grains; the 2.5 cm diameter holder area is equivalent to a monolayer of around 50,000 100 um

Table 1
K, Th and U concentrations for one of the pits used in this study. Values on left were attained via ICPMS and those on the right from in-situ gamma spectrometry. Ratios (at bottom) between the two show excellent agreement.

ICPMS			NaI		
K (%)	Th (ppm)	U (ppm)	K (%)	Th (ppm)	U (ppm)
1.6995	1.15	0.37	1.423	0.998	0.257
1.6504	0.92	0.25			
1.6049	0.82	0.24			
1.6884	0.64	0.23			
1.6081	0.56	0.21			
Mean			Ratio		
1.65026	0.818	0.26	0.862288	1.220049	0.988462

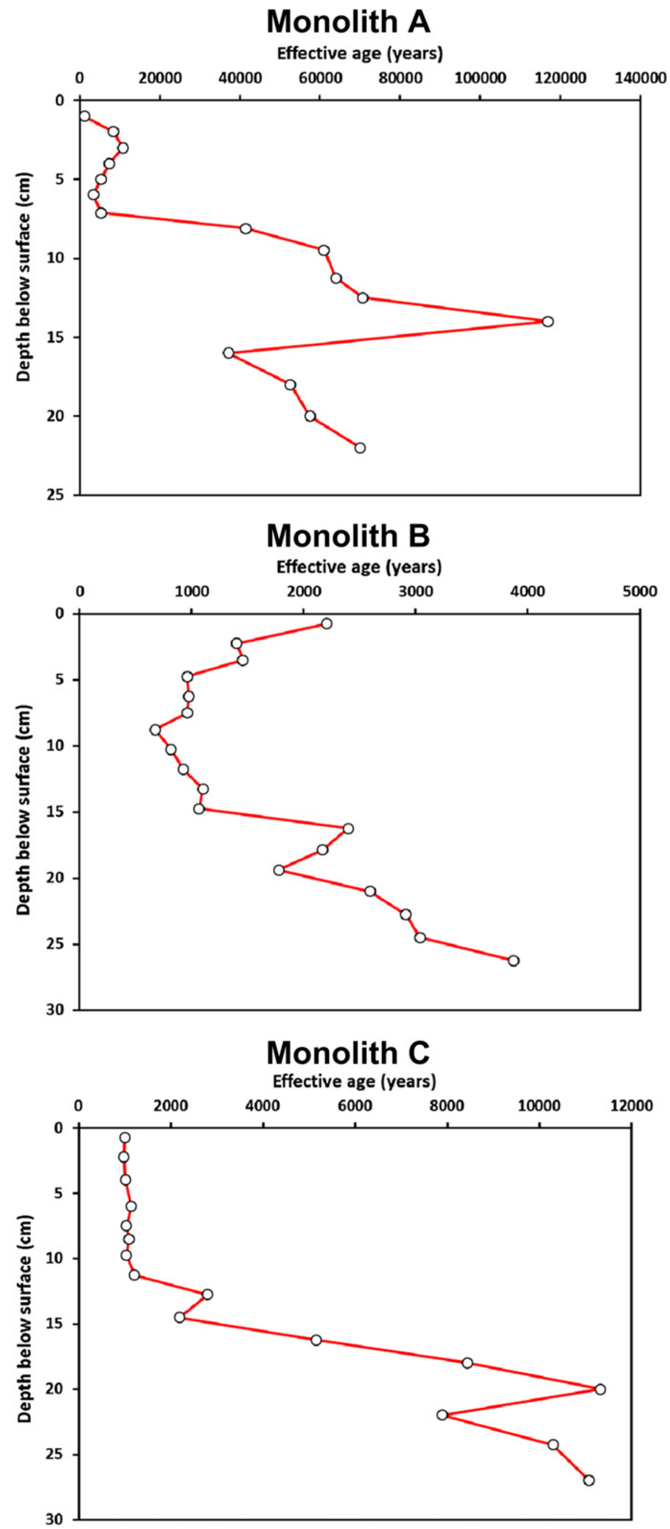

Fig. 4. Plots of effective age versus depth for Monoliths A, B, and C, as described in text.

grains. This combined signal represents the sum of grains with different recent histories, some recently zeroed at the surface and some having moved up from below after being weathered from bedrock. The conversion of the signal to apparent age is useful as it provides some sense of scale for the grain mixing processes, but these values must not be interpreted as the age of specific events.

The alternating pulse measurements (described in Section 2.2) did not change with depth, therefore the signal is a likely a property of the material, rather than the testing procedure. Because the results remained consistent, their plots are not shown herein.

4. Discussion

4.1. Profile interpretation

Since the plotted profiles in Fig. 4 show such variation in intensity patterns, and not simply the saturation of signal intensity at depth, it is believed that multiple processes are at work, diffusing grains in a vertical fashion. Monolith A, shown in Fig. 4-A, expressed two places where intensity was abruptly reduced with increasing depth. It is the authors' interpretation that these changes represent zeroing events in the history of the soil sample, and these points were once brought to the surface and their signals reset.

The high number of times the signal intensity switched from high to low seen in Fig. 4-B suggests a very active turn-over history for this particular monolith. The cause of this highly variable signal is likely a result of heavy bioturbation.

The observed trend for the homogenous signal observed in the top 12 cm of the monolith plotted in Fig. 4-C, is potentially explained by a macropore or burrow being filled during or a storm or hillslop slumping event. Rapid emplacement of material must have been required to result in the observed minor variation in signal intensity for such a depth.

While we were able to determine effective ages for our monolith subsamples, the conversions were more complex than originally thought, and not uniform for all samples.

4.2. Diffusion model

When intensity is modeled as being dependent only on vertical diffusion of grains with zeroing occurring at the surface, complicated profiles cannot be generated. As shown in the Fig. 5, the modeled intensity profile saturates at depth without any of the complications illustrated in all of our data (Fig. 4). This model assumes that grains are close to saturation at 800,000 yrs and the likelihood of exchanging grains between 1 cm layers atop or below is at 0.1% yr^{-1}, and 0.8% yr^{-1} for horizontal movement within the same layer. Even if the parameters are altered, the time may change, but the shape does not. While this is a first order model, it illustrates that multiple processes must be at work in controlling these vertical soil turn-over histories, not merely diffusion alone if complex profiles are observed in nature.

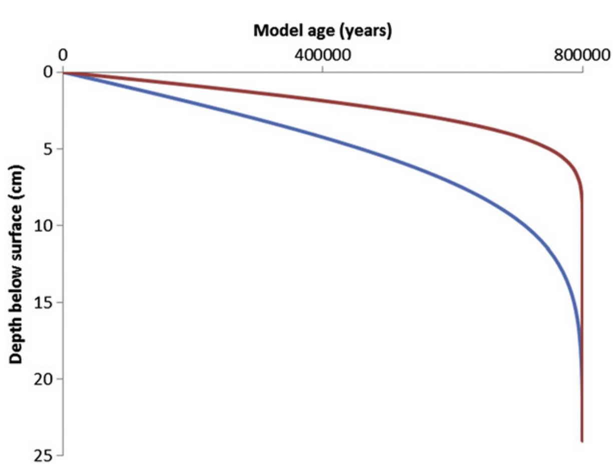

Fig. 5. Simple model of grain diffusion showing characteristic saturation with depth. Note lack of complexity observed in actual monoliths.

5. Conclusion

We have measured luminescence intensities using contiguous sampling of three soil profiles in the San Gabriel Mountains, California, that vary widely in terms of grain mixing patterns. Macroscale (cm and larger) features dominate the apparent age vs. depth profiles, clearly demonstrating that at these sites, processes other than simple grain diffusion are most important in soil development. This study suggests that use of OSL and IRSL profileshas excellent potential for 1) assisting in selecting sites suitable for TCN sampling, 2) determining patterns and processes of soil mixing, 3) determining rates of soil mixing, and 4) in the future, providing meaningful values for landscape diffusion constants.

Acknowledgments

Thank you to all of the collaborators on this project and C.A. Peterson (CSULB) for assistance in the field.

Editorial handling by: R. Grun

References

Buylaert, J.P., Murray, A.S., Thomsen, K.J., Jain, M., 2009. Testing the potential of an elevated temperature IRSL signal from K-feldspar. Radiation Measurements 44, 560–565.
Braun, J., Heimsath, A.M., Chappell, J., 2001. Sediment transport mechanisms on soilmantled hillslopes. Geology 29, 683–686.
Critelli, S., Le Pera, E., Ingersoll, R.V., 1997. The effects of source lithology, transport, deposition and sampling scale on the composition of southern California sand. Sedimentology 44, 653–671.
DiBiase, R.A., Whipple, K.X., Heimsath, A.M., Ouimet, W.B., 2010. Landscape form and millennial erosion rates in the San Gabriel Mountains, CA. Earth and Planetary Science Letters 289, 134–144.
Dietrich, W.E., Bellugi, D.G., Sklar, L.S., Stock, J.D., Heimsath, A.M., Roering, J.J., 2003. Geomorphic transport laws for predicting landscape form and dynamics. Prediction in Geomorphology, AGU Geophysical Monograph 135, 1–30.
Heimsath, A.M., Dietrich, W.E., Nishlizumi, K., Finkel, R.C., 1997. The Soil production function and landscape equilibrium. Nature 388, 358–361.
Heimsath, A.M., Chappell, J., Spooner, N.A., Questiaux, D.G., 2002. Creeping soil. Geology 30, 111–114.
Heimsath, A.M., Chappell, J., Spooner, N.A., Questiaux, D.G., 2005. The illusion of diffusion: field evidence for depth-dependent sediment transport. Geology 33, 949–952.
Ingersoll, R.V., 1999. Three-stage evolution of the Los Angeles basin, southern California. Geology 27, 593–596.
Ingersoll, R.V., 2008. Reconstructing southern California. In: Spencer, J.E., Titley, S.R. (Eds.), 2008. Ores and Orogenesis: Circum-Pacific Tectonics, Geologic Evolution, and Ore Deposits, vol. 22. Arizona Geological Society Digest, pp. 409–417.
Kaste, J.M., Heimsath, A.M., Bostick, B.C., 2007. Short term soil mixing quantified with fallout radionuclides. Geology 35, 243–246.
Lifton, N.A., Chase, C.G., 1992. Tectonic, climatic and lithologic influences on landscape fractal dimension and hypsometry: implications for landscape evolution in the San Gabriel Mountains, California. Geomorphology, 77–114.
Murray, A.S., Olley, J.M., 2002. Precision and accuracy in the optically stimulated luminescence dating of sedimentary quartz: a status review. Geochronometria 21, 1–16.
Murray, A.S., Wintle, A.G., 2000. Luminescence dating of quartz using an improved single-aliquot regenerative-dose protocol. Radiation Measurements 32, 52–73.
Murray, A.S., Wintle, A.G., 2003. The single aliquot regenerative dose protocol: potential for improvements in reliability. Radiation Measurements 37, 377–381.
Niemi, N.A., Oskin, M., Burbank, D.W., Heimsath, A.M., Gabet, E.J., 2005. Effects of bedrock landslides on cosmogenically determined erosion rates. Earth and Planetary Science Letters 237, 480–498.
Rhodes, E.J., 1988. Methodological considerations in the optical dating of quartz. Quaternary Science Reviews 7, 395–400.

Rhodes, E.J., 2011. Optically stimulated luminescence dating of sediments over the past 200,000 years. Annual Reviews of Earth and Planetary Science 39, 461–488.
Sanderson, D.C.W., Murphy, S., 2010. Using simple portable OSL measurements and laboratory characterisation to help understand complex and heterogeneous sediment sequences for luminescence dating. Quaternary Geochronology 5, 299–305.
Schumm, S.A., 1963. The disparity between present rates of orogeny and denudation. U.S. Geological Survey Professional Paper 454-H, 1–13.
Tyler, A.N., Sanderson, D.C.W., Scott, E.M., Allyson, J.D., 1996. Accounting for spatial variability and fields of view in environmental gamma ray spectrometry. Journal of Environmental Radioactivity 33, 213–235.