AGE AND MOBILITY OF ARID REGOLITH: ASSESSMENT BY LUMINESCENCE DATING METHODS

Ed Rhodes[1], John Chappell[1] & Nigel Spooner[2]

[1]CRC LEME, Research School of Earth Sciences, Australian National University, ACT, 0200
[2]DSTO, Adelaide

INTRODUCTION

Regolith in arid and semi-arid Australia includes colluvial and alluvial mantles, aeolian sand sheets and dunes, and aeolian silts. Mixtures of dissimilar materials are widespread; for example, stony gibber pavements commonly overlie bodies of aeolian silt. Until the recent advent of luminescence dating and cosmogenic isotope methods, age-estimates of these materials were poorly constrained, and their mobility in the landscape could be inferred only indirectly from imprecise evidence. The determination of regolith (soil) production rates using cosmogenic isotopes is reported in a companion paper (Chappell 2003). Here, we introduce the application of different methods of luminescence dating for determining regolith transport processes, based on thermoluminescence (TL) and optically stimulated luminescence (OSL) signals in quartz particles. We highlight recent technical advances that significantly enhance the precision and range of contexts where these methods are applicable.

A BRIEF OVERVIEW OF LUMINESCENCE DATING METHODS

Luminescence dating relies on the gradual trapping of charge within the crystal lattice of common rock forming minerals including quartz and feldspar, when exposed to natural environmental radiation. Heating releases electrons from their traps; recombinations within the crystal then emit photons of light. This phenomenon forms the basis of thermoluminescence (TL) dating, which initially was used to date previously heated materials such as potsherds, hearths and volcanic rocks. When it was discovered that certain TL signals are bleached by daylight, the method was extended to dating the time of burial of sediments, although residual TL signals from unbleachable traps limit application to particles that were very well-exposed before burial, such as aeolian sands.

Optical dating, based on optically stimulated luminescence (OSL), emitted when quartz grains are exposed to intense light of certain wavelengths, enables measurement of the burial-time of sediments that had only brief exposure to daylight. The early application was to quartz but the method has been extended to feldspars, which may also be measured using infra-red stimulation (IRSL). Recent developments increase the scope and applicability of the method. Firstly, OSL application of the protocol known as single aliquot regenerative-dose (SAR: Murray & Wintle 2000) has extended the dating range for sand-size quartz particles from a few years to about 1 Ma, in advantageous circumstances. This method also helps identify samples with mixed grain populations that arise from processes such as bioturbation. Secondly, recently developed equipment enables OSL measurements of single grains of quartz; the single-grain age-distribution for a sample containing many grains then reveals details of the mixing or transport history of a regolith sample. Thirdly, research into certain ("slow") OSL signals in quartz using linear modulation (LM-) OSL opens the prospect of obtaining transport and burial information over periods up to 10 Ma (Smith & Rhodes 1994, Singarayer *et al.* 2000). Indeed, advances in the physics of TL and OSL signals promise better assessments of the environmental and geological histories of grain populations.

We now describe several ways in which luminescence measurements may be used to examine regolith age and processes. Where applications have been developed only recently or are under development we draw on examples from other contexts to highlight the potential of these methods to regolith studies.

DATING COLLUVIAL DEPOSITS

Of the factors affecting the applicability of optical dating to sediments, the degree of daylight bleaching prior to burial is generally considered the most important. OSL experiments with samples from different modern environments show that aeolian sediments (dunes and loess) generally are well-zeroed before burial, while less well-zeroed signals are observed in alluvial and marine sediments. There has been little work on modern colluvial sediments but studies of older material suggest good potential for dating slope deposits. Modern glacigenic deposits can contain thermal transfer signals that may reflect the particle histories prior to the last depositional event (Rhodes 2000), and similar phenomena are expected in other regolith where grains have

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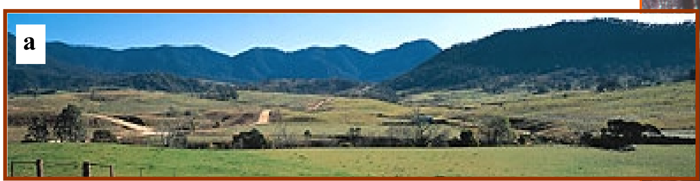
been transported only a short distance since their erosional release from bedrock. We illustrate this with results from colluvial deposits at sites in the UK.

EVALUATING REGOLITH TRANSPORT PROCESSES

It is clear that many types of regolith are comprised of transported particles, from colluvial aprons and soil mantles to sand sheets and dunes. While provenance may be determined from heavy minerals and detrital zircon ages, it is difficult to evaluate transport rates and processes. OSL age determinations of single grains provide a key, as recently shown in a study of soil creep on a forested ridge in southeast NSW (Heimsath *et al.* 2002).

Creep occurs because soil is stirred by various agents (e.g., ants, worms, wombats or tree-throw), and gravity causes stirred particles to drift downhill. Particles reaching the surface may return to the soil body or may be lost to slopewash. New particles enter the soil from below. Using the principle that OSL measures the time elapsed since a grain was exposed to daylight (i.e., the time since a grain last visited the surface), the mixing process can be evaluated from ensembles of ages of individual grains, sampled from different points in the soil body. For example, if transport is dominated by diffusion within a shallow mobile layer, then grains within this layer are intermittently visiting the surface and would show finite ages, but grains beneath the mobile layer would have infinite ages. Alternatively, a finding of finite-aged grains from soil surface to soil base would indicate stirring of the entire soil column and would imply that the entire mass is in motion.

Figure 1 shows a conceptual sketch of creeping soil, together with the field area in upper Bega Valley, NSW, used by Heimsath *et al.* (2000) in their OSL-based study of soil creep. A continuous soil mantle 5-90 cm thick overlies 10-20 m of saprolite weathered from the regional granite. In summary, soil pits were sampled at several depths, and ensembles of single-grain OSL ages were determined for quartz grains extracted from each sample. Age-data for each ensemble were reduced to the following statistics: mean age, coefficient of variation (age standard deviation/mean age), and percentage of infinite-age grains (i.e., grains that had not been to the surface). Broadly, the mean ages increase with depth, coefficient of variation decreases with depth, and the percentage of grains that had never been to the surface increases with depth. To investigate processes that could generate this pattern, a computer simulation of diffusive creep involving random particle displacements was set up. Using Monte Carlo methods, the same types of statistics were extracted for grain ensembles from different positions in the simulated slope profile (Table 1 shows typical results). By obtaining a good match between model and observed data, Heimsath *et al.* (2002) concluded that creep at the study site is dominated by centimetre-scale particle displacements and that slopewash accounts for 20-30 % of the total transport.



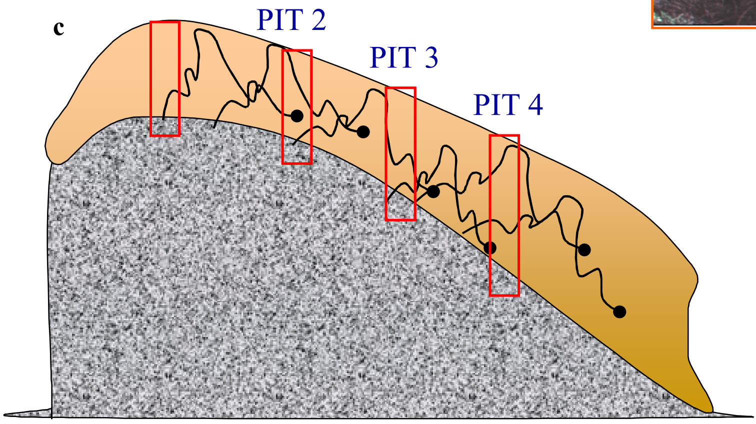


Figure 1a (above left): View west towards Brown Mountain, upper Bega Valley, NSW.

Figure 1b (above): Study site near base of Brown Mountain escarpment at the head of Bega Valley, NSW.

Figure 1c (left): Conceptual model of soil particle movements and OSL sample pits.

In summary, mixing processes as well as regolith history can be determined from single-grain OSL ages from ensembles of grains, from samples at different depths in a regolith profile. In addition to the case study reviewed above, a similar study was reported for basalt soils in north Queensland by Pillans *et al.* (2002). Furthermore, when OSL data such as these are combined with determinations of long-term rates of soil production based on in situ cosmogenic nuclides (Heimsath *et al.* 2000; see also Chappell 2003), then both rates as well as processes of regolith transport can be determined. We look forward to applying the dual method to a range of Australian regolith materials.

Table 1: Statistical data (Roman typeface) for ensembles of OSL single-grain ages from samples taken from different depths in three soil pits on a downslope profile (c.f. Figure 1). The OSL age represents the time elapsed since a grain last visited the ground surface (ages in kyr). Statistics include the mean age of a set of single-grain ages in each sample (usually 48 dated grains per sample), the coefficient of variation (standard deviation/mean age), and the percentage of grains in each sample that had never visited the ground surface (Sat. %). Numbers in italics represent comparable statistics derived from a computer model of regolith creep by particle diffusion.

Pit 2				**Pit 3**				**Pit 4**			
Depth (m)	**Mean age**	**coef. var.**	**Sat. %**	**Depth (m)**	**Mean age**	**coef. var.**	**Sat. %**	**Depth (m)**	**Mean age**	**coef. var.**	**Sat. %**
0.2	0.6	0.7	29	0.1	0.9	0.8	35	0.1	1	1.0	37
	1.8	*1.0*	*33*		*0.9*	*2.0*	*10*		*0.9*	*2.0*	*10*
0.4	3.5	0.4	66	0.3	4.4	0.7	44	0.5	4.4	0.7	72
	3.3	*0.6*	*58*		*3.4*	*1.0*	*41*		*6.9*	*0.8*	*52*
0.8	5.2	0.4	66	0.6	4.9	0.2	44	0.8	11.4	0.2	67
	4.2	*0.3*	*94*		*5.8*	*0.6*	*71*		*8.7*	*0.7*	*75*

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