Contributions of Luminescence Dating to Geomorphological Research

-A Southern African Case Study-

Kennedy Munyikwa

Professor, Dept. of Geography Education, Seoul National University

1. Introduction

Advances that have been made in improving luminescence dating techniques over the past decade have ushered in new powerful tools in geomorphological research. The method was initially developed for archaeological purposes as a dating technique for fired artefacts such as pottery, tiles and bricks. It is based on a property possessed by insulating or semiconducting materials that enables the grains in the clay matrix of the artefact to acquire and store energy emanating from decaying radioactive impurities contained within the artefact itself or its immediate surroundings (Aitken, 1985). When the mineral grains are heated, this energy can be released in the form of light in a process called luminescence. Luminescence that is stimulated by heating is termed thermoluminescence (TL). It was noted that by measuring the released luminescence energy accurately, in conjunction with determining the rate at which the radioactive energy was acquired by the mineral grains, an age representative of the time period that had elapsed since the last heating process occurred could be calculated. Given that it is also possible to release energy stored within the mineral lattice by exposure to sunlight, the method was subsequently applied to the determination of burial ages of detrital grains, particularly wind deposited sediments. Aeolian dune sands and loess deposits are exceptionally suitable for dating using luminescence techniques because the subaerial exposure that they experience during transport ensures that they are completely emptied (zeroed) of previously acquired energy prior to burial. With time, investigators (Huntley et al., 1985) discovered that it was also possible to use light to stimulate energy release during measurement (optical stimulation). Thus, optically stimulated luminescence (OSL) dating was introduced and rapidly developed into an effective technique that offered distinct advantages over the TL method (Stokes, 1992). Luminescence dating continues to evolve and, currently, there are no less than 50 laboratories around the world carrying out OSL and TL dating research.

Benefits that have been brought by the dating technique to geomorphological research and palaeoenvironmental reconstruction are noteworthy. By enabling the direct dating of a wide variety of detrital sediments, the method permits chronological control that is essential in ascertaining rates of geomorphological processes over extended periods of time. It has also enhanced the possibilities for quantitatively analysing palaeoenvironmental dynamics of aeolian systems in ways not previously possible. Between 1995 and 2000, a number of luminescence dating exercises were carried out in the Kalahari region of southern Africa (Stokes et al., 1997; Thomas et al., 1997; Blmel et al., 1998; O'Connor and Thomas, 1999; Thomas et al., 2000; Munyikwa et. al., 2000). In this paper, a review of the data acquired from the dating exercises is presented as a case study (Figure 1). Lessons that have been learnt are detailed and the limitations of the technique when applied in palaeonvironmental reconstruction are also discussed. In addition, ways for dealing with the deficiencies that were encountered are explored.

2. Study area

The Kalahari Sands that mantle the southern African subcontinent stretch from the 5 to the 28 S latitudes. They are thought to constitute the world's largest continuous aeolian sand body (Stokes et al., 1997). Their thickness varies from a thin veneer at the edges to tens of metres in the central part. The sediments are generally loose, unindurated sands. Mineralogically, they essentially comprise quartz whilst feldspars and some heavy minerals constitute minor components (Munyikwa et al., 2000). No primary depositional structures that are usually associated with eolian sand structures or environmental markers, such as palaeosols, have been documented (Stokes et al., 1997; Munyikwa et al., 2000; Thomas et al., 2000). Surface expression of the sands is in the form of longitudinal dunes that exceed 100 km in places. Analysis of LANDSAT imagery shows that the aeolian structures over the central Kalahari form a large anticlockwise whirl opening to the southeast (Figure 1). This orientation suggests the dunes may have formed under the influence of the winds blowing around the southern African anticyclone system (Thomas et al., 2000). Present climate is semi-arid and, with the exception of a few localities, the dune structures are inactive and support considerable vegetation. Nonetheless, the aeolian deposits are indicative of past periods during which the climate in the region was less humid. Prior to 1995, very little information was known about the chronology of the environmental evolution within the Kalahari. Few reliable absolute ages existed and, of these, most were either radiocarbon (C14) dates from sources that included pedogenic calcretes (Lancaster, 1989) and molluscs (Heine, 1981). In other cases 234U / 230Th data from speleotherm deposits were used for the age determination. Without exception, since no efficient method of dating the aeolian deposits was available, these dating exercises attempted to infer the ages of the deposition of the aeolian units indirectly by using proxy indicators such as reduced precipitation.

3. Luminescence dating exercises and results

The possibilities offered by luminescence dating presented investigators working in the Kalahari region with an ideal opportunity to solve questions that had vexed previous workers. For once it was now possible to date eolian deposits directly to determine their depositional ages. In all cases, the dating was carried out on pure quartz coarse grain separates (90 120 m) using either the TL method (Blmel et al, 1998; Munyikwa et al., 2000) or the OSL technique (Stokes et al., 1997; O'Connor & Thomas, 1999; Thomas et al., 2000). For the purpose of discussion, the study area has been divided into four zones: the northern sector centred around western Zambia; the southern sector encompassing southeastern Namibia, southwestern Botswana and northern South Africa; the central dune fields covering Botswana and northern Namibia and the eastern sector covering western Zimbabwe.

Luminescence dating results from the eastern Kalahari include work by Stokes et. al. (1997) and Munyikwa et al. (2000). In this region, Stokes et al. (1997) acquired dates that indicated four major periods of aeolian activity over the past ca. 120 ka. They identified dune building phases at 115-95, 46-41, 26-20 ka and another period after 20 ka. These episodes of landscape instability were presumed to be interspersed with periods during which the climate was more humid. Significantly, however, no firm stratigraphic evidence of wetter climate was identifiable in the field sections that were studied (Stokes et al., 1997). Working within the same region Munyikwa et al. (2000) confirmed that a significant proportion of the dune sands in the areas investigated were deposited during the period between 100 and 14 ka. Underlying this main body of sand, they also

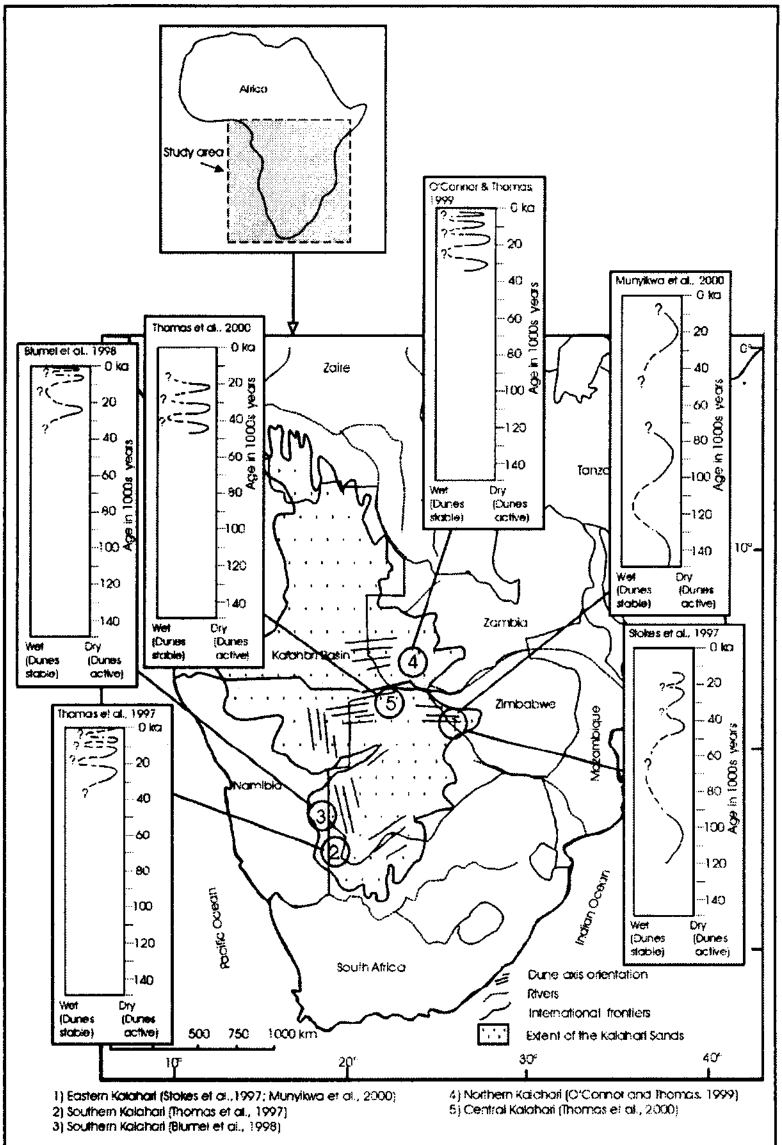

Figure 1. Study area in southern Africa indicating luminescence chronology of aeolian dune reactivation.

identified a ferricrete bed (suggestive of a more humid phase) that overlay more eolian dune sands. This ferricrete horizon was constrained at between 140 and 100 ka. However, they also pointed out the difficulty posed by the general scarcity of environmental markers within the stratigraphy of the sands and the problems this presented in reconstructing the chronology of the climate variations.

From the southern Kalahari region, Stokes et al. (1997) identified a major dune building period between 17 and 10 ka. Analysing dune sands from the same area, Thomas et al. (1997) distinguished depositional phases at 27 23 and 17 10 ka. In addition, they identified more recent dune activity at 6 and 1-2 ka. At a locality slightly further to the north, Blmel et al. (1998) recognised that the bases of longitudinal dunes in the area were aged between 17 and 9 ka. Dune crests in this area are active in places and very young ages of less than 1 ka were produced, making these some of the youngest luminescence ages to have been obtained from the Kalahari region.

O'Connor and Thomas (1999) produced luminescence ages from the northern central part of the study area in western Zambia. Here the dates point to multiple dune building episodes at 32 27, 16 13, 10 8 and 5 - 4 ka. These aeolian depositional phases are thought to have been interspersed with periods during which the precipitation was higher and dune surfaces stable. These data were generally in agreement with the episodic nature of dune building periods that were identified by Stokes et al. (1997) in the eastern Kalahari but, similarly, no evidence of humid climate within the dune stratigraphy was identified.

Data from the central Kalahari were presented by Thomas et al. (2000) who dated longitudinal dune sequences from northern Namibia. Here they obtained luminescence ages that ranged from ca. 120 ka to 48 ka. As in other regions, the stratigraphic sequences from which the samples were collected displayed a massive character, lacking any evidence of breaks in deposition or climatic change. However, after statistically analysing the data (weighted mean), they reported clusters at 48 41, 36 29 and 23-21 ka, which they concluded were suggestive of episodic deposition.

4. Discussion and conclusions

Cursory inspection of the results shows that, contrary to suggestions made by earlier literature (Lister, 1987), the Kalahari Sands did not accumulate during a single event. The dune structures constitute composite forms representing various episodes of sand deposition that occurred over a long period of time. These dune building periods are thought to have been interspersed with phases during which the landscape was probably stable. Notably, however, there is very poor correlation between the dating exercises from the various localities and, thus, it is presently not possible to come up with a unified chronology for aeolian periodicity throughout the Kalahari region. The lack of identifiable environmental markers such as old soil surfaces within the dune profiles is a significant impediment towards the elucidation of a region-wide chronology. Nonetheless, the scale of the dune structures (exceeding 100 km in places) points to formation under climatic conditions of regional magnitude. It is also noticeable that dune sequences in eastern and northern Kalahari seem to cover longer periods of depositional history (ca. 100ka) than in the south (ca. 25 ka). This is attributed to a limited supply of sediments in the southern region that results in the total reworking of existing dune structures before new ones are formed (Thomas et al., 2000).

Longitudinal dune dynamics are poorly understood (Pye and Tsoar, 1990). However, it appears from the analyses of the acquired results that there has been a tendency to view longitudinal dune structures as purely accretionary structures (Thomas et al., 2000). This may not be very accurate. The almost total absence of any preserved palaeosurfaces within the dune sequences at all sites investigated is a strong indicator towards the erosive character of the longitudinal dunes in the Kalahari. This would imply that there was extensive reworking of the upper parts of old dune structures before new sediment was available for deposition. Critically, however, it is not possible to ascertain how much material was removed before new sediment was deposited on an individual dune structure. This uncertainty over the degree of dune truncation presents a very significant problem for palaeoenvironmental reconstruction. The limits of the depositional episodes identified using data from luminescence dating techniques only represent minimum ages (Munyikwa, 2000). A method applied by some (Stokes, 1997; Thomas et al., 2000) is to statistically analyse the data for identification of natural breaks in age distributions. This is attractive in theory but hardly satisfactory as applied to the Kalahari. At best, it may serve as an approximate indicator. Alternatively, for statistical analysis to succeed, an extremely large number of dune profiles would have to be sampled and analysed.

It is also imperative to address the causative agents for environmental change in the study area but the driving forces behind climate variations in the low latitudes remain unclear. Attempts have been made to compare the chronology of environmental change within the Kalahari area with climatic fluctuations in the high latitudes (Stokes et al, 1997; Thomas, 2000). Indeed, there is ample modelling evidence that points to significant cooling of sea surface temperatures in the tropics in response to changes in the high latitudes during glacial periods. There are also other localised factors such as landmass effects that influence landscape responses to atmospheric forcings (Stokes et al., 1997). A more accurate regional chronology for landscape responses would, however, contribute towards understanding of the driving mechanisms behind the environmental fluctuations in the Kalahari.

In summary, luminescence dating carried out in the Kalahari has provided ages for depositional periods of aeolian sediments. The absence of preserved environmental markers within the dune sequences themselves makes it difficult to create a comprehensive environmental reconstruction. It is, therefore, necessary that supplementary data be sought to complement luminescence dating efforts. Possibilities for acquiring environmental data from other sources within the region such as lake sediments (e.g. Lake Mkagadigadi or Okavango) should be explored fully. Alternatively, more dune structures with more complete stratigraphic sequences should be identified where more continuous data can be extracted with luminescence dating. Despite these shortcomings, it is evident that information acquired from luminescence dating has permitted quantitative analyses of some of the geomorphic processes that operate within the Kalahari. This has led to improved knowledge of the palaeoclimatic evolution of the region.

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