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2015

Dating techniques: illuminating the past

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Recommended Citation
Roberts, Richard G. and Lian, Olav B., "Dating techniques: illuminating the past" (2015). *Faculty of Science, Medicine and Health - Papers: part A*. 3193.
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Dating techniques: illuminating the past

Abstract
The technique of optical dating was first reported 30 years ago, and has since revolutionized studies of events that occurred during the past 500,000 years. Here, two practitioners of optical dating assess its impact and consider its future.

Disciplines
Medicine and Health Sciences | Social and Behavioral Sciences

Publication Details
Roberts, R. G. & Lian, O. B. (2015). Dating techniques: illuminating the past. Nature, 520 (7548), 438-439.

This journal article is available at Research Online: https://ro.uow.edu.au/smhpapers/3193

Illuminating the past

The optical dating technique was first reported 30 years ago, and has since revolutionized studies of events that occurred during the past 500,000 years. Two experts assess its impact and consider its future.

Richard G. Roberts & Olav B. Lian

Thirty-year anniversaries are traditionally associated with pearls, which are renowned for the lustre produced by the reflection, refraction and diffraction of light. It is fitting, then, that in this International Year of Light and Light-based Technologies we also celebrate the dawn of the optical dating technique, first reported three decades ago by Huntley *et al*. in *Nature*[1]. Optical dating was proposed by the authors as a method for determining the time since wind-blown and water-borne mineral grains were last bleached by the sun's rays before becoming buried. It has since become an essential arrow in the quiver of scientists worldwide, enabling geological, biological and archaeological events to be placed on a calendar-year timescale extending from the present to half a million years ago or earlier — well beyond the 50,000-year limit of radiocarbon dating.

Optical dating exploits the physical properties of light-sensitive electron traps in ubiquitous minerals — chiefly quartz and feldspar — as atomic 'time capsules'. These traps are rapidly emptied when exposed to sunlight, but steadily refill if mineral grains are buried within a deposit and concealed from light, because of the energy received from background environmental radiation (Fig. 1). The time elapsed since the grains were last bleached by sunlight is calculated as the laboratory estimate of the past radiation dose divided by the rate at which ionizing radiation from environmental sources is absorbed by the grains after burial[1–7].

Huntley, with then postdoctoral fellow Ann Wintle, had previously been pivotal in developing reliable procedures for thermoluminescence (TL) dating of unheated sediments[8]. This technique is closely related to optical dating, except that TL traps are emptied by heating grains — a process that evicts electrons from both optically-inert traps and light-sensitive ones. Optical dating, by contrast, enables the latter to be accessed directly. Huntley *et al*.[1] achieved this using the green beam from a powerful argon-ion laser to induce dim, optically stimulated luminescence (OSL) from quartz grains[3]. This OSL signal was compared with those obtained from laboratory radiation doses to estimate the past radiation dose and, therefore, the burial time of the grains.

Their approach was promptly implemented by another team using a similar laser[9], but optical dating spread more widely only after it was discovered that feldspars were acutely sensitive to infrared stimulation[10], enabling the convenient use of infrared light-emitting diodes (LEDs). By the late 1990s, the technique had matured into a powerful tool for dating sediments from the Quaternary period (the current geological period, which began about 2.6 million years ago), shedding new light on the evolution of desert dunes and other landforms and on the timing of past human activities, particularly in Australia and Europe[2].

Applications proliferated after the turn of the millennium, following a decade of development of ‘single aliquot’ procedures[2] to determine the burial dose — an idea originally proposed by Huntley and colleagues[1]. The adoption of optical dating by laboratories worldwide was spurred by the advent of single-aliquot regenerative-dose (SAR) procedures[11], the use of established statistical methods to analyse OSL data[12] and the incorporation of sufficiently bright LEDs and compact solid-state lasers to stimulate quartz and feldspar grains in purpose-built, automated instruments[13]. By making repeated OSL measurements on individual grains or separate groups of grains, many independent estimates of the burial dose can be obtained for a sediment sample using SAR procedures.

The resulting studies have addressed questions ranging from landscape dynamics, climate change and soil development to studies of human evolution and dispersal over the past few hundred millennia, as well as more recent archaeological events[3–7]. For example, optical dating has revealed that symbolic markings, personal ornaments and innovative technology associated with early modern humans appeared more than 70,000 years ago in southern Africa, and were widespread across the region by 60,000 years ago[14–16] — fifteen millennia before modern humans entered Europe. The technique has also played a key role in establishing that humans arrived in Australia by 50,000 years ago[17] and that the last of the 'megafauna' — the giant marsupials, reptiles and flightless birds that once roamed the continent — perished soon after[18], during a period of increasing aridity but preceding the most extreme climatic phase[4,17].

Methodological and instrumental developments continue to drive advances in optical dating. Many quartz grains have physical properties ill-suited to SAR procedures, and two further possible complications are insufficient bleaching of grains prior to deposition and mixing of sediments after burial. Measurements of individual sand-sized grains — the fundamental unit of analysis in optical dating — allow for each of these factors to be investigated using SAR procedures[12]. This has helped to improve the accuracy of optical ages by reducing the uncertainties inherent in measuring composite OSL signals from multiple grains[7,15].

There nonetheless remain other constraints on optical dating that will keep researchers busy searching for solutions. A key limitation is the time range, which is governed by the maximum number of electrons that can be caught in light-sensitive traps and their long-term stability at environmental temperatures. Optical dating applications have largely been restricted to the past 200,000 years, and efforts to push the maximum limit beyond the 800,000-year timespan investigated by Huntley *et al.*[1] have mostly ended in disappointment. But new vistas are now opening up, with the recent identification of longer-range optical dating signals in quartz and feldspar[5–7]. If these are confirmed as reliable chronometers, then optical dating of major events in Earth and human history during the Early Pleistocene — the period from about 2.6 to 0.8 million years ago — has a bright future.

Developments are also afoot to map the distribution of optical ages for individual grains on the cut surfaces of intact sediments and artefacts[7]. The ability to acquire such spatially-resolved ages would be an advance over the current practice of disaggregating samples to extract grains for OSL measurements, which results in the loss of valuable contextual information, and would yield fundamental insights on a par with those obtained from single-crystal dating in other branches of geology and single-cell analysis in biology.

New frontiers for optical dating also include the use of OSL signals to investigate the long-term exhumation of landscapes and evolution of mountain ranges[19], and the *in situ* dating of minerals on Mars using robotic devices, which would propel optical dating into space[20]. These applications are extremely challenging, but if the last 30 years of progress is any guide to the future, we can expect optical dating to illuminate much more of the history of this planet — and perhaps others — before celebrating its 50th anniversary.

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Figure 1 │ Electron traps as timekeepers in mineral grains. a, Mineral grains are exposed to sunlight during transport or when deposited on the ground surface. Electrons caught in light-sensitive traps in the crystal lattices of the grains are evicted by the light and return to their normal atomic sites. **b**, When grains are buried and hidden from sunlight, environmental radiation causes electrons to leave these sites and be captured by the traps. **c**, If the grains are collected — taking care to conceal them from daylight — and illuminated by infrared, green or blue light in the laboratory, emptying of these traps gives rise to optically stimulated luminescence (OSL). The past radiation dose — from which the burial time of the grains is determined — is calculated as the equivalent dose of laboratory radiation needed to produce an OSL signal of the same intensity[1]. Grains are heated before and during measurement of the OSL signals, which are separated from unwanted luminescence emissions using filters.