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OPTICAL DATING OF ARCHAEOLOGICAL SEDIMENT

by

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ABSTRACT

The new technique of Optical Dating, primarily applicable to unburnt sediment which has been exposed to sunlight during transportation by wind or water, is briefly described. The technique is compared to TL (Thermoluminescence) dating of sediments, to which it is closely related. The particular advantage of using zircon grains is indicated as well as the likely age range for the techniques in general, and expected archaeological applications.

INTRODUCTION

Luminescence Dating comprises the well-established technique of Thermoluminescence (TL) Dating together with the new technique of Optical Dating recently demonstrated by HUNTLEY, GODFREY-SMITH and THEWALT (1985), the latter being based on Optically Stimulated Luminescence (OSL) and seen as being primarily advantageous in application to unburnt sediment. For TL dating of burnt material the event being dated is the last heating in excess of about 400°C and for calcite it is the time of crystal formation. For sediment TL it is the last time at which there was substantial exposure to sunlight, eg during transportation by the wind before deposition. If OSL is used the necessary duration of exposure is at least an order of magnitude less than if TL is used; this gives the possibility of dating sediment that has had relatively brief exposure such as during transportation by flood water or while lying on the surface prior to burial by succeeding layers.

THE BASIC TECHNIQUE

Both types of luminescence represent the release of energy that has been stored in the crystal lattice of the mineral concerned (eg quartz, feldspar, zircon, calcite). This storage is in the form of electrons that are trapped at defects in the crystal lattice and when released (by heat in the case of TL; by light in the case of OSL) some of the de-trapped electrons find *luminescence centres* thereby causing light to be emitted (these centres are usually formed by impurity atoms present in the crystal lattice).

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The amount of light emitted is proportional to the number of trapped electrons (to a good approximation). These latter are the result of exposure to nuclear radiation and there is a weak flux of this from the radioelements (potassium-40, thorium and uranium) naturally present in all sediment. The trapped electrons build up to an equilibrium level during geological times and an essential requirement for dating is that the number of trapped electrons is reduced to near zero at the time of the event being dated; by sunlight in the case of sediment dating.

The important difference betwen OSL and TL, and the real advantage of OSL over TL is that in OSL, light from a laser source is used to release electrons from only those traps which are sensitive to light. Hence, the signal measured is produced by electrons from the most easily light-bleachable traps. These are the traps which are emptied first on exposure to sunlight during deposition. For sunlight to reduce the signal in quartz to a few percent of its original value, it takes only a few hundred seconds in the case of OSL, while it takes tens of hours in the case of TL. It is this rapid bleaching which ensures the zeroing of the OSL of sediments, allowing dating of sediments which have had only a brief exposure to sunlight during deposition. For further details see HUNTLEY *et al.* (1985) and AITKEN *et al.* (1986).

The basic equations for both TL and OSL are

$$\text{Age} = \frac{\text{Palaeodose}}{\text{Annual Radiation dose}} \qquad (1)$$

and

$$\text{Palaeodose} = \frac{\text{Accrued luminescence}}{\text{Luminescence per unit dose of radiation}} \qquad (2)$$

The ACCRUED LUMINESCENCE, more usually referred to as the 'NATURAL', is the luminescence observed, by means of a photomultiplier, when the sample is heated (for TL) or exposed to a laser beam (for OSL). The LUMINESCENCE PER UNIT DOSE, or SENSITIVITY, is evaluated by measurement of the 'ARTIFICIAL' signal (TL or OSL) observed after exposure of the sample to radiation from a calibrated radioisotope source. Thus the PALAEODOSE represents the total dose that the sample must have received since the traps were last empitied; alternative terminology is EQUIVALENT DOSE, ARCHAEOLOGICAL DOSE, ACCRUED DOSE, etc.

The ANNUAL DOSE, or DOSE-RATE, is determined by both laboratory and on-site measurements. For on-site measurements we use (i) TL capsules and (ii) a portable gamma spectrometer. A TL capsule, usually of copper, contains a highly-sensitive TL powder and is buried in the soil in a situation that represents that of the sample as closely as possible; it is about 8 mm diameter and 40 mm long. Minimum burial time is a few months, a year being preferred. The portable gamma spectrometer measurement time is only an hour (per level).

The annual dose is influenced by the water content of the sediment during antiquity. Though an upper limit to the effect is obtained by measuring the saturation water content and the present day value can be measured, there is a degree of uncertainty about the situation in the past and at some sites this may significantly limit the accuracy attainable.

Laboratory measurements by thick-source alpha counting combined with gamma spectrometer determination of relative proportions of radioisotopes (allowing for identification of disequilibrium) are made.

For further information refer to AITKEN (1985), WINTLE and HUNTLEY (1982), MEJDAHL (1986) and BERGER (1986).

AGE RANGE

For quartz, the age range is dependent on the luminescence characteristics of the sample and the radioactivity of the environment. The upper limit is not yet firmly established but certainly it reaches to 100,000 years. The lower limit for sediment dating is set by the effectiveness of the zero setting and the sensitivity of the sample. This is expected to be around 1,000 years.

ZIRCON DATING (SUTTON and ZIMMERMAN, 1976; TEMPLER, 1986)

The levels of thorium and uranium in zircon are several hundred parts per million and consequently the annual dose for a grain of 0.1 mm or more is dominated by the internal contribution. This means that uncertainty about water content and other environmental factors (eg geochemical leaching and radioactive disequilibrium effects) are relatively unimportant. This removes an important source of systematic error. However the technique is a much more difficult one than dating by conventional TL or OSL, and so far its success has been demonstrated only for zircon grains extracted from pottery, bricks and lava. Nevertheless there is good prospect that it will shortly become available for sediment. The technique involves the manipulation of single grains and so it is to be expected that it will not be applicable to very fine grained sediments. About 100 grains are required; these have to be extracted and identified using only a dim red light (to avoid bleaching of the 'natural') and it is only worth attempting to use this technique for sediments known to be fairly rich in zircon.

ACCURACY AND APPLICATION

The accuracy attainable, as for TL dating of sediments, is currently in the range 5-10% of the age (and in adverse conditions it is worse), though zircon dating may prove to be more accurate. Obviously, because of this accuracy limitation the technique is not necessarily the best one to use. However for sites beyond the range of radiocarbon, the technique will hopefully prove to be an important new dating tool.

Because of the necessity to sample the sediment without exposure to light and to make on-site radioactivity measurements, samples are usually collected by laboratory staff. Depending on the number of levels sampled the time taken is usually less than one day. About two kilograms of sediment are removed, an auger hole of 0.3 metres depth and 65 mm diameter being made. If possible, a dosimeter capsule (as mentioned above) is left buried.

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