III. 2 ABSOLUTE CHRONOLOGIES: LUMINESCENCE DATING OF EGYPTIAN ARTEFACTS

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The phenomenon of luminescence in solids has been used as a dating method in archaeology since the late 1960s. Since then the method developed as an important and universal tool alongside radiocarbon dating and dendrochronology. It is based on the property of a number of minerals to store and release radioactive decay energy. Two minerals frequently occurring in archaeological contexts, quartz and feldspar, show this effect very distinctly which makes the application of luminescence analysis in archaeology particularly useful. In the field of the geological sciences luminescence dating has caused a decisive increase of knowledge and is regarded meanwhile as indispensable. In the following it will be discussed in which parts of archaeology the use of the method may be inadequate.

Luminescence Dating: Basic Principles

Radioactive traces (U-238, U-235, Th-232, K-40, Rb-87) are constituent in clay, in soil, and in rocks. During spontaneous decay, these elements release energy into the environment. When quartz or feldspar occurs in the environment, the emitted energy may be stored in the crystal lattice of these minerals. After an archaeological storage time the stored energy can be released in form of light. The longer the archaeological storage time, the larger the accumulated energy (phys. the *dose*) and the stronger the light signal. Luminescence dating is a dosimetric dating method requiring no external calibration. The necessary zero-setting event is achieved by heating or exposure to light when the energy stored in the lattice over geological times is zeroed and the accumulation can begin again.

Due to different ranges and to different effectiveness in producing luminescence, the three types of radioactive decay radiation (alpha-, beta- and gamma radiation) need to be taken into account separately. Consequently, more than one physical quantity must be measured in the laboratory and, hence, the number of measurements results in a complex error of the age which is one of the major differences from C-14 dating. The total error of a thermoluminescence single date of an object amounts to between 7 to 12% of the total age expressed in years. In absolute numbers this amounts to roughly ±450 years for an OK date. The range of uncertainty is much smaller, if several samples from the same archaeological context are analyzed; the so-called context error can be reduced to approx. ±5% which still corresponds to ±230 years for the OK.

Thermoluminescence ages are calculated according to the following formula:

$$\text{age} = \frac{\text{archaeological dose}}{\underbrace{a \cdot \text{dose-rate}_\alpha + \text{dose-rate}_\beta}_{\text{internal dose-rate}} + \underbrace{\text{environmental dose-rate}}_{\text{external dose-rate}}} \qquad \text{(Eq. 1)}$$

A feature peculiar to Egyptian artefacts is the low radioactive trace-element content which explains the low internal dose-rates frequently encountered in Egyptian artefacts. Consequently, thermoluminescence ages become dependent on the ratio of the internal to external dose-rate (see Eq. 1). Should the two dose-rates come close to or equal each other, the external dose-rate may determine the thermoluminescence age. Fig. III. 2.1 illustrates the effect of the dose-rate ratio on the thermoluminescence age.

Thermoluminescence produces the best results when applied to artefacts as they are excavated, i.e. when the measurement of the environmental dose-rate can be made on-site. No access to the site limits the usefulness of the method, e.g. analysis of museum objects of unknown provenance cannot produce definitive results. The humidity of a sample also requires access to the site, as humidity is a correcting factor for the age of a sample. Variation of the humidity during storage times has to be taken into account.

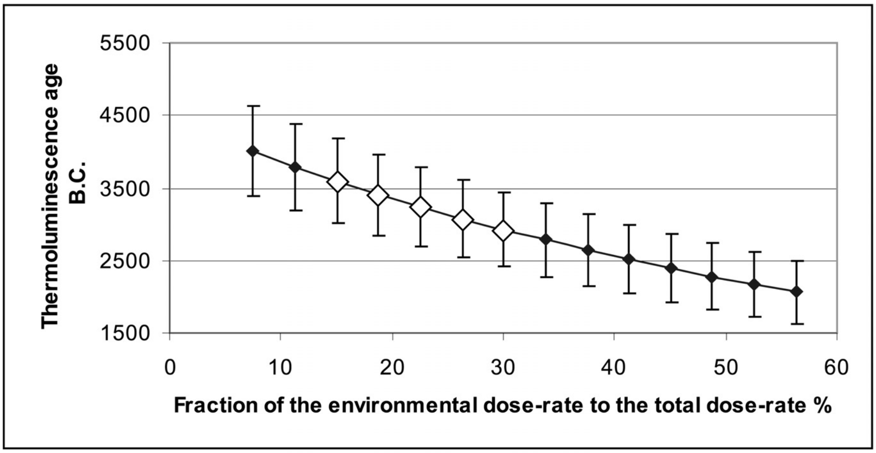

Fig. III. 2.1. Effect of the environmental dose-rate on thermoluminescence age; the example shows a typical ceramic sample from the OK. The fraction of the environmental dose-rate most probably prevailing in Egypt lies between ca. 15 and 30.

Luminescence techniques can be used to date:

A. fired materials: ceramics (minimum firing temperature 500°C), stones (firesides), casting cores of bronzes
B. unfired materials: sediments (aeolian, fluvial, colluvial), mortar

How Useful is Luminescence Dating for Dynastic Egyptian Objects? Answers Based on Published Dates

Considering the usual error margins of 7–12%, thermoluminescence dating of Egyptian artefacts cannot contribute much to chronological evidence. The method may prove useful for a piece which cannot be attributed to any period on stylistic criteria. Even the range of context errors exceeds the possible imprecision of the Egyptian chronology which in its present state is better than 5% in all periods. Hence it is not surprising that published examples of luminescence dating for Egyptian artefacts are few. Recent culling of various bibliographical sources including CAS (chemical abstracts services) turned up the following papers.

Thermoluminescence Dates Quoted in the Literature

Two nearly identical papers deal with pottery of the fourth dynasty.[1] The instrumentation used and the reported error of 2.3% cast some doubt on the seriousness of both; the standard calculation will not result in an error that small.

A French team notes that the pigment Egyptian Blue results from a thermal reaction thus making dating of this material possible.[2] The attempt to date a large chunk of Egyptian Blue from Karnak is described resulting in a reasonable date. However, dating pigments from paint-layers is not feasible due to dosimetry problems arising from paint-layer thickness which usually is smaller than the range of beta-particles.

Some unpublished results of the author (Rathgen-Forschungslabor in Berlin) on potsherds from excavations at Abu Minshat Omar can be mentioned here. A comparison of the results with radiocarbon data from the same site revealed a systematic deviation towards younger ages.

Samples of vitrified silt from the Early Dynastic tombs at Abydos turned out to be undatable. Secondary firing resulted in a high degree of vitrification making luminescence dating impossible.

For earlier periods with a comparatively fluid chronological framework luminescence dates, even including the above quoted errors, may furnish a valuable chronological contribution. However, even for this period luminescence has rarely been used. Whittle's early study dealt with potsherds from Hemamieh and Qurna-Tarif.[3] Environmental dose-rate data were obtained in the laboratory by alpha-counting of soil samples. An archaeological evaluation of the data obtained was not attempted. Two additional studies considered Middle Palaeolithic

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[1] S. A. Elfiki, M. S. Abdelwahab, N. Elfarawamy & M. A. Elfiki, "Dating of ancient Egyptian pottery using thermoluminescence techniques", *Nuclear Instruments and Methods* 94 (1994), 91–94.—M. S. Abdel-Wahab, S. A. Elfiki, M. A. Elfiki, M. Gomaa, S. Abdel-Kariem & N. El-Faramawy, "Annual dose measurements and TL-dating of ancient egyptian pottery", *Radiation Physics and Chemistry* 47 (1996), 697–700.

[2] M. Schvoerer, M. C. Delavergne & R. Chapoulie, "The thermoluminescence of Egyptian Blue", *Nuclear Tracks and Radiation Measurements* 14 (1988), 321–327.

[3] E. H. Whittle, "Thermoluminescent dating of Egyptian pre-dynastic pottery from Hemamieh and Qurna-Tarif", *Archaeometry* 17 (1975), 119–122.

settlements.[4] Dating Neolithic cultures by thermoluminescence and radiocarbon in the Sudan Nile valley was the aim of a French working group.[5]

Outlook

Luminescence techniques other than thermoluminescence, e.g. optically stimulated luminescence (OSL), are not very likely to improve the situation; conversely, the sensitive dependence on the dose-rate ratio will become even more important. Corresponding to the zero-setting event (bleaching by sun-/daylight) these techniques are more appropriate for use in geological sciences. About half a dozen studies devoted to sediment dating and shoreline development have been done.[6]

[4] N. Mercier, H. Valladas, L. Froget, J. L. Joron, P. M. Vermeersch, P. Van Peer & J. Moeyersons, "Thermoluminescence dating of a Middle Palaeolithic occupation at Sodmein Cave, Red Sea Mountains (Egypt)", *Journal of Archaeological Science* 26 (1999), 1339–1345.—P. M. Vermeersch, E. Paulissen, S. Stokes, C. Charlier, P. Van Peer, C. Stringer & W. Lindsay, "A Middle Palaeolithic burial of a modern human at Taramsa Hill, Egypt", *Antiquity* 72 (1998), 475–484.

[5] P. Guibert, C. Ney & M. Schvoerer, "Datation croisée TL/C14 de cultures néolithiques de la Vallée du Nil, Soudan, sites d'El Kadada et d'El Ghaba", *Archéologie du Nil Moyen* 5 (1991), 129–141.—P. Guibert, C. Ney, F. Bechtel, M. Schvoerer & F. Geus, "TL and radiocarbon dating of neolithic sepultures from Sudan: intercomparison of results", *Radiation Measurements* 23 (1994), 393–398.

[6] O. Bubenzer & A. Hilgers, "Luminescence dating of Playa Sediments of the Egyptian Plateau, Western Desert, Egypt", *Quarternary Science Reviews* 22 (2003), 1077–1084.—H. M. El-Asmar & P. Wood, "Quaternary shoreline development: the northwestern coast of Egypt", *Quaternary Science Reviews* 19 (2000), 1137–1149.