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Original article

Surface luminescence dating of some Egyptian monuments

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ABSTRACT

Surface luminescence dating to Egyptian monuments of the age range 3000 B C to Hellenistic times has been applied for first time. Monuments include the Giza plateau (Sphinx Temple, Valley Temple, Mykerinus), the Qasr-el-Saqha, the Khasekemui tomb and the Seti I Temple with Osirion at Abydos. Equivalent doses were measured by the single and multiple aliquot additive and regeneration techniques, and dose rates by portable gamma ray probes, and with laboratory counting and dosimetry systems. The resulted ages have confirmed most conventional Dynastic dates, while in some cases, predating was obtained by some hundred of years. The dates are discussed in the light of current archaeological opinions.

1. Introduction

Physical methods for the determination of age of stone structures (monuments, altars, temples, monoliths, buildings, cairns, field walls, mortars etc. [1]) almost always use material associated with the construction period, that may contain ^{14}C datable material rather than material directly from the fabric of the construction. However, in many cases, appropriate organic debris is either not available, or the association with the archaeology is insecure. The direct dating of stone surfaces has been an ongoing subject of research since its first application [2,3], until today, and it is coined surface luminescence dating (SLD).

Sole archaeological dating relies on several grounds such as:

- excavated finds from inside and around a building, and written sources;
- thorough attribution of finds to correct stratigraphic order;
- masonry typology and building technique, as well as, investigation of later repairs;
- use of buildings by later habitants [4].

Though archaeological dating in Egypt relies on written sources, there are instances where the Dynastic chronologies do not satisfy the construction age of some monumental structures. Here, we have applied SLD to a selection of six Egyptian monuments for revisiting their dating in the light of current opinions (Fig. 1).

2. Surface luminescence dating (SLD)

Since 1994, application examples derive from Greece, Peru, and elsewhere covering the period third millennium to Classical and Medieval times [5].

The surface luminescence dating (SLD) works as follows: during the process of the preparation of stone blocks (cutting and carving, or sculpturing) and prior to the setting one upon the other (or construction of a building), the solar radiation (UV and optical spectrum) bleaches the stored geological luminescence in the carved stone surface, down to a depth determined by the depth of penetration of light in that material. This exposure – just minutes required for quartz and feldspar bearing rocks used here i.e. granite and sandstone – erases the luminescence to a zero or a near zero residual value. On construction, shielding of the surface occurs and re-accumulation of (archaeo-) luminescence is initiated due to irradiation from ambient radioactivity and continues till excavation and measurement.

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Fig. 1. Map of Egypt from GoogleEarth. The sites are pined in the map.

In fact, the decay of natural radioactivity viz. uranium, thorium, potassium and rubidium along with cosmic rays, provide as a first approximation a constant irradiation field. The minerals in stonewall are therefore irradiated at a constant rate, and hence, acquire latent luminescence at a constant rate. The latent luminescence is released upon exposure to light, setting the signal to zero or near zero, whence the trapping process begins anew. Events which zero the pre existing geo- or archeo-luminescence are intentional (construction) or accidental (seismic events, destruction, that follows sediment cover) exposure to daylight which provides sufficiently energetic photons to induce zeroing.

In the laboratory, the same process is mimicked. The trapped electrons population can be measured by stimulating the crystal by heat (mostly up to ~400 °C) or visible [mostly blue or green diodes or infrared (IR)] light. These stimulations lead to release of charges some of which eventually recombine with opposite charges and emit luminescence in either or all of ultraviolet (UV) and visible spectrum. The intensity of this light is proportional to the number of charges recombining and this in turn is proportional to trapped charges. This fact is exploited to convert light units to dose units.

The intensity of the emitted light is proportional to the concentration of trapped charges/electrons and hence, to the radiation dose. The relationship is proportional. The latent luminescence signal increases till a saturation of trapped charges occurs.

Complete eviction of electrons from traps of crystalline minerals is desirable although a residual unbleachable (residual) luminescence component often remains. Quartz and feldspars in monolayer are bleached within minutes of sun exposure, but in rocks, it needs dozen of minutes to zero the signal due to overlying layers. This is because sunlight penetrates the upper nano to micron scale depths easier, resulting in fast total bleaching, and goes further too attenuated according to Beer–Lambert's law and other scattering phenomena more complicated, implying random transport of photons in matter through pathways and cascade effects [6]. The direct optical transition to the conduction band (photoionization) gives rise to the near-exponential dependence of bleaching efficiency on photon energy [7–9]. Theoretical calculations and experimental tests define the penetration depth of solar radiation that comply with experimental data on various rock types (marble, granite) i.e. a complete absorption at around 4–5 mm [6]. However, reservations are made for the penetration as exposure time indicates slow bleaching at greater depths. For calcitic rocks, the bleaching is much slower in the order of hours to several dozens of hours, where a residual luminescence level is reached. The latter serves as the initial level upon which radiation growth builds up [6,8,10–12]. Attenuation factors μ were found 0.52–0.90 mm^{-1} for Penteli and Naxos marble quarries and 0.41–0.52 mm^{-1} for granites (± 10%).

Laskaris and Liritzis [6] have produced a generalized approach for the bleaching of luminescence signal as a function of depth for every surface rock (marble, marble schist, granite), promoting the functional behavior of cumulative logarithmic or normal distribution type of error function and attributing to the variable coefficients a physical meaning. The construction of a particular equation unique for each material exposed to sunlight versus depth and exposure time has been tested on various rock types and data sets inhering variable errors, that at the end, offers a new way to surface luminescence dating and authenticity. The residual TL/OSL at top surface layer for $CaCO_3$ of marbles is discernible while for granite and quartz is anticipated near zero. An excellent convergence between predicted and experimentally found paramegers reinforce the new procedure.

For ancient walls made by limestone/marble, the solar penetration can reach depths of 5–10 mm, a useful sampling depth for dating of face wall, provided that sampling is made properly during excavation avoiding exposure to sunlight. Otherwise, sampling from internal contacts between two overlied blocks, solar penetration ensures complete zeroing only in the first 1–3 mm from surface. Incomplete bleaching from variable solar exposure may be determined by applying the dose plateau test. For granites, the complete bleaching of luminescence in top layers of rocks varies