Tristan Bench

Report on: Addressing Rock Artifact Degradation in Mount Diablo State Park, California

Exposure dating of rock surfaces using luminescence offers the ability to determine the duration of time ($<10^2$-10^4 years) since a surface was last buried or unexposed to sunlight. This is a technique that can allow age calculations for a variety of rock surfaces with geological, archaeological, and forensic significance within decamillennial timescales under current model approaches, and perhaps longer timescales with improved theoretical models.

The measured chronometer is luminescence, the emission of light induced by the release of electrons trapped in crystal lattice mineral defects. In the case of optically stimulated luminescence (OSL), blue-green light wavelengths allow for the detrapping of electrons from quartz lattice charge defects, resultingly emitting ultraviolet light that is measured for dating. The intensity of OSL emitted from quartz corresponds to the amount of time since the mineral was last exposed to light. The exposure dating technique assumes pre-exposure that all electron traps in quartz are filled within a sample. With exposure to daylight, saturated quartz-bearing rock samples will begin to release OSL from the subsurface at a depth dependent rate, characterized by the rock's detrapping properties, the ability for light to attenuate into the rock, and from the intensity of sunlight applied to the incident surface.

Back in 2019, a trial OSL exposure dating study was conducted on sandstone surfaces in the Morgan Territory Regional Preserve near Mount Diablo, California, with the aim of determining the timescale of cupule rock artifact generation in the area to highlight possible modern anthropogenic disturbances to artifact surfaces. Evidence would then be utilized to provide a cultural protected status to the artifacts in the Preserve.

Right away in the trial study, however, there were issues with the application of the dating technique. Traditional sampling procedures for obtaining exposure dating model parameters for a rock surface require the presence of compositionally and morphologically matched rock surfaces with known exposure ages. Of the three possible proximal surfaces that were sampled onsite, none produced viable depth profiles for parameter extrapolations. It became apparent that this sampling requirement limited the accuracy and applicability of the dating technique. Further, traditional measuring procedures for depth profiles involve measuring the OSL of millimeter slices from surface core samples. This measuring procedure offers poor resolution datasets and thus limits parameter and age fitting accuracies.

These experiences brought new motivation to resolve sampling and measuring limitations imposed on the exposure dating technique. New modified sampling and measuring procedures incorporating controlled exposure experiments (CEE) and OSL scanning methods were performed in a trial study on 11-year exposed quartzite rocks. CEE sampling approaches attempt to reliably determine exposure dating model parameters directly from the rock surface of interest using OSL saturated core samples subjected to controlled light exposures. OSL scanning measures are used in tandem to record sub-millimeter resolution OSL depth profiles from transverse slices of core surface samples.

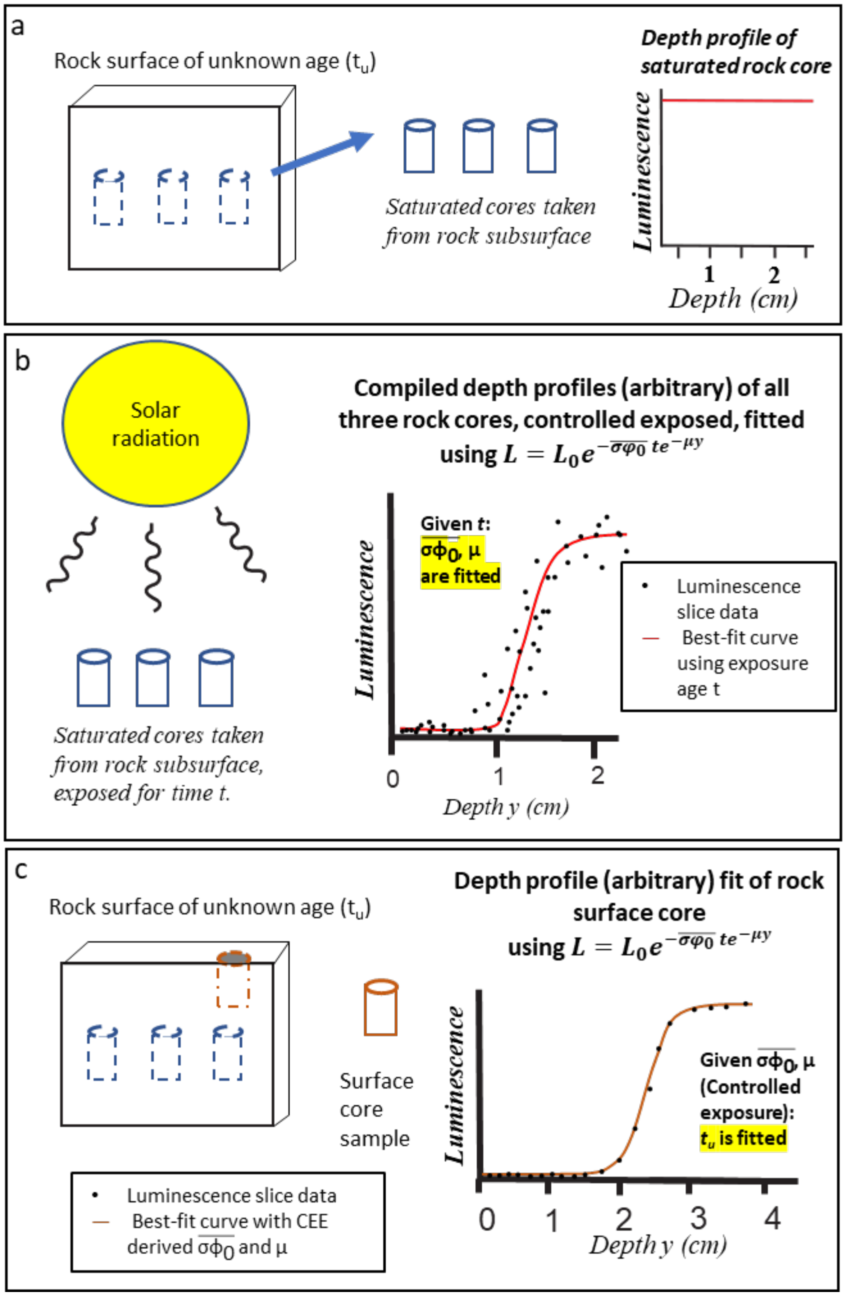
The trial study showed that these modified sampling and measuring procedures improve fitted parameter and age certainties over the parameters and ages derived from traditional procedures,

deriving an age of ~10.7 years (0.79 σ sup, 1.82 σ inf) for an 11-year exposed surface. Traditional techniques produced an age of 40 years for the same surface.

Using CEE and scanning techniques, the applicable scope of the technique can now be expanded beyond locations that host known-age rock surfaces. Artifacts at the Morgan Territory Regional Preserve can now be dated using these techniques. Further, the improvements offered by the new techniques allow for the testing of more sophisticated exposure dating models now that it is possible to obtain higher resolution datasets. Such work is now being trialed on $10^3 – 10^4$ year aged samples from the Foothills Erratics Train in Alberta, Canada.

It was with funding from the Quaternary Research Center that gave the opportunity to trial methods that expand the applicable reach of optical surface exposure dating. The study has provided significant improvements to the dating technique, and will influence how and where exposure dating is conducted in future.

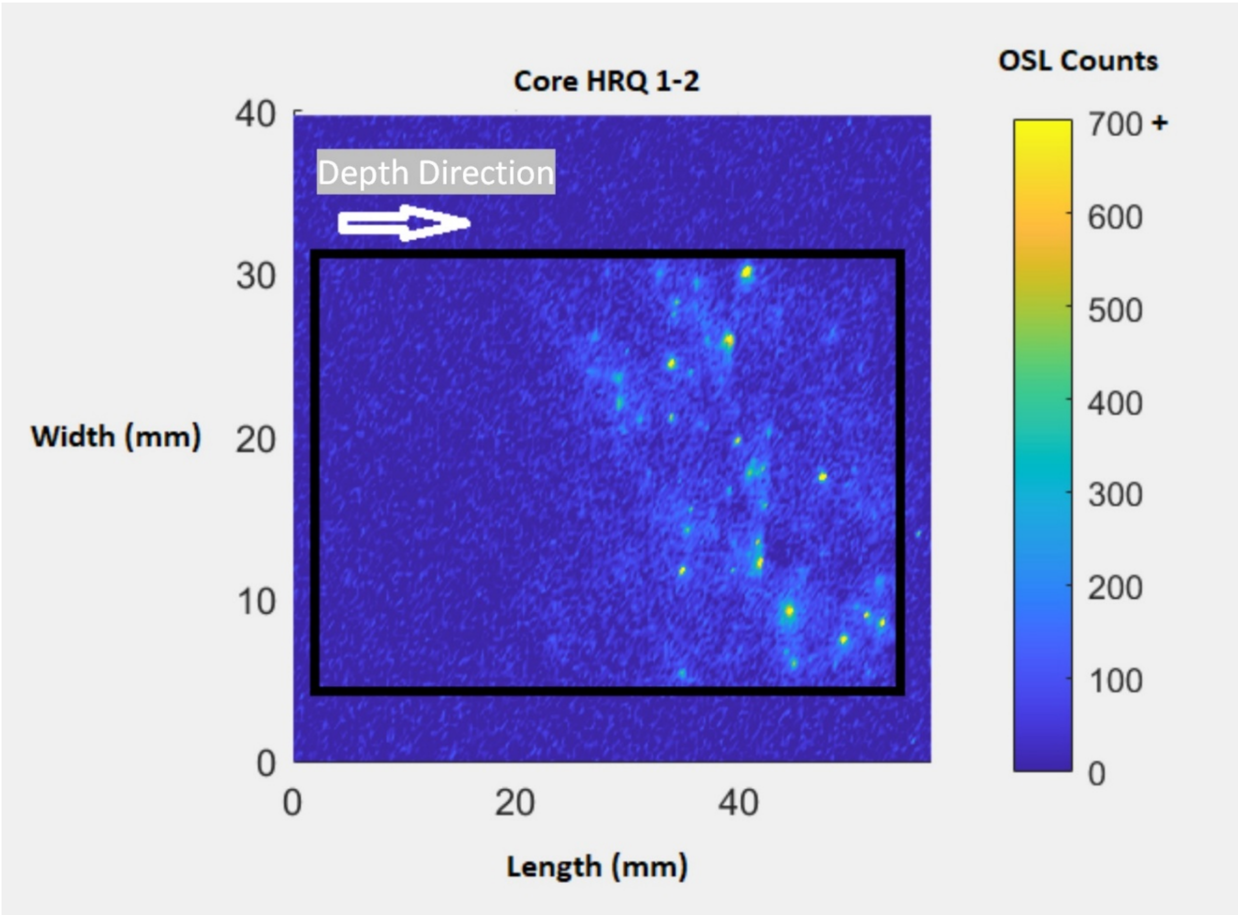
Cupule rock artifacts at Morgan Territory Regional Preserve. Thousands of cupules exist within the Preserve with no government protected status. The aim was to sample from the inside of a few cupules near parking and campsites in the Preserve to determine if a number of cupules were altered or manufactured by modern society. With evidence of degradation, protected statuses for the artifacts could be proposed to the State of California.



Outline of the controlled exposure experiment technique for extrapolating parameters $\overline{\sigma\varphi_0}$ and μ directly from the rock of interest. A commonly used exposure dating model utilizes the measured luminescence intensity at depth y (L) relative to a normalized saturated intensity (L_0) in the form as defined in Sohbati et al (2012): $L(y) = L_0 e^{-\overline{\sigma\varphi_0}\, te^{-\mu y}}$ which incorporates parameter estimates of μ (mm^{-1}), the exponential optical attenuation of surface photon fluence rates relative to depth into the surface, and $\overline{\sigma\varphi_0}$ (s^{-1}), representing the integration over the solar spectrum of σ, the effective photoeviction cross-section for a trapped charge (cm^2), and φ_0, the incident solar photon flux ($cm^{-2}s^{-1}$). Exposure ages (t) are obtained using the equation by fitting known parameters $\overline{\sigma\varphi_0}$ and μ against luminescence depth profiles. (a) At least three cores are sampled from the rock of interest, ideally in locations where there exhibits a natural saturation of filled traps. To ensure complete luminescence saturation, rock core samples can be irradiated to saturation using a preferred radiation source. (b) Luminescence saturated cores undergo exposure to an equivalent solar radiation, considering the solar path, for a controlled period t. The luminescence depth profiles of each core are then measured. Using t, parameters $\overline{\sigma\varphi_0}$ and μ are extrapolated from each core to note *heterogeneities in light attenuation and luminescence bleaching. Compiled data from all three cores should be fitted to determine the functional* $\overline{\sigma\varphi_0}$ *and* μ*. (c) Cores sampled from the surface of the rock of interest is used to calculate the rock's surface age* t_u*, using the functional* $\overline{\sigma\varphi_0}$ *and* μ *gathered from the controlled exposure experiments.*

Lane Mountain Quarry, Washington state. Trial site for controlled exposure experiment and OSL scanning study for OSL exposure dating. Site hosts 11-year exposed quartzite surfaces. June 30, 2021.

Controlled exposure experiment of Lane Mountain samples in progress on the roof of the Atmospheric Sciences and Geophysics Building, University of Washington, Seattle. Cores were exposed for 1 million seconds to natural sunlight in August 2021, matching roughly the annual daytime irradiance and solar path for the Lane Mountain Quarry site in Addy, Washington.



An example of a scanned sample core of quartzite is shown here, from an 11-year exposed surface. This sample was measured in 250-micron steps, offering ~400 OSL datapoints per millimeter depth, a significant improvement in resolution over the 1 point per millimeter depth offered form traditional OSL measuring techniques. The black square represents the dimensions of the transverse slice that was scanned.