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Started by the late David Zimmerman in 1977

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# **Reducing computation time in the R-package 'BayLum'**

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## Abstract

'BayLum' is an R-package that facilitates the application of Bayesian models to the field of OSL dating. Here we present two recent feature updates to 'BayLum', significantly reducing computation time and improving general use. The first feature allows users to parallelize the computations involved in the MCMC sampling of values, while the second introduces the ability to extend a 'BayLum' model, which has run to completion without converging. All updates are automatically available with 'BayLum' v0.3.1.

Keywords: Age model, Chronology, MCMC algorithm, Luminescence dating, OSL

# 1. Introduction

'BayLum' is an R – package (R Core Team, 2022) that gives users the tools to easily apply the Bayesian models presented in Combès et al. (2015) and Combès & Philippe (2017) to luminescence dating data. See, for example, the work of Heydari et al. (2020), where an OSL chronology is provided for the paleolithic site of Mirak, Iran, using 'Bay-Lum'. In this work, they showed that the age uncertainty can be reduced significantly by imposing stratigraphic order – a feature of 'BayLum'. Since the introduction of 'BayLum' (Philippe et al., 2019), 'BayLum' has grown by drawing resources from the ever-developing R-landscape around it. The latest iteration of 'BayLum' (v0.3.1) (Christophe et al., 2023) now employs 'runjags' (Denwood, 2016) as the R to JAGS (Plummer, 2003) facilitator, which has made possible two key features of 'runjags' to be used inside 'BayLum': (i) MCMC-sampling parallelization and (ii) the ability to extend a model (drawing additional MCMC samples after a model has already run to completion). This paper will highlight these two new features of 'BayLum' and show examples of how to use them.

# 2. Problem: Stationary distributions require long run times

The Bayesian models produced with 'BayLum' infer parameter estimates (such as equivalent dose and age) from marginal posterior distributions of these parameters. This is to say that 'BayLum' takes the output of the Bayesian approach, a posterior distribution, and evaluates the dimensions of individual variables. 'BavLum' constructs these distributions via Markov Chain Monte Carlo sampling. The result of the MCMC sampling is a chain of values, each link consisting of a combination of values from all parameters in the Bayesian model. A distribution can then be constructed for each parameter, given its value in each link. To let the MCMC converge on the solution, we skip a number of the first iterations (burn-in phase) and only then begin constructing the distributions. To be confident in the results, the distributions must be stationary - that is, the location and shape of each distribution must not change if we draw additional samples. 'BayLum' assesses if distributions are stationary and independent of initialization of the MCMC by constructing multiple chains instead of one. If the distributions from each chain agree with each other, we can be confident that the chains have converged to a single solution. By default, 'BayLum' uses three MCMC chains – a suitable balance between the power to detect non-convergence and the computational resources required (the number of chains is fully customizable by the user). 'BayLum' formalizes the question of convergence by incorporating as output the Rubin and Gelman diagnostic (Gelman & Rubin, 1992), which compares within-chain and between-chain variance. A common rule of thumb is that the upper 95 % credible interval limit of this diagnostic value indicates convergence when below 1.05.

For many practical applications of OSL dating, the number of iterations (or links in each chain) required to reach convergence is high (>500 000) – and higher still when 'Bay-Lum' models incorporate many OSL samples as is the case with high-resolution chronologies. Because MCMC chains are to be processed consecutively, the overall process can become very time-consuming. For example, using a computer equipped with a  $11^{th}$  Gen i7-1185G7 clocking at 3.0 GHz (which has a relatively high single-core threading performance rating), runtimes can extend beyond several days. Furthermore, even when a model completes, not all of the model's parameters may have converged – a result which could require a complete re-run of the 'BayLum' modelling function.

# 3. 'BayLum' feature: MCMC parallelization

Previous versions of 'BayLum' could only process MCMC chains consecutively using a single processor core. With parallelization, it is now possible to assign n chains out onto n CPU processor cores. This allows each chain to be processed concurrently, and the runtime will (ideally) approach 1/n when compared to the time for running n chains using a single core. We tested this using 'BayLum' models where OSL example sets GDB3 and GDB5 were used (both included with the 'BayLum' package) to produce 2-sample models. Figure 1A shows that when running 4 000 total iterations per chain, we see a significant runtime reduction when running the model using parallelization (jags\_method = "rjparallel") as compared to using only a single CPU core (jags\_method = "rjags"). Reduction increases with the number of MCMC chains constructed in the model, which is what we expect. We observed a reduction of 65%for a 3-chain setup and 72 % for a 4-chain setup. The minor differences we see from the theoretical 1/n-rule most likely arise from runtime inside the 'BayLum' model functions, which is not due to the iteration of MCMC sampling. We also see from Figure 1B that this reduction is consistent with increasing numbers of iterations. Example 1 (Sec. 3.1) shows how to apply parallelization in 'BayLum' v0.3.1. Note that our model testing was carried out using the High-Performance Computing Cluster "Sophia" (Technical University of Denmark, 2019). The same code run on a desktop PC will show the same relative reductions but may show poorer runtimes, not only because of lower overall computation power but also - and more likely - due to advanced power throttling measures of modern CPU architectures implemented to prevent overheating in prolonged high-load situations.

# 3.1. Example 1

In the example below, which we kept as simple and user-friendly as possible, we show how to achieve parallelization. The key argument to set is jags\_method = "rjparallel". We use the example data included within 'BayLum' at installation.

#### Example 1: R Code: Achieving parallelization

```
# MCMC parallelization example ####
   # load libraries
   library(BayLum)
   # load example DataFiles GDB3 and GDB5
6
   data(DATA1)
   data(DATA2)
   # combine DataFiles
9
   # (we now have a 2-sample DataFile)
10
  DF <- combine_DataFiles(DATA1, DATA2)</pre>
11
   # construct BayLum model
13
  BayLum_model <- AgeS_Computation(</pre>
14
     DATA = DF,
     SampleNames = c("GDB3", "GDB5"),
16
     Nb_sample = 2,
     BinPerSample = c(1, 1),
18
     LIN_fit = FALSE,
     Origin_fit = TRUE,
     Iter = 1e+03,
     burnin = 5e+02,
     adapt = 5e+02,
     n.chains = 3,
24
     jags_method = "rjparallel"
25
   )
```

# 4. 'BayLum' feature: extend the 'BayLum' model

Unfortunately, 'BayLum' model chains will not always converge within the specified number of iterations. In previous versions of 'BayLum', the 'BayLum'-model would likely need to run again with a higher number of iterations. The added runtime of re-running 'BayLum' can now be avoided by extending the non-converged model instead of building it again from scratch. In this case, all non-converged model iterations are treated as burn-in. See Example 2 (Sec. 4.1) for an illustration of how to extend 'BayLum' models.



Figure 1: (A): Runtime reduction in percentage when running a 'BayLum' model with fixed iterations vs a varying number of MCMC chains using GDB3 and GDB5 example sets included within 'BayLum'. (B): Runtime in seconds vs the number of MCMC iterations for a 3-chain 'BayLum' model also using GDB3 and GDB5. All estimates show mean  $\pm$  sd (n=8). To run the model, we used the High-Performance Computing cluster named "Sophia" owned by DTU. Arguments "rjags" and "rjparallel" entail whether 'BayLum' is run using a single CPU core ('rjags') or run in parallel on several cores ('rjparallel').

# 4.1. Example 2

In Example 1 (Sec. 3.1), a model was built to show how parallelization could be achieved. The Rubin and Gelman convergence diagnostics from that model reveal evidence that not all MCMC chains converged (see "D (Dose)" for GDB5, Table 1).

Table 1: Rubin and Gelman convergence diagnostics for three parameters of the 'BayLum'-model in Example 1. We show only the upper 95 % credible interval limit.

Sample	A (Age)	D (Dose)	sD (Stand. deviation)
GDB3	1.006	1.022	1.004
GDB5	1.007	1.065	1.000

However, we can now add iterations to the 'BayLum'model in order to achieve convergence:

Exampl	le 2:	R	Code:	Extending	mod	el
--------	-------	---	-------	-----------	-----	----

```
# extend MCMC sampling of BayLum_model
BayLum_model_extended <- AgeS_Computation(
DATA = BayLum_model,
SampleNames = c("GDB3", "GDB5"),
Nb_sample = 2,
BinPerSample = c(1, 1),
LIN_fit = FALSE,
Origin_fit = TRUE,
Iter = 1e+04,
burnin = 0,
adapt = 5e02,
jags_method = "rjparallel"
```

Rubin and Gelman's convergence diagnostics now show we can be confident about all the parameters (Table 2).

Table 2: Rubin and Gelman convergence diagnostics for three parameters of the 'BayLum' model from example 1 (Sec. 3.1). We show only the upper 95 % credible interval limit.

Sample	A (Age)	D (Dose)	sD (Stand. deviation)
GDB3	1.002	1.007	1.000
GDB5	1.001	1.010	1.004

# 5. Conclusions

In this report, we introduced two feature updates to the R-package 'BayLum'. Together, they allow users to parallelize MCMC sampling and extend BayLum-models - both features significantly reduce the time needed to build a viable 'BayLum'-model.

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## Reviewer

Geoff Duller





# Fine grain settling protocols for luminescence dating of museum objects sampled using the minimum extraction technique

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# Abstract

This paper communicates a suitable laboratory protocol for settling the  $4-11 \mu m$  fine grain fraction for OSL dating of archaeological samples from museum artefacts sampled using the minimum extraction technique. It provides a step-by-step methodology to facilitate adapting this protocol for use more broadly and demonstrates its ability to successfully isolate the fine grain fraction from tiny samples.

Keywords: fine grain settling, Stokes' Law, minimum extraction technique, ceramics, museum artefacts, optically stimulated luminescence

# 1. Introduction

The use of polymineral fine grains in luminescence dating has long been established and routinely used where a larger grain size fraction cannot be obtained. With fine grain dating, using typically  $4-11 \,\mu\text{m}$  grains, the alpha component of the dose rate, with a range of 20  $\mu\text{m}$ , irradiates the entire grain, so there is no need to remove an alpha attenuation layer (Wintle 1997; p. 770). Of course, including the alpha component to the dose rate requires estimation of the alpha efficiency, which will vary depending on the composition of the sample.

The fine grain method was first described by Zimmerman (Zimmerman, 1967, 1971), although subsequent alterations have been made to the Zimmerman method (e.g. Frechen et al. 1996; Fleming 1975; Fleming 1979, p. 58-59). While the method has both its pros and cons (a full discussion of this topic is beyond the scope of this paper), it is still very useful in a wide range of applications in luminescence dating

today, particularly in archaeological settings (e.g. Anderson & Feathers 2019; Feathers 2009; Janz et al. 2015; Zink & Porto 2005).

The minimum extraction technique (MET) and extended MET sampling protocols are used to optimize OSL dating of archaeological artefacts housed in museum collections by extracting minute sample sizes (Hood & Schwenninger 2015; Hood 2022). MET protocols generally yield a sufficient quantity of fine grains for dating; however, as is to be expected, the process for isolating the  $4-11 \mu m$  grain size fraction from the MET sample necessitates an adapted protocol compared to more standardised fine grain protocols, owing to the tiny sample sizes being worked with. Below, this adapted methodology, using the principle of Stokes' Law, is presented.<sup>1</sup>

# 2. Methodology: Fine grain sample preparation

Samples extracted using the (extended) MET protocol are in the form of drilled ceramic powder. A four-step process, as set out below, allows accurate isolation of the  $4-11 \mu m$ fine grain fraction from the bulk MET sample.

**Step 1: Dry sieving**. When the MET sample is initially sieved (using small mesh or electro-formed hand held sieves<sup>2</sup>) to extract the coarse grain fraction, the  $< 90 \,\mu\text{m}$  grain size fraction is retained for the fine grain technique.<sup>3</sup>

<sup>&</sup>lt;sup>1</sup>It is also possible to sieve out the polymineral fine grain fraction of a MET sample using size specific electro-formed sieves, however the cost of such equipment and the labour-intensive cleaning process can be a deterrence.

<sup>&</sup>lt;sup>2</sup>An electro-formed sieve is created by electro-deposition of a metal that allows precision construction of very fine sieves.

 $<sup>^{3}</sup>$ It should be noted that other fine grain methodologies frequently incorporate an H<sub>2</sub>O<sub>2</sub> and/or HCl wash into their fine grain preparation. However this has, to date, been avoided for MET samples owing to the extremely

**Step 2: First settling**. To isolate the  $4-11 \mu m$  fraction from the < 90  $\mu m$  fraction, it is necessary to settle the grains in a water column, using Stokes' law to determine the correct settling times for procuring this size fraction. The first settling step requires the removal of the ~ 12-90  $\mu m$  grain size fraction using Stokes' Law (see, for example, Batchelor 2010, p.230-235). A calculation was made to determine the time it would take grains > 11  $\mu m$  to settle in a solution of deionised water, based on the density and viscosity of the water, the temperature of the water, and the height of the graduated cylinder in which they were being settled.<sup>4</sup>

After adding the water to the cylinder, the MET sample is placed on a sheet of weighing paper, then rolled into a funnel so as to rapidly shoot the sample directly into the centre of the water column to avoid it adhering to the cylinder walls. A rapid movement of the sample into the water column is necessary to help break the surface tension of the water which can hold the MET sample owing to its extremely low mass. In the event of the sample staying on the surface of the water column, the surface tension can be broken by gently agitating it with a pin (or similar).

A 10 mL glass graduated cylinder is used for this first settling step owing to both its small size being the most appropriate for ease of dealing with MET-sized samples, and the glass facilitating the decanting of the sample.<sup>5</sup> Resulting settling times are presented in Table 1; the settling times presented in Table 1 and Table 2 are based on an average temperature of 19 °C; however, the ambient temperature of the deionised water was observed to fluctuate between 19 °C and 26 °C and thus the water used for each sample was measured prior to settling, and the exact temperature was used to calculate settling times).

Cylinder	Cylinder	Drop height	Settling
volume	height	(average)	time
10 mL	8.6 cm	4.3 cm	6 min 46 sec

Table 1: Settling times (at 19 °C) to remove the  $11-90 \ \mu m$  grain size fraction.

At the end of the allotted settling time, the water column now holds in suspension grains  $\leq 11 \ \mu m$ , and the base of the cylinder holds the > 11  $\mu m$  grains. The water

must now carefully be decanted into an identically sized graduated cylinder, leaving the settled material (i.e. the > 11  $\mu$ m material remaining at the bottom on the cylinder) in approximately 1 mm of water, ensuring that none of the settled material is transferred during the decanting process. Upon being decanted into the next cylinder, the second step should begin immediately.<sup>6</sup>

**Step 3:** Second settling. Once the water in which the  $\leq 11 \ \mu m$  fraction is suspended is decanted into a glass 10 ml cylinder, the next step to isolate the 4–11  $\mu m$  grains from the  $\leq 3 \ \mu m$  fraction begins immediately. As we are now isolating the 4–11  $\mu m$  grain size fraction, the settling times are adjusted accordingly (see Table 2). Once the settling time is complete, the water column (which now contains grains 3  $\mu m$  or smaller in suspension) can be poured off and discarded, or kept according to preference. The material now in the base of the cylinder is the desired 4–11  $\mu m$  grain size fraction, and can now be collected in Step 4.

Cylinder	Cylinder	Drop height	Settling
volume	height	(average)	time
10 mL	8.6 cm	4.3 cm	51 min 8 sec

Table 2: Settling times (at 19 °C) to remove the  $4-11 \ \mu m$  grain size fraction.

**Step 4: Preparation of liquid suspension**. The material left in the base of the cylinder after Step 3, that is, the  $4-11 \mu m$  grain size fraction, is now carefully washed into a small glass vial using acetone<sup>7</sup> and is then stoppered and kept in liquid suspension until fine grain aliquot preparation is carried out.

Upon the completion of the four steps above the sample is then ready to be mounted as fine grain aliquots. To make an aliquot, as with the coarse grain technique, a small aluminium disc 10 mm in diameter and 0.5 mm thick is used. The disc is placed in a small glass vial (measuring 12 mm in diameter and c. 38 mm in height, to facilitate subsequent removal of the aliquot). However, it is essential that the disc is lying flat on the base of the vial so that the fine grains cannot become trapped under the disc, which could affect the preheating of the aliquots when being measured. This can be achieved by placing  $\sim 0.25$  mL of acetone in the vial first and then placing the aluminium disc on top of the acetone, as this creates a suction force, ensuring the disc remains at the bottom of the vial. The glass vial containing the sample

small sample mass and the likelihood of sample loss if another treatment step is introduced at this stage. However, ultimately, this decision should be made based on the individual nature of the material one is working with, i.e. a large carbonate and/or organic component to the sample may necessitate employing these additional steps, even at the expense of precious sample loss.

<sup>&</sup>lt;sup>4</sup>A selection of online calculators are available to facilitate the calculation of settling times.

<sup>&</sup>lt;sup>5</sup>If the sample is irreplaceable, i.e. there is no ability to obtain more, it may be preferable to use new glass cylinders only in MET fine grain preparation, in order to avoid potential sample contamination which could occur during cleaning between samples since fine grain material is invisible to the naked eye and MET samples are usual a 'once-off' without the possibility of obtaining more material in the event of sample contamination. However, the environmental and financial impact must also be considered for such a decision, and it is perhaps better practice to only use a new cylinder on particularly valuable/irreplacable sample.

 $<sup>^{6}</sup>$ The ~ 12 – 90 µm fraction can be washed into a glass vial and stored in liquid suspension if required.

<sup>&</sup>lt;sup>7</sup>It is also possible, of course, to use acetone instead of distilled water in the aforementioned steps, and indeed there is an argument to be made for this facilitating drying and settling. However, owing to additional considerations (costs and additional chemical use), our preference has been to only use acetone in this final step. The minute amount of mixing between water and acetone in this step has, in our observation, not hindered aliquot preparation. Additionally, if acetone is being used instead of water in all steps, then the potential issue with surface tension noted above for distilled water is usually avoided.



Figure 1: SEM image showing distribution of fine grain sizes for the brick test sample after settling to isolate the  $4-11 \mu m$  fraction.

suspended in acetone prepared in Step 4 above is then gently agitated to ensure that all grains are once again in suspension (the vial should not be inverted so as not to trap fine grains around the lid) and, using a disposable pipette, 1 mL of liquid sample is added to the vial and is left to settle onto the disc.<sup>8</sup> This vial is then left open and placed in a fume cupboard so that the acetone can dry off. Once the acetone is evaporated, the disc can be removed carefully from the vial using tweezers. The aliquot will now have a thin monolayer of fine grains which have settled upon its surface during the evaporation process and is ready for measurement.<sup>9</sup>

# 3. Results

The fine grain preparation process was tested to ensure that it was accurately isolating the  $4-11 \mu m$  grain size fraction. For a test sample, once aliquots were prepared a selection were examined under a scanning electron microscope (SEM) to quantify grain sizes.

SEM examinations showed that the described methodology is suitable for isolation of fine grains for OSL dating. The majority of grains observed were within the  $4-11 \mu m$ grain size fraction, although with some slightly smaller (~  $3 \mu m$ ) and some slightly larger (~  $12-17 \mu m$ ) grains occurring too (Figure 1). Given that this slightly increased grain size distribution is inevitable due to the use of average drop heights and assumption of spherical grain geometry upon which Stokes' law is based, this variance is considered acceptable, and even the slightly larger grains are still smaller than the alpha range, i.e.  $20 \,\mu\text{m}$ .

# 4. Conclusion

This paper has presented a step-by-step methodology to isolate fine grains for OSL measurement from samples obtained using the MET or extended MET protocol. It provides a means by which to maximise the quantity of measurable material from OSL dating when working with museum objects — for which only minute sample sizes can be obtained — by making use of the multi-mineral fine grain fraction as well as coarse grain mineral fractions. The methodology can be readily and easily implemented by other luminescence practitioners working with minute museum samples, or indeed wherever only small sample sizes are available for luminescence dating.

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<sup>&</sup>lt;sup>8</sup>In standard fine grain aliquot preparation, it is necessary at this step to be very careful not to use too much liquid and thus allow too many fine grains to adhere to the disc. It is often also necessary, in standard methodology, to dilute the sample suspension. However, due to the very small amounts sampled during MET extraction, it has been observed that the quantity of fine grain material usually retained from a MET sample, when prepared in accordance with the steps outlined above, produces a good grain density for aliquot making (i.e. not too cloudy, that is, not too many grains present), which means it is not necessary to dilute the sample. However, as there can be a considerable amount of variation between different sample types, practitioners may still find dilution necessary for some samples.

<sup>&</sup>lt;sup>9</sup>This monolayer should not be visible to the naked eye, and thus it is not necessary to attempt to add more grains via additional liquid suspension.

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# Reviewer

Jim Feathers

# **Thesis Abstracts**

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# Chloé Bouscary Sub-Quaternary Himalayan tectonics inferred from luminescence thermochronometry

December 2022 Institute of Earth Surface Dynamics, University of Lausanne, Lausanne, Switzerland

> Degree: Ph.D. Supervisor: Georgina King

Luminescence thermochronometry is a very lowtemperature thermochronometer that allows reconstruction of the thermal histories of the upper first few km of the Earth's crust within the last few 100 kyr (late Quaternary); a spatial and temporal scale hitherto at the sensitivity limit of other methods. Despite the potential of this method for deriving changes in landscape and subsurface evolution, it has until now never been applied to a large-scale study area, or been validated as a multi-thermochronometer approach.

I calibrated the multi-luminescence measurement protocol for feldspar thermochronometry by analysing three sets of samples (independently known thermal histories samples, synthetic thermal history samples created following irradiation at high temperature in the laboratory, and unknownthermal history samples). As the reconstruction of a sample's thermal history depends on the thermal kinetic parameters extracted from isothermal decay experiments, I tested the validity of thermal kinetic parameters obtained from different combinations of isothermal holding data by trying to recover the sample's temperature. I found that the temperatures inferred from inverting the data vary depending on the combination of isothermal holding temperatures used for thermal kinetic parameter derivation, and that the inclusion of isothermal holding data above 250 °C result in kinetic parameters that underestimate modelled temperatures. For appropriate thermal kinetic parameter derivation, and thus accurate thermochronometric data, I recommended using a new protocol with four isothermal holding temperatures between 190 and 250 °C.

The improved multi-luminescence thermochronometry method was then used as a tool to constrain the late Quaternary exhumation history of the Himalayas, where two endmember competing models have been proposed to describe the kinematics of the central Nepal Himalayas in the last few Myr. They differ in their interpretations of which surface breaking faults accommodate current shortening and the kinematics responsible for driving rapid exhumation in the topographic transition zone around the Main Central Thrust (MCT). These locally higher uplift and erosion rates in the High Himalaya could reflect thrusting over a midcrustal ramp with the growth of a Lesser Himalaya duplex at midcrustal depth, or out-of-sequence thrusting along the front of the High Himalaya, possibly driven by climatically controlled localized exhumation. To address this debate, I successfully measured and analysed more than 100 rock samples with luminescence thermochronometry ( $10^{4-5}$  yr), filling the temporal gap between GPS measurement, palaeoseimic ( $\leq 10^2$  yr), Holocene fluvial terrace records ( $10^{3-4}$  yr) and geological estimates ( $\geq 10^6$  yr) of exhumation rates.

I first focussed on the Sub-Himalayas, the most frontal fold-and-thrust belt of the Himalayan orogen. Samples collected along six transects across the Siwalik foothills yield exhumation rates of  $\sim 3 - 11$  mm/yr over the past  $\sim 200$  kyr, which convert to thrust slip rates of  $\sim 6 - 22$  mm/yr. Comparing these rates with geodetic convergence rates indicates that at least half of the Himalayan convergence is accommodated by the Sub-Himalayan fold-and-thrust belt, and particularly by the Main Frontal Thrust, since the late Quaternary, consistent with this fault being a high seismic hazard zone. Data also record exhumation rates on local Sub-Himalayan intrawedge thrusts throughout the same time period, implying that internal deformation of the orogenic wedge and strain partitioning may have occurred, potentially endangering an entire population.

I then compared existing low and medium-temperature thermochronometric data (<sup>40</sup>Ar/<sup>39</sup>Ar on muscovite, apatite and zircon (U-Th)/He, and apatite and zircon fission track), to newly acquired luminescence thermochronometry data from the High Himalaya of central Nepal. All of the thermochronometric data show younger ages and higher exhumation rates around the topographic transition and the MCT zone. For the higher temperature thermochronometers, a continuous trend towards younger ages from the Lesser Himalaya through the topographic transition and the MCT zone suggest that the duplexing model best describes the thermochronometric ages of this study area on Myr timescales. However, the luminescence thermochronometry data highlight a systematic sharp transition at the MCT, pointing to out-of-sequence activity at this tectonic boundary on 100kyr timescales. Whether this difference in tectonic model between the two timescales is due to low resolution of the higher temperature thermochronometers, shallow isotherms deflected by fluid circulation and hot spring activity near the MCT, or to a change in tectonic regime during the last 200 kyr, out-of-sequence activity of the MCT needs to be considered in seismic hazard models as it could put the local population at risk.

A PDF of this thesis can be obtained by contacting the author: chloe.bouscary@unil.ch

# Christopher Garcia Development of an Instrument for Spatially Resolved, Optically Stimulated Luminescence Dosimetry of Cobble and Dosimeter Surfaces

June 2023

Department of Physics, East Carolina University, Greenville, NC, USA

# Degree: Ph.D.

Supervisor: Regina DeWitt

Optically stimulated luminescence (OSL) dosimetry is a method used to determine the amount of energy stored within a crystalline insulator due to ionizing radiation. At its most fundamental, OSL dosimetry requires optical stimulation to induce a sample to emit luminescence, a light detection apparatus to collect the luminescence signal, and a calibrating radiation source to convert the acquired signal into an equivalent dose. Conventional instruments have successfully integrated these components to perform OSL dosimetry on sediment and dosimeters. In this dissertation, an instrument was developed that allows dose-mapping: LuCIDD (Luminescence instrument with Confocal and Imaging unit for Dating and Dosimetry) is based on the principles of a confocal microscope. This dissertation outlines the requirements for spatially resolved dosimetry mapping and describes the design and construction of LuCIDD. Tests of the integrated lasers' ability to perform spatially resolved stimulating measurements were made by measuring their focal spot size, power density, and penetration depth. Used for calibration, the built-in X-ray source's energy spectrum, uniformity, and dose rate were characterized. The minimum resolution and stimulation time for measurements were determined, quantifying the amount of time to complete a dose map of a sample's surface. Lastly, LuCIDD's ability to recover a known applied dose from single points was verified to provide a proof-of-concept for future dose-mapping measurements.

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# **Compiled by Sebastien Huot**

# From December 1, 2022 to May 31, 2023

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