Modeling the effect of convex upward deformation and horizontal sectioning on paleolimnological data

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# Abstract

We analyzed photos of convex upward deformation in photos of split cores to obtain reasonable parameters with which to model the effect of convex upward deformation on paleolimnological data, and, using a 3-dimensional raster model, modeled the effect of this deformation on paleolimnological concentration data. The data indicated that convex upward deformation has the effect of integrating sample from an increasingly wider range of stratigraphic layers with increasing degree of deformation. After applying deformation, extruded concentration profiles were nearly identical despite varying the extrusion interval between 0.1 cm and 1 cm. Collectively our data suggest that checking for deformation due to coring is essential prior to conducting high-resolution analysis of horizontally sectioned samples.

# Introduction

That deformation and compression of lake sediment occurs during coring has long been known (Martin and Miller 1982; Wright 1993), and designs of new coring devices have striven to minimize the conditions that promote deformation during coring (Martin and Miller 1982; Lane and Taffs 2002). Compression of sediment occurs during coring is a widely accepted phenomenon (Glew et al. 2001), however convex upward deformation, while widely observed (Wright 1993; Rosenbaum et al. 2010), is infrequently discussed. The idea that horizontal sectioning (extrusion) of deformed sediment is undesirable has been previously noted (Rosenbaum et al. 2010), however the degree to which this deformation occurs and the effect that deformation has on paleolimnological data derived from horizontal sectioning has never been investigated quantitatively.

Rather than suggest that deformation does not occur or that a particular coring method prevents this from happening, we take the approach that acknowledging deformation and its effect on paleolimnological data is a the most reasonable approach. We suspect, given the innumerable paleolimnological studies that use coring and extrusion to produce reasonable and reproducible results, that either deformation or its effect on the data is minimal. This paper is our attempt to quantify and constrain the degree to which convex upward deformation adds bias to horizontally sectioned paleolimnological data.

# Methods

We used R statistical software (R Core Team 2013) to model, manipulate, and visualize our data. Packages *dplyr* and *ggplot2* were used for manipulation and visualization of data, respectively (Wickham et al. 2016; Wickham and Francois 2016).

## Core photo analysis

To calculate parameters for the deformation model, we loaded 12 scale photos of deformed cores from 6 sources into ImageJ software and digitized deformed strata (Table 1). Coordinates were transformed to r and d values for individual strata by subtracting the minimum d value from the rest of the values, and subtracting the central x value from the rest of the values. Power regression (quadratic) was performed on the data to obtain reasonable coefficients for minimum, maximum, and mean levels of deformation.

## Deformation model

We modeled horizontal sections with height *H* and diameter *D* as a 3-dimensional raster grid with a cell size of 0.5 mm (Fig. 1). For each cell *i*, an original depth *d0i* was calculated with reasonable minimum, maximum, and mean parameters obtained from digitized strata. Density histograms were then obtained to estimate the contribution of each original depth *d0* to the slice. For each slice, *d*=0 refers to the middle of the slice. We produced these models for *D*=6.5 cm, as this represents the barrel width of our Glew (1989) gravity corer. Compression was not modeled using this method, although modification of this model would make including compression possible.

## Effect on paleolimnological data

To model the concentration (mass fraction) we would obtain by sectioning and homogenizing a sample with variable concentration and density, we need to calculate total mass of the target substance divided by the mass of the slice. With a 3-dimensional raster grid using *n* cells, this value can be written as a sum of the product of concentration (), density (), and volume (*V*) divided by the sum of the product of *V* and (1).

We can remove *Vi* from the summation in both the numerator and denominator because the cell size is constant for each *i*, and write and as functions of *d0i*.

Equation (2) in combination with our deformation model allows for modeling the effect of sectioning, homogenization, and deformation given high-resolution un-altered data. We used fictional generated data to test our deformation model inspired by 1 mm resolution XRF core scanner data (Guyard et al. 2007; Brunschön et al. 2010; Kylander et al. 2011), and a linear dry density gradient from 0.1 to 0.5 g/cm3. Generated data was transformed and smoothed random log normal data with a set seed for replicability purposes.

# Results

## Core photo analysis

We digitized 49 deformed layers from 12 scale photos of split cores. The quadratic regression was able to model the data well (*r2* from 0.58 to 1). Coefficients for *x2* in the quadratic regression ranged from 0.054 to 0.51, with a mean of 0.21 (Fig. 2). We chose 0, 0.1, 0.2, and 0.4 as coefficients for our model to produce a reasonable summary of the deformation that was observed (Fig. 3).

## Deformation model

Slices of size 0.1 cm, 0.5 cm, and 1 cm were modeled with a core barrel diameter of 6.5 cm. When *d*=0, *d0* values ranged from 0 cm to -4 cm and were more negative with increasing deformation (Fig. 4; Fig. 5). Slices represented a wider range of *d0* values with increasing deformation (Fig. 5; Fig. 6), and when deformation was >0.2, slice sizes smaller than 1 cm did not result in decreasing the range of *d0* values.

## Effect on paleolimnological data

As expected, increasing the size of the extrusion interval decreased the detail that was visible in the data (Fig. 7). The original data include thin (<0.5 cm) layers of high concentration (>60 units), only some of which were resolvable at extrusion intervals greater than 1 mm. Peak values were lower with increasing extrusion interval size, reflecting the inclusion of less concentrated material within the interval. High values in the topmost sample are an artifact of the model; it is likely that the behavior of deformation differs at the top of the core compared to deformation below. Increasing the degree of deformation also decreased the resolvability and peak values of thin, high concentration layers, in addition to increasing the depth at which peak values were observed. When deformation occurred, decreasing the extrusion interval size did not result in increasing the effective resolution of the data. In particular, the extrusion interval of 0.1 cm and 0.5 cm produced nearly identical results when any deformation was applied.

# Conclusions

The data indicated that even minimal deformation has an effect on paleolimnological data. Many deformed core photos that were analyzed were of cores collected by percussion coring, which is known to produce intense convex upward deformation (Reasoner 1993), however some photos of split gravity cores also contained a small degree of deformation. Even when a small degree of deformation occurred, decreasing the extrusion interval did not result in an appreciably different stratigraphic profile (Fig. 7) or in decreasing the range of depths represented by the slice (Fig. 6). Extrusion methods are now able to easily extrude intervals of less than 0.1 cm (Cocquyt and Israël 2004), however our data suggest that reducing the extrusion interval beyond a certain point does not increase the effective resolution of the data if deformation occurred. Our data suggest that checking for deformation due to coring is essential prior to conducting high-resolution analysis of horizontally sectioned samples.

# Acknowledgements

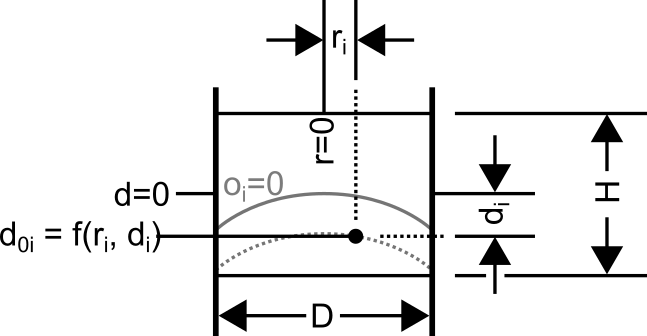
We acknowledge funding from the Natural Sciences and Engineering Research Council (NSERC) of Canada and the comments on this manuscript from the Department of Earth & Environmental Science at Acadia University.

# Tables

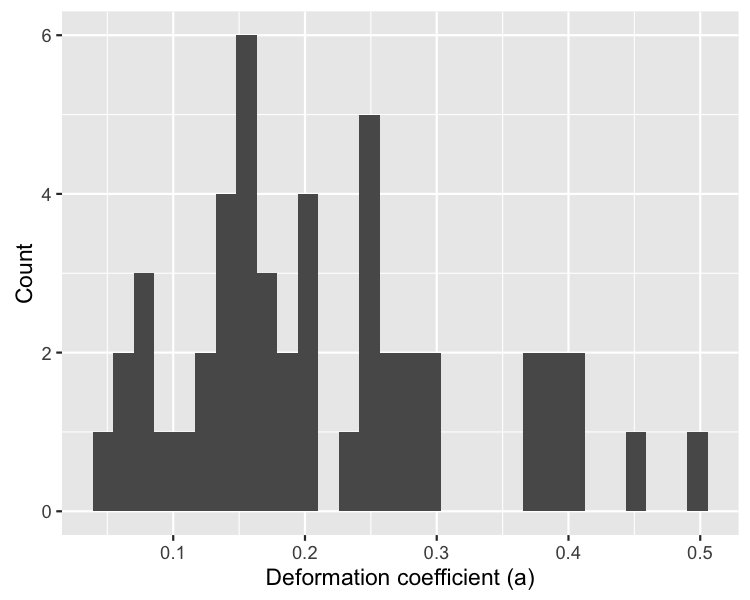
Table 1. Sources of core photos that contained digitized layers used in this study.

|  |  |  |
| --- | --- | --- |
| Photo ID | Layers Digitized | Reference |
| cheak1 | 8 | Menounos and Clague (2008) |
| cheak2 | 8 | Menounos and Clague (2008) |
| crevice\_lake | 12 | Rosenbaum et al. (2010) |
| ds\_unpubl1 | 1 | Dunnington and Spooner (unpublished data) |
| ds\_unpubl2 | 2 | Dunnington and Spooner (unpublished data) |
| ds\_unpubl3 | 1 | Dunnington and Spooner (unpublished data) |
| ds\_unpubl4 | 1 | Dunnington and Spooner (unpublished data) |
| longlake\_pc1 | 1 | White (2012) |
| suzielake\_1 | 4 | Spooner et al. (1997) |
| suzielake\_2 | 9 | Spooner et al. (1997) |
| whistler\_gc4 | 1 | Dunnington (2015) |
| whistler\_gc8 | 1 | Dunnington (2015) |

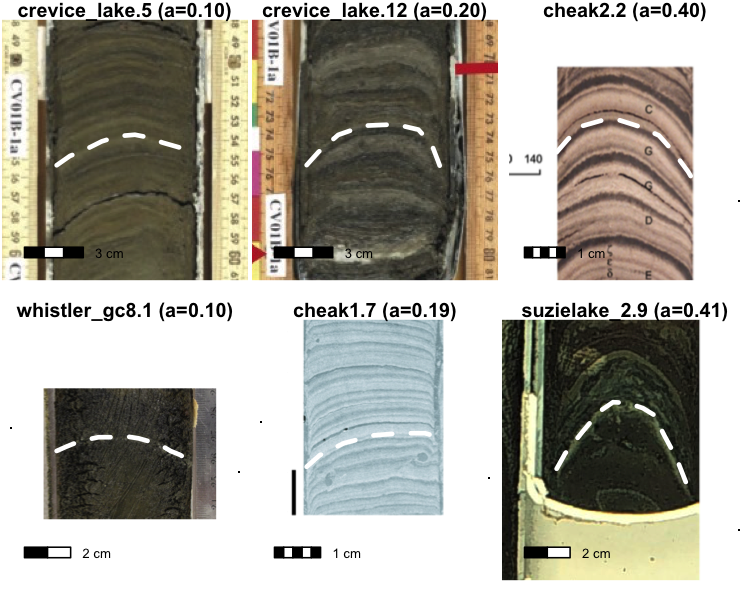
# Figures



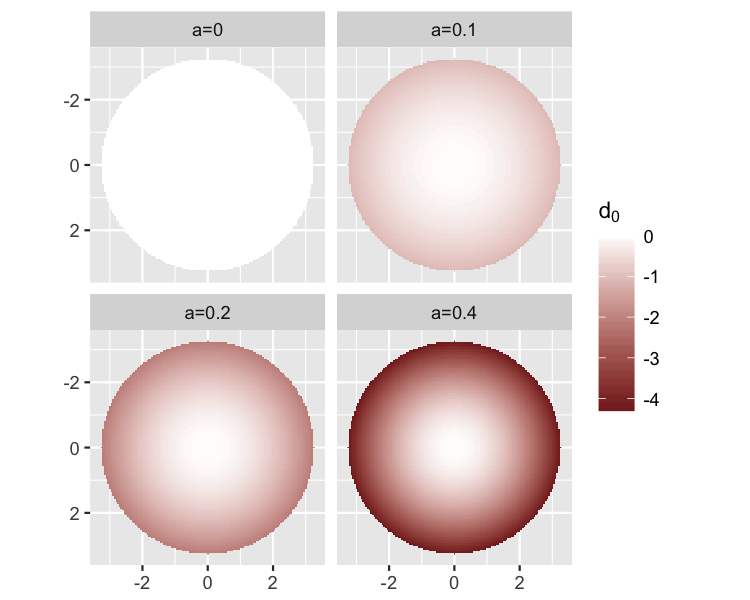
*Fig. 1* Schematic of variables used in the deformation model.



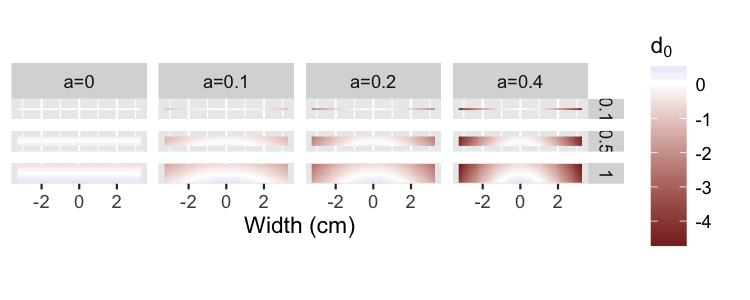
*Fig. 2* Histogram of deformation coefficients from digitized layers.



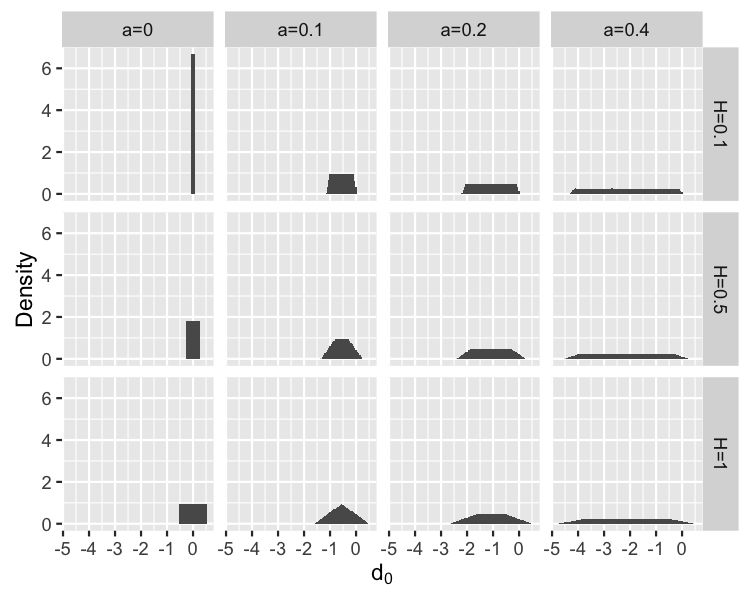
*Fig. 3* Representative layers for selected deformation coefficients.



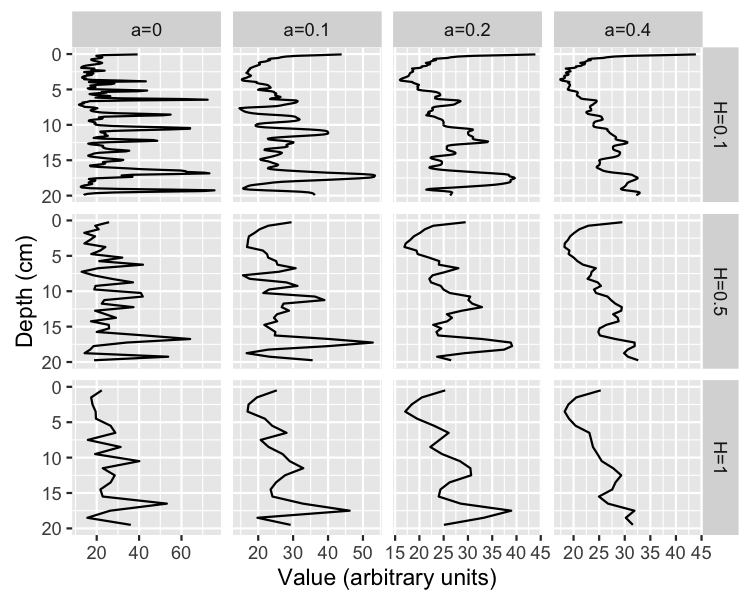
*Fig. 4* Distribution of d0 for d=0 by deformation coefficient.



*Fig. 5* Distribution of d0 of a vertical sliced section for multiple deformation coefficients and slice sizes.



*Fig. 6* Distribution of d0 values modeled for multiple deformation coefficients and slice sizes.



*Fig. 7* Extrusion and deformation modeled for artificial 0.5 mm resolution concentration data.

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