Cryptotephra: An Alternative Dating Method to Radiocarbon

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Abstract

Cryptotephra, or microtephra, are microscopic deposits of ash resulting from volcanic eruptions. Once found, they can be traced back to a volcano with a known eruption date based on the mineral or geochemical composition of the glass shards that make up the ash. After detection and correlation back to that specific volcano and eruption, this research allows for the verification, correction, and improvement of age models developed by radiometric dating. This relatively new tool is a versatile and cost effective way to improve individual site chronologies due to each layer's unique signature and well-constrained age, while also allowing for correlation to other sites. The primary result of this research will be an improved age model for a paleoecological record of past vegetation and climate from the Spicer Lake site in Indiana, USA. If confirmed, the presence of known cryptotephras in the record would allow for more precise dating of past environmental change, giving us a better idea of what to expect in the future.

Introduction

The use of tephra layers as a stratigraphic dating method has a long history because it is a simple way to date a volcanic ash layer and then extrapolate the ages of proximal layers, or interpolate those deposits' ages between two separate tephra layers (Lowe 2013). This of course assumes the Law of Superposition, which states that sedimentary layers are deposited sequentially, with the oldest material on the bottom and the youngest at the top (Feibel 1999). Determining the unique mineralogical or geochemical signature of a given tephra requires analysis and subsequent tracing back to a specific volcano with known eruption dates. In this way, when found in a stratigraphic sequence, tephras can provide a date that is more precise than conventional radiometric dating.

Figure 1. Points of Interest
This map of North America depicts the location of the four volcanoes responsible for our target eruptions, as well as the site of the lake core used in this experiment – Spicer Lake in northern Indiana

This practice does have some issues, however; the biggest of which is that it is only plausible for areas in the vicinity of a volcano to the point where they can collect a visible layer of ash. Recently though, extraction methods have improved to the point where microscopic glass shards, known as micro-tephra, (or more commonly cryptotephra) can be detected, allowing regions far away from volcanoes to employ tephrochronology as well (Blockley et al. 2005). Once a layer has been identified and aged, it can be used to match its counterparts in other areas based on stratigraphy and composition. This is a valid practice because even though the ash is deposited at different times as it makes its way across the globe, deposition of ash occurs within a year, a difference negligible in regards to geologic time (Lowe 2013).

In this study, we have identified four major eruptions from the Pacific Rim – three in Alaska and one in Oregon – and will sample sediment from a lake core from Spicer Lake in northern Indiana to look for cryptotephra deposits (Figure 1). It is currently unclear whether ash originating from western North America will be present in the Great Lakes region, because wind patterns at the time of an eruption may result in deposition elsewhere. If cryptotephras are found, this would be among the first discoveries of cryptotephras in the southern Great Lakes region.

Methods

Range Identification

To determine which core depths to sample for cryptotephras, we used previously-collected radiocarbon dates to identify depth ranges that corresponded to four well-known eruption events (Figure 2). The rest of the methods section is a modified version of a previous publication by Blockley et al.; see their 2005 paper for more detailed information like measurements and times.

Sampling and Ashing

With ranges of depths to sample for crytotephras determined, 1 cm^3 sub-samples were obtained at 1 cm intervals from the lake core. These sub-samples are then exposed to 550℃ for 2 hours to remove organics from the sediment. However, this step is only done in initial cryptotephra scanning stages. If tephras have already been discovered at a certain depth, then resampling for geochemical analysis is needed to trace back to a specific eruption and this step is skipped to avoid chemical alterations. From there the baked sub-samples are then consolidated into 5 cm ranges by core depth (0-5 cm deep, 5-10, etc.) and ground up with a mortar and pestle.

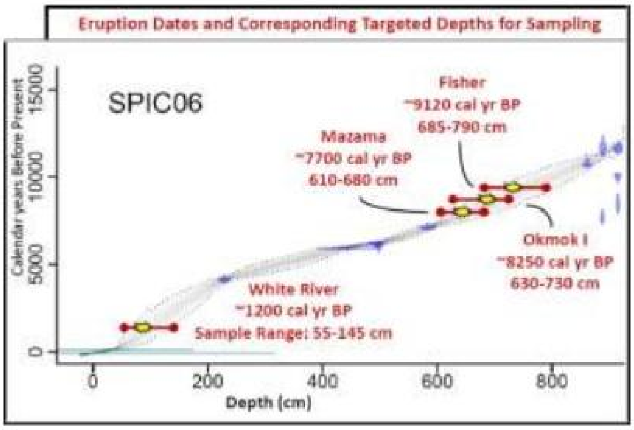

Figure 2. Age-Depth model of Spicer Lake core
This graph was developed from radiocarbon dates (polygons) from Spicer Lake, Indiana. The horizontal bars are the target depths based on eruption dates (dots at middle of each line). If successful, this project will be able to lessen the uncertainty of this model by narrowing the dotted areas in the backdrop and provide further preliminary evidence of tephras in the Great Lakes region.

Carbonate Removal

Sub-samples are then rinsed with 10% HCl to remove carbonates. The acidic solution is then sieved at 20 µm to remove particles that are too small for analysis. The remaining material is then mixed with deionized (DI) water and placed in conical tubes for centrifuging. The spinning down leaves the sediment nicely packed in the bottom, cone-shaped portion of the tube, with the water resting on top of it. This allows for easy decanting as the sediment clings to the bottom.

Density Separation

In this study, we used sodium polytungstate (SPT) to isolate the desired crytoptephra particles by using liquids with lower and higher densities than tephras. First, each tube received the less dense solution and was agitated using a vortex mixer in order to assure that each sample is thoroughly mixed with the solution so that true density separation is taking place. After decanting the overlying SPT, this process is repeated to ensure separation, with particles such as detrital material, sponge spicule, and some diatoms being removed (Blockley et al. 2005).

Next the heavier solution is added to the centrifuge tubes to remove material that is denser than cryptotephras. After rinsing with deionized water, the tubes hold just the remaining particles that fall in the density range of the volcanic glass (2.1-2.5 g/cm^3), ready to be mounted on microscope slides. The slides are placed on a hot plate momentarily to evaporate off the remaining water before being mounted, labeled, and ready for inspection under the microscope.

Microscope Scanning

One very helpful tool in scanning for tephra shards is the use of cross-polarized light. This function requires a specialized type of microscope that allows the user to view their samples under plane-polarized or cross-polarized light by the use of a little slide that can be slid in or out to dictate which type of light is passing through the sample slide. The actual, visible difference between tephra and just plain silica can be difficult to distinguish, with most of the common particles present appearing shades of brown. Cryptotephra itself ranges from colorless and transparent (Figure 3) to tan and translucent, but when the cross-polarization is switched on, recognizing the tephra becomes much easier. Whereas some particles shine a white or yellow color against the black backdrop, the cryptotephra actually changes to a somewhat unique black, blending into the background due to its isotropic properties.

Figure 3. Cryptotephra shard at 400x magnification
A confirmed piece of volcanic glass identified at a depth of 715-720 cm from the Spicer Lake core. Due to the depth from which it was extracted, the ash is presumed to be from Mt. Fisher in the Aleutian Islands of Alaska. Geochemical analysis is needed in order to verify this, however.

Results

Thus far this research has been relatively unsuccessful in discovering the typical large amounts of tephra (hundreds to thousands of shards), but a small yield has been found. Several particles have been photographed that fit the description of cryptotephra, but after those images have been sent to a colleague (Dr. Britta Jensen at Queen's University Belfast) for confirmation, many have been dismissed as missing one or another of the necessary characteristics; namely a lack of vesicles, whether that be a rib on a platy shard or holes in a pumicey (roughly textured) shard. Those traits

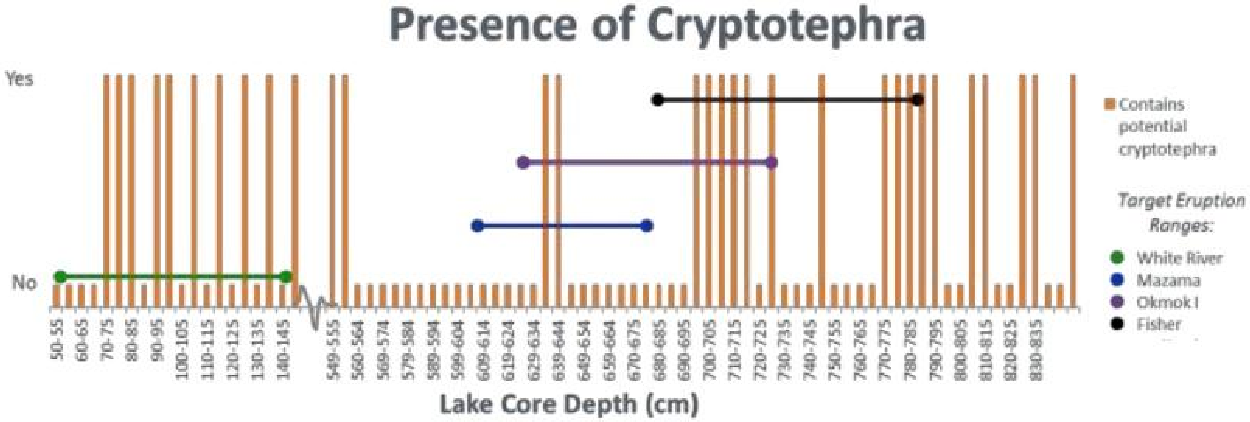

Figure 4. Results graph of cryptotephra presence in Spicer Lake core

will be the keys to look for moving forward.

The lines in Figure 4 represent the presence of potential tephra shards found at each depth, with the tall lines signifying yes, presence, with the shorter lines meaning no presence (as opposed to no data). The various horizontal bars each correspond to one of our target eruptions, with strong correlation appearing as the tall lines being confined to those eruption bars. There seems to be little correlation between the age model's target depths and where tephra was potentially found for some of the older eruptions, but there does appear to be some correlation with the younger White River ash. This is the eruption we hypothesized as the most likely to be found. Additionally, a lack of stark contrast between presence and non-presence is somewhat expected, as sediment often gets 'reworked' – disturbed and mixed up – although this is less of a problem at the bottom of a lake than on land.

In the closing weeks of the program a scholar visiting from the University of Alberta examined some of our shards. This was Lauren Davies (of Dr. Jensen's former lab) and she was able to confirm one of our images as indeed being cryptotephra (Figure 3). With this knowledge, that area can be resampled and the methods process repeated, but without some of the structure-altering steps. Once completed, the extraction of actual shards is then needed for analysis of composition in order to begin the correlation process.

Discussion

It remains possible that there is in fact very little tephra to be found at this site, with a number of possible explanations. The most likely is that the wind patterns during and immediately after the eruptions did not carry and deposit much tephra to this site in northern Indiana (Pyne-O'Donnell 2011). After all, the target volcanoes are very far from Spicer Lake, anywhere from 3000-6000 km.

Additionally, there are a few reasons why so much of the North American tephra work has been done in the Upper Midwest and Canada. The first is simply their relative proximity to these volcanically active areas, or at least in regard to Indiana. The second is a matter of the abundance of old, natural bodies of stagnant water. The reason lake sediment cores are used is because they typically provide undisturbed sedimentary records that preserve biological and geochemical remains for thousands of years. There are many more suitable lakes in the Upper Great Lakes region than in regions further south that were never glaciated, and while Spicer Lake is still a kettle lake and the product of glaciation, its location in the Lower Great Lakes region keeps it intriguing.

Another plausible reason for a lack of tephra would be that the volcano simply did not produce enough ash to be carried that far of a distance. In addition, the process of rain-flushing could contribute to the absence of ash at Spicer Lake. If precipitation of even moderate intensity was experienced on a concentrated area it could result in a highly localized accumulation of ash, resulting in deposits of far greater magnitude than purely dry-air deposition since the water pulls the ash downward (Kobayashi et al. 2005). If this phenomenon occurred before the ash cloud could reach the southern tip of Lake Michigan, then there might not have been much or any ash left to deposit once it did pass over Spicer Lake.

Finally, the possibility remains that there is an issue with our methods. One possibility is that during flotation with SPT the tephra may not have been in our assumed density range. Any tephra shards slightly less or more dense than our 2.1-2.5 g/cm^3 range would not have been mounted on our slides and therefore would not be visible underneath the microscope. This can be a trial and error process, with the tephra densities varying slightly from site to site. It is also plausible that our methodology inadvertently destroyed, damaged, or excluded ash particles.

Despite these limiting factors, the potential use of cryptotephra to improve age models in the Great Lakes region provides incentive to continue searching for ash deposits in different sediment cores, especially in the southern Great Lakes region, improving our methods for cryptotephra analysis in the process. Due to its low tephra yield thus far, the Spicer Lake core is not necessarily a wise selection for any future work, but utilizing other cores from elsewhere in the state or neighboring Ohio would be a logical next step.

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