Glacial Varved Sediments

Varved sediments (varves) refers to the annually laminated sediment deposited at the base of some lakes, or marine settings[1]. These sediments are incredible resources for researchers who look into changes in climate and environmental systems in the past. This is because they can record changes to these systems at an annual, or even seasonal resolution. Becasue the sediment accumulates in annual layers, it means the chronology of the sediment is robust as you can count back the annual layers, just like an ice core making these sediments much more accurate than other methods of reconstructing past changes. This article focusses on two different types of varves in glacial regions, the first is glaciolacustrine in lake settings, and the second glacimarine, in marine settings.

Different Types of Varves

The term 'varve' was initially used to describe the cyclic deposits of proglacial clay in eastern Sweden. However, it is now used to describe all annually laminated sediment found in both lake and marine settings in temperate, and glacial regions[1]. The varves that we will be focussing on this article are clastic varves, formed in glacial settings, however other varves do exist, such as biogenic varves, which have different characteristics in terms of the their formation and composition (Figure 1).

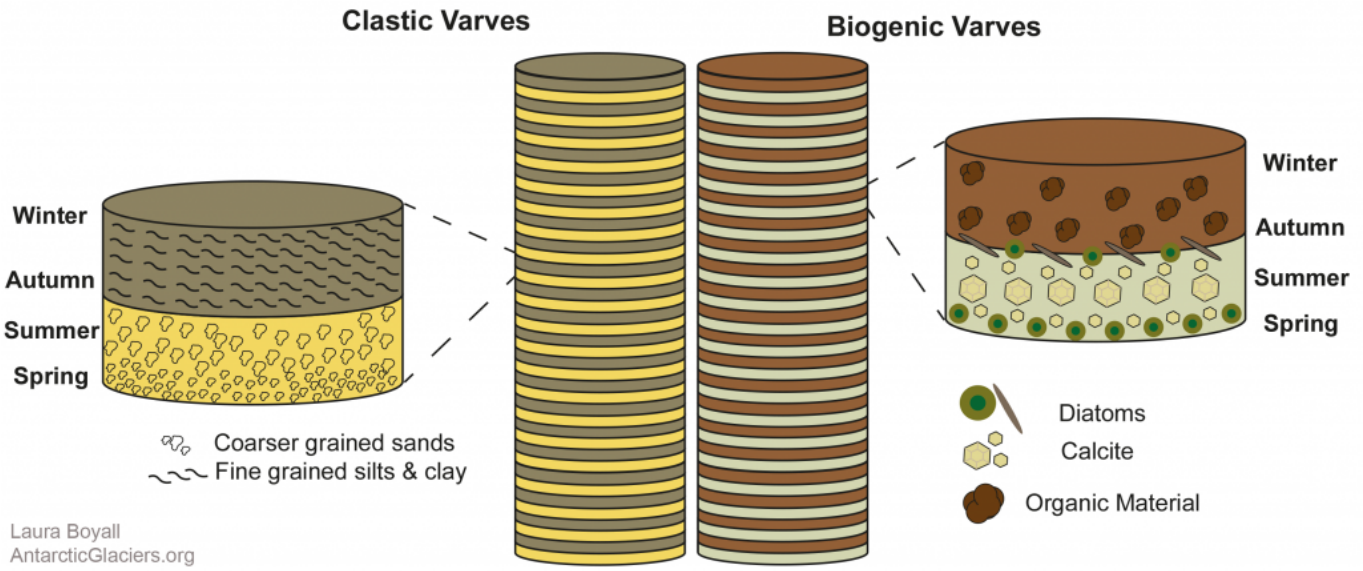

Figure 1. Differences in seasonal sediment deposition in clastic and biogenic Varves. Figure based on Sturm and Lotter (1995); Zolitschka et al. (2007).

Glaciolacustrine varves

Proglacial lakes, or those fed by glacial meltwater tend to be subjected to seasonal changes in sediment supply, typically associated with the summer melt season, and the winter accumulation season. These seasonally changing sediment contributions are what can cause annual laminations (Figure 1). Each individual lake has different characteristic making their formation slightly different, however, here we are discussing the classic conceptual model of glaciolacustrine varves as described

in Zolitschka et al (2015)[1].

It is really important to understand however that not all glacial lakes which receive seasonally different sediments can form, or preserve varves. Instead, only a few can as they require very specific conditions, most importantly the absence of oxygen (anoxia) at the base of the lake throughout the whole year. This is important as this stops the presence of biological organisms from living at the water-sediment interface and limits the disturbance of the uppermost sediments[2].

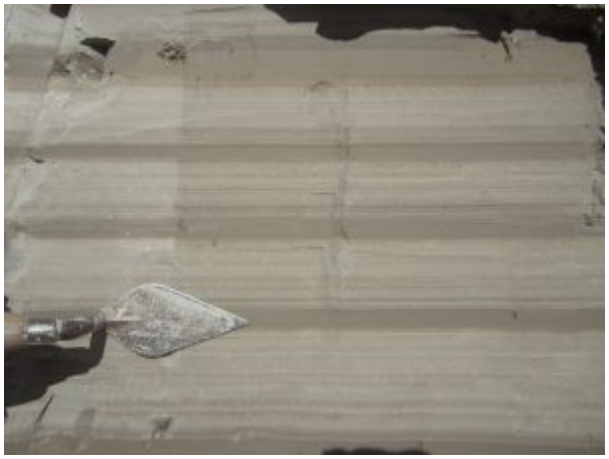

Figure 2. Glaciolacustrine varve deposits from Patagonia

Figure 3 shows the two different states a varve forming glaciolacustrine lake may be in during the winter accumulation season, and the summer melt season. During the winter season, when temperatures are much cooler, there is typically much less glacier melt. This limits the available runoff to transport sediment from the catchment to the lake basin. In addition to this, the lake's surface may also be frozen creating a barrier between the lake and external meteorological conditions, such as winds[1,2].

Because there is less water being inputted into the lake, and winds do not have much influence, the lake is less turbulent and can begin to stabilise. When this happens, fine grained sediment, such as silts and clays which are normally kept in suspension, are able to fall to the bottom of the lake. This layer of fine-grained sediment therefore characterises the winter layer in glaciolacustrine varves (Figure 1)[3].

Different processes exist during the summer melt season (Figure 3). Firstly, ice on the lake surface begins to melt and thus removing the barrier between the lake and the atmosphere. This allows the lake to be more susceptible to wind, and can result in the water column to become partially mixed. Melting snow on the glacier and surrounding catchment means this season is characterised by high levels of meltwater runoff[1,3]. This meltwater tends to be concentrated with high sediment loads due to its relatively high energy and thus is able to deposit coarser-grained sediment into the lake. This characterises the summer layer (Figure 1).

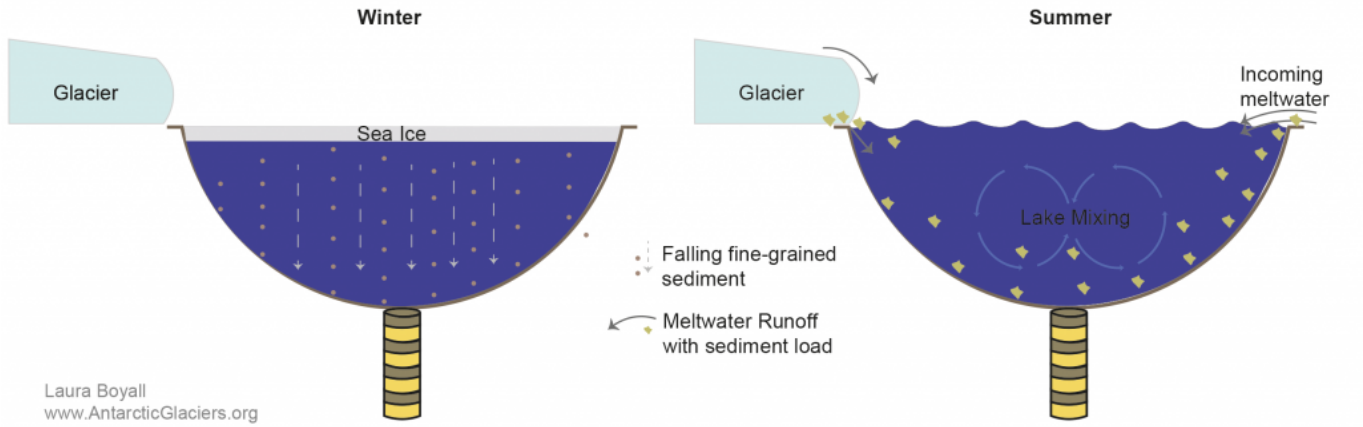

Figure 3. Summer and winter conceptual model of sediment supply and deposition into a glacial lake basin.

Glacimarine varves

Marine varves in general, are found in more geographical regions than lacustrine varves[4]. However, because of the high cost of sediment core extraction in marine settings, they are not as readily available. Similar requirements are needed to form marine varves to those deposited in lacustrine settings, including the seasonal supply of sediment, and the requirement for a complete absence of oxygen at the base of the water. Despite these overarching requirements, the glacimarine varve models are less well understood and their lacustrine counterpart.

Glacimarine environments are marine areas which are directly influenced by glacier processes. These my be in fjords, bays surrounding glaciers or ice shelves, tidewater glaciers, or other regions in which glaciers are in direct contact with the sea[4,5]. Glacimarine varves can provide insights into glacial processes in the past including periods of higher ice rafting, length of sea ice seasons, and much more[4,5].

A review from Schimmelmann et al (2016)[4] summarised previous research on glacimarine varves including in Disenchantment Bay, in the Gulf of Alaska which is characterised by winter clastic diamicton fed by ice rafting debris, and a summer mud layer. These alternating seasonal layers are only able to be preserved because the dominant glacier in contact with this region, the Hubbard glacier, forms a meltwater plume resulting in water stratification and the absence of oxygen on the marine floor[6].

Not all glacimarine varves have the same characteristics, or forcing mechanisms as those described above[4]. For example, varves found in the Adélie Basin on the Antarctic Margin have varves deposited in the Holocene which are characterised with many sub-laminations representing different seasons. These include a biogenic diatom layer deposited at the beginning of spring when the sea ice retreats, followed by a different accumulation of diatom species when the water is fully open with limited sea ice present. This is then followed by darker clastic-rich sediments, once again deposited by ice rafting processes[5].

Summary

Varved sediments in both lacustrine and marine environments are exceptional archives, of past changes. However, as highlighted here, understanding the driving mechanisms behind the seasonal laminations is critical to interpret the past climate and environmental conditions[1].

References

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