A Paleolimnological Study of Holocene Sediments in St. Albans Bay, Lake Champlain

A Thesis Progress Report Presented

by

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to

The Faculty of the Geology Department

of

The University of Vermont

December 6, 2010

Accepted by the Faculty of the Geology Department, the University of Vermont in partial fulfillment of the requirements for the degree of Masters of Science specializing in Geology.

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I. Introduction

Undisturbed lake sediments retain information on ecosystem changes within the lake and surrounding watershed (Schelske & Hodell, 1991, 1995; Meyers, 1997; Smol et al., 2001; Meyers & Teranes, 2001). Therefore, a multi-proxy analysis of lacustrine sediment cores is a useful way to create paleoenvironmental reconstructions. The chemical and physical characteristics of lake sediments can provide us with information about sources of organic matter, lake productivity, and a record of previous climatic fluctuations (Smol, 2008). Lake Champlain (Vermont, USA) has environmental, economical, and historical importance; therefore, it is beneficial for scientists to study the quality and climate history of the lake system, and the anthropogenic and natural processes that have affected the chemistry, water quality, and sedimentation rates over time.

A previous study (Burgess, 2007) used a sediment core from St. Albans Bay, Lake Champlain (Fig. 1&2) to investigate the last 4500 years of the bay's history (though the study focused on the past 400 years). There is a significant pattern in the data (Fig. 3), where a higher amount of sedimentary organic matter (OM) in older sediments mimics amounts recorded in recent sediments. However, we predict that the *causes* for the higher amounts of OM differ between the older and younger sediments. Recent elevated amounts of OM are thought to be a consequence of human-induced eutrophication (SOURCE), though this cannot be the cause of high amounts of OM in the older sediments. Archaeological studies (SOURCE) indicate that there was not a large enough population of humans before about 1750 in the Champlain Valley to significantly alter nutrient loading in the lake. This suggests that in the lower portion of the sediment core, elevated OM productivity in the lake was related to natural climate change.

This study compares proxy results from long sediment cores, encompassing the last ~9000 years, to the results from the Burgess (2007) study. I have begun analysis on two sediment cores collected in St. Albans Bay that are used to record the response of St. Albans Bay to climatic fluctuations, and to determine if the bay shows similar responses to natural climate variability versus anthropogenic eutrophicaition. I will also determine the rates of deposition and origins of organic matter in Holocene sediments in the bay. Proxies for this study include magnetic susceptibility, organic matter content (measured as $\%C_{org}$), C/N ratios, biogenic silica (BSi), particle grain size, and stable carbon isotopes. Based on a literature review and some preliminary findings, I hypothesize that:

- St. Albans Bay has higher amounts of OM in the younger sediments due to anthropogenic eutrophication, and higher amounts of OM in the older sediments due to natural climate variability.
- Increases in OM productivity (represented as both BSi and $\%C_{org}$) in the older sediments are related to changes such as natural increases in temperature and nutrient loading in the bay; In contrast, decreases in OM productivity relate to cooler temperatures and decreased availability of nutrients in the bay.
- Differences in proxies between the two cores that I collected are related to the differences in water depth; the shallower core shows greater sensitivity to climate changes than the deeper core.

II. Work Completed to Date

Sediment Core Processing

St. Albans Bay was chosen for sediment core extraction based on two key factors: the bay has been previously studied (King, 1993; Burgess, 2007) and it has problems with eutrophication (LCBP, 2002). Two cores (SAB1, 259 cm and SAB2, 271 cm long) were collected from the bay in March, 2010 using a Reasoner-type piston corer (Fig. 4). The cores were then cut lengthwise in half in order to access the sediment, and logged with a digital camera. One half was carefully wrapped and stored in a refrigerator as an archive, while the other half was scooped out at 1cm intervals (Fig. 5), placed in 20 ml sample bottles, and freeze-dried. The sediment cores were both mostly a gray-brown color, without visible laminations and consisted mostly of silty clay. Each sample was weighed wet and dry in order to calculate the percentage of water. Once dry, each sample was powdered in its container on a hot dog roller (which continuously turned the bottles, with metal balls enclosed to break up sediment), to ensure homogeneity of the sediment.

Magnetic Susceptibility

Before the cores were split lengthwise, they were analyzed for magnetic susceptibility on a Bartington magnetic susceptibility meter, model MS2, with an ASC automated core logging system. Cores were logged at 1 cm intervals, including an extra 10 cm on both ends of each core section. The ends of the sections were then overlapped to ensure consistency and precision.

Elemental Analysis

I determined %C_{org} and %TN on a CE Instruments NC 2500 elemental analyzer (EA) using Eager 200 data handling software. I analyzed at 1 cm intervals for the top 40 cm, 2 cm intervals from 40-100 cm, and 4 cm intervals from 100 cm until the bottom of the core. For each sample, about 50 mg of sediment was placed in a tin capsule, sealed, and the weight was recorded. The capsules were then placed in the EA and ignited, and the traceable amounts of C and N were recorded. I then calculated a C/N ratio by dividing %C_{org} by %TN.

Biogenic Silica

I have completed BSi analysis on SAB2, and on the top ~100 cm of SAB1. BSi concentration is analyzed at 2 cm intervals for the top 50 cm of each core, and at 4 cm intervals for the remaining portion of the core. The analysis follows a method modified from DeMaster (1981) that involves hourly extractions for five hours of sample aliquots in a 0.1 M $NaCO_3$ solution, placed in a hot water bath. Reagents, including 2 mL of molybdate and then 3 mL of reducing solution are added to each sample and standard to develop a blue color that is measured in a spectrophotometer. The sample's absorbance is then compared to the standard curve to calculate the concentration of silica in the solution.

Geochronology

I chose five macrofossils from the sediment cores based on the results of the $\%C_{org}$ analysis. I chose samples from depths that showed significant changes in $\%C_{org}$ and at least one sample from each core at the lowest possible depth. Both sediment cores contained abundant macrofossils. For SAB1, I chose macrofossils from depths of 46 cm, 162 cm, and 258 cm. For SAB2, I chose macrofossils from depths of 127 cm and 264 cm. These samples were sent to Woods Hole Oceanographic Institution in Massachusetts for radiocarbon dating on an accelerator mass spectrometer, and we expect to have the results by the end of December 2010.

III. Initial Results and Interpretations

To clarify, the use of the term "1 cm" refers to the sediment between 0 and 1 cm depth from the surface of the sediment, or the top of the sediment core. Until the results of the macrofossil dating are analyzed, I am assuming that approximately 18 cm of sediment was lost from each core (discussed below). Without these age constraints on the sediment, it is difficult to correlate changes in the proxies with specific events.

Age Correlation of Sediments

Burgess (2007) collected a gravity core at the SAB1 location in order to analyze the sediment-water interface (which is typically lost during piston core extraction) and then overlapped the data from the gravity core with her piston core. She dated the most recent sediment using alpha spectrometric analysis of ^{210}Pb activities (Appleby, 2001), but was only able to collect one radiocarbon date from the lower portion of the core, which she used to interpolate age data for the remaining sediment (Fig. 6).

When I correlate my sediment cores with the age model produced by Burgess (2007), which infers a constant sedimentation rate of about 1 cm per 54 years in the older sediments, I get a maximum date of almost 14,000 years ago for the lowest part of SAB1. This date would get a few hundreds of years older if we take into account the fact that I have only collected a piston core, and therefore the sediment-water interface is most likely missing. It is unreasonable to assume a constant sedimentation rate for the past 10,000 years, which is why this date seems so old. Therefore, it is important that we get several ^{14}C dates of the macrofossils to better constrain the ages of sediment layers and sedimentation rates in the bay.

To determine how much sediment is potentially missing at the top of my cores, I correlated the $\%C_{org}$ data that I collected at SAB1 with the data from the Burgess 2007 study, taken at the same location in St. Albans Bay (Fig. 7); it appears that I am missing about 18 cm from the top of the sediment core. Since this correlation is easily done for SAB1, it is unnecessary to obtain a short gravity core. However, it may be necessary to collect a gravity core from the SAB2 location in order to determine how much of the most recent record is missing in the SAB2 core.

Magnetic Susceptibility

Magnetic susceptibility (MS) is a measure of the degree of magnetization of a material in response to an applied magnetic field (Nowaczyk, 2001). With this analysis, we can potentially gain information on the sedimentary history of the lake as it relates to erosion of the surrounding basin. For example, Parris et al. (2009) found significant increases in magnetic minerals in sediment layers deposited by paleostorms. Increased runoff and erosion will result in an increase of magnetic minerals within the bay. The data show some interesting patterns in both SAB1 and SAB2. Both cores show higher MS values in the top portions of the cores (Fig. 8). SAB1 shows two peaks at about

20 cm and 65 cm depth, which could relate to increased erosion, and therefore a higher concentration of inorganic, magnetic material in the sediment (Smol, 2008; Brown et al., 2000). I hypothesize that the most recent peak in SAB1 SI is a response to modern development in the St. Albans watershed. Without age constraints, it is difficult to know what the second peak is a response to. SAB2 also shows a peak in SI in the top of the core, which is probably related to development as well. The MS values in the lower portions of both cores are much lower than the top, suggesting lower rates of accumulation of magnetic material, and therefore lower erosion rates (Parris et al., 2009).

Elemental Analyses

Organic matter typically contains about 50% carbon; therefore, the concentration of total organic carbon (TOC, expressed as %C) is a fundamental parameter for determining the abundance of organic matter in sediments (Meyers & Teranes, 2001). Changes in climate, both natural and anthropogenic, can affect the availability of nutrients within a lake system that limits productivity in lakes; as availability increases, so does productivity. Increased production generally results in increased accumulation of OM in the sediment, reflected by increased %C values (Engstrom & Wright, 1983). The %C_{org} values for both SAB1 and SAB2 show peaks in the most recent sediments (Fig. 9), which can be interpreted as responses to anthropogenic eutrophication. However, SAB1 shows a lot more variability over time; this is probably related to its closer proximity to shore. This location is more affected by changes in lake level and also variations in runoff intensity from the watershed.

Interestingly in SAB1, %C_{org} are also high (~5%) at depths of ~110-150 cm, and again at the bottom of the core at ~250 cm. These patterns cannot be explained by human activity, and so must be related to natural climate variability. Some possibilities to explain increased OM burial during these time intervals include: an increased influx of nutrients from the surrounding watershed, possibly due to increased precipitation (although this could also result in increased inorganic material accumulation); a drop in lake level, creating a better habitat for rooted aquatic plants (macrophytes).

Carbon and nitrogen weight percentages are used to determine the C/N mass ratio, which can tell us whether the OM originated from aquatic as opposed to land sources. For example, phytoplankton OM typically has C/N values between 4 and 10, whereas OM from vascular land plants (cellulose rich and protein poor) typically has values of 20 or more (Meyers & Teranes, 2001). Soil from the surrounding watershed can also enter the lake, and often has a C/N value of about between 12-18. Recent studies show that the soil in the SAB watershed and surrounding area has a C/N of about 17 (Villars, personal communication). SAB1 has C/N ratios fluctuating between 9 and 12, whereas in SAB2 C/N values are consistently below 10 (Fig. 10). In the top ~150 cm, SAB1 was dominated mostly by algae; however, based on a high concentration of fibrous macrofossils, this sediment most likely had a macrophyte influence as well which would slightly raise the C/N values. In the lower portion of the core, the productivity of OM was controlled primarily by algae. The entirety of SAB2 shows predominantly algae-controlled OM productivity.

Biogenic Silica

The past total biomass of siliceous organisms can be established by determining the amount of amorphous biogenic silica (BSi) in sediments. Changes in BSi often correlate with increased or decreased nutrient loading and productivity in the lake; therefore, inferences can be made about past trophic states of the lake (DeMaster, 1981; Conley & Schelske, 2001; Smol, 2008). In addition, changes in climate affect the loading and availability of nutrients in a lake system. Increased availability of nutrients in a lake initially results in increased diatom production and accumulation of BSi, and then decreased BSi abundance once the dissolved silicate in the water is depleted. Therefore, an increase followed by a decrease in BSi in the sediment record is a proxy for dissolved silica depletion in the lake (Conley & Schelske, 2001). SAB1 shows this pattern in BSi in the top of the core, and again around 40 cm depth (Fig. 11), which means that there was most likely an influx of nutrients to the lake prior to both of these spikes, where the highest values represent depletion of dissolved silicate. There is a similar pattern in SAB2 at ~60 cm depth (Fig. 11). The top of SAB2 shows highly variable BSi values, and therefore it is difficult to pinpoint these patterns. Since this was the first BSi analysis run, I plan to re-analyze the top 40 cm of SAB2 for BSi to ensure accuracy.

IV. Discussion

Several proxies show similar patterns over time, which can be explained as how the lake responded to environmental fluctuations. Modern increases in OM productivity, shown as %C_{org} and BSi, are related to human induced eutrophication. Humans significantly alter the amount of runoff from the watershed and nutrients that enter the bay (eg. fertilizer from agricultural practices). This can lead to increased productivity within the bay, as documented by the increase in OM in the sediment. The patterns of increased % C_{org} and BSi values in the older sediment that was deposited before permanent human settlement, however, can only be explained by natural climate variability. In SAB1, both %C_{org} and BSi show increases at approximately the same depths (~2 cm and 40 cm; Fig. 12), indicating that increased availability of nutrients has a similar effect on both of these proxies.

I predict that differences in proxies between SAB1 and SAB2 are related to the differences in water depth where these cores were collected; the shallower core (SAB1) shows greater sensitivity to climate fluctuations than the deeper core (SAB2). In almost every analysis measured so far, SAB1 shows more variability than SAB2. SAB1 would be more sensitive to changes in lake level than SAB2, and also more sensitive to factors such as water clarity and temperature. These would greatly affect aquatic productivity levels. This site could also be more sensitive to runoff from the watershed since it is closer to shore than SAB2, and therefore would likely contain a higher amount of soil and magnetic materials from the watershed.

V. Remaining Work

There are two analyses that I have yet to perform, particle size analysis and the carbon isotopic composition of sedimentary OM in both SAB1 and SAB2. The cores will be analyzed for grain size at 4 cm intervals (smaller if higher resolution is needed). Each sample will be treated with H_2O_2 and NaOH to dissolve organic matter, and then analyzed on a Beckman Coulter LS230 laser scattering particle size analyzer. Organic material found at 4 cm intervals (more if deemed necessary… or selected samples??) in the core will be analyzed for $\delta^{13}C$. This material will be combusted to generate CO_2, which will be purified cryogenically and analyzed on a VG SIRA II stable isotope ratio mass spectrometer. If we feel that collecting a gravity core at SAB2 is necessary, then that sediment will be analyzed for $\%C_{org}$, %TN, C/N.

Timeline:

• Fall Semester 2010	• Elemental analyses • BSi analysis on SAB2 • Progress Report 12/6/10 • Finish BSi analysis on SAB1
• Winter 2010-2011	• Particle Size analysis • C isotope analysis • Correlate sediment cores with radiocarbon dates • Collect gravity core at SAB2? • Start writing thesis
• Spring Semester 2011	• Finish analyses • Present at NEGSA • Write and defend thesis

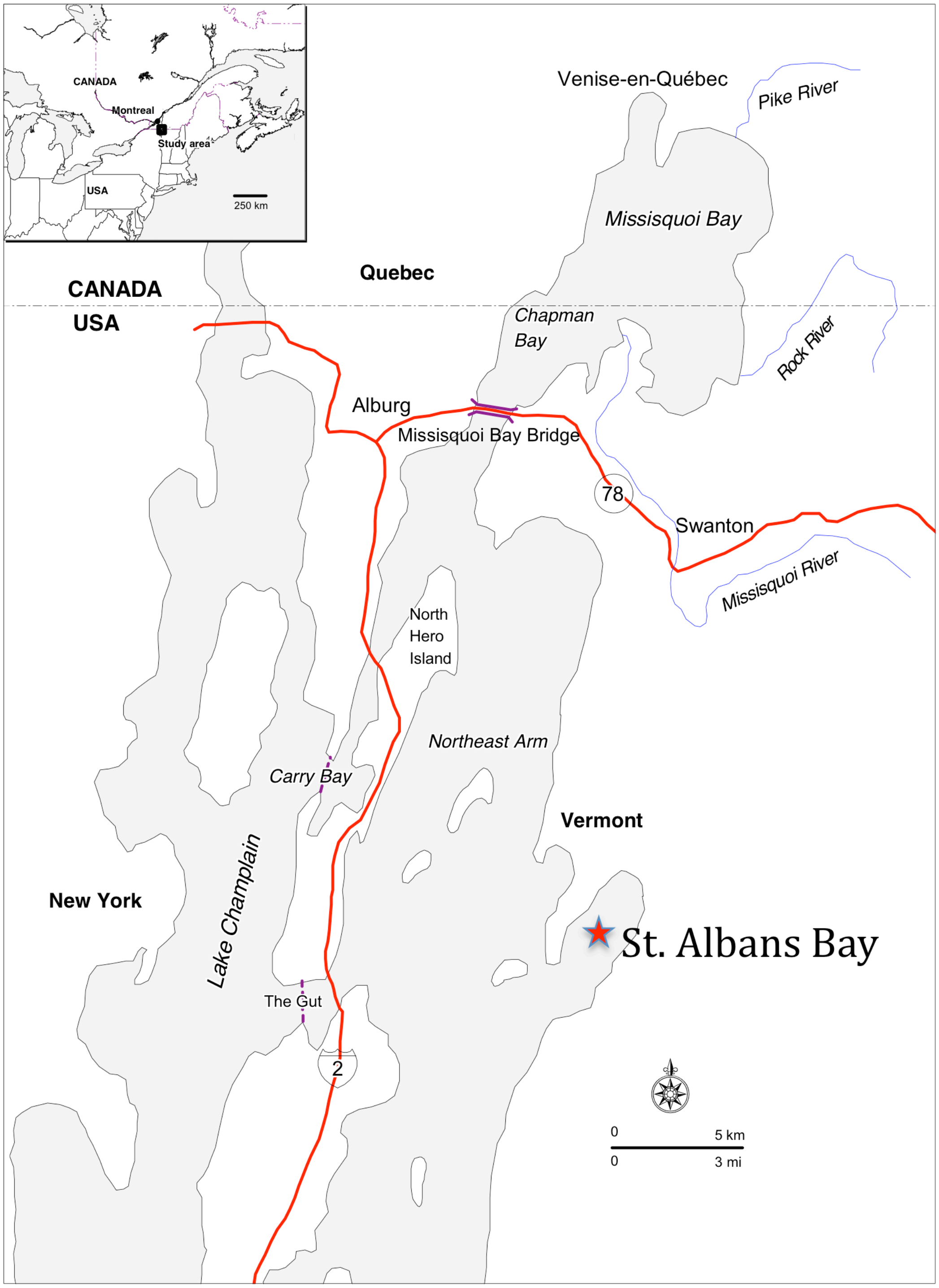

Figure 1: Map of Northeastern US, showing location of Lake Champlain and St. Albans Bay.

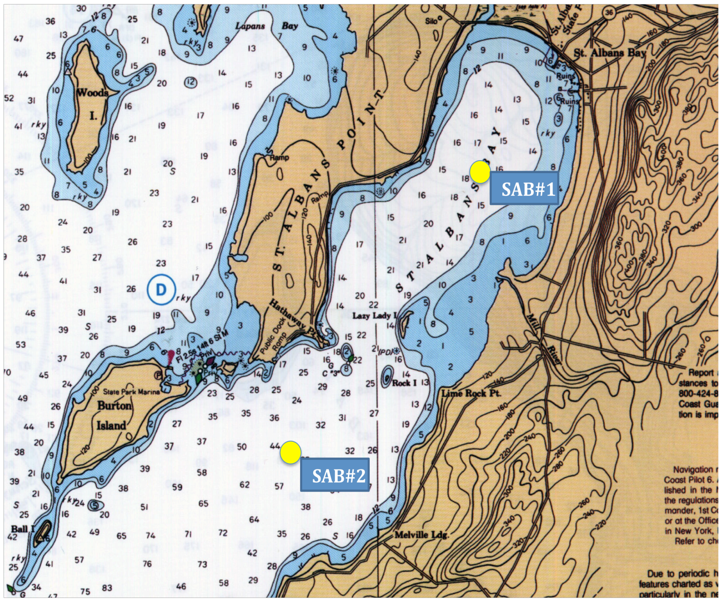

Figure 2: Map of St. Albans Bay, showing location of the two coring sites.

Core	Coordinates	Water Depth (ft)	Ice Thickness (ft)
SAB#1	44° 47’ 48.0” N 73° 09’ 0.0” W	16.8	1.3
SAB#2	44° 46’ 7.1” N 73° 10’ 38.0 W	36.8	1.3

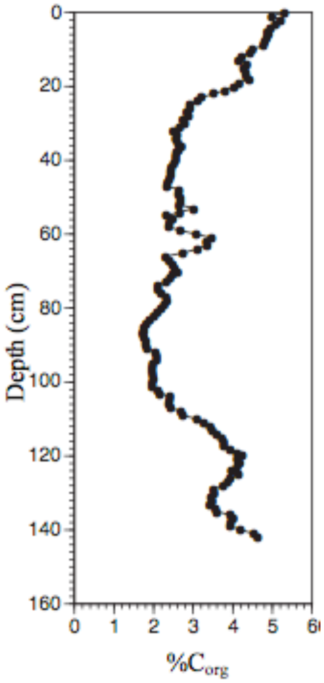

Figure 3: Organic matter (represented as %C_{org}) data from St. Albans Bay, showing a similar amount of %C_{org} in the recent sediments and in the older sediments (Burgess, 2007).

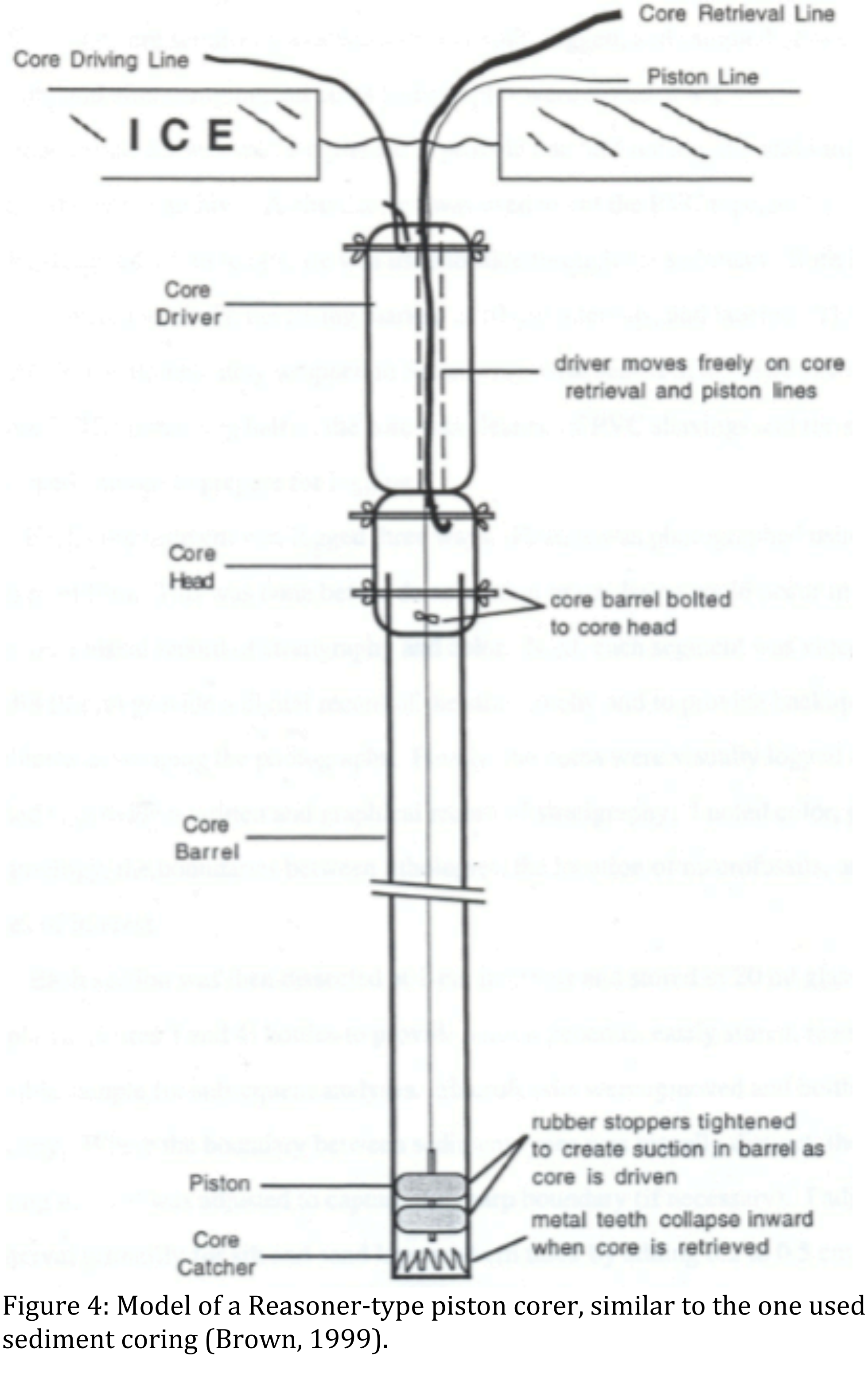

Figure 4: Model of a Reasoner-type piston corer, similar to the one used for St. Albans Bay sediment coring (Brown, 1999).

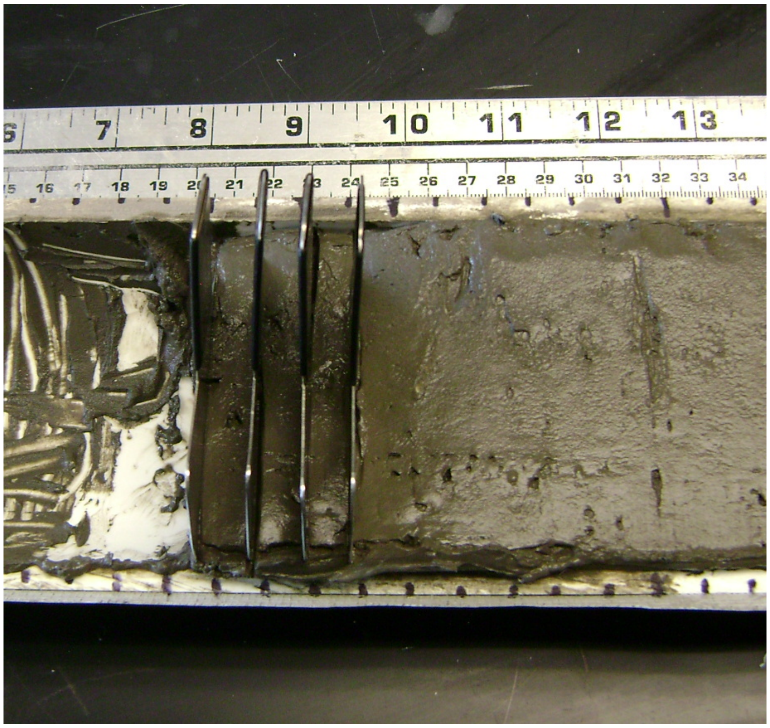

Figure 5: Image of a sediment core interval with blades to separate cm levels.

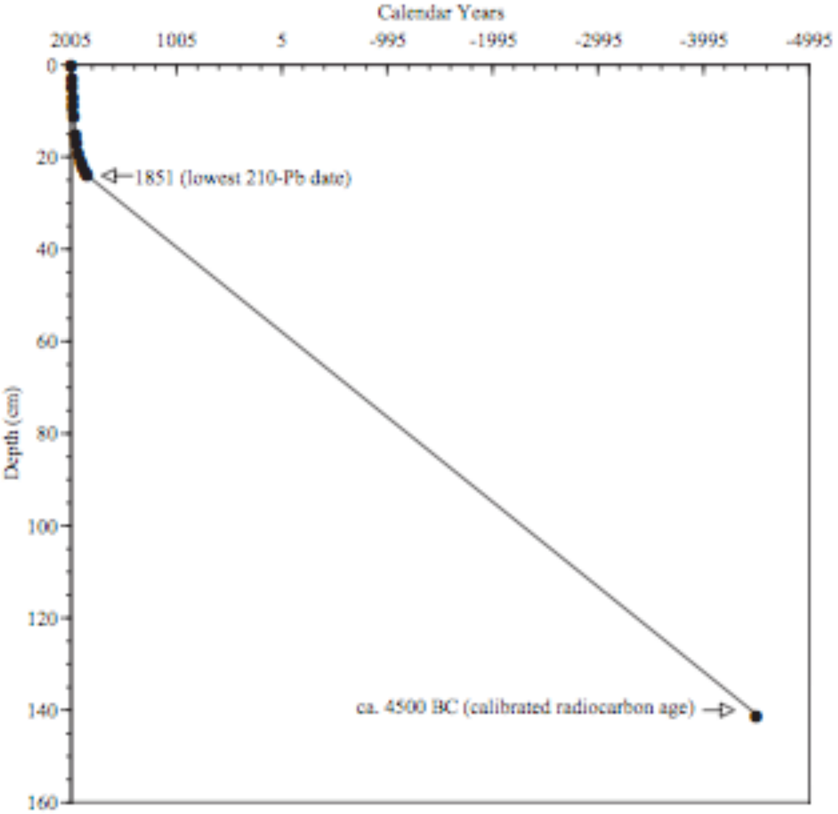

Figure 6: Age model constructed from ^{210}Pb and ^{14}C dates (Burgess, 2007).

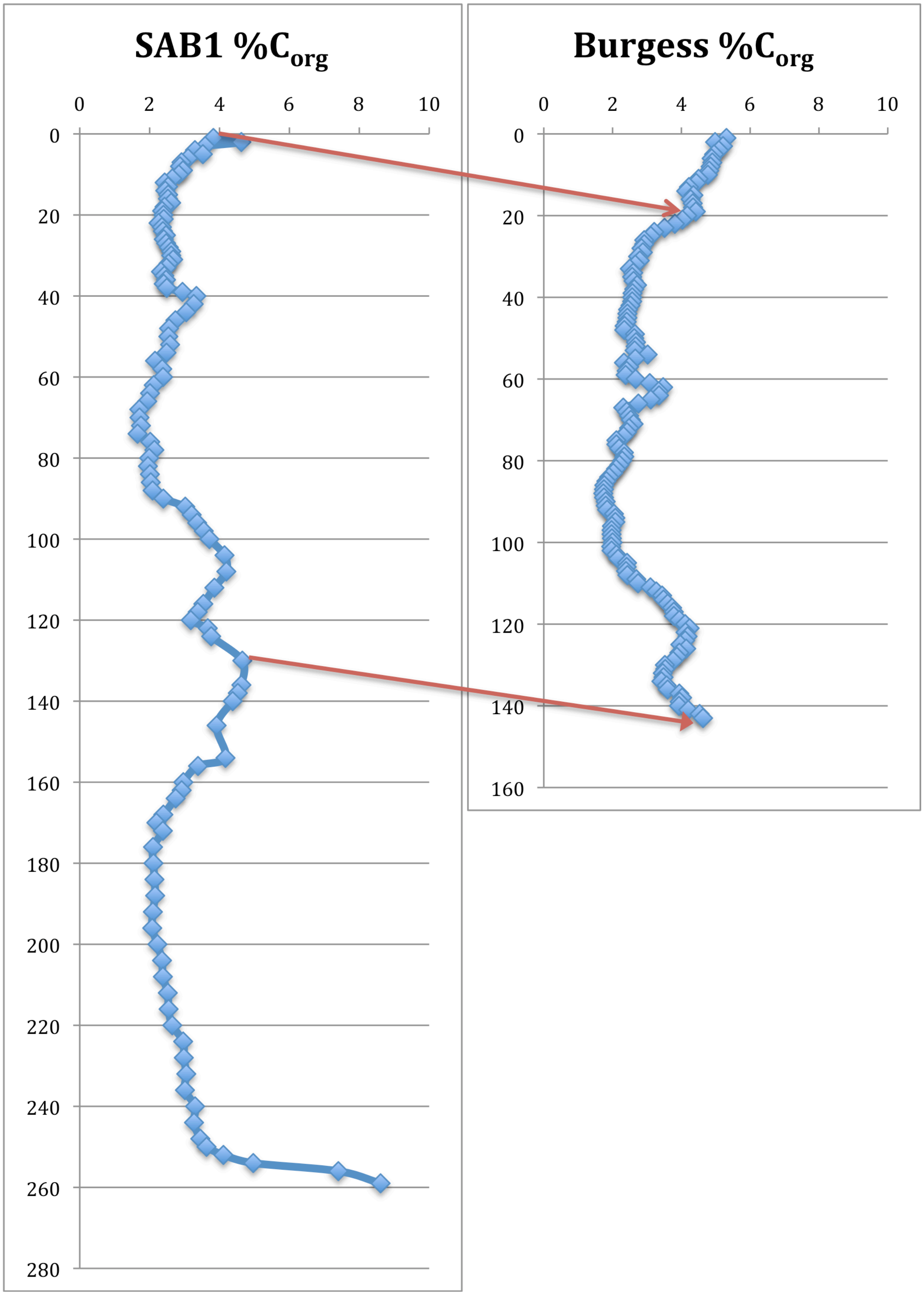

Figure 7: Correlated %C_{org} data from SAB1 and Burgess (2007). ~18 cm appear to be missing from my sediment core.

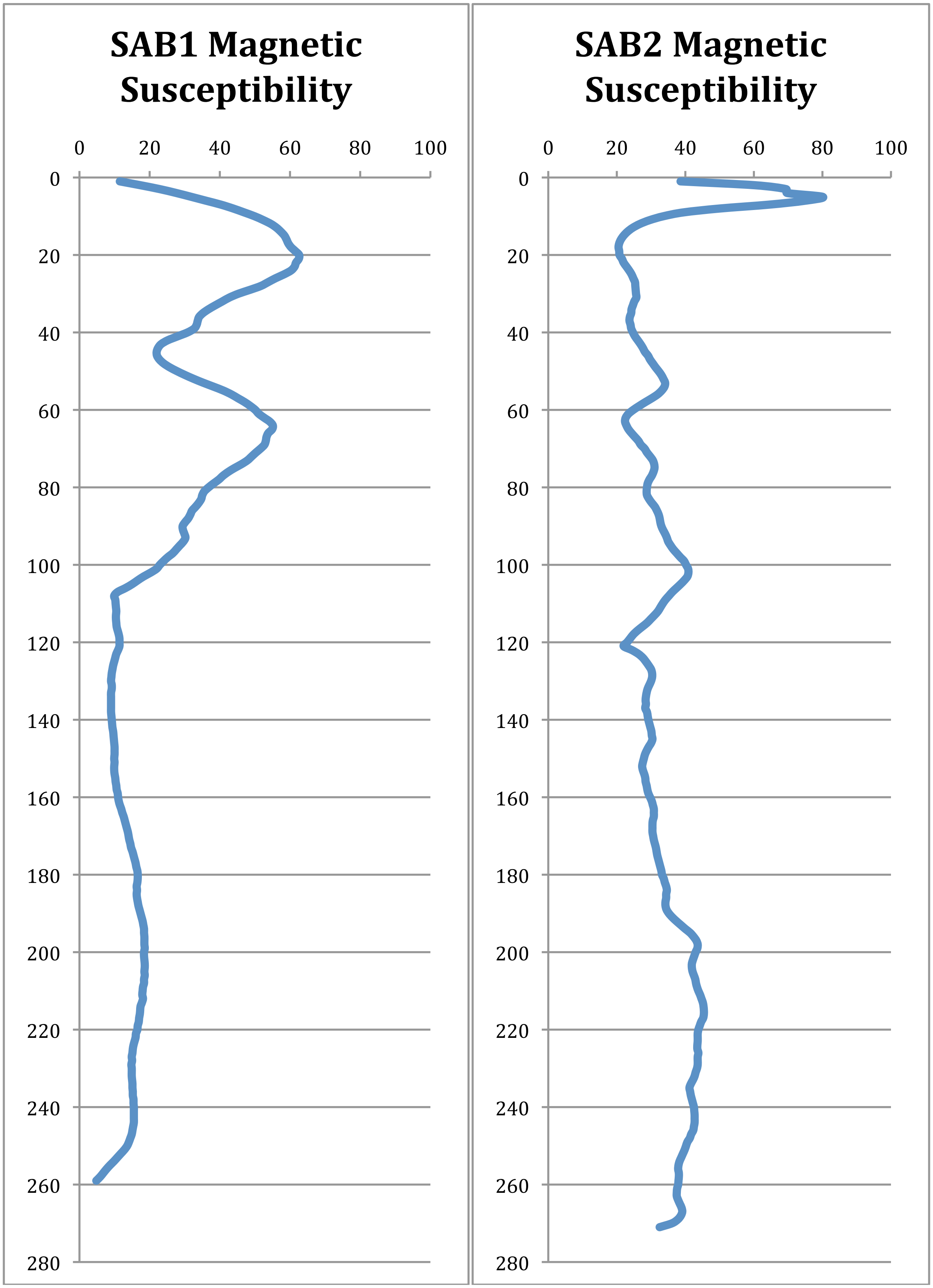

Figure 8: Magnetic susceptibility for SAB1 and SAB2, measured in SI.

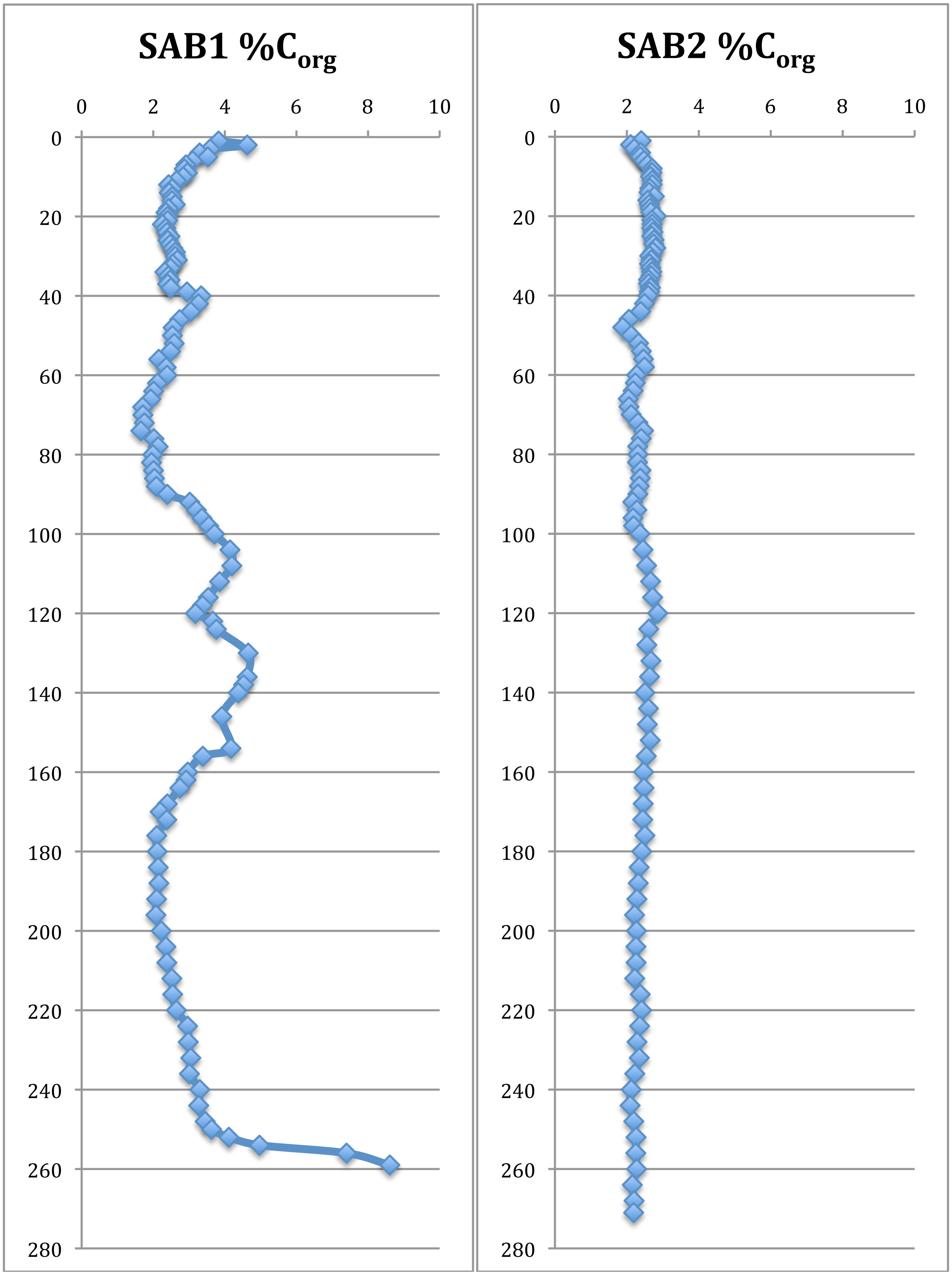

Figure 9: $\%C_{org}$ values for SAB1 and SAB2.

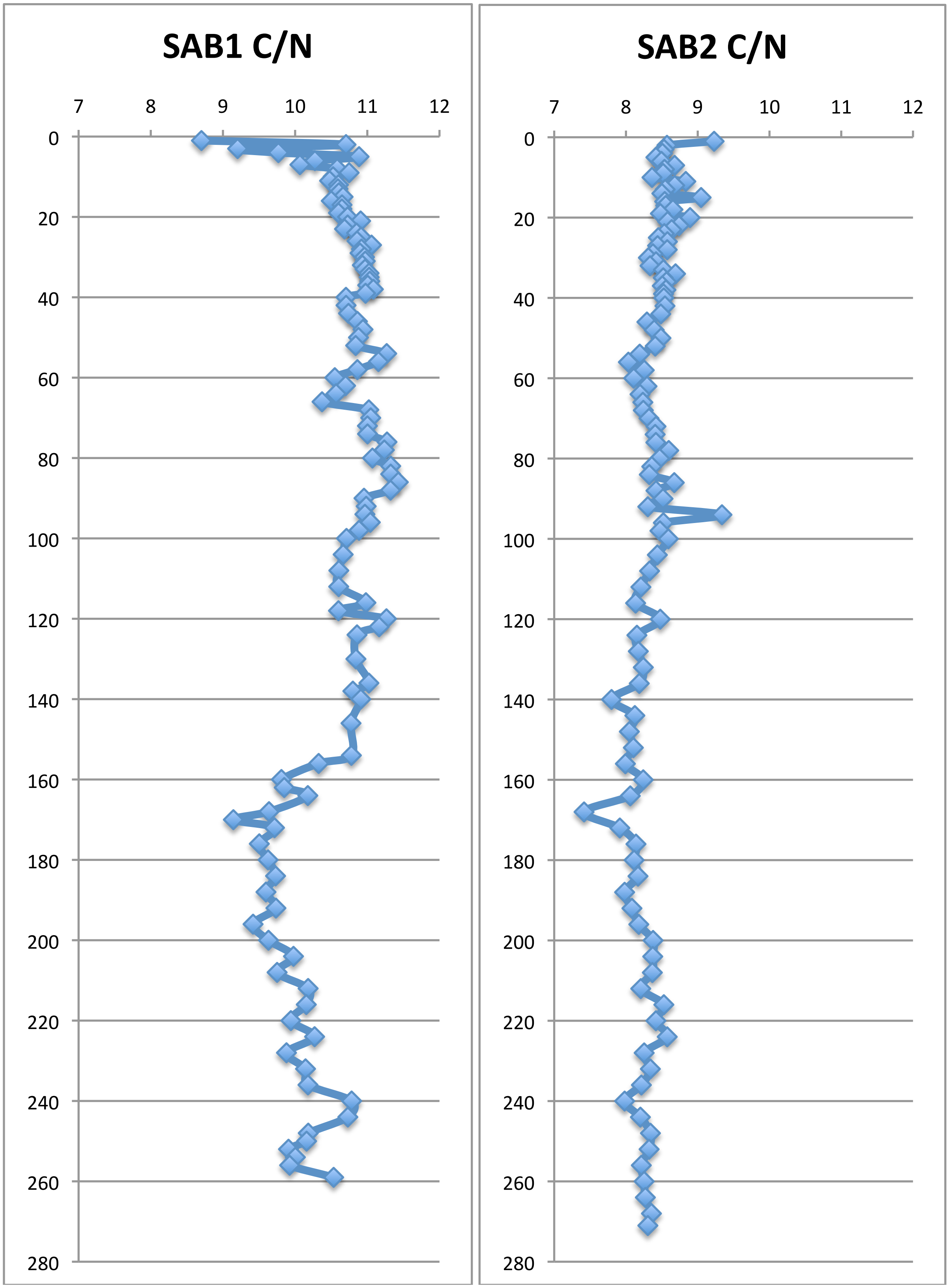

Figure 10: C/N ratio values for SAB1 and SAB2.

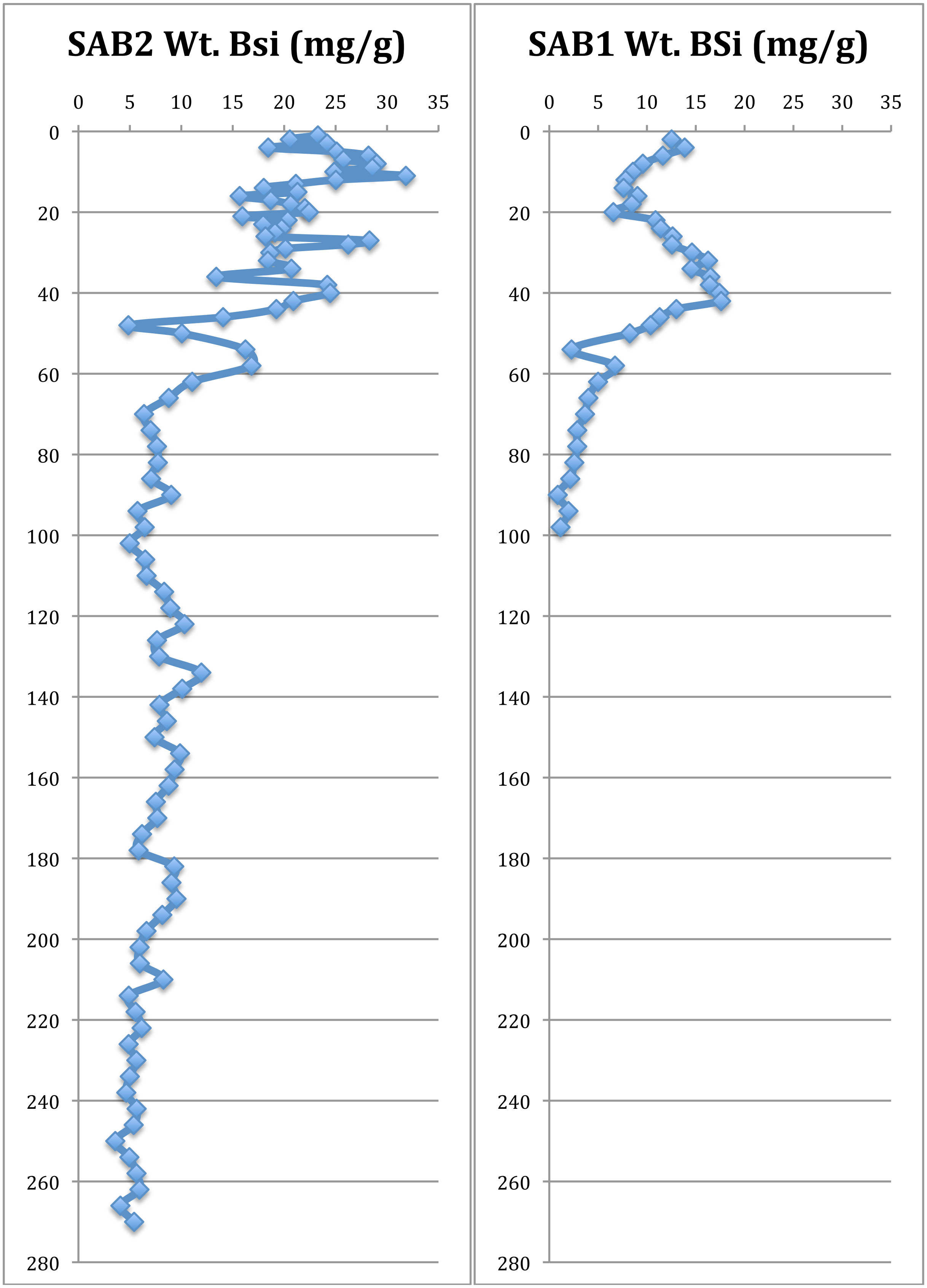

Figure 11: BSi results for all of SAB2 and ~100 cm of SAB1.

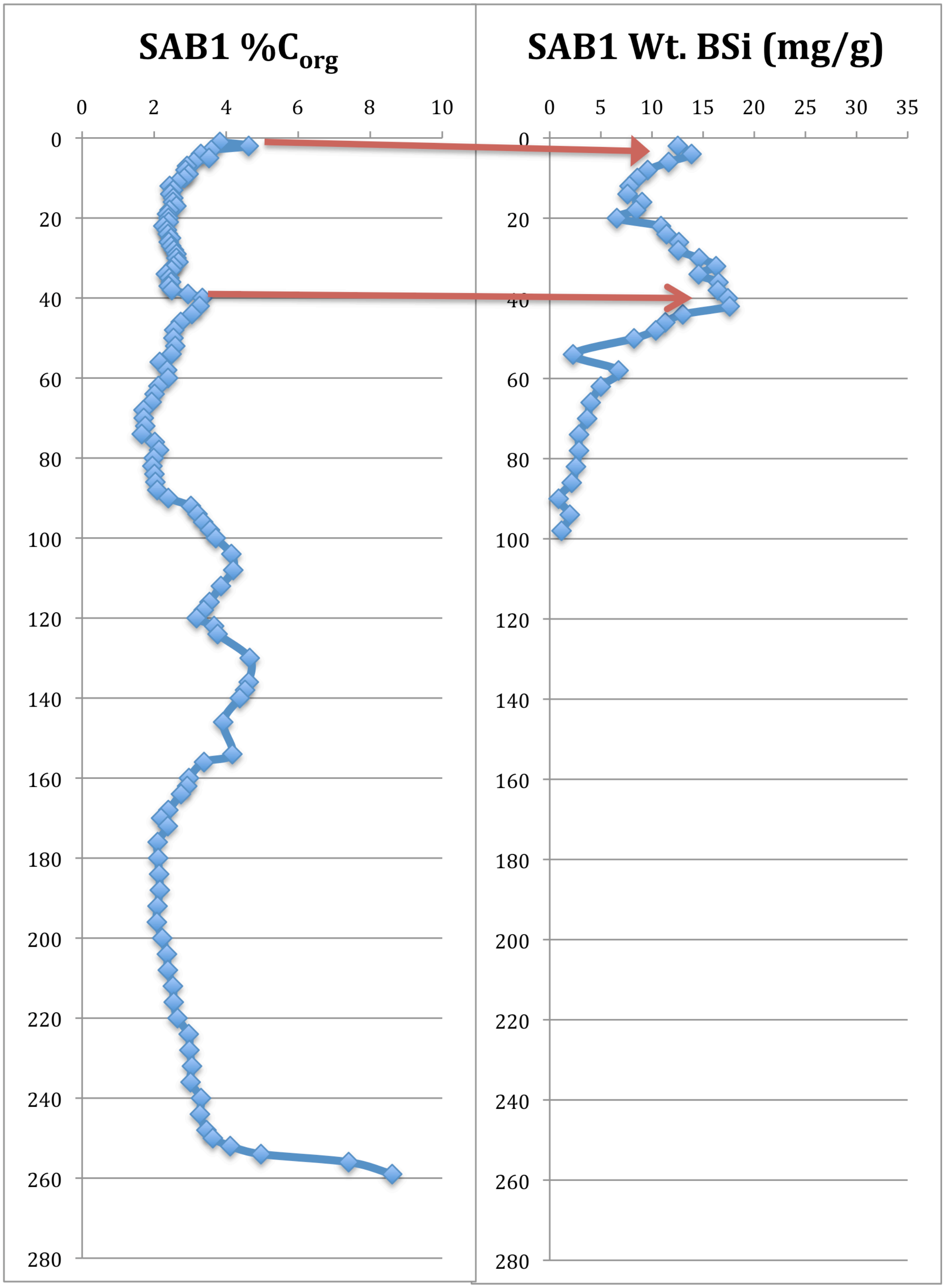

Figure 12: %C_{org} and BSi for SAB1. Arrows show similar peaks in both proxies.