14. BIOGENIC SILICA

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Introduction and history

Siliceous microfossils, particularly diatoms, are commonly used as proxies in paleolimnology for studies related to eutrophication and acidification of surface waters, and hydrologic and climate change on a regional scale (see Stoermer & Smol, 1999 for further references). Biogenic silica (BSi), a chemically determined proxy, measures the amorphous Si content of sediments. It has been shown to be a good proxy for diatom abundance (Conley, 1988) and for other siliceous microfossils including sponges (Conley & Schelske, 1993) and phytoliths (Schwandes, 1998). Therefore, as a single proxy, BSi provides an index of both diatom abundance and, in many systems, of diatom productivity (Ragueneau et al., 1996).

Techniques to estimate the BSi content of sediments can be classified into 5 broad categories: 1) X-ray diffraction (Goldberg, 1958), 2) point counting of diatoms (Pudsey, 1992), 3) infrared analysis (Fröhlich, 1989), 4) a normative calculation technique whereby BSi is estimated by difference from mineral silicates (Leinen, 1977), and 5) the wet-alkaline digestion techniques (Hurd, 1972; DeMaster, 1979, 1981, 1991; Eggiman et al., 1980; Mortlock & Froelich, 1989; Müller & Schneider, 1993). Wet-alkaline techniques are most often used because of their ease of use and reliability.

Although early measurements of alkali soluble Si had been made in paleolimnological studies (Hansen, 1956; Diggerfeldt, 1972; Renberg, 1976), reliable wet chemical methods were not available to measure BSi until the early 1980s (DeMaster, 1979, 1981; Eggiman et al., 1980). While other methods had been used in the literature, none provided the ease of use or the theoretical underpinning that DeMaster (1979) provided. Consequently,

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widespread paleolimnological applications began in the 1980s (e.g., Schelske et al., 1983) and determination of BSi in sediments is currently one of the routine measurements made in paleolimnological studies.

Methods

We recommend that investigators employ one of the wet chemical digestion techniques for the measurement of biogenic silica (BSi) in sediments. Three basic modifications of this technique are commonly used: 1) A moderate strength base is used (2 M Na_2CO_3) and the sample is digested for 5 hours after which the amount of Si extracted is measured (Mortlock & Froelich, 1989); 2) A weak base is used for the extraction solution (1% Na_2CO_3) and the aliquots are withdrawn at selected intervals (3, 4, and 5 h) and the amount of Si extracted is measured on these sub-samples. A least-squares linear regression is made to correct for mineral dissolution during the digestion and the amount of BSi in the sample is determined by extrapolation to the intercept (DeMaster, 1979, 1981); 3) a strong base is used (0.5–1 M NaOH) with the amount of Si extracted continuously measured and a mineral correction made from the slope of the increase in the amount of Si extracted with time (Müller & Schneider, 1993). Comparison of chemical estimates of BSi with diatom microfossil point counts demonstrate (Conley, 1988) that these wet chemical extraction techniques for the measurement of BSi in sediments provides a valid proxy for the abundance of diatom microfossils in sediments.

We recommend that the specific technique or techniques selected by an investigator should be tested to confirm its reliability for a specific application. There are a variety of amorphous siliceous components in sediments, including chrysophycean cysts (Newberry & Schelske, 1986), diatoms (Conley, 1988), phytoliths (Schwandes, 1998), radiolarians (Eggiman et al., 1981), silicoflagellates, and sponge spicules (Conley & Schelske, 1993). In addition, there is a wide range of BSi concentrations observed in nature, from high BSi concentrations found in diatomites (Mortlock & Froelich, 1989), to low BSi concentrations found in nearshore sediments (Gehlen & van Raaphorst, 1993). Therefore, one must optimize the selected technique for the type of sample analyzed.

In a recent comparison of laboratories that included a broad representation from the aquatic science community, e.g. paleolimnologists, paleoceanographers, limnologists, estuarine scientists and oceanographers, 23 of 30 participating laboratories analyzed all samples with acceptable precision in an interlaboratory comparison of variability in measurement of BSi in sediments (Conley, 1998). This comparison demonstrated that the X-ray diffraction technique overestimated BSi relative to methods based on wet chemical digestion. In addition, neither digestion solution (Na_2CO_3 or NaOH) nor methodology (DeMaster, 1981 versus Mortlock & Froelich, 1989) was a significant factor in the measurement of BSi in these samples from contemporary environments that did not contain sponge spicules nor radiolarians.

Theoretical considerations

The wet chemical digestion techniques rely on the ability of a weak base solution to quantitatively dissolve all amorphous Si components of the sediments, while dissolving only a small fraction of the mineral silicates. Either a "mineral correction" is made for

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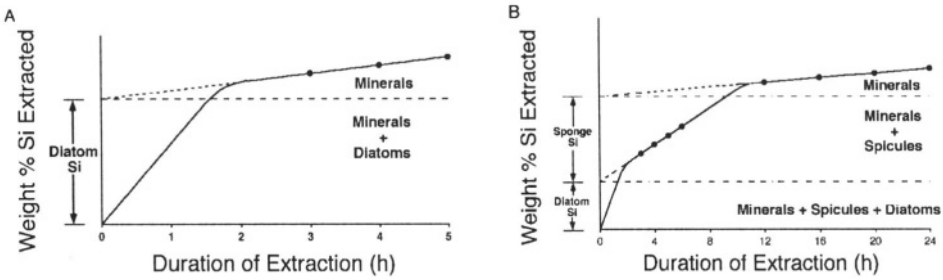

Figure 1. Hypothetical diagram describing the extraction of Si from sediments during digestion in 1% Na_2CO_3 at 85 °C as a function of time. The solid line depicts the hypothetical increase in the weight % of Si extracted with time in sediments with different amorphous Si components, the points represent the weight % Si extracted at different sampling times during the digestion process, and the dotted lines represent extrapolation to the intercept to determine the amorphous Si fraction. A) Sediments containing only diatoms and silicate minerals (modified from DeMaster, 1979) and B) sediments containing diatoms, sponge spicules and silicate minerals (modified from Conley & Schelske, 1993).

separation between the two components (e.g., DeMaster, 1981) or in sediment samples with high BSi concentrations the relative difference between Si extracted from amorphous compounds and from mineral silicates is large so that the "mineral correction" is ignored (Mortlock & Froelich, 1989; Conley, 1998). During a typical extraction (1% Na_2CO_3, 85 °C) in sediments where only diatoms and mineral silicates are present, the diatoms are rapidly dissolved (<2 h) and any increases after that time period are due strictly to digestion of mineral silicates (Fig. 1A). In this case, a least-squares linear regression is made and the extrapolation to the intercept gives the BSi concentration (DeMaster, 1979). Continuous measurement of the amount of Si extracted (Müller & Schneider, 1993) provides the best estimate of the contribution of mineral silicates (Conley, 1998), although this technique requires a level of sophistication beyond the capability of most paleolimnological laboratories. Mineral corrections can also be made by simultaneous measurement of Al concentrations during the digestion (Kamatani & Oku, 2000).

During a typical extraction (1% Na_2CO_3, 85 °C) in sediments where sponge spicules as well as diatoms and mineral silicates are present, the diatoms are rapidly dissolved (<2 h), sponge spicules are dissolved during the first 8–12 h of the digestion, and increases in Si extracted after that time period are due to digestion of mineral silicates (Fig. 1B). In this case, two least-squares linear regressions are made to the data giving the total amorphous Si extracted, the diatom Si extracted and the sponge Si by difference (Conley & Schelske, 1993). The procedure for separating diatom BSi from sponge BSi probably underestimates sponge BSi because smaller and/or lightly silicified sponges can be completely dissolved early during the digestion process (Conley & Schelske, 1993). Sponge BSi can comprise a significant portion of the total amorphous Si extracted from sediments and may act as a significant biogeochemical sink of amorphous Si in sediments (Conley & Schelske, 1993; Bavestrello et al., 1996).

Other amorphous Si *compounds in sediments*

While some success has been achieved separating diatom BSi from sponge BSi, it is difficult to separate chemically the various amorphous Si components of sediments. For example,

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the Si contained in radiolarians is typically dissolved by using a strong base solution (Mortlock & Froelich, 1989) and is measured as part of total BSi. Marsh sediments can have a significant contribution of phytoliths to the total BSi content of sediments (Norris & Hackney, 1999), e.g., the amorphous Si structures found in many plants (Wilding et al., 1977). Schwandes (1998) has shown that phytoliths (Piperno, this volume) from terrestrial plants extract more rapidly into a base than diatom BSi, suggesting that some component of the BSi measured in aquatic sediments can potentially be comprised of phytoliths. In addition, there are other forms of amorphous Si that are present in the environment, e.g., duripans (Wilding et al., 1977), precipitation from hydrothermal spring emissions (Juniper et al., 1995), and volcanic glasses (Chadwick et al., 1989), but they, in general, do not comprise a significant portion of BSi measured in most sediment types. Inorganically precipitated Si deposits have been reported in sediments from an African soda lake (Verschuren, 1999).

Sample preparation

Sediment samples should preferably be freeze-dried and not oven dried because better sample integrity is obtained with freeze-drying. In addition, one does not have to worry about loss of volatile organic compounds or other components with oven drying in case sediment samples are used for other purposes. Samples also should be homogenized with a mortar and pestle. Samples should not be mill ground because higher BSi concentrations will be obtained from the exposure of new surfaces available for dissolution (Krausse et al., 1980) and samples should not be combusted before analysis (Conley, unpub. data).

Sediment weight

A 60% reduction in BSi extracted was reported by Flower (1993) with increasing sample weight, e.g. from 2 to 100 mg. Conley (1998) argued that the results can largely be explained by a methodological flaw, with the likely explanation being sorption losses back onto sediments (Mortlock & Froelich, 1989). No significant differences in BSi extracted has been found for sample weights between 20 and 40 mg of dry sediments (Conley, unpub. data). However, because of the potential for weight effects, it is recommended that a consistent weight be used for all samples, e.g. ca. 30 mg.

Methodology

We use a modification of the DeMaster (1979, 1981) technique in our laboratories. We believe this is the simplest and most robust method to use for sediments with a large range in BSi concentrations. Weighed (30 mg), freeze-dried sediments are placed into 125ml polypropylene round bottles. Immediately prior to digestion 40 mL of 1% Na_2CO_3 solution is added to the bottles. The bottles are placed in a covered shaking bath at 85 °C and 100 rpm with caps slightly loosened to vent gases. After 3 h the bottles are removed, placed into a room temperature water bath and cooled for 5 minutes to retard further dissolution reactions by bringing temperatures down to near room temperature. The bottles are sub-sampled (1 mL) and the sub-sample pipeted into plastic bottles containing 9 mL of 0.021 N HC1 to neutralize the Na_2CO_3 digestion solution. After sub-sampling the bottles are placed back into the heating-shaking bath and the sub-sampling procedure is repeated at 4 and

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5 h of digestion time. The original technique as published by DeMaster (1979) called for sub-sampling at 2, 3, 4 and 5 h. We have statistically analyzed the sub-sampling strategy and have found out that only three samples are necessary and that sampling at 3, 4 and 5 h provides the best replicability (Newberry, Schelske and Conley, unpub. data).

The sub-samples are analyzed for dissolved silicate by any standard accepted analytical method for the measurement of dissolved silicate. In our laboratories we use variations of the molybdate blue methodology (Technicon Industrial Method 186-72W-Modified) with ascorbic acid as the reductant on a Technican AutoAnalyzer II system. A least-squares regression analysis is made on the increase in Si extracted versus time (taking into account the various dilution steps and the amount of sediment used) and extrapolation to the intercept is made to estimate BSi concentration. If there is no consistent increasing trend in Si extracted with time, then a mean concentration is taken of the 3 sub-samples (Conley, 1998).

Strength of digestion solution

We strongly recommend that the remaining sediment in the digestion bottle of selected samples be examined under the microscope to ensure complete dissolution of all amorphous silica components in the sediments. Numerous studies have clearly shown that when BSi concentrations are high (for example, Mortlock & Froelich, 1989) or if sponge spicules (Conley & Schelske, 1993) orradiolarians (Mortlock & Froelich, 1989; Müller & Schneider, 1993) are present in the sample, a stronger base may be required for complete dissolution. On the other hand, using a stronger base than required to dissolve all the amorphous Si may overestimate BSi concentrations in sediments with low BSi concentrations (Gehlen & van Raaphorst, 1993).

Examination of the slope of increases of Si *extracted during the digestion*

One also can tell if dissolution is complete from examination of the slope of the increase in the amount of Si extracted with time. If the concentrations of the Si extracted are rapidly increasing it is likely that the amorphous Si in sediments is not all dissolved because increases in dissolved silicate concentration from the dissolution of minerals should be relatively small. The presence of other forms of amorphous Si in a sample such as sponge spicules, and spicules being significantly larger than diatoms takes longer to dissolve (Conley & Schelske, 1993), can contribute to increases in the amount of Si extracted with time.

At low BSi concentrations, slope corrections are absolutely necessary so that BSi concentrations are not overestimated (Conley, 1998). At high BSi concentrations, slope corrections are often not necessary as the error associated during the extraction of BSi can be larger than increases in dissolved silicate concentration from mineral dissolution (Conley, 1998). In these cases, the mean concentration from the three sub-samplings is used instead of the intercept to estimate the BSi concentration.

Additional considerations

It is well known that the use of plastic ware is essential when working with Si measurements (Tarapchak et al., 1983). In addition, since dissolved silicate is only a weakly

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charged species, contaminated water may be found in laboratories without a good water purification system. The widespread use of digestion of the sample in conical centrifuge tubes is strongly discouraged. Conical tubes focus sediments into the container bottom removing the solids from contact with the digestion solution. Conical centrifuge tubes also must be intermittently shaken, which subsequently can influence the bath temperature, and differential expansion of the cap and bottle may cause digestion solution to be lost upon shaking. It is recommended, therefore, that a flat-bottom digestion vessel be used while gently shaken in a heating-shaking bath to ensure continuous contact of sediments with digestion solution throughout the incubation.

Applications

Silica depletion and productivity

Measurements of sedimentary BSi in the Laurentian Great Lakes provide a signal of anthropogenic nutrient enrichment resulting from historic, nutrient-driven changes in BSi production by siliceous phytoplankton (Schelske, 1999), with changes in BSi accumulation used to infer increased diatom production and sedimentation resulting from nutrient enrichment (Schelske et al., 1983). Increased nutrient loading initially results in increased diatom production and accelerated sedimentation of BSi (Schelske & Stoermer, 1971), but ultimately results in decreased diatom abundance after the reservoir of dissolved silicate in the water mass is depleted and diatom production is limited by dissolved silicate. A hypothetical model proposed by Schelske et al. (1983) is supported by BSi profiles in sediment cores from these lakes (see Fig. 4.2 in Schelske, 1999). A BSi peak that is found in the late 1800s in the sediment record of Lake Ontario is inferred to represent increased phosphorus loading resulting from European settlement and forest clearance in the drainage basin (Schelske et al., 1983). This model predicts that a peak in BSi accumulation in the sediment record is a proxy for dissolved silicate depletion in the water column. Two peaks, one resulting from epilimnetic dissolved silicate depletion (Schelske et al., 1983) and a second resulting from water-column dissolved silicate depletion (Schelske et al., 1986; Stoermer et al., 1985b) are found in the sediment record (Schelske, 1999).

The sedimentary BSi record is a sensitive indicator of anthropogenic nutrient enrichment because it integrates seasonal uptake of dissolved silicate utilized in diatom production (Schelske, 1999). Paleolimnological results show that BSi production increased historically in Lake Superior and Lake Huron, lakes with mean TP concentrations ranging from 4–5 μg P/L. Historic BSi production in Lake Michigan with a slightly higher mean TP concentration (8 μg/L) also increased, but decreased as predicted by the hypothetical model to reflect the onset of summer epilimnetic dissolved silicate depletion in the 1970s. Due to the integrative effect, sedimentary BSi provides a record of nutrient enrichment even though a distinguishable change in the TP record, a proxy for the forcing variable, is not apparent (Taylor, 1999). That BSi provides a sensitive measure of nutrient enrichment in these lakes is supported by parallel studies based on diatom microfossils (see Stoermer et al., 1993). Nutrient enrichment effects were found in Lake Superior, using diatom microfossils (Stoermer et al., 1985a) and BSi as proxies of anthropogenic nutrient enrichment (Schelske, 1999). In addition, inferences from both diatom microfossils and BSi show nutrient enrichment effects in another large lake, Great Slave Lake in the Northwest Territories, Canada

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(Stoermer et al., 1990). These results are significant because Lake Superior and Great Slave Lake were considered to be pristine lakes with little or no known impact from anthropogenic nutrient loading with the postulated source of nutrient enrichment in Great Slave Lake being atmospheric deposition (Stoermer et al., 1990).

Paleolimnological records from the North American Great Lakes (Schelske et al., 1983) provided the first evidence that small increases in nutrient loading in these P-limited lakes could increase diatom production and result in epilimnetic depletion of dissolved silicate on a time scale of one or two decades (see Schelske, 1999). Varved sediments in Lake Zurich, Switzerland provide evidence of an even more rapid biogeochemical response. A known increase in production of *Tabellaria fenestrata* resulting from increased loading of domestic sewage only lasted three years (from 1896–1898), but this increased production was recorded in the varved sediments both as an increased concentration and sedimentation of BSi (Schelske et al., 1987). Nuisance blooms of *Oscillatoria rubescens* began after the bloom of *T. fenestrata,* a response that would be predicted if diatom production was limited by dissolved silicate (Schelske & Stoermer, 1971). Lake-wide depletion of dissolved silicate resulting from nutrient enrichment has been reported in recent studies from other lakes (Verschuren et al., 1998; Wessels et al., 1999).

The use of BSi as index of paleoproductivity is probably restricted to oligotrophic systems and to systems with long biological residence times. As a paleoproductivity proxy, the use of BSi in most lakes may be confounded by biogeochemical depletion of dissolved silicate or by other system characteristics that control this integrative measure of system responses to forcing functions. In some systems, large inputs of dissolved silicate are utilized to sustain high diatom production over decades. The discharge from such systems may be largely depleted of dissolved silicate (Conley et al., 1993). For example, the large outflow of relatively dissolved silicate rich water from Lake Huron provides a dissolved silicate source for high BSi production in the phosphorus-enriched waters of the central basin of Lake Erie (Schelske, 1999). As a consequence the outflow through the Niagara River to Lake Ontario is low in dissolved silicate. We, therefore, would advise that researchers consider implied assumptions in using BSi as an indicator of paleoproductivity, the primary assumption being that historic supplies of dissolved silicate were replete and not limiting for diatom production.

The depletion of dissolved silicate occurs over the course of river systems as has been shown for the Mississippi River (Turner & Rabalais, 1991). These decreases in dissolved silicate from the Mississippi River basin were hypothesized to occur by nutrient-driven increases in diatom production and sedimentation in the watershed. Recent results suggest that simply the building of dams (Conley et al., 1993) and providing a sedimentation area where none previously existed can also account for decreases in dissolved silicate from the Danube River (Humborg et al., 1997) and from Swedish rivers (Humborg et al., 2000). The interacting roles of dam building and eutrophication are certainly both responsible for the reported declines in dissolved silicate and further research is needed to disentangle the mechanisms behind watershed changes in dissolved silicate concentrations.

Eutrophication is undoubtedly one of the causes of the depletion of dissolved silicate in coastal marine systems (Conley et al., 1983). Increases in the sedimentary signal in BSi concentrations have also been reported in a variety of coastal areas (Turner & Rabalais, 1994; Cornwell et al., 1996). Ecological consequences of reductions in dissolved silicate concentrations are severe with large-scale changes in food webs as has been shown in the

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Gulf of Mexico (Turner et al., 1998), in the Baltic Sea (Rahm et al., 1996; Humborg et al., 2000) and the Black Sea (Humborg et al., 1997).

Biogeochemistry/sedimentation/preservation

Whether or to what degree diatom microfossils or BSi are preserved in the sediment record is often questioned in paleoecological studies. Undoubtedly heavily silicified frustules are preserved better than lightly silicified frustules and constitute the largest fraction of reconstructed BSi in sediments (Conley, 1988). Therefore, certain lightly silicified species may be poorly represented in the microfossil assemblage. In addition, the degree of silicification may change in response to variable environments; for example, frustules of *Aulacoseira italica* became lightly silicified in Lake Ontario as historical dissolved silicate supplies in the water column decreased (Stoermer et al., 1985b). Theoretically, preservation of such lightly silicified forms is poorer than for more heavily silicified forms. The implicit assumption in paleoenvironmental studies is that the sediment record is not confounded by time-varying changes in preservation of specific microfossil populations. The sediment record of BSi provides one means of testing whether sedimentary amorphous silica is preserved and whether the quantity preserved varies over time.

By contrast, conclusions from ecological data on diatom productivity stated that the depletion of dissolved silicate would not occur because 80–100% of BSi production by diatoms is recycled (see Schelske, 1988). Depletion of dissolved silicate on a short time scale, however, is possible as shown in a Si mass-balance for Lake Michigan even when as much as 95% of the dissolved silicate is recycled (Schelske, 1985). High rates of sedimentation and recycling of Si were reported for three reservoirs in Seine River, France (Garnier et al., 1999). In Lake Vesijarvi, Finland the spring diatom bloom depleted dissolved silicate to 0.10 mg/L, sedimented diatom cells then disappeared from the sediment surface at a rate of $5\%\ d^{-1}$, or on a scale of a few weeks (Tallberg, 1999). Without such high rates of Si recycling, dissolved silicate supplies in overlying waters would be severely depleted in the absence of large inputs from other sources. Therefore, high rates of dissolution are to be expected; but even with such high rates, the BSi sedimentary record and diatom microfossils can be preserved.

For geochemical purposes, the quantity of sedimented amorphous Si can be estimated directly from measurements of BSi in the sediment record. Such measurements provide a quantitative estimate of the sedimentary BSi sink when combined with mass sedimentation rate determined from dated cores. It is also possible to infer relative changes in BSi sedimentation from relative changes in BSi concentration in sediments. Such inferences are made with the implicit assumption that relative differences in BSi concentration are not affected significantly by changes in mass sedimentation rate. Using the BSi record in the sediments of the lower Great Lakes to demonstrate biogeochemical silica depletion as discussed above is one example. Quantification of the BSi sedimentary sink is based on changes in the water-column dissolved silicate reservoir that can be described using a mass balance approach (Schelske, 1999).

Climate change

The BSi sedimentary record has been used to study climate change. In Lake Baikal, diatom productivity inferred from BSi varied over the past 5 million years in response to orbital

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insolation (Colman et al., 1995; Williams et al., 1997). This signal is very strong with BSi varying from <5–50% sediment dry weight. BSi accumulation and paleoproductivity during the Holocene were also studied in Lake Baikal by Qiu et al. (1993). BSi has been shown to provide a record of changes in paleoproductivity with changes in paleoclimatic conditions in Lake Biwa over the past 145,000 years (Xiao et al., 1999).

Oxygen isotopes in BSi have recently been used as hydrologic proxies in studies of climate change (Proft, 1994), and as climatic proxies to study the Allerød-Younger Dryas temperature shift (Shemesh & Peteet, 1998), and the climatic record in lacustrine sediments in other systems (Rietti-Shati et al., 1998; Rosqvist et al., 1999). The temperature effect on the oxygen isotope signal in diatoms was studied experimentally (Brandiriss et al., 1998). The oxygen isotopic composition of opaline phytoliths also records variation in environmental oxygen isotopic composition, providing a potential tool for climatic reconstruction using terrestrial plants (ShahackGross et al., 1996). Using oxygen isotopes extracted from BSi to study climate change (Shemesh et al., 1992) is a very promising technique and undoubtedly will be applied in many future studies.

Other BSi techniques used in marine research may have potential applications in freshwater paleoenvironmental research. Measuring the silicon isotopic composition of diatoms can provide a record of environmental change (De La Rocha et al., 1998). The $^{30}Si:^{28}Si$ ratio provides a proxy for diatom productivity in that fractionation of the heavier isotope increases with increasing productivity. Because the silicon isotopic ratio in BSi is not affected by dissolution, it may provide a better proxy for some purposes than direct measurements of BSi. The ratio, however, is dependent on the fraction of BSi preserved in the sediment record and, thus, may be affected by differential dissolution among species. In addition, cosmic-ray produced ^{32}Si can be measured with accelerator mass spectrometry and the 178 y half-life of this radionuclide provides the potential for extending radiochronologies to roughly 1000 years (Nijampurkar et al., 1998). This is important because chronologies obtained with ^{210}Pb are realistically no greater than 150 years.

Future directions

Reliable, easy-to-use wet-alkaline techniques for the measurement of BSi in sediments have been developed over the last 20 years and have been shown to have great utility in paleolimnological studies. BSi is an important, valid, and useful proxy in paleoenvironmental studies. As a single proxy, it provides an index of diatom abundance and can provide information on productivity and climate change. Combined with diatom microfossil abundance, inferences about system-wide changes, especially those resulting from eutrophication, are possible. New studies combining measurements of BSi with analysis of stable isotopes of oxygen and radiometric isotopes of Si in BSi show great promise for paleoenvironmental research.

Summary

The measurement of the biogenic silica (BSi) content of sediments is a chemical estimate of the siliceous microfossil abundance. Briefly, sediments are leached with a weak base, usually Na_2CO_3, for a period of time (2–5 hours), and aliquots withdrawn over time. The

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aliquots are then measured for the amount of Si extracted and a least-squares regression is made on the increase in concentration with time to separate the Si extracted from amorphous Si compounds, e.g. diatoms, sponges, etc., from that of mineral silicates. Comparison of chemical estimates of BSi with diatom microfossil point counts demonstrate that the extraction techniques provide a valid proxy for the abundance of diatom microfossils in sediments. However, the exact choice of methodology will depend upon the type of siliceous components in the sediments and the ability of the digestion solution to dissolve those components. Therefore, both the strength of the digestion solution used and the time over which subsamples are taken should be adjusted for depending upon the type of sediment used. Application of these techniques as a proxy for siliceous microfossil abundance have been instrumental in unraveling the response of aquatic systems to nutrient enrichment and has provided important information on paleoproductivity in particular in studies of paleoclimate.

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