USE OF PALEOLIMNOLOGICAL TECHNIQUES TO ASSESS THE EFFECTS OF ACID ROCK DRAINAGE

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EXECUTIVE SUMMARY

Environmental effects monitoring, which includes monitoring of biological populations or communities, is becoming increasingly important in assessing the impacts of operating mines, including impacts associated with acid rock drainage (ARD). However, in many cases, the interpretation of biological data is severely limited by lack of adequate baseline studies against which to compare post-mining changes. Therefore, the B.C. Acid Mine Drainage Task Force contracted Norecol Environmental Consultants Ltd. to investigate the potential for using paleolimnological techniques to provide "baseline" data.

Large scale studies in North America and Europe have successfully used paleolimnological indicators to show that acid precipitation has affected lakes on both continents. Norecol reviewed these studies to evaluate whether similar techniques could be applied to ARD monitoring.

The acid rain studies have used diatoms, chrysophytes, chironomids, various zooplankton, plant macrofossils, pollen, plant pigments and sediment chemistry as indicators of past environmental conditions. Of these, the diatoms have been most intensively studied, and they have proven useful indicators of changes which occurred over periods of five years or less. Calibration equations have been developed to allow prediction of past pH conditions based on "fossil" diatom assemblages. There is also considerable information on chrysophytes and chironomids, which have some potential as indicator taxa. Zooplankton, plant macrofossils, and plant pigments have not proven particularly useful, while pollen and sediment chemistry can provide evidence to support the dating of environmental change.

It should be possible to apply the paleolimnological techniques developed for acid rain studies to monitoring ARD in British Columbia lakes. However, it first will be necessary to develop a calibration data set which relates species assemblages of the chosen indicator taxon to levels of ARD-related parameters (pH, iron, aluminum, copper, zinc, and/or other metals) in British Columbia lakes.

Diatoms are recommended as the indicator taxon. A preliminary study to calibrate diatom distributions in lake sediments with water chemistry should be undertaken in a limited geographical area which contains some ARD-impacted lakes. The Smithers/Houston is suggested, as it contains several lakes which have received acidic and other mine drainage.

The report recommends a methodology for carrying out the calibration study. The suggestions include statistical tests for data analysis, coring techniques to obtain an undisturbed sediment record, laboratory analytical techniques, and quality assurance/quality control procedures.

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INTRODUCTION

1.1 Background and Objectives

Environmental effects monitoring, which includes monitoring of biological populations or communities, is becoming increasingly important in assessing the impacts of operating mines, including impacts associated with acid rock drainage (ARD). However, in many cases, the interpretation of biological data is severely limited by lack of adequate baseline studies against which to compare post-mining changes.

In lakes potentially impacted by ARD, it may be possible to substitute paleolimnological indicators for missing baseline data. Paleolimnological indicators would provide a useful "baseline" if they could answer either of the following questions:

- Does the sediment profile provide a record of recent changes in planktonic or benthic species that can be correlated with the progress of mining and/or with documented water quality changes? or

- Are living species assemblages significantly different from "fossil" species assemblages present prior to the commencement of mining?

In addition, to demonstrate that paleolimnological changes in the indicator assemblage likely were caused by ARD, the data should be able to answer another question:

- Can the indicator species be related to particular water quality conditions and/or can the indicator assemblages be used to predict past water quality conditions?

It is necessary for paleolimnological indicators to be able to demonstrate changes over a short time period. Known acid-producing mines in British Columbia have been releasing ARD from less than 10 to more than 60 years. During the past decade, early detection has resulted in monitoring of ARD discharges from such mines as Equity Silver and Gibraltar during the first few years following the onset of acid generation (Errington and Ferguson 1987). However, even where early detection has occurred, complementary biological assessments of ARD impacts have been hampered by lack of baseline data (see, for example Wilkes and Maclean 1987). Thus, for paleolimnological techniques to be useful in evaluating known ARD discharges, they should be able to detect changes that have occurred over a time span of ten years or less. If these techniques are to be applied to monitoring new mines, they should be able to detect changes over as short a period as possible, certainly less than five years.

The rapidly growing body of literature on the use of paleolimnological indicators of lake acidification related to acid rain may provide some insights into the application of paleolimnology to ARD studies. Indicators of lake acidification investigated to date include diatoms, chrysophytes, chironomids, some zooplankters, plant macrofossils, pollen and a variety of sediment chemistry parameters that reflect biological communities. The British Columbia AMD Task Force Monitoring Sub-Committee is interested in the potential for using one or more of these indicators to monitor ARD impacts in British Columbia lakes. Therefore, the Task Force contracted Norecol Environmental Consultants Ltd. to review a representative portion of the paleolimnological studies associated with acid rain and related literature. The objective of the review was to determine whether paleolimnological techniques can be applied to evaluating ARD impacts in British Columbia and, if so, to recommend the appropriate monitoring techniques.

This report summarizes the methodology employed and results produced by paleolimnologists in other regions during their efforts to document recent lake acidification. Since little paleolimnological research has been directed specifically toward ARD impacts, the review relies heavily on efforts in northern Europe and eastern North America to reconstruct recent changes in lake acidity resulting from acid rain. The report:

- assesses the value of each paleolimnological indicator of lake acidification;
- reviews the distribution of various indicator taxa in British Columbia (where information is available) and aspects of taphonomy (fossilization);
- discusses the taxonomic status of each indicator;
- discusses the time period over which the changes in indicator taxa can be detected; and
- considers the extent to which techniques developed to monitor the effects of pH changes related to acid rain apply to monitoring ARD, for which the impacts of elevated metal levels can be more significant than pH depression.

The report concludes with an outline of a paleolimnological research strategy tailored to the BC AMD Task Force Monitoring Sub-Committee's specific needs.

1.2 The Use of Paleolimnology

Paleolimnological research, in its broadest sense, is directed at reconstructing lake history. Sediments produced by a variety of biological and chemical processes accumulate in an orderly fashion over time on the lake bottom, producing a "graveyard" of past lacustrine communities. The structure, chemistry and fossil content of these sediments provide detailed information on lake conditions at the time of deposition. A continuous, undisturbed section of lake bottom sediment thus provides a long-term record of lake dynamics that may be equated to a book with each page of lake history represented by a discrete layer of sediment.

Due to the complexity of lake systems, the goal of paleolimnological research is not to reconstruct all aspects of the lake ecosystem or the dynamics of entire communities of organisms such as phytoplankton. Rather, paleolimnology employs indicator taxa to reconstruct particular aspects of lake history, for example, by using diatom stratigraphies to reconstruct past changes in lake pH.

To be a useful indicator taxon an organism must be:

- taxonomically well defined;
- easily identifiable;
- distributed within a narrow, well-known ecological range; and
- controlled in its distribution primarily by the environmental factor under investigation (Siver and Hamer 1989).

These criteria are used to evaluate the indicator taxa discussed in Section 2.

1.3 Paleolimnological Research Aimed at Reconstructing Lake Acidity

A paucity of baseline data hindered early assessment of acid rain impacts on lakes in northern Europe and eastern North America. While the process and consequences of lake acidification due to atmospheric pollution were reasonably well understood (Gorham 1976; Gorham and McFee 1980; Wright and Gjessing 1976), the absence of reliable long-term limnological records made documentation of the impacts of acid precipitation on freshwaters problematic. The recognition that paleolimnological techniques could provide the missing data spawned multidisciplinary efforts such as the Paleoecological Investigation of Recent Lake Acidification (PIRLA) project in North America (Charles and Smol 1990) and the Surface Water Acidification Project (SWAP) in Europe (Battarbee and Renberg 1985). Both groups utilized paleolimnological indicators to show that acid precipitation had affected several lakes on the two continents. Their research provided much needed data on the rates at which these processes had occurred.

Recent developments in paleolimnology have included testing the reliability of various indicators of lake acidification by comparing them with water chemistry measurements (Charles et al. 1990; Flower and Battarbee 1983) or with changes in living species assemblages observed in artificially manipulated lakes (Dickman et al. 1988; Leavitt et al. 1989; Schindler et al. 1985). Such tests have confirmed the validity of the paleolimnological approach and defined the indicators best suited for reconstructing lake acidity. In addition, analyses of replicate cores extracted from a variety of locations within a single lake basin have shown that a single core from the deepest portion of the lake adequately represents changes occurring throughout the lake (Charles et al. 1990). Other recent advances, notably in radiometric dating and sediment collection and sampling techniques, have allowed paleolimnologists to examine in detail recent changes in lake history with a precision at times on the order of five to ten years (Smol 1990). Such precision makes studies of very recent changes in lake acidity possible. These developments suggest that paleolimnological techniques may provide the baseline data required to assess ARD impacts on freshwater lakes in British Columbia.

The discussion in Section 2 of specific paleolimnological indicators focuses on recent research related to acid rain because it provides a large body of current data on the use of paleolimnological indicators of environmental change. Although the approaches used in these studies may be directly applicable to ARD monitoring, the data probably are not. Research related to acid rain emphasize the effects of pH shifts on indicator taxa. Although ARD can cause pH shifts in lakes, its initial and probably more significant impact is an increase in concentrations of dissolved metals. Acid rain studies which address the effects of elevated metal levels (eg. Dixit et al. 1991) do not attribute significant effects to metals such as copper and zinc which are important components of ARD.

PALEOLIMNOLOGICAL INDICATORS OF LAKE ACIDITY

2.1 Diatoms

Diatoms are single-celled algae which are encased in a siliceous cell wall or frustule whose size, shape and sculpturing is species-specific and resistant to decay (Dixit and Smol 1989). As a result, these algal remains are readily preserved and are found in great numbers in lake sediments.

For over sixty years the close relationship between diatom assemblages and lake water pH has been recognized, and various strategies have been employed to quantify this association (Battarbee et al. 1986). Since the ecological limits of many cosmopolitan diatom species are reasonably well known, diatoms are considered excellent indicators for paleolimnological reconstruction of acidification.

Originally, diatoms were classified according to their distribution in waters of varying acidity (Battarbee et al. 1986):

- **Alkalibiontic** - occurring at pH values >7;
- **Alkaliphilous** - occurring at pH about 7 with widest distributions at pH >7;
- **Indifferent (Circumneutral)** - equal occurrences on both sides of pH 7;
- **Acidophilous** - occurring at pH about 7 with widest distribution at pH <7;
- **Acidobiontic** - occurring at pH values <7, optimum distribution at pH $\leq$5.5.

Shifts in the relative abundance of alkalibiontic to acidophilous and acidobiontic species clearly track trends in lake acidification. These categories proved useful for outlining the direction of past changes in lake pH, but quantification of the changes required the development of indices. The original indices used to reconstruct the degree of change were calculated using relative abundances and somewhat arbitrary weighting of the five diatom categories (see Charles 1985 for a discussion of the merits of four commonly used indices). A regression between lake pH and the index calculated from diatom assemblages in the surficial sediments was determined and used to predict past lake pH from diatom assemblages in core samples (Flower 1986).

Although the early attempts to quantify the diatom - pH relationship provided reasonably accurate estimates when compared to direct measurements, the indices have recently been superceded by multivariate statistical techniques. Because diatoms are so abundant in most lake sediments they are well suited to multivariate analysis (Brugam and Vallarino 1989). Recent efforts have strengthened the predictive power of diatom assemblages and have allowed the generation of a measurement known as Diatom-Inferred pH (DIpH).

The DIpH technique relies on multiple-lake data sets to calibrate inferential models (Davis 1987). A data set consists of samples of the uppermost surficial sediment combined with information on lake water chemistry for each collection site. The most reliable data sets consist of large numbers of lakes embodying a wide range of physical and chemical characteristics found in the geographic area of interest.

To develop the model, surficial sediments are analyzed for their diatom content (usually characterized by a tally of 500 to 600 diatom valve identifications). Differences in diatom distributions among lakes are determined by statistical ordination or clustering procedures. The diatom groups identified are related to the chemical parameter(s) of interest (usually pH; see for example Charles 1985; Davis et al. 1990; A.S. Dixit et al. 1988; S.S. Dixit 1986; S.S. Dixit et al. 1988; Dixit et al. 1990; Flower 1986), and a mathematical expression (usually a multiple regression equation) is derived to describe the association between diatom species groups and pH. This equation is then applied to diatom distributions in reliably dated core sections to predict former lake pH levels.

Such techniques have produced accurate DIpH inferences within specific geographic areas. Similar calibration techniques have been used to associate changes in diatom assemblages with other types of disturbances such as deforestation and urbanization (Brugam and Vallarino 1989). However, due to the influence of factors such as climate, soil, vegetation and anthropogenic impacts on local diatom communities, calibration equations developed for one geographic region cannot be transferred to another (Flower 1986).

2.2 Chrysophytes

In contrast to diatoms, whose value as an indicator of lakewater pH has been a focus of investigation for several decades, the use of chrysophytes to monitor acidity changes has only recently received serious study. Scaled chrysophytes (the genera *Mallomonas* and *Synura*) are free-swimming, unicellular or colonial, golden-brown flagellates with a cell surface covered with silica scales and bristles (Cronberg 1990). These scales are species-specific (see Dixit et al. 1989b and Siver 1988 for a listing of taxonomic keys) and preserve well. In addition, the pH indicator value of various chrysophyte taxa is well documented. Therefore, scaled chrysophytes are useful paleolimnological indicators of lakewater pH.

Like the approach used in developing calibration data sets for diatoms, considerable effort has been directed toward documenting the current distribution of chrysophytes in lakes spanning a range of chemical characteristics. Cumming et al. (1990) documented chrysophyte distribution in surficial sediment from 25 soft-water

Norwegian lakes. Smol and Dixit (1990) provided similar documentation for 47 Adirondack Mountain (New York) and northern New England lakes, and as did Dixit et al. (1989a,b) for 72 recently acidified lakes in the Sudbury, Ontario area. In addition, Siver (1988) tabulated the distribution of chrysophytes in 17 lakes in the Adirnodack Mountains, while Siver and Hamer (1989) tallied chrysophyte populations in 45 Connecticut lakes. These researchers unanimously agreed that lakewater pH is instrumental in governing the distribution of chrysophytes.

Chrysophyte subfossil representation in sediment cores has been successfully used to reconstruct recent acidity changes associated with acid rain deposition in northern Europe (Cronberg 1990), Quebec (Dixit et al. 1987a) and the Adirondack Mountains (Charles et al. 1990). In the Sudbury area, where records of lake pH changes span as much as four decades, chrysophytes and diatom assemblages in recent lake sediments were used to produce DIpH and chrysophyte inferred pH (CIpH) for the period of record (Dixit et al. 1989a; Dixit et al. 1990). In all the lakes examined, CIpH and DIpH accurately tracked historic pH measurements. In addition, chrysophyte responses predated diatom changes, suggesting that chrysophytes may be more sensitive to changes in lakewater pH (Dixit et al. 1990). A similar pattern was noted in paleolimnological investigations in the Adirondack Mountains (Charles et al. 1990). Dixit et al. (1990) hypothesized that, because chrysophytes are euplanktonic and generally bloom in late spring and early summer, they respond to seasonal pH depressions associated with elevated inputs of acidic water during spring runoff. Diatoms, on the other hand, do not track such short term fluctuations because most of the taxa recorded are summer-blooming benthic forms rather than the vernal-blooming planktonic forms, which are more responsive to acid inputs during snow melt.

Charles and Smol (1988) evaluated the utility of diatoms and chrysophytes to infer pH in 47 low alkalinity lakes (pH 4.7 to 7.8) in the Adirnodack Mountains. They concluded that the best predictive equations incorporated both indicators, although chrysophytes were determined to be more sensitive indicators in the lower pH range (<5). Furthermore, chrysophytes were tallied more quickly than diatoms because there were much fewer taxa. Charles and Smol (1988) proposed a set of chrysophyte pH categories based on an abundance-weighted mean (AWM) calculated for each taxon:

- **group 1** - AWM pH <5.5;
- **group 2** - AWM pH between 5.5 and 6.5;
- **group 3** - AWM pH between 6.5 and 7.0;
- **group 4** - AWM pH >7.0.

Despite their apparent value as pH indicators, there are some limitations to the use of chrysophytes for reconstructing lake pH history. For example, Cumming et al. (1990) noted differences in one indicator species' tolerance to acidity between Norway and eastern North America. Furthermore, the taxonomy of this group is not as well established as that of diatoms (Cumming et al. 1990; Siver 1988). Scanning electron micrographs have alleviated many taxonomic problems (Siver and Hamer 1989) but have resulted in the identification of more species than can be determined using the light microscope. Thus, taxonomic uncertainties may throw into question the results of researchers such as Charles and Smol (1988), who have based indices on identifications made with light microscopy. In addition, the use of SEM technology to analyse stratigraphic variation in sediment cores would increase analysis time and cost substantially.

2.3 Chironomids

Chironomids compose a family of true flies (Diptera) whose larvae are the most abundant bottom-dwelling macro-invertebrates of aquatic ecosystems (Walker and Mathewes 1987). Chironomid head capsules are well preserved in lake sediments and may be identified to the generic level and, at times, to species. Thus, they are considered valuable paleolimnological indicators. Stratigraphic variations in chironomid representation in lake sediments have been used to trace paleoproductivity, assess anthropogenic eutrophication, monitor salinity fluctuations and reconstruct aspects of postglacial climatic change (Walker 1987). Moreover, observations of enhanced chironomid emergence in an artificially acidified lake in northwestern Ontario (Schindler et al. 1985) suggest remains of chironomid larvae in lake sediments may be a useful guide to lake acidification.

Despite this potential, few studies of chironomids preserved in lake sediments have been directed toward monitoring acidification impacts. Hendrikson et al. (1982) reported on chironomid stratigraphies in the upper 15 cm of sediment obtained from two acidified (pH 4.3 to 4.7), oligotrophic lakes in southwestern Sweden. The authors noted an overall decline in the total number of head capsules in the uppermost sediments, with more recent assemblages dominated by *Chironomus* and *Dicrotendipes*. Since these genera emerge in June and July, later than the pH minimum observed in lakes due to spring runoff, the dominance of *Chironomus* and *Dicrotendipes* may be related to lake acidification. However, Hendrikson et al. (1982) suggested that other factors, such as metal mobilization, increased oxygen deficit, decreased organic matter decomposition rates, changes in algal flora (a major source of food for chironomids) and altered predator-prey relationships may adequately account for the observed changes.

Walker et al. (1985) analyzed surficial sediment samples from 29 lakes in Atlantic Canada which spanned a pH range of 4.0 to 7.3. Their results showed that *Chaorobus* spp. occurs in all strongly acidic lakes of the region. Uutala (1990) analyzed recently deposited sediments from five lakes in the Adirondack Mountains for changes in *Chaorobus* populations, and found increases in some species but decreases in others. *Chaorobus* species function primarily as predators of zooplankton but are preyed upon by fish. Uutala (1990) therefore interpreted post-1930 changes in chironomid stratigraphy in terms of altered predator-prey relationships. He concluded that changes ultimately stemmed from lake acidification which eliminated trout populations, resulting in increased populations of the *Chaorobus* species preferred by this predator.

Although chironomids have considerable potential as paleolimnological indicators of lake acidity, the direct response of individual chironomid species to acidity is not well known. However, since acidification may alter predator-prey relationships, increase metal mobilization, reduce decomposition, and alter the algal flora, changes in chironomid stratigraphy may be related to secondary effects of lake acidification.

2.4 Zooplankton

Although the category zooplankton spans several possible paleolimnological indicator taxa, the only zooplankton that have been used to evaluate lake acidity are the cladocerans. Studies of artificially acidified lakes have shown that shifts in cladoceran populations were significant (Schindler et al. 1985; Leavitt et al. 1989), and laboratory tests have indicated that cladocerans are the zooplankton most susceptible to acid stress (Price and Swift 1985).

However, limnological studies of cladoceran responses to acidity have produced ambiguous results. Paleolimnological analysis of recently deposited sediments in Sweden (Renberg et al. 1990), Scotland (Jones et al. 1990), Germany (Arzet et al. 1986) and Finland (Uimonen-Simola and Tolonen 1987) suggest that changes in cladoceran populations are consistent with either DIpH or directly observed acidification. In contrast, similar analyses in Adirondack Mountain lakes (three recently acidified, one not acidified) revealed that cladoceran changes over time were similar in all four lakes. Thus, the changes could not be unambiguously attributed to the effects of acidification (Charles et al. 1990).

Arzet et al. (1986) considered littoral taxa to be the best indicators of acidification in German lakes. In contrast, Uimonen-Simola and Tolonen (1987) concluded that planktonic cladocerans displayed the greatest response to acidification in Finnish lakes. Nilssen and Sandoy (1990) arrived at the same conclusion, based on a survey of Norwegian lakes of varying acidity.

In spite of the fact that predation is a dominant influence on cladoceran populations (Eriksson et al. 1980), Davis et al. (1983) present data from New England lakes indicating that changes in the littoral cladoceran population predated the decline of predatory fish. Although cladoceran population dynamics are most likely related to the combined effects of acidification and altered predator-prey relationships, these processes are not yet clearly understood. As a result, it may be premature to attempt paleolimnological inferences based on zooplankton population dynamics in ARD-impacted lakes.

2.5 Plant Macrofossils

Plant macrofossils include any identifiable plant remains but are often limited to seeds of flowering plants. Plant macrofossil analyses have not been a part of paleolimnological studies of lake acidification to date, likely because these subfossils are not usually present in great numbers in lake sediments.

However, aquatic macrophytes may be useful indicators of lake acidification. Observations on the aquatic macrophyte composition of six Swedish lakes revealed that a dramatic increase in *Sphagnum* lake bottom coverage (to a maximum depth of 6 m) accompanied acidification (Hendrey et al. 1976; Grahn 1977). Arzet et al. (1986) cited historical accounts documenting the growth of extensive stands of *Sphagnum* spp. and *Juncus bulbosus* var. *fluvitans* in recently acidified German lakes. Catling et al. (1986), following a survey of aquatic macrophyte distribution in 20 acid lakes (pH 4.4 to 6.0) in Nova Scotia, noted that the more acidic lakes displayed reduced diversity compared to neutral waterbodies. *Sphagnum* (mainly *S. macrophyllum*) frequently dominated mucky organic substrates but was not significantly more abundant in acidic waters.

Jackson and Charles (1988) surveyed 31 small oligotrophic lakes (pH 4.5 to 7.8) in the Adirondack Mountains and concluded that acidification of softwater lakes in this area could be accompanied by significant changes in the aquatic macrophyte flora, but a significant amount of the variation could not be accounted for by pH. In addition, there was no evidence that *Sphagnum* increased in abundance in the more acidic lakes of this region. Noting the evidence that a blossoming *Sphagnum* population was observed in acidified European lakes, the authors suggested that vegetation changes associated with acidification likely differ geographically.

Until more extensive information on macrophyte variation accompanying acidification (including specific information for British Columbia lakes) is available, macrofossil analysis is not likely to yield definitive information on recent lake acidification.

2.6 Pollen

Pollen stratigraphies have also been little utilized in paleolimnological studies of recent acidification. In lacustrine assemblages the abundance of pollen from terrestrial sources invariably overwhelms input from aquatic macrophytes. This, combined with a limited understanding of the effects of increasing acidity on aquatic macrophyte populations, has restricted the use of pollen analysis to a subsidiary role as a chronological tool.

Due to the limited number of ways to accurately date recently deposited non-laminated lake sediment, paleolimnologists have utilized pollen stratigraphies as a means of dating historic events such as deforestation and agricultural practices in the lake catchment (Charles et al. 1990; Kingston et al. 1990). Such land-use practises exert a significant impact on terrestrial vegetation which is reflected in the local pollen record. While pollen does not appear to be an appropriate indicator of ARD impacts, its use as a chronological tool may prove valuable for ARD studies.

2.7 Sediment Chemistry

Sediment chemistry has been used to supplement microfossil analyses, but data interpretation can be difficult. For example, Charles et al. (1990) analyzed a number of chemical parameters in lake sediments as part of their paleolimnological study of lake acidification in the Adirondack Mountains. Although many of the elements analyzed displayed altered concentrations in sediments deposited during the period of lake acidification, the timing of chemical and biological acidity indicators was not uniform.

This difference most likely was due to the mobility of elements between the water column and sediments. As pH decreases, metals may be released from bottom sediments due to desorption of heavy metals adsorbed to iron and manganese oxide particles. Metals and sulphate in the lake water may also diffuse through the sediment column to a depth where the sulphate is reduced to sulphide and metal sulphides are precipitated. This effect can occur at various depths within the sediments, depending on the sediment organic content, which controls oxidation reduction reactions. In addition to these chemical factors, organisms utilize elements, which can reduce deposition of some minerals (Short et al. 1990).

In spite of these limitations, the concentration of labile aluminum appears to provide a relatively unambiguous record of lake acidification due to acid rain. Increased aluminum abundance often correlates with rapid periods of lake acidification (Charles et al. 1990), since acid rain can cause aluminum mobilization from soils in the catchment. Acidification also stimulates increased retention of labile aluminum in lakes (Driscoll and Schafran 1984).

Sedimentary sulfur concentrations can reflect sulfur inputs to the lake, but like many other mineral species, sulfur is mobile within the sediment. Moreover, hypolimnetic sulphate reduction can obscure the significance of measured sulphur. Mitchell et al. (1985) documented increased amounts of sedimentary sulfur in Adirondack Mountain and Maine lakes. The authors theorized that the increase was related to the prevalence of coal combustion in the northeastern United States beginning about 1850.

In contrast to lakes affected by acid rain, lakes in close proximity to major industrial sources of acidity and heavy metal outputs contain clear-cut indications of these activities in their sediment chemistry. Nriagu and Coker (1983) documented "spectacular" increases in sedimentary sulfur in Sudbury area lakes associated with SO_2 fallout. Palmer et al. (1989), using high resolution particle-induced x-ray emissions, showed that concentrations of anthropogenically produced elements (sulphur, iron, nickel, copper, zinc, arsenic, and lead) in 72 Sudbury area lakes were consistently higher in surficial sediments than 25 cm below the sediment-water interface. Verta et al. (1989) showed that the greatest accumulations of copper and nickel in Finnish lake sediments occurred in a lake situated 10 km from the largest copper mine and concentration plant in the country. It is likely that lake sediments could display dramatic increases in trace element abundance as a result of ARD discharge and other metal releases from mining activities.

2.8 Plant Pigments

Plant pigments preserved in lake sediments may also prove a valuable indicator of lake acidification. Although little-used to date, plant pigment content of sediments proved a useful guide to changes in the watershed associated with artificial manipulation of lake acidity and other parameters (Leavitt et al. 1989). Moreover, Arzet et al. (1986) noted that acidification in German lakes was accompanied by a rapid increase in plant pigment concentrations in the lake sediment. Although only preliminary, these observations suggest that analysis of sedimentary plant pigments may be a useful indicator of lake acidification.

2.9 Conclusions

The remains of diatoms, chrysophytes, and chironomids all have been used as indicators of lake acidification and have potential for use in ARD monitoring. Of these taxa, diatoms are the most-studied. Their relation to lake pH is the best understood of any of the indicator taxa, but less information is available on their relation to metals. Recent studies suggest that chrysophytes potentially are as good or better pH indicators than diatoms, but some problems with the taxonomy of chrysophytes may limit their usefulness. The effect of pH on chironomid distributions is not as well understood. Changes in abundances of chironomid species in acidified lakes may be related more to secondary effects, such as altered predator-prey interactions, than to pH or other water quality changes. Taxonomic groups or indicators such as cladocerans, seeds of flowering plants, and plant pigments have occasionally been included in lake acidification studies but are not understood well enough to be considered useful indicators.

Two other indicator groups may play useful supporting roles in ARD monitoring. Pollen grains are a valuable tool for dating sediment cores when the history of vegetation change in the watershed (for example, logging) is known. Sediment chemistry may also be a useful chronological tool if, for example, increased metal concentrations in near-surface sediments can be correlated with the beginning of mining.

However, the interpretation of sediment chemistry data can be difficult because of the many factors influencing the mobility of elements between the water column and the sediments. The effects of metal leaching from lake sediments due to desorption by low pH water, and deposition of metal-bearing sediments tend to produce opposite effects. In addition, variations in reduction-oxidation conditions in the sediments resulting from differences in organic content, and increase in sulphate concentrations can result in precipitation of metal sulphides within the sediments at a range of depths, irrespective of acidic inputs from acid rain or ARD.

APPLICATION TO ASSESSING ARD IMPACTS IN BRITISH COLUMBIA LAKES

3.1 Introduction

Based on the literature reviewed in Section 2, it is apparent that the sediment profile can provide a record of changes in diatom, chrysophyte, and chironomid remains that can be correlated with water quality changes due to acid rain. Supplementary indicators, such as pollen grains and sediment chemistry, can provide temporal markers of changes in the watershed. How useful these indicators can be for monitoring ARD impacts in British Columbia depends upon several factors:

- the chemistry of ARD and the resulting impact(s) of ARD on potential indicator organisms;
- the status of knowledge of potential indicator species in British Columbia with respect to taxonomy, distribution, and pH and metal tolerances; and
- the ability of the paleolimnological record to distinguish changes over a very short time scale, preferably five years or less.

These factors are considered in Sections 3.2 to 3.4. Section 4.0 addresses methods of actually utilizing paleolimnological indicators to monitor ARD impacts, including the possibility of comparing existing diatom, chrysophyte, or chironomid assemblages with "fossil" assemblages present prior to the commencement of mining.

3.2 Use of Paleolimnological Techniques in ARD Studies

Paleolimnological techniques have not commonly been used to evaluate ARD impacts, and no papers dealing directly with the calibration of paleolimnological indicators to ARD impacts were encountered during this literature review. However, two manuscripts describe utilizing diatom stratigraphies and sediment chemistry to document lake recovery from ARD.

Fritz and Carlson (1982) analyzed a 50 cm long core recovered from a southern Ohio lake created by strip mining in 1918. The core was sampled every centimetre. The diatom record showed a pronounced swing from an acidophilous to an alkaliphilous flora in the upper 7 cm, corresponding to records of pH changes in the basin. The most common acidophilous diatom encountered in the Ohio study, *Pinnularia biceps*, as well as alkaliphilous species such as *Fragilaria construens* and *Cyclotella comta*, are a part of the Pacific northwest diatom flora (Brugam and Vallarino 1989).

Brugam and Lusk (1986) employed similar methods to assess the rate of recovery from acidification exhibited by 48 lakes created by strip mining operations in Missouri, Illinois and Indiana. The authors found a strong relationship between fossil diatom assemblages and lake pH and were able to document differential rates of recovery. Once again, acidic indicators (pH <4.5) used in the study, such as *Pinnularia biceps*, *Frustularia rhomboides* and *Anomoeoneis serians*, as well as circumneutral taxa (*Cyclotella stelligera*), have been recorded in British Columbia lakes (Brugam and Vallarino 1989).

These two studies suggest that the diatom-pH relationship is adequate for assessing recovery of lakes from ARD, but the starting point of the studies involved lakes that were highly acidified. For example, Brugam and Lusk (1986) noted that acidity changes in the ARD-impacted lakes were more pronounced than changes exhibited by lakes affected by acid precipitation. However, no instances of such severe ARD impacts have been reported for lakes in British Columbia.

The impact of ARD on a lake involves not only an eventual lowering of pH but also increased loadings of many metals. While increased aluminum levels are typically associated with acid rain impacts, ARD is usually associated with increases in aluminum, iron, copper and zinc and, in many cases, arsenic, lead, or other toxic metals (Errington and Ferguson 1987). In the initial phases of ARD discharge, particularly in well-buffered lakes, the impacts from elevated metal levels may predate measurable alterations in lake pH. Thus, calibration of indicator taxa with pH alone is unlikely to address ARD impacts adequately.

3.3 Knowledge of Indicator Taxa in British Columbia

3.3.1 Diatoms

A regional diatom - pH calibration has not yet been developed for British Columbia, nor has there been any attempt to calibrate diatom distributions with environmental metals levels. However, there is a limited amount of information on the effects of metals on distributions of living diatom species (eg. Ennis 1977). In addition, there is some available information on the diatom flora of the region and its response to human disturbances. Edmondson (1991) related recent changes in diatom assemblages from Lake Washington to limnologic and climatic factors and human activities in the catchment. Munch (1980) examined diatom stratigraphies as part of a detailed study of recent sediments deposited in Hall Lake, Washington, and concluded that human activities (road construction and sawmill activity) adjacent to the lake had impacted the diatom flora.

Brugam and Vallarino (1989) constructed a diatom calibration set for the Pacific Northwest to aid interpretation of four sediment cores collected from lakes in the state of Washington. A total of 66 lakes were included in the calibration set, including 36 in British Columbia (the majority from the coastal lowland region). This calibration set was used to outline the nature of watershed responses to human activity, in particular logging.

Although none of these studies were directed toward reconstructing changes in lake acidity or metals levels, they are important to the question of monitoring ARD impacts in British Columbia because they provide relevant information on local diatoms species, lake types and sediment variation, sedimentation rates, and the sensitivity of the diatom flora to human activity. In addition, these publications reveal that acidophilic species, for example *Tabellaria floculosa*, (Charles 1985; Davis 1987; Flower 1986), and other known indicators of circumneutral and alkaliphilic conditions are found in British Columbia.

Since diatom assemblages have successfully been utilized in reconstructing acidity changes associated with acid rain as well as impacts other human disturbances, it is likely they would prove useful indicators of environmental changes associated with ARD in British Columbia. However, much of the groundwork necessary for using diatoms to provide quantitative estimates of acidity changes has not been completed. In spite of this limitation, diatom communities have high potential for providing the most clear-cut indications of recent acidity changes and likely other changes (such as increased metal levels). In addition, the taxonomy of this group is well established and several taxonomic keys are available (see Charles et al. 1990).

3.3.2 Chrysophytes

Little is known regarding the distribution of chrysophytes in British Columbia lakes. Random collections by Kristiansen (1975) in Alberta and British Columbia and Green (1979) on Vancouver Island indicate that the chrysophycean flora of western Canada is likely very rich. Many of the taxa identified in samples from British Columbia are also found in Scandinavia (Cronberg 1990) and eastern North America (Charles and Smol 1988). However, without adequate distributional information, it is not clear whether the factors controlling chrysophyte distribution in eastern North America also influence chrysophyte distribution in British Columbia lakes. For example, *Mallomonas hamata*, assigned to group 1 ($pH<5.5$) on the basis of its distribution in Adirondack Mountain lakes (Charles and Smol 1988), has been found in Vancouver Island lakes whose pH ranges from 6.5 to 7.3 (Green 1979). Although chrysophytes have been proven important indicators of lake acidity elsewhere, and will likely prove useful in western Canada, accurate interpretation of chrysophyte stratigraphies in British Columbia lakes with respect to pH alone would require a considerable amount of groundwork. Further work would be needed to determine the relationship of chrysophyte distributions to metals levels.

3.3.3 Chironomids

Chironomid distribution in British Columbia lake sediments has recently been reported by Walker and Mathewes (1989), who analyzed surficial sediment from 30 lakes in the province. A listing of appropriate taxonomic keys may be found in Walker (1988).

Thus, part of the groundwork necessary for using chironomid remains as water quality indicators has been completed. However, it would be necessary to collect water quality samples from the 30 lakes studied by Walker and Mathewes (1989) to develop a calibration model for chironomids. The usefulness of this exercise would depend, in part, on the range of pH and metals levels in the lakes.

3.3.4 Supplementary Indicators

Pollen grains have been successfully used as supplementary indicators of watershed changes in the Pacific Northwest. For example, Brugam and Vallarino (1989) used pollen analysis combined with logging records for dating paleolimnological changes in Washington lakes. There is adequate information on local pollen and plant communities so that this parameter can be employed as a date marker without extensive groundwork wherever the history of human disturbance to a watershed is known.

Sediment chemistry has also been used to track temporal changes due to mining impacts on British Columbia lakes. Godin (pers. comm. 1992) studied metal and silica levels in cores of Goosly Lake sediments. The cores were dated using ^{210}Pb. Based on the estimated sedimentation rate, there was a correlation between increasing metal levels and the start of mining at Equity Silver upstream from the lake. In addition, a significant decrease in silica in the cores, suggesting a possible decrease in the diatom populations, apparently corresponded to a 1982 sulphuric acid spill at the mine. The dating of the cores was somewhat uncertain since the ^{210}Pb analyses were unsupported by ^{226}Ra or pollen analyses. Nevertheless, the results indicate that sediment metal levels may provide a useful chronological marker to support microfossil analyses.

3.4 Resolution of the Paleolimnological Record

As noted in Section 1.3, paleolimnological techniques can identify changes in lake history with a precision of five to ten years. Annually laminated sediments (varves), which have visible seasonal striations, provide the most precise temporal control. Such sediments can allow resolution of much less than five years. The most precise resolution has been obtained using SEM to analyze laminated sediments. In this manner, Edmonson (1991) was able to detect not only annual changes in Lake Washington diatoms but also a shift from *Fragilaria crotonensis* to *Stephanodiscus* within a single season. The paleolimnological evidence matched the known temporal distribution of diatom species in this intensively studied lake.

These extremely high resolution records can be obtained only under rather specific circumstances. Laminated sediments are produced only in lakes which are >15 m deep and stratified. The lake basin must not be steep-sided, as slumping and debris flows will disrupt laminations. In addition, bioturbation, particularly by dense populations of tubficids, can disrupt laminations or potentially even produce false laminations (Edmonson 1991). Finally, a high-resolution record requires that the sample be collected without disturbing the uncompacted upper sediment surface. Methods of collecting such a sample are discussed in Section 4.4.

In the absence of finely laminated structures, methods of dating sediment cores are less precise. For unlaminated sediments, researchers typically have employed ^{210}Pb dating. This radioactive element decays very rapidly (its half-life is 22.26 years), and measurements of its abundance downcore allow calculation of average sediment accumulation rates spanning the last century. If deforestation has occurred in the watershed, the ^{210}Pb dating may be verified by utilizing pollen stratigraphies to locate the logging disturbance in the sedimentary record. The literature generally indicates that even with ^{210}Pb dating verified by pollen analyses, only an approximation of average rates of sedimentation will be possible. However, results of current studies related to eutrophication of British Columbia lakes, indicate that ^{210}Pb can provide a resolution on the order of two to three years (McKean, pers. comm. 1992).

Sedimentation rates vary widely between basins (Joshi 1985; Stoermer et al. 1990). For basins with rapid sedimentation, a recently developed technique for sampling every 0.25 cm (Smol et al. 1991) will allow fine-scale analyses but apparently will not produce the desired precision of five years. This procedure may, however, allow a assessment of changes in lake acidity on a scale of 10 to 15 years.

3.5 Conclusions

In order for any paleolimnological indicator taxon to be successfully applied to ARD monitoring in British Columbia, there should be an understanding of the metals and pH tolerances of local species. In addition, it must be possible to distinguish changes in indicator species on a time scale of five to ten years or less.

Paleolimnological techniques are available to provide the required temporal resolution in certain environments. These environments are limited to lakes from which undisturbed sediment cores can be retrieved, and the most promising lakes are those with laminated sediments. Paleolimnological techniques are not applicable to streams where seasonal changes in flow periodically disturb the sediments.

The understanding of the tolerances of indicator taxa is incomplete. There is some information on the distribution and the pH and (to a lesser extent) metals tolerances of diatoms in British Columbia. More limited information is available for chrysophytes and chironomids. However, even for diatoms the available information is inadequate. Before diatoms can be used conclusively as paleolimnological indicators of ARD, it will be necessary to develop some type of calibration relating diatom distributions to ARD-related water quality parameters. This type of calibration is possible, as will be described in Section 4.

PALEOLIMNOLOGICAL METHODOLOGY FOR MONITORING ARD IMPACTS

4.1 Introduction

Direct comparison of microfossils with living communities is not recommended because the paleolimnological record is not identical to the living community from which it was formed. Not all species within a single indicator group (for example, diatoms) are preserved equally well in the sedimentary record. Depending on their preservation characteristics, common living species may be rare in sedimentary assemblages, and some species may not be preserved at all. Thus, even in the absence of disturbance, differences between living and "fossil" assemblages are likely to be significant.

Despite not being directly comparable to living communities, remains present in surficial sediments correlate well with these communities. In addition, they are directly comparable to remains of the same indicator group found in downcore (deeper) sediments. Thus, it is the remains present in surficial sediments which should be compared to "baseline" data from the paleolimnological record.

This chapter describes the recommended approach to monitoring ARD impacts using paleolimnological indicators. The approach involves developing a calibration data set which relates assemblages of the indicator taxa in surficial sediments to levels of ARD-related parameters (likely pH and metals) in British Columbia lakes. Once developed, the calibration data can be used to evaluate ARD-impacted lakes by comparing the indicator assemblages in surficial sediments with assemblages in deeper sediments which predate the onset of acid generation.

The following sections identify a preferred indicator group. They describe statistical techniques for analyzing the calibration data and comparing indicator assemblages in surficial and downcore sediments. They also describe appropriate sampling techniques, analytical techniques, and quality assurance/quality control (QA/QC) procedures and suggest methods of reducing or assessing potential biasses due to bioturbation.

4.2 Indicator Group

Based on the analysis of indicator groups presented in Sections 2 and 3, it is apparent that diatoms have the highest potential for monitoring ARD impacts. In addition, samples are available which may allow the a preliminary data calibration without additional field work (see Section 4.3). Therefore, the recommendations in the following sections emphasize the use of diatoms. However, other taxa, including chrysophytes and chironomids may prove useful indicators in the future. The sampling and statistical techniques recommended for diatoms could also be used for these groups.

The use of supplementary indicators is also recommended. Pollen grains should be considered to refine core dating (Section 3.4) where laminated sediments are unavailable. Sediment metal concentrations may also prove valuable, particularly for identifying increased loadings associated with the start of mining or release of ARD.

4.3 Statistical Approaches

The first step toward using diatom remains to monitor ARD impacts is to develop a calibration data set relating diatom assemblages to ARD-related water quality variables in British Columbia lakes. Generally samples from about 30 lakes are required to provide adequate calibration data, but because of the wide geographic differences three or four separate calibration sets may be necessary to characterize the entire province (McKean, pers. comm. 1992). For this reason, the initial study should be limited to a single ecoregion and probably to some subset of the selected ecoregion.

The calibration data set should include diatom remains from surficial sediments from approximately 30 lakes covering a range of water quality conditions. It should encompass lakes known to have received ARD discharges. It should also include currently undisturbed lakes in mineralized areas where there is potential for acid generation and/or future mine development and other undisturbed lakes which are in geological areas unlikely ever to produce ARD.

The Smithers/Houston area is suggested for the initial study. This region contains several lakes known or suspected to have received ARD discharges from mines. Candidate lakes in the area which have received mine discharges include Goosly Lake (Equity Silver Mine), Babine Lake (Bell Mine), and Owen Lake (Silver Queen Mine). Nanika Lake in the same general region is downstream of the currently undeveloped Berg property, a porphyry-copper deposit with potential for acid generation.

Calibration water quality data should include measurements of pH, dissolved metals (iron, aluminum, copper, zinc), alkalinity and specific conductivity. Measurements of total metals may also be valuable. Data should also be collected for other parameters which can control diatom distributions, such as phosphorus and nitrogen species and water clarity (turbidity and/or Secchi disc depth).

Diatom assemblages should be identified and related to water quality using multivariate statistical techniques. The canonical correspondence analysis described by Dixit et al. (1991) can be used to determine the relative contributions of numerous variables (eg. pH, aluminum, copper, iron, zinc) to variance in the distributions of diatom species. Multiple regression analysis can then be used to develop inference models for variables that contribute significantly to the differences in species distributions. In this manner, it may be possible to predict past pH and/or metals concentrations based on diatom distributions.

An alternative approach is to use ordination or clustering techniques which do not assume a linear relationship between variables (Brugam and Vallarino 1989). The cluster analysis groups samples with the most similar diatom assemblages. Clusters can be related to factors such as presence/absence of mine discharges or to mean or median levels of selected water quality variables. Bootstrapping (Nemec and Brinkhurst 1988) can be used to test the statistical significance of the clusters.

Once the relationship between diatom assemblages in the surficial sediments and water quality has been established, core samples from one or more ARD-impacted lakes can be analyzed. The positions in the clusters or ordination of successive downcore diatom assemblages should be determined. For example, if surficial sediment samples of ARD-impacted cluster together but downcore samples cluster with samples from unaffected lake, an impact on the diatom flora can be inferred. If multiple regression equations have been developed, they can be used to infer probable water quality conditions (pH, dissolved metals levels) at the time the downcore sediments were deposited.

It may be possible to develop a preliminary calibration data set without field work. Colin McKean of the B.C. Ministry of Environment, Lands, and Parks has collected water quality data and diatoms from surficial sediments of approximately 500 lakes across British Columbia to provide a calibration between diatoms and lake eutrophication. The corresponding water quality data include pH measurements but few, if any, low level metals data. However, sediment metals data are available (McKean, pers. comm. 1992). The diatom samples, water quality and sediment data likely could be made available for a test calibration. If cores from the Smithers/Houston area are available, data analysis might at least indicate the types of lakes whose conditions (apart from the presence/absence of ARD) and diatom assemblages are similar enough to be included in the study. Alternatively, the available information might suggest that the study should focus on a different ecoregion.

A field study would eventually be required evaluate diatoms as paleolimnological indicators of ARD impacts.

4.4 Preferred Sampling Methods and Field QA/QC

In order to obtain high resolution paleolimnological records for ARD evaluation, it is critical to collect an undisturbed surface sediment sample. Controlled testing and direct observation by SCUBA reveal that the best methods employ either a piston corer (Davis and Doyle 1969) or a freeze corer (Wright 1980). Early piston corers (Livingstone 1955; Vallentyne 1955) were designed to penetrate compacted sediment and are not suited for collection of loose material near the sediment-water interface. Modifications to the piston corer have been used successfully to collect the uppermost sedimentary horizons intact, but are expensive (Davis and Doyle 1969). Various types of gravity corers have also been employed to collect surficial sediment from deeper basins (see for example Mackereth 1969), but recent tests question the ability of these samplers to collect undisturbed sediment (Blomqvist 1985; Crusius and Anderson 1991; Evans and Lasenby 1984). The most reliable, relatively inexpensive samplers for high resolution studies are:

- the Brown sampler (Brown 1956), a relatively inexpensive, lightweight offspring of the early piston corers: this device has been used to collect surficial sediments from lakes in British Columbia (R.W. Mathewes, per. comm. 1988); and

- the core freezer (Shapiro 1958), a lightweight, inexpensive means of collecting uncompacted upper sediments: this apparatus has proven ideal for extremely loose sediments, although some rippling of extremely thin laminations (a consequence of the freezing process) has been noted (Renberg 1981).

Both of these devices are lowered to the sediment surface with pipe, so are difficult to use in very deep basins (>20 m). If such a basin is chosen for sampling, a gravity corer may be required (see Davis and Doyle 1969).

The coring device does not have to be large. As all the recommended indicators require no more than a few cm^3 of sediment, the commonly used 5 cm or 7.5 cm diameter coring devices should suffice. Collection of at least two replicate cores is recommended, however, to ensure a supply of sediment in the event that the primary core is not available for analysis (Smol et al. 1991). Replicate cores can also accommodate additional analyses or procedures that need be repeated, they can or be used to characterize within-lake variability.

Cores should always be checked upon retrieval for evidence of disturbed lamination. Smol et al. (1991) recommend sectioning cores at the lake shore to avoid disturbance in the sediment stratigraphy during transportation. An extrusion system such as the

Glew (1988) sectioner, which allows close-interval sectioning of cores with negligible vertical contamination, should be used.

4.5 Analytical Methods and QA/QC

Diatom analytical methods are described by Battarbee (1986). Preparation of core samples for analysis involves digestion (oxidation) to remove organic matter. The actual procedure selected will depend to some extent upon the composition of the sediments but could include using hydrogen peroxide or a combination of nitric acid and potassium dichromate. Digestion procedures should be documented and validated (Smol et al. 1991).

For counting, a few drops of diatom suspension are usually dropped on a cover slip, dried and permanently mounted. Diatoms are counted under oil emersion (100X), with counts continuing until 500 to 600 frustules have been identified and enumerated.

Smol et al. (1991) recommend that the analytical QC program consist, at a minimum, of the following:

- preparation of a compendium of photographic plates of taxa encountered to ensure taxonomic consistency;
- replicate analyses of the same microscope slide by one counter to assess intra-slide variability;
- replicate analyses of the same microscope slide enumerated by different counters to assess inter-counter variability;
- replicate analyses of different microscope slides by the same counter to assess inter-slide variability; and
- replicate analyses of microscope slides prepared from different aliquots from the same sediment increment to assess intra-core variability.

4.6 Evaluating Effects of Bioturbation

Bioturbation can reduce the resolution of the paleolimnological record by mixing sediments and can bias results if its influence is not recognized. In some cases, benthic populations may be lower in the deeper parts of lakes, and the effects of bioturbation may be minimized by collecting cores from these areas. The potential for bioturbation effects should be assessed by collecting additional samples and examining them for the presence of tubficids and living chironomids. Where laminated sediments are present, it may also be possible to examine the cores for disturbance to the laminations which would indicate mixing by bioturbation.

CONCLUSIONS AND RECOMMENDATIONS

Diatom remains show considerable promise as a tool for reconstructing past conditions to provide "baseline" data against which to evaluate potential ARD impacts. There may also be potential for using chrysophyte or chironomid remains for this purpose. However, techniques for using the latter two taxa as indicators of past water quality are not as well developed as methods for diatoms. Further pursuit of chrysophytes and chironomids as paleolimnological indicators is not recommended at this time.

In order to use diatom remains to provide baseline data with which to evaluate ARD impacts, it will first be necessary to develop a calibration data set which relates diatom assemblages in British Columbia lakes to ARD-related water quality parameters (pH, metals). It is recommended that such a calibration initially be developed for lakes within a limited geographic area (for example, northwestern British Columbia in the vicinity of Smithers/Houston). The calibration set should include unimpacted lakes and lakes impacted by mine discharges including ARD. Several lakes in the Smithers/Houston area, including Goosly, Babine, and Owen Lakes, have received discharges of ARD. Equations or relationships established using the calibration data set should be used to evaluate possible differences in the sedimentary diatom assemblages from various depths in cores from lakes which have received ARD.

The information for developing a preliminary calibration data set may be readily available through Colin McKean of B.C. Ministry of Environment, Lands and Parks. This possibility should be pursued.

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