

THE GEOCHEMISTRY AND DIATOM ASSEMBLAGES OF VARVED SEDIMENTS
FROM SAANICH INLET, B.C.

by

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ABSTRACT

Varved, anoxic sediments in Saanich Inlet, British Columbia, are formed by the annual cycle of summer deposition of diatom frustules and winter inputs of terrigenous material derived from land runoff. The objective of this study was to sample the varve record in order to develop a palaeoceanographic history of the Inlet. Box-cores of varved sediments were collected from Finlayson Arm, Saanich Inlet. The cores were quick frozen upon recovery, to preserve the laminae, were subsequently sectioned and X-radiographs of the sections prepared. The varves were individually sampled and analysed for their diatom assemblages together with carbon, carbonate, major and minor element concentrations and ^{210}Pb activity.

The chronology of a representative core determined by ^{210}Pb was inconsistent with that determined by varve counting. The geochemical data indicated that the upper 15cm of the core had a distinct elemental composition and a lower porosity that indicated a changed sedimentation rate. It also appeared that around 20 years of sediment had been lost from the core-top. The upper sediment contains a carbonate increase linked to a dust dump from a local cement plant which occurred between 1960-1963. In the lower section of the core, both the diatom and the geochemical data indicate seasonal variation expected from the formation of annual

varves. However, a well constrained chronology cannot be obtained for this core because of the non-steady state sedimentation. This makes the interpretation of inter-varve variations in the light of regional climatic records impossible. Nevertheless, a change in production on a cycle of approximately 10-15 years is evident and this study provides conclusions that will be useful to future palaeoceanographic investigations on longer cores from a part of the Inlet where sedimentation is more constant.

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CHAPTER 1: INTRODUCTION.

1.1 The study of varved sediments.

During the past 20 years, there have been a number of studies of diatomaceous sediments which accumulate in anoxic bottom waters along the west coast of North America (Gross and Gucluer, 1963; Calvert, 1964, 1966a, 1966b; Gucluer and Gross, 1964; Soutar, 1966; Soutar and Isaacs, 1974; Soutar and Crill, 1977; Donegan and Schrader, 1982; Schrader and Baumgartner, 1983; Heusser, 1983 and Baumgartner et al. 1985).

Since anoxic bottom waters, defined here as waters containing less than 0.1ml./L. oxygen, require special oceanographic and/or geological conditions, their occurrence is limited to a small number of localities. The studies referred to concentrate on three such environments:

1: The Gulf of California; particularly the Guaymas basin (Calvert, 1964, 1966a, 1966b; Donegan and Schrader, 1982; Schrader and Baumgartner, 1983; Baumgartner et al. 1985.)

2: Block-faulted basins on the continental margin of southern California (Bruland et al., 1974), particularly the Santa Barbara basin (Soutar, 1966; Soutar and Isaacs, 1974; Soutar and Crill, 1977).

3: Saanich Inlet, British Columbia (*Gross and Gucluer, 1963; Gucluer and Gross, 1964; Gross, 1967; Heusser, 1983*).

All these studies have recognised that where benthic macrofauna are excluded by the anoxic nature of the bottom waters and, hence, bioturbation is absent, the sediments contain a record of deposition in layers that conform to the definition of varves first proposed by *De Geer (1912)*, namely distinctly marked annual deposits. Furthermore, these studies showed that the varves consisted of alternating light and dark laminations and that the light layers consisted mainly of biogenous silica, and thus represented a record of seasonal production by phytoplankton in the surface waters, while the dark layers contained more lithogenous material derived from terrestrial runoff during the season of high rainfall.

In the central Gulf of California, production appears to be almost continuous throughout the year, although local patterns are complicated by wind-driven upwelling. The season of high rainfall occurs during the summer. Variations in the rainfall, and hence terrestrial runoff, were originally thought to produce the varves (*Calvert, 1966b*); however, *Donegan and Schrader (1982)* have since shown that the diatom frustules which they contain reflect seasonal variation in primary production in addition to the terrestrial input.

In the California basins and Saanich Inlet, on the other hand, biological production and periods of high rainfall are clearly seasonally defined. Here the peak in phytoplankton production occurs in the spring/summer, while the highest rainfall occurs in the winter. In Saanich Inlet, there is an additional input of terrestrial material during the early summer which is derived from the Fraser River freshet, at its maximum in June. In these two locations the light and dark layers in the varves have been associated with summer and winter deposition, respectively (*Gross and Gucluer, 1963; Soutar and Crill, 1977*). A review of the depositional settings and the oceanography of these areas is provided by *Soutar et al. (1981)*.

Scientific interest in these sediments has been stimulated by two observations. Firstly, the sediments represent modern analogues of the diatomaceous Monterey Formation of California and thereby provide modern equivalents of the source rocks for the extensive oil reserves of California (*Donegan and Schrader, 1981; Ingle, 1981*). Secondly, and of far greater interest to the new discipline of palaeoceanography, the seasonal and annual record represented by the varves provides both a convenient sediment chronology and a record of climatic and oceanographic changes that have occurred in the past. Lamina thickness has been correlated with variations in rainfall (*Soutar and Crill, 1977*) making them analogous to tree-rings, as predicted by *Calvert (1966b)*. In addition, inter-layer differences in the diatom

assemblages preserved in such sediments have been correlated with oceanographic changes, especially the El Nino/Southern Oscillation (ENSO) by *Baumgartner et al* (1985), while in the Gulf of California *Murray and Schrader* (1982/83) have correlated the silicoflagellate record with changes in the oceanographic regime of that area. The record obtainable from such sediments, epitomized by the 152m. hydraulic piston core collected by the Deep Sea Drilling Project at Site 480 in the Gulf of California (*Curry and Moore*, 1982), has been regarded as a significant tool for the study of palaeoceanography.

In addition to work on the diatom assemblages of these sediments, *Soutar* (1966) and *Soutar and Isaacs* (1974) have studied the occurrence of fish scales in the Santa Barbara basin varves and have related their variations to changes in the flow of the California Current system and to annual fluctuations in commercial fish stocks, especially the Pacific hake *Merluccius productus* and the Pacific sardine *Sardinops caerulea*. Palynological studies of the sediments of Saanich Inlet have focused on vegetation and climatic changes since the retreat of glacial ice some 12,000 years ago and on recent changes in land use (*Heusser*, 1983).

Limited studies of the geochemistry of the laminations within such sediments have been reported by *Gucluer and Gross* (1964) and *Gross* (1967) in Saanich Inlet, and by *Calvert* (1966a) and *Donegan and Schrader* (1982) in the Gulf of California. However, these geochemical studies often

looked only at short sections of the laminated sediment records. No study has reported results from a complete core analysed varve by varve starting at the sediment/water interface, and only *Donegan and Schrader (1982)*, reporting work in the Gulf of California, have attempted to link geochemical variations from a detailed study of short varved sections to signals of climatic or oceanographic change.

1.2 Objectives of the study.

The original aim of this study was to construct a palaeoceanographic and palaeoclimatic record for the area by sampling a varved box core from Saanich Inlet. The intention was to sample each varve lamina by lamina and perform a full geochemical and diatom analysis on the samples collected and to compare these data with available climatic and oceanographic records. Such a study would:

1: Identify an easily measured geochemical variable which might be linked to climatic or oceanographic variations in the region.

2: Provide a record of the effects of ENSO events on the Strait of Georgia system by determining the occurrence of warm water diatoms (eg: Planktoniella sol and Pseudoenotia doliolus) carried north along the west coast of North America and into Saanich Inlet.

3: Provide an indication of past changes in the primary production of Saanich Inlet.

4: Corroborate the assumption that the laminae and varves found in the Inlet do indeed represent annual deposition.

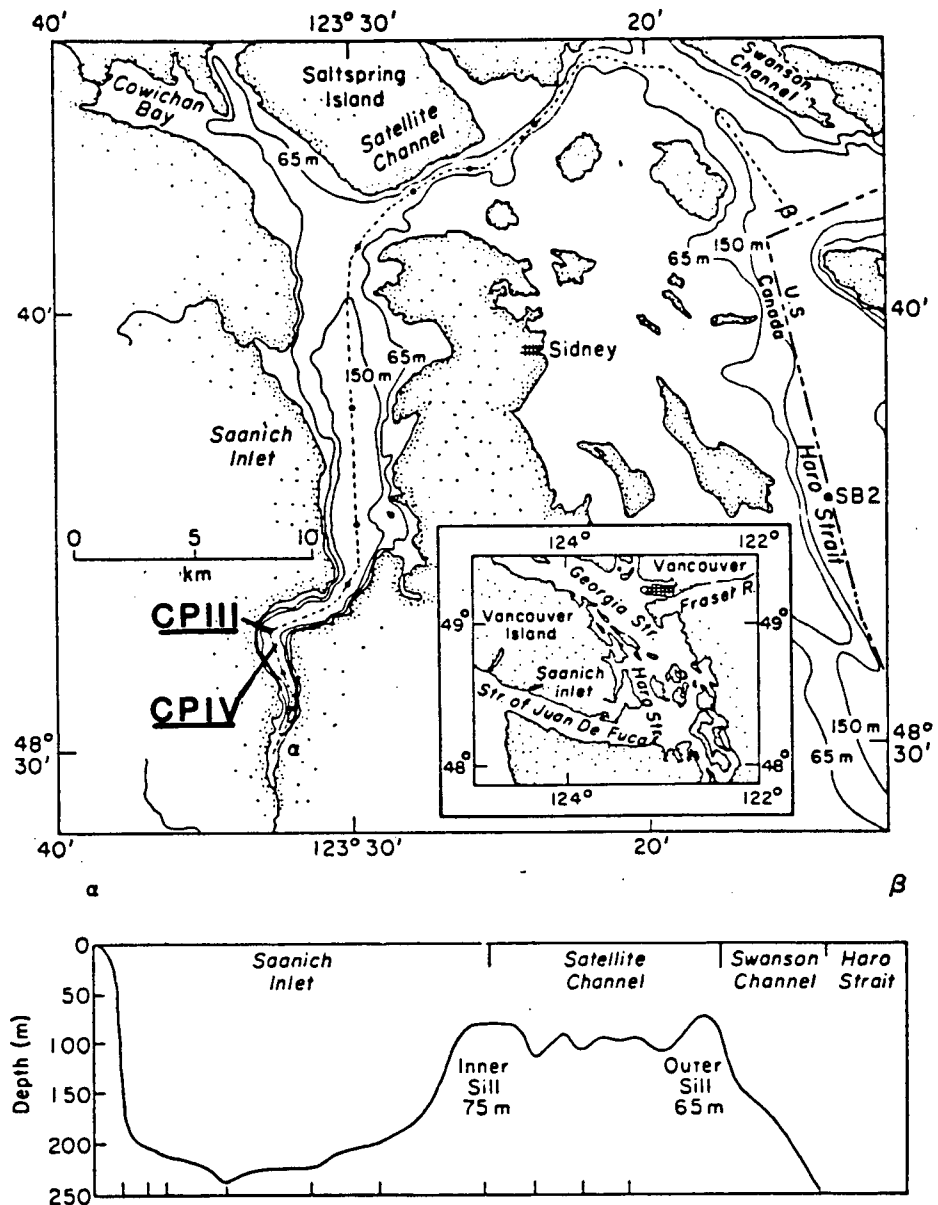
These objectives depended on the establishment of a sound chronology for the core. It was essential that any trends observed could be dated and thus related to climatic information available for the area. It was hoped that the varves, in conjunction with the measurement of ^{210}Pb , would provide such a chronology. However, a comparison of varve counts in the top of the core studied and ^{210}Pb data revealed a major discrepancy in ages assigned to the collected samples.

Because of the observed discrepancy in the initial chronology, the emphasis of the study was changed so that the cause of these chronological differences and the mechanism of varve generation in Saanich Inlet could be studied. To do this, the data collected on the geochemistry and diatom assemblages within varves from the top 32.5cm of a core from Finlayson Arm are presented in order to determine the sedimentary history of this part of Saanich Inlet.

1.3 A Review of the oceanography of Saanich Inlet.

Saanich Inlet is a fjord on the southeastern coast of Vancouver Island approximately 24km. long and 7.2km. wide at its widest point. The bathymetry of the inlet is characterized by a central basin, with a maximum depth of 234m, and a sill at the mouth rising to a depth of 65-75m

Fig: 1.2.1 Location of Saanich Inlet showing its bathymetry and indicating coring locations. (adapted from Anderson&Devol,1973)



(Fig.1.2.1). The Inlet has been extensively studied in the past, and the following short review of its oceanography is based on work published by *Herlinveaux* (1962), *Anderson and Devol* (1973), and *Hobson* (1981).

As is typical of fjords in general, the water column of Saanich Inlet is characterized by a surface layer, where seawater is diluted by freshwater runoff, separated by a halocline from higher salinity water below. However, this Inlet is somewhat unusual in that the major source of the fresh water in the surface layer is not at the head of the Inlet, as is generally the case in fjords, but outside the mouth, namely the Cowichan and Fraser Rivers (Fig.1.2.2). Since the input of fresh water from the Goldstream River at the head of the Inlet is rather small, flow in the surface waters is only weakly estuarine and largely driven by the wind. This circulation results in a net flow out of the Inlet in the surface which is balanced by an inflow of water from the Strait of Georgia at sill depth. This weak circulation results in further stratification of the deeper waters in the central basin and a secondary halocline exists at or below sill depth below which the deep waters are effectively isolated. The dissolved oxygen content of the deep waters is therefore depleted because the consumption of oxygen by the oxidation of organic detritus derived from primary production near the surface exceeds oxygen replenishment by the circulation. The deep waters of the inlet

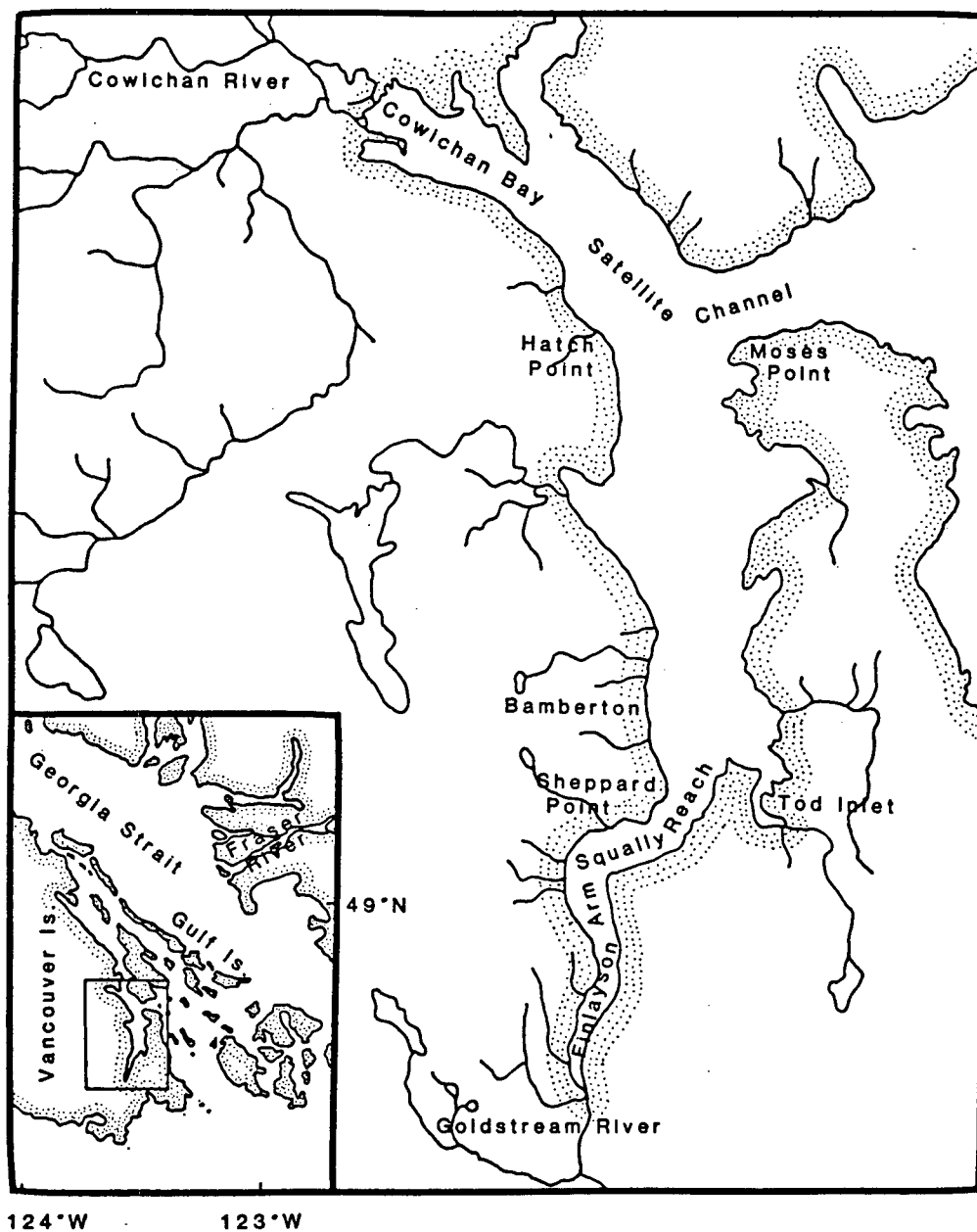
consequently contain hydrogen sulphide throughout most of the year.

The deep waters are, however, subject to renewal in so called 'flushing events'. Evidence is presented in the literature that this occurs annually (*Anderson and Devol, 1973*). Although no data series longer than 2-3 consecutive years is available, it is recognised that the flushing occurs characteristically during the autumn. Circulation in Haro Strait (see Fig. 1.2.1), mixes surface and intermediate waters of the Strait of Georgia with colder, dense water that is carried in from the upwelling region in the mouth of the Strait of Juan de Fuca. This produces dense, oxygenated water which moves through Haro Strait following a channel (Fig.1.2.1) and cascades over the sill of the inlet. This dense water displaces the bottom water in the central basin causing it to rise and mix with the surface waters of the inlet. Available estimates of the volume of flushing water range from 18-33% of the deep water volume of the inlet (*Anderson and Devol, 1973*).

Runoff into the inlet is at a maximum during the winter months following the annual rainfall pattern of the region. Annual averages at Patricia Bay on Saanich Inlet are around 81.5cm and maximum monthly rainfall (around 14 cm.) generally occurs in December (*Herlinveaux, 1962*).

Freshwater runoff is derived from three sources. The smallest flow is from the Goldstream River entering Finlayson Arm. The largest input comes from the Cowichan River

Fig: 1.2.2 Saanich Inlet showing the main rivers,
Bamberton and Finlayson Arm.
(after Francois, 1987)



discharging into Cowichan Bay 6km north of the mouth of the inlet and is at a maximum in December. The Fraser River provides water and sediment during its 'freshet' flow, derived from snow-melt in the river's watershed, which is at its maximum in June. There are reports of white, silt-laden water entering the inlet at this time (Herlinveaux, 1962; Francois, 1987) but the relative importance of this source to the sediments of the inlet has not been clearly defined.

Tides within the inlet are quite small, with an average annual range of around 1.5m.; however, tidal flow over the sill is often sufficiently strong to generate a front which is characterised by high biological production in response to mixing and consequent replenishment of nutrients in the surface layer (Parsons et al., 1983).

Biological production in the Inlet follows the bimodal pattern common in temperate and high latitude waters, that is an intense spring bloom followed by a smaller bloom in the autumn. Diatoms are the main component of the phytoplankton throughout most of the year although flagellates may dominate during the light-limited winter months (Takahashi et al., 1978).

The spring bloom has been shown by Huntley and Hobson (1978) to consist of two distinct peaks. The first bloom consists of Thalassiosira spp., mainly T.nordenskiöldii, T.aestivalis and T.pacifica, and it is reduced by zooplankton grazing which both decreases the population and releases nutrients into the water. This allows a

second bloom to occur which is dominated by Chaetoceros spp., mainly C.didymus and C.radicans, and by Skeletonema costatum. This second bloom is protected from grazing because the herbivore population is now subject to predation by the medusa Phialidium gregarium.

Primary production is generally confined to the surface 5-15m. because of stratification of the water column. However, *Takahashi et al.* (1977) have shown that disruption of the stratification by wind-driven upwelling introduces nutrients into the surface resulting in short blooms of phytoplankton during the summer months. These occasional summer blooms follow the general species succession, although flagellates may dominate some of the late summer blooms.

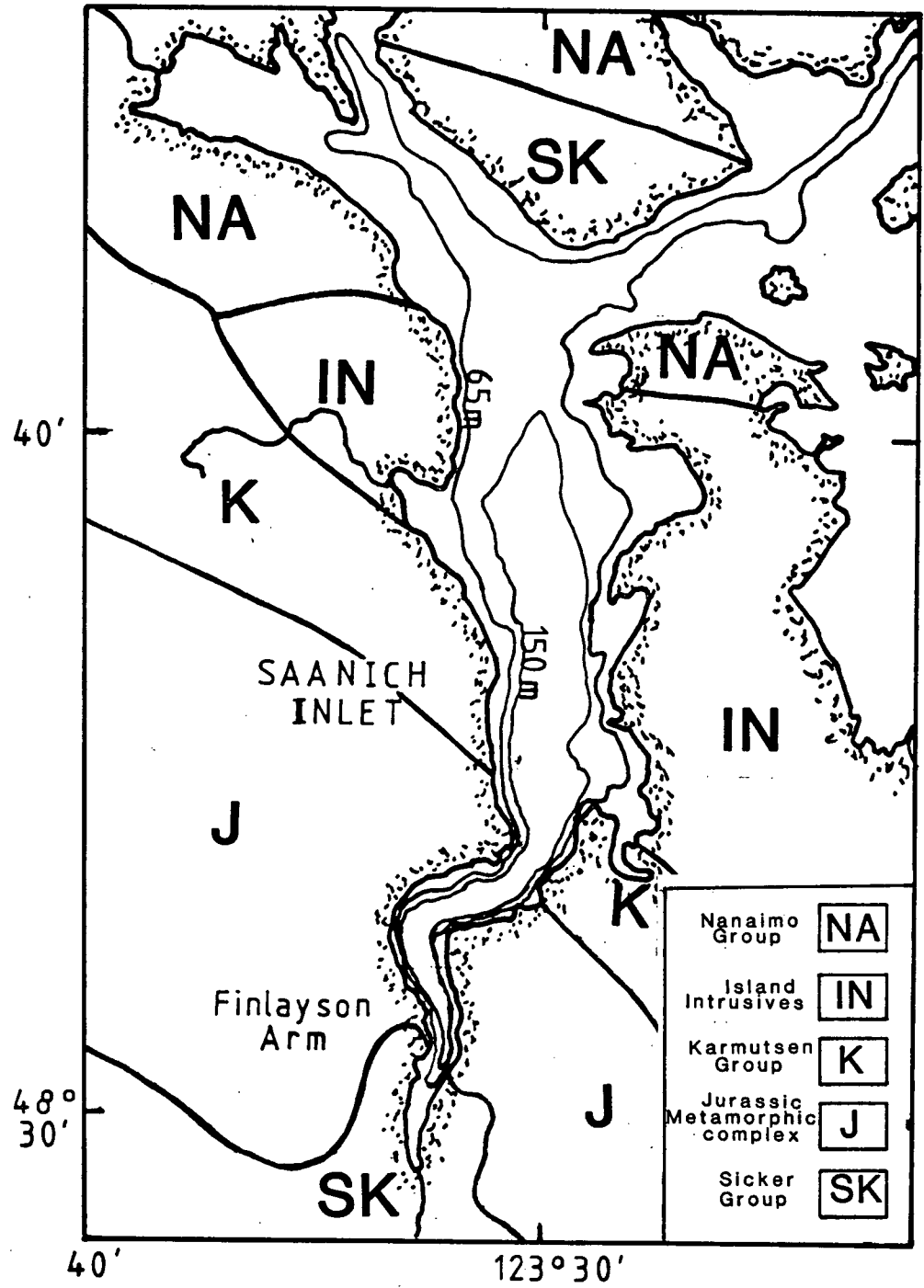
Resting spores, especially those of the Chaetoceros group, are a common feature of the phytoplankton and sediments (*Harrison*, 1983). Their germination rate in shallow waters is high and they probably seed the summer blooms (*Hollibaugh et al.*, 1981).

1.4 Geological summary of the Saanich Inlet area.

The following summary is based on *Clapp* (1912; 1913) and *Muller* (1980). Fig.1.3.1 shows a sketch map of the main geological features of the area.

The oldest rocks outcropping in the area belong to the pre-Permian Sicker Group. This consists of flow and explosive volcanic rocks, intrusive microdiorites and sedimen-

Fig:1.3.1 Geological sketch map of Saanich Inlet.



tary rocks which have all been extensively metamorphosed to schist grade. The volcanic rocks are mostly andesites and the sediments were probably originally tuffs. The intrusive rocks are quartz feldspar porphyry and granodiorite bodies.

The Triassic Karmutsen volcanics, originally called the Vancouver Volcanics, are basic andesites and have also been highly metamorphosed. In the vicinity of Saanich Inlet, a brecciated form occurs which has a higher feldspar content and also contains kaolinite.

The Jurassic 'metamorphic complex' consists of a diorite/quartz diorite gneiss batholith. It contains andesine and hornblende, with accessory quartz, magnetite and titanite.

Above these are the Island Intrusives, the principal intrusive rock of southern Vancouver Island, and this group is represented here by the Saanich granodiorite. It contains plagioclase, orthoclase, some hornblende and microperthite with accessory biotite, magnetite, titanite, kaolinite and pyrite.

The youngest bedrock of the area consists of the Cretaceous rocks of the Nanaimo Group, comprising of conglomerates, sandstones and shales.

The topography of the western side of Saanich Inlet is steeper and bedrock outcrops are common. In contrast, the eastern side of the Inlet is more subdued and the bedrock of the Saanich peninsular is generally covered by glacial drift.

CHAPTER 2: METHODS.

2.1 Core Collection and sample preparation.

The sediments of the central basin of Saanich Inlet are generally referred to as black, varved, diatomaceous clayey-silts (*Matsumoto and Wong, 1977*), an 'odious ooze' reported by *Clapp (1913)*. In addition, the lack of significant bioturbation because of the anoxic nature of the still bottom waters, and the diatom-rich and organic-rich nature of the deposits, causes the sediments to be very fluid until depths are reached where compaction has a significant effect upon consolidation.

These were important considerations in planning the sampling, since the development of a chronology, basic to the interpretation of any geochemical or fossil trends, required that the sediment/water interface be collected. In order to preserve the interface, coring was carried out using a 1m.x 15cm.x15cm. freely-vented Kasten Box corer. Previous studies in Saanich Inlet by U.B.C personnel had obtained a sediment interface successfully with this equipment.

Coring was carried out in Finlayson Arm, (see Fig.1.2.1 for locations of CPIII and CPIV), an area of the inlet expected to be minimally disturbed by previous bottom

sampling. One core was also collected off the Bamberton cement works in the hope that a carbonate increase might provide a time marker coincident with the beginning of quarrying activity, but this core has not been sampled.

A total of seven box cores were collected.

Table I Details of Recovered Cores.

DATE CORE NO.	RECOVERED LENGTH	DEPTH	POSITION
9/8/85 CPI	102 cm	208 m	123 32 17W 48 31 40N
8/10/85 CPII	107 cm	204 m	123 32 16W 48 31 40N
10/10/85 CPIII	69 cm	203 m	123 32 18W 48 31 32N
4/11/85 CPIV	54 cm	202 m	123 32 48W 48 32 40N
7/11/85 CPV	74 cm	208 m	123 32 44W 48 31 48N
16/12/85 CPVI	86 cm	224 m	123 30 46W 48 35 24N
18/12/85 CPVII	41 cm	203 m	123 32 42W 48 32 42N

Coring was carried out from C.S.S. Vector and the cores were frozen on board. Freezing was achieved by placing the corer upright in a tall barrel containing 300 litres of isopropyl alcohol cooled to around -60°C by the addition of 100 kg. of dry ice. The core was allowed to freeze for 3-

4hrs. after which time both ends of the corer were removed and the box section warmed with hot water. This thawed the outside of the sediments and allowed the frozen core to be removed. The cores were wrapped in plastic and transported to Vancouver in an insulated box. In Vancouver they were stored in a chest freezer at -10°C .

Only cores CPIII and CPIV were sampled. In cores CPI-CPIII the recovered interface was lost because of expansion on freezing or insufficient alcohol-dry ice mixture; however, core CPIII was sampled because a prominent layer near its top appeared to correspond with a layer at the base of CPIV. CPV contained a preserved interface, but X-radiography of this core showed that the laminae were disturbed and it is thought that this was caused by the corer doors. Cores CPVI, collected off the cement works at Bamberton, and CPVII both have preserved interfaces but were not sampled.

The cores were sectioned, using a stone-masons band saw at Chandler Memorials, Vancouver, such that the outer edges of the core were removed and the central section preserved for sampling. The central sections measured approximately $14\text{cm} \times 7\text{cm} \times$ recovered length of the core.

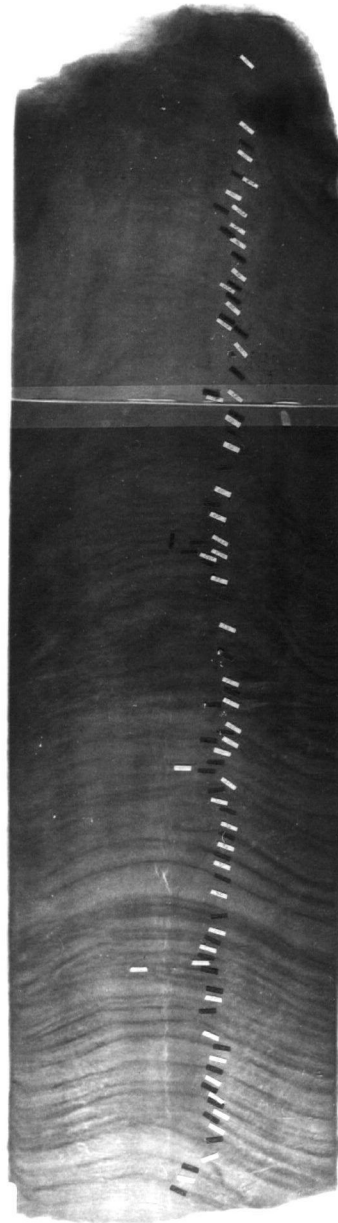
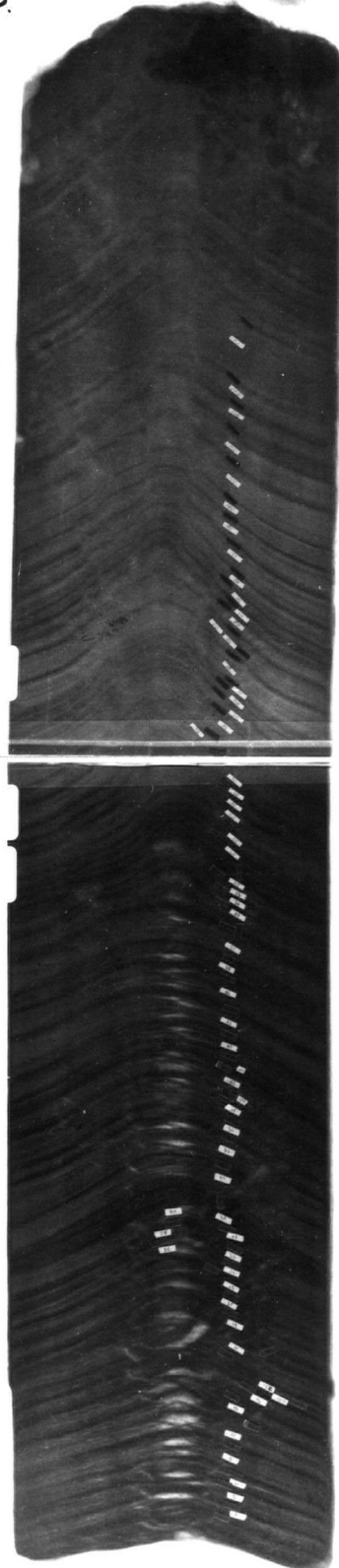
X-radiographs were made of these sections in order to determine their internal structures and to allow the X-ray plates to be used as a guide during sampling. The sections were placed on top of EKC "AA" film plates ($16 \times 20"$) and exposed to 180 Kv X-rays at a distance of 170 cm for 90 seconds. Fig.2.1.2 shows reduced X-ray images taken of the

PLATE I X-radiograph of the sampled cores.

CP III SAANICH - FINLAYSON ARM
10/10/85 125° 32' 18"
203m 48° 31' 32"
NO INTERFACE.

CP IV: SAANICH - FINLAYSON ARM
4/11/85 123° 32' 48"
202m. 48° 32' 50"
INTERFACE INTACT.

TOP.



0
5
10
15
20
25
30
35
40
45
50
DEPTH (cm.)

● DARK SAMPLES.
○ LIGHT SAMPLES.

two sampled cores. X-raying was performed by Industrial Non-destructive Testing Ltd. in Vancouver.

On the basis of the X-ray images obtained, further work was concentrated on cores CPIII and CPIV. Although the interface of core CPIII had been lost, the pattern of the varves at the top of the recovered section appeared to match that at the base of core CPIV, a core with the sediment/water interface intact. It was hoped that sampling both would allow an extended time period to be studied.

Subsequent studies of the diatom flora of some prominent layers in both cores showed that they were not, in fact, the same layers and, consequently, that it was not possible to construct a longer record. The study reported here concentrates on core CPIV.

An 2.5cm wide strip down the length of the central section was preserved frozen as archive material. The remaining part of the central section was sampled layer by layer in a walk-in freezer at the Institute of Ocean Sciences, Patricia Bay, B.C. Sampling was started at the bottom of the preserved sections and the layers were scraped using glass microscope slides with the scrapings being caught on a clean glass plate. The scrapings were stored frozen in plastic pots.

Every care was taken to follow the layers as closely as possible. It was found that the layers could be distinguished both from their colour and by their frozen texture. It was also noted that the dark layers issued a

strong smell of hydrogen sulphide. Recognition of these characteristics allowed sampling in the top 15 cm. of the core although the X-ray images showed indistinct layers. In core CPIV, notes taken during sampling indicate that the laminae were becoming indistinct and thus harder to follow from sample 70 upwards to the preserved interface. During sampling, an attempt was made to discard the interface between layers so that the samples collected represented the true characteristics of each identified layer. Measurements were taken down the centre of the core before and after each layer was scraped to allow each sample to be matched with a particular layer on the X-ray plates.

Before each layer was scraped, a small plug of the sediment was removed using a 'cork-borer'. These samples were carefully cleaned so that they were representative of only one layer and were collected so that the diatom assemblage could be studied. They were kept frozen in glass vials until prepared in the laboratory.

In Vancouver, the scrapings were allowed to air-dry and were then ground by hand in agate and weighed. Any large wood fragments were removed to avoid erroneous values in the determination of organic carbon. The dried samples ranged in weight from 10.5 g. to 2.2 g. with a mean of 3.5 g.

2.2 Geochronology using ^{210}Pb .

Dating was carried out by determining the ^{210}Po activity of the sediments by alpha-spectrometry and assuming equilibrium with ^{210}Pb ($t_{1/2} = 22.2\text{yrs.}$). An extensive review of geochronology using ^{210}Pb is found in *Robbins* (1978).

Sample preparation consisted of digesting the sediments in hydrofluoric and nitric acids together with a yield tracer of ^{209}Po , plating the ^{210}Po onto nickel discs in an acidic solution (HCl), and counting the discs by α -spectrometry.

The method used is described by *Smith and Walton* (1980) and is based on that published by *Flynn* (1968). The only difference between the published methods and those used in this study is the substitution of nickel for silver discs. Nickel has been found to have very similar plating efficiencies to silver and is considerably cheaper (*J.N. Smith. pers. comm.*).

Counting of ^{210}Po and ^{209}Po activities was performed on an ORTEC 567a Alpha spectrometer using ORTEC surface barrier detectors with an area of 450mm^2 . Samples were counted for 24hrs. An extended description of the method used and an estimate of precision ($\pm 6.33\%$ RSD 2σ) can be found in Appendix A.

2.3 Determination of bulk mineralogy and the major and minor element concentrations by X-ray analysis.

The bulk mineralogy of the samples was determined qualitatively using X-ray diffraction on a Philips PW 1729 generator/goniometer and a Philips PW 1710 diffractometer control unit. Raw sediment samples were pressed into discs with a backing of instant coffee and were scanned from $3.0-35.0^{\circ}2\theta$ at a scanning speed of $0.01^{\circ}2\theta/s$. and a time constant of 3 seconds.

The elemental composition of the samples was determined by X-ray fluorescence using a Philips PW 1400 spectrometer. Determinations were made of the major elements: Si, Al, Fe, Mg, Ca, K, P, Ti and S, and the minor elements Ba, Cu, Cr, Mo, Ni, Pb, Sr, Rb, V, Y, Zn, and Zr. Mn and Na are determined in both the major and minor element analytical programs since some sodium is lost as volatiles during the fusion process used in sample preparation for major element analysis, and since manganese is present in anoxic sediments in such low concentrations, typically around 500-600 ppm. The values for these elements reported in this study are those derived from the minor element analysis program. Sulphur and Mo were determined using separate programs because the international rock standards used for calibration have low concentrations of these elements and this required that synthetic standards be made.

Cobalt and Pb were also measured in the minor element measuring program; their concentrations were very low

(5-15ppm) and the fact that the Co $K\alpha$ line is very close to the Fe $K\beta$ line and that the Pb $L\beta$ line is of low intensity rendered the determinations of these elements somewhat uncertain. The results obtained for Co are not reported; however, the Pb results are reported in Chapter 3 in conjunction with the carbonate data.

The major elements were determined using fused glass discs and the trace and minor elements were determined on pressed powder pellets. A full description of the methods used in sample preparation and analysis, together with estimates of precision, are provided in Appendix B.

Salt corrections were derived from the chlorine concentrations of the samples as determined by dissolving the salt in distilled water and titrating the chloride against silver nitrate. A full description of the method used is provided in Appendix C together with the factors used to correct the element concentrations.

2.4 Determinations of carbon, nitrogen and carbonate.

Total carbon and nitrogen determinations were done using an automated Carlo-Erba CHN analyser which measures N_2 , CO_2 and H_2O produced by combustion gas chromatography. A full description of the method used and a precision estimate ($\pm 0.73\%$ for carbon and $\pm 2.6\%$ for nitrogen, RSD, 2σ) are reported in Appendix D.

Carbonate carbon was determined by coulometry after digestion in 10% HCl. A full description of this method is also found in Appendix D.

2.5 Sample preparation and counting of diatom frustules.

The original intention of this work required an analysis of the diatom and silicoflagellate fossils preserved in the sediments. It was hoped that any trends which might be discovered in the assemblage could be dated and correlated with historical records of climatic and oceanographic data.

The problems encountered with the dating meant that the diatom flora needed to be counted for another reason. It was necessary to determine if the varves were indeed seasonal and whether the samples collected from the top of the core reflected the seasonal deposition.

To this end samples were collected as previously described and they were cleaned, mounted on microscope slides and counted using methods described in Appendix E.

It was decided to count groups of diatoms which should show a distinct seasonal signal: Thalassiosira spp., Chaetoceros spp. and Skeletonema costatum representing the spring bloom and summer production, while benthic species, such as Paralia sulcata, and pennates within the Navicula, Nitzschia and Grammatophora genera were counted as a group

which might represent run-off and resuspension activity which is thought to be characteristic of the winter.

These groups were selected from studies of diatom material recovered from sediment traps moored in Saanich Inlet as part of an ongoing UBC study. Some of the results of the diatom record for 1984-1985 trap material are given by *Sancetta and Calvert (1987, in press)*.

CHAPTER 3: RESULTS.

A certain protocol is followed in the presentation of the results in this chapter. Since the core was collected in early November 1985 it was assumed that the sample taken from the sediment/water interface (No:86) represents summer production. However, it will be shown in this chapter that the interface recovered in this core may not be the true sediment/water interface, that the uppermost part of the sediment column may have been lost and that the sampled section contains two distinct sediment types.

The core was sampled from the base upwards and this led to the light layers being given EVEN numbers and to the dark layers being given ODD numbers. The topmost sample, number 86, was thought to be a light layer deposited in summer 1985. An annual varve is taken to be a light layer and the dark layer above it.

The element profiles presented in this chapter are annotated with an estimate of precision as the 2σ RSD error associated with the mean value and the light and dark samples are indicated.

3.1 Chronology of the core by ^{210}Pb .

Table II presents the ^{210}Pb activities found in core CPIV. The measured values at the top of this core are slightly lower than those recorded in the Inlet by previous workers. For example, *Bruland* (1974), using beta counting

Table II Results of ^{210}Pb . Analysis.
Core CPIV.

SAMPLE	WEIGHT(g)	DEPTH(cm)	CORRECTED DEPTH*	DPM/G. 210 Pb#
86	1.004	0	0	10.1 \pm .29
85	1.001	3.8	6.2	12.1 \pm .37
83	1.000	7.5	15.4	8.6 \pm .29
81	1.005	7.7	15.6	5.7 \pm .2
79	1.001	9.8	22.1	4.2 \pm .11
75	1.007	11.8	28.2	3.8 \pm .17
73	1.004	13.3	33.3	2.9 \pm .15
71	1.001	15.4	41.0	1.7 \pm .13
68	1.001	18.3	51.4	1.6 \pm .12
63	1.005	19.9	57.5	1.1 \pm .12
57	1.006	24.3	74.8	1.3 \pm .13
53	1.009	29.7	96.3	1.2 \pm .13
49	1.001	32.9	107.7	1.1 \pm .22

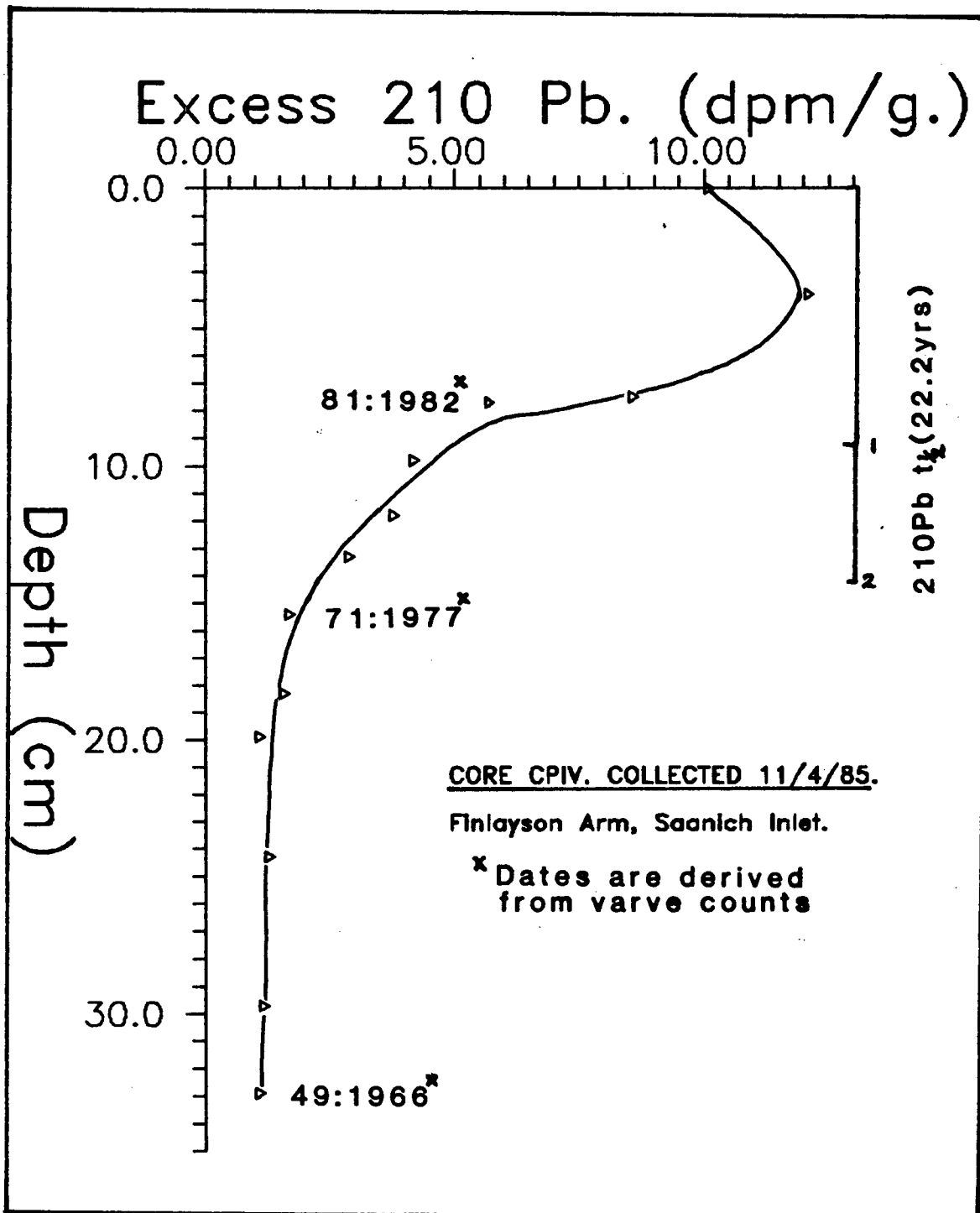
* Depth corrected for compaction using porosity data from Matsumoto & Wong (1977).

dpm/g. EXCESS ^{210}Pb . 1.2dpm/g subtracted, Bruland (1974). Values are Salt Corrected. \pm 2 sigma. Error estimates are calculated from ORTEC output and include correction for yield.

of ^{210}Bi , found values of 14.9–15.9 dpm/g in the surface sediments, while *Matsumoto and Wong* (1977), also using the ^{210}Bi method, found values of 15.7–21.7 dpm/g in the top 7 cm of a core from Squally Reach. This observation might be explained by different sedimentation rates at the different coring locations, or it might indicate the loss of sediment from the top of this core. *Carpenter and Beasley* (1981), using the same method as that used in this study, report a surface value of 10.7 dpm/g at a station in Finlayson Arm; however, they attribute the low values to incomplete isotope profiles. It will be shown in section 3.3 that the carbonate data for this core also indicates that sediment has been lost from the top of this core.

Fig.3.1.1 presents the ^{210}Pb data in graphical form; it includes an indication of the 22.2yr. half life of ^{210}Pb , and the dates obtained by varve counting assuming the preserved interface to be 1985. It will be shown in section 3.3 that this assumption is probably false, that the true interface has been lost and that the core top appears to be sediments which accumulated between 1960–1963. However, in both cases there is clearly a major discrepancy between dates determined from the ^{210}Pb activity and those from varve counts. The ^{210}Pb profile (Fig.3.1.1) shows no indication of mixing or disturbance of the sediment column; however, observations derived from the major element chemistry (section 3.4) indicate that there is a different sediment type in the top 15 cm of the core and it will be

Fig:3.1.1 Profile of ^{210}Pb activity



shown in this section that this change in sediment is probably accompanied by a change in sedimentation rate.

The discrepancy between the ^{210}Pb profile and the varve counts made it necessary to check the validity of the ^{210}Pb profile. To do this some samples were analysed for ^{137}Cs at the Lamont Doherty Geological Observatory. These samples were measured by gamma spectrometry using an ORTEC GWL-90210 spectrometer with well-type intrinsic germanium detectors; details of the sample preparation, calibration and estimates of accuracy are not available.

Samples were selected based on both the ^{210}Pb chronology and on the varve counting and assuming the interface to be 1985. The aim of this selection was to define the 1963 peak of 'bomb' caesium (*Robbins and Edgington, 1975*). The results are presented in Tables III and IV.

Table III Comparison between ^{210}Pb Chronology and ^{137}Cs Activity.

SAMPLE NO. &DEPTH	^{210}Pb DATE	^{137}Cs ACTIVITY
83 6.4cm	1968	190±50 dpm/kg.
80 9.5cm	1963	150±50 dpm/kg.
78 10.9cm	1958	<20±50 dpm/kg.
76 11.5cm	1953	<20±50 dpm/kg.

Table IV Comparison between Varve Count dates and ^{137}Cs Activity.

SAMPLE NO. &DEPTH	VARVE DATE	^{137}Cs ACTIVITY
50 32.2cm.	1968	<20±50 dpm/kg.
40 35.7cm.	1963	86±56 dpm/kg.
30 40.0cm.	1958	67±55 dpm/kg.

The ^{137}Cs activities seem to be consistent with the ^{210}Pb chronology rather than with the varve counts. However, it does appear that the peak of ^{137}Cs associated with 1963 was not clearly defined. *Carpenter and Beasley* (1981) report surface ^{137}Cs values of 412dpm/kg in Finlayson Arm which rise to 800dpm/kg at 2-4cm. *Robbins and Edgington* (1975) report values of around 370dpm/kg for the 1963 peak in Lake Michigan. The sample (sample 83) thought to represent 1968 by ^{210}Pb chronology has more ^{137}Cs than that given the ^{210}Pb date of 1963. This observation leads to the

conclusion that the top of the core, assumed to be the sediment/water interface in order to derive the ^{210}Pb dates, is not the interface, and can only mean that some sediment has been lost from the core top. This conclusion is supported by the lower ^{210}Pb activity compared to other data from Saanich Inlet and by carbonate data presented in section 3.3. More detailed sampling would be required to determine the significance of the slight increase in ^{137}Cs activity lower in the core (Table IV).

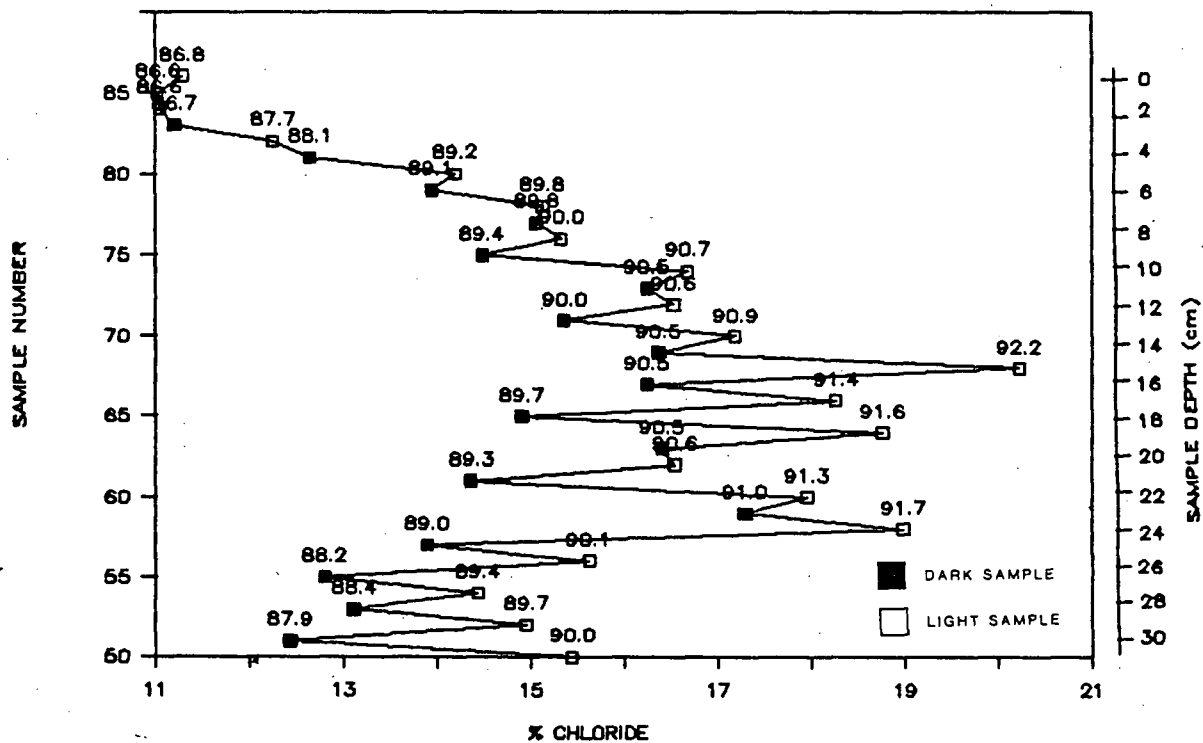
Since the objectives of this study required an accurate chronology, the study was refocused on the cause of the discrepancy between the ^{210}Pb chronology and that of the varve counts. Detailed geochemical analyses and counts of the major diatom groups were carried out on the top of core CPIV. The data reported are the results of work on samples 86 (the sediment/water interface) to 50 (32.2cm), with the exception of the ^{137}Cs samples based on varve counts which were taken from lower in the core (see Table IV).

3.1.1 Calculation of sediment accumulation rate.

The calculation of both the sedimentation rate (cm/year) and the sediment accumulation rate ($\text{g}/\text{cm}^2/\text{year}$) require porosity data in order to take account of compaction to derive a corrected depth. Precise determination of porosity requires the careful measurement of pore water volume and this was not possible on this core because of the necessity to freeze it on recovery in order to preserve the

Fig: 3.1.2 CHLORIDE CONTENT.

Annotations show water contents.



* Numbers represent water contents
calculated for a bottom water salinity of 31‰.

varves. However, the chlorine content of the dried samples could be used to determine the amount of seawater in a given sample and thus allow the calculation of porosity. The chlorine profile obtained is presented in Fig.3.1.2.

Two interpretations of this profile are possible. Firstly, it could indicate a migration of water into the central section of the core as a result of dewatering at the surface before freezing. Since the sediments are known to be very fluid, this seemed a reasonable assumption since the freezing process could influence the porosity of the sediments. This interpretation meant that the chlorine profile could not be used to calculate porosity and estimates of the sedimentation and accumulation rates were obtained using the porosity data in Saanich Inlet reported by *Matsumoto and Wong (1977)*.

However, once the data on the major element chemistry became available and it appeared that there was a different sediment type in the top 15cm of the core (see section 3.4), it became a possibility that the chlorine profile did, in fact, reflect the true porosity of these sediments. The decreased chlorine contents at the top of the core were coincident with a distinct sediment type, containing higher Fe and Ti for example, and probably has a different porosity. This interpretation is supported by the marked differences in the chlorine content between the light and dark samples lower in the core which implies that the water contents of discrete layers have been preserved. It is

therefore unlikely that a significant amount of water migration has occurred. Hence, the sample water contents can be used to determine porosity. Estimates of sedimentation rates are made using the two methods.

3.1.2 Determination of the sedimentation rate using porosity data from Matsumoto and Wong (1977).

In order to estimate the mass accumulation rate, the porosity data from *Matsumoto and Wong (1977)* have been used. The method for calculating the sedimentation rate and the accumulation rate can be found in *Robbins and Edgington (1975)* and *Matsumoto and Wong (1977)*.

The data used come from a core at their station SI-3, situated just to the north of core CPIV in Squally Reach. (see Fig.1.2.1)

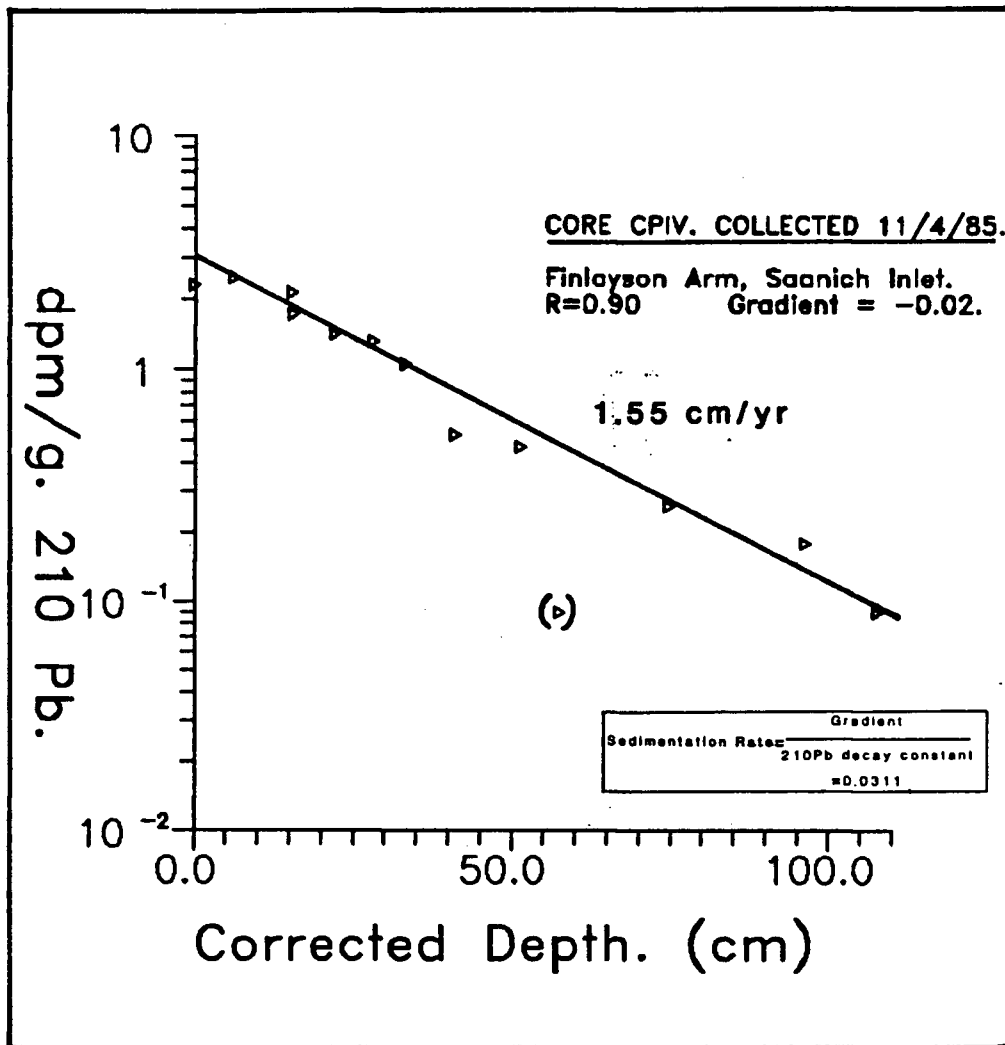
The sample depth was first corrected for compaction using;

$$fz = \frac{1}{1-\phi_0} \left[z (1-\phi') + \frac{(\phi z - \phi_0)}{\beta} \right] \quad (1)$$

where ϕ_0 = interface porosity = 0.984
 ϕ' = estimated porosity at final compaction = 0.933.
 β = constant = 0.109
 z = depth
 $\phi_z = (\phi_0 - \phi')e^{-\beta z} + \phi'$ = porosity at depth z

The plot of corrected depth against excess ^{210}Pb (Fig.3.1.3) gives the sedimentation rate by the slope of the regression line. The rate obtained for core CPIV is 1.55 cm/year. This sedimentation rate can then be used to calculate an accumulation rate as follows;

Fig:3.1.3 Corrected depth against excess 210Pb



$$w = S_o(1-\phi_o)p_s \quad (2)$$

where

p_s = grain density = 2.06 ± 0.05 g/cm³

ϕ_o = surface porosity = 0.984

S_o = sedimentation rate at surface
= 1.55 cm/yr.

An accumulation rate of 51 mg/cm²/yr-1 was obtained. This value agrees with other rates in the literature for Saanich Inlet, and it confirms the trend of a decreasing rate from the mouth to the head of the inlet.

Table V Sediment Accumulation Rates in Saanich Inlet.

STATION NUMBER	Accum. Rate mg/cm ² /yr-1	REFERENCE
SI-9	257	R. Francois (pers. comm.)
SI-7	270	Matsumoto and Wong (1977)
G	144	Carpenter and Beasley (1981)
I	90	Carpenter and Beasley (1981)
SI-3	94	Matsumoto and Wong (1977)
SN 0.8	95	R. Francois (pers. comm)
CPIV	51	This Study

3.1.3 Calculation of porosity from the measured chlorine concentrations.

The results of the chloride determination, performed by titration against AgNO₃, were converted to a weight % water content taking 31‰ as the salinity of the bottom water in Saanich Inlet (M. Soon pers. comm; Matsumoto

Table VI Results of Calculations using Chloride as an indicator of true porosity.

SAMPLE	DEPTH	WATER (wt.%)	SEDIMENT DRY WT (g)	WEIGHT WATER (g)	POROSITY
86	0	86.8	1.004	6.602	0.93
85	3.8	86.6	1.001	6.469	0.93
83	7.5	86.7	1.000	6.519	0.93
81	7.7	88.1	1.005	7.440	0.94
79	9.8	89.1	1.001	8.182	0.94
75	11.8	89.4	1.007	8.493	0.94
73	13.3	90.5	1.004	9.564	0.95
71	15.4	90.0	1.001	9.009	0.95
68	18.3	92.2	1.001	11.832	0.96
63	19.9	90.5	1.005	9.574	0.95
57	24.3	89.0	1.006	8.139	0.94
53	29.7	88.4	1.009	7.689	0.94

Weight of Water and Porosity calculated using a Saanich bottom water density of: 1.02 g/cm³ and a sediment grain density of: 2.06 g/cm³. Both values are given by Matsumoto and Wong (1977).

and Wong, 1977). These values are shown on Fig.3.1.2. From the water contents it is possible to calculate the weight of water that would be associated with the mass of dry sediment used to determine the ^{210}Pb activity and, using a density of Saanich Inlet bottom water of 1.02 g/cm^3 and a grain density for Saanich Inlet central basin sediments of $2.06 \pm 0.05 \text{ g/cm}^3$ (both values given by Matsumoto and Wong, 1977), porosity can be calculated from:

$$\text{Porosity} = \frac{\text{water volume}}{\text{water vol.} + \text{sediment vol.}}$$

where; Water volume = Weight of water/water density and Sediment volume = Weight of dry sediment/sediment grain density.

The results of this calculation are shown in Table VI. There is a distinct change in porosity between samples 68-71. Sample 68 is seen to have the highest porosity (0.9598) in this section. Above this level, porosity decreases to a value at the core-top of 0.930, a value which is lower than the porosity at final compaction estimated by Matsumoto and Wong (1977). Porosity is also seen to decrease below sample 68.

These data imply that there has been a change in sedimentation within Finlayson Arm and that the sediment at the top of this core, above 15cm depth, is distinct from that in the lower part. Support for this observation is pro-

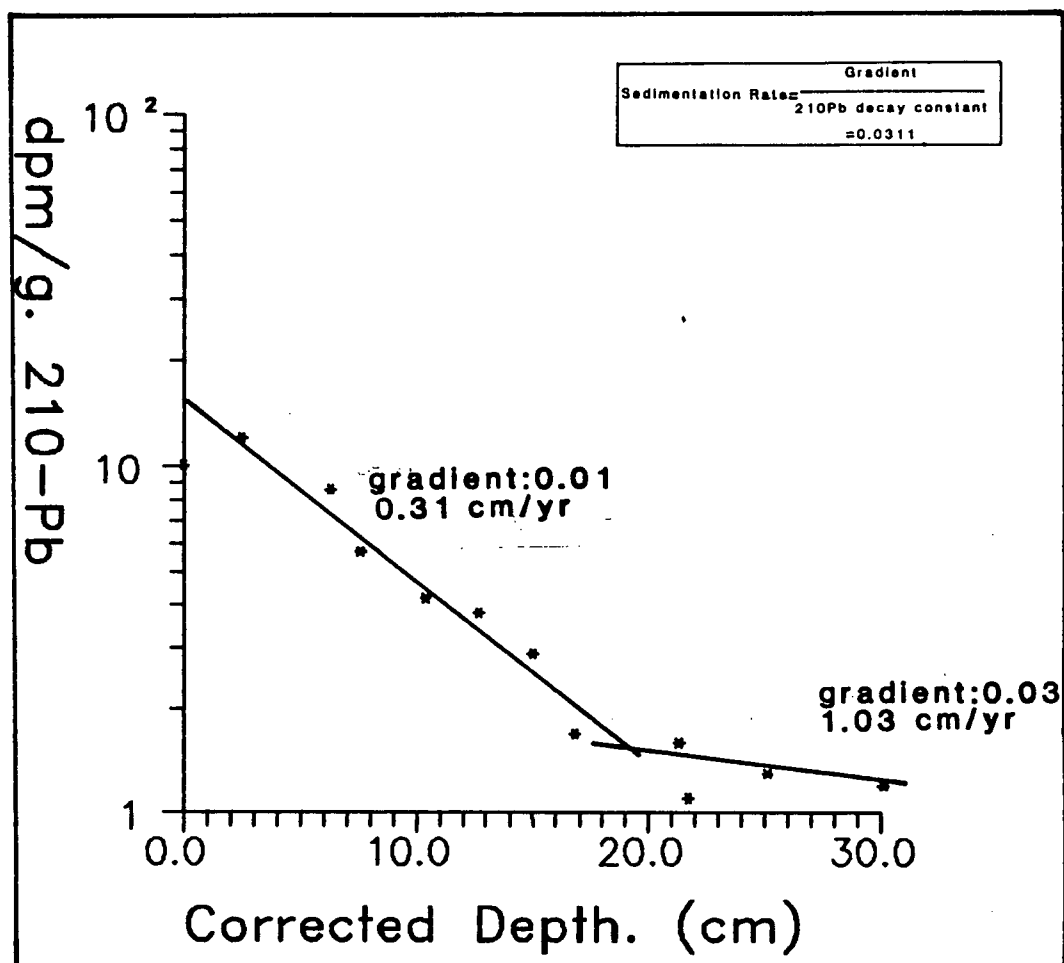
vided by the data on major element geochemistry in section 3.4.

Using the formula of *Robbins and Edgington* (1975), the sample depths must be corrected for compaction assuming steady-state sedimentation. Because of the non-steady-state implied by these data, the sedimentation rate cannot be estimated.

Variations in the sedimentation rate might result in variation of the flux of ^{210}Pb to the sediment surface. Hence, observed decreases in ^{210}Pb activity cannot be directly used to derive a sedimentation rate from the half-life of the isotope (22.2 yrs). This, in turn, means that it is not possible to determine a chronology for core CPIV.

In an attempt to verify the change in sedimentation within the top 15cm of the core, the calculated porosity for the surface was taken to be surface porosity and the porosity at final compaction was assumed to be 0.929, a value close to that of *Matsumoto and Wong* (1977). This avoids the problem of the porosity at final compaction being greater than the surface porosity. The results of these calculations are shown in Fig.3.1.4. Although this calculation is somewhat questionable, the results show that there is a distinct change in sedimentation at around sample 70, with the upper section having a lower rate. Above sample 70 a rate of 0.3cm/y is calculated while below that sample the sedimentation rate increases to 1.03cm/y. *Carpenter and Beasley* (1981) found

Fig:3.1.4 Corrected depth (based on porosity calculated from chloride) against excess ^{210}Pb



erratic ^{210}Pb profiles in cores from Finlayson Arm and attributed this to episodic or discontinuous sedimentation at that site.

Another example of discontinuous sedimentation has been reported by *Smith and Walton* (1980) in the Saguenay fjord, Quebec. They observed layers of sandy mud intercalated in the normal fine-grained sediments of the fjord with very low ^{210}Pb activities; these sandy layers were interpreted as turbidites containing ^{210}Pb -depleted terrestrial material. They avoided the problems associated with non steady-state sedimentation by assuming that these layers were deposited quickly and that the activity profile of the isotope in the fine-grained sediments had not been disturbed, so that sedimentation rates could still be estimated.

In core CPIV, it appears that layers in the bottom half of the section are true varves and represent seasonal deposition (see sections 3.4 and 3.5), while the top of the core contains sediments in which the seasonal signal is severely reduced. This sediment does not, however, have the low ^{210}Pb activities that characterize the rapidly deposited terrestrial layers described by *Smith and Walton* (1980) and ^{210}Pb activities appear to be consistent with other surface or near-surface values found in Saanich Inlet. There is also some indication from the Si, Ba and diatom data that there is a change in production associated with this change in sedimentation. The geochemical data, especially Sr and V,

and many of the major elements, show light/dark variation in the part of the core below sample 70 indicating pulses of lithogenous input to Finlayson Arm, which can only be attributed to seasonal variations in runoff. Notes taken during the scraping of the samples show that the laminae became indistinct and hard to follow around sample 70 and continued to be so up to the top of the core.

It is difficult to reconcile the preservation of seasonal signals in the geochemical (see section 3.4 and 3.5) and the diatom data (see section 3.6), with the observed decrease in ^{210}Pb activity. The decrease in activity means that there are approximately 3 half-lives (67 yrs) within the section studied, while the varve counts indicate only 18 years of deposition. One explanation for this is that large, naturally-induced fluctuations in the sedimentation rate and thereby of the flux of ^{210}Pb to the sediments, have occurred. However, this should have produced fluctuations in the profile of ^{210}Pb activities (Fig.3.1.1). These are not observed within the sampling resolution available.

An alternative explanation of the ^{210}Pb data is that the deposition of the uppermost sediment, assuming that it is of terrestrial origin with low ^{210}Pb activity (Smith and Walton, 1980), has diluted the natural flux of ^{210}Pb to the sediment. In this case the decrease in ^{210}Pb in this section could not be assumed to be via radioactive decay.

A third possibility is that the sediment type at the top of the core represents many years of deposition and that the layers sampled within it do not represent annual deposition. ^{210}Pb is seen in Fig.3.1.1 to have decreased from a surface value of 10 dpm/g to around 2 dpm/g. by sample 70. This indicates that the top layer contains approximately 45 years of sediment if a constant sedimentation rate is assumed and if dilution by terrestrial material has not occurred. Below sample 70 and down to the base of the core, ^{210}Pb is not seen to reach background activity (1.0 dpm/g in Saanich Inlet, *Bruland, 1974*); sample 50 has an excess activity of around 1.0 dpm/g. This indicates that the bottom section of the core spans a period of less than one ^{210}Pb half-life, approximately 15 years, and this is in agreement with the number of varves sampled (sample 50-70, ten years).

Large fluctuations in the flux of ^{210}Pb to the sediment surface would require consideration of any variation of ^{210}Pb input to the Inlet and must also be considered in light of the fact that coastal waters are generally thought of as being particle-rich, which would provide a ready and constant source of material to transport ^{210}Pb to the sediments.

It is proposed that the top of core CPIV consists of a distinct sediment type which was deposited during a period of decreased sedimentation rate and a period when terrestrial material may have diluted the ^{210}Pb activity asso-

ciated with the flux of marine detritus to the sediments. This sediment is characterised by a decreased seasonal signal of production, or of a signal preserved on a scale so fine that it could not be sampled discretely. Below this change in sediment type, there is a series of varves in which a seasonal signal of deposition within Saanich Inlet is preserved. It will be shown that the actual point at which the seasonal signal breaks down varies depending of the indicator considered. For example, major element signals seem to show a change around sample 70 (section 3.4), while V concentrations (section 3.5) and the counts of Chaetoceros (section 3.6) appear to indicate that the change occurs in conjunction with the carbonate increase around sample 78 (see section 3.3).

3.2 Organic carbon and the carbon:nitrogen ratio.

Surface sediments in Finlayson Arm have been shown to have the highest content of organic carbon found in the Saanich Inlet. Values of around 5% have been reported by *Francois* (1987) in Finlayson Arm, while *Gross and Gucluer* (1964) report reducing capacity, as equivalent grams of carbon, of 7%. Organic carbon is generally seen to decrease with distance from the Goldstream River to around 3-4% in the central basin of the Inlet. However, this distribution is not thought to represent input from the Goldstream; rather, it is caused by lower sedimentation rates at the head of the Inlet, meaning that the carbon is not diluted by

lithogenous input. Table VII presents a summary of the data obtained from core CPIV.

The organic carbon profile (Fig.3.2.1) shows surface values of around 5% decreasing to 3.2% at around 25cm. and then increasing again to values similar to those found at the core top. This increase in carbon at the top of the core might be explained by the lower sedimentation proposed on the basis of the ^{210}Pb data. Similarly, the increase at the base of the core might represent a change in sedimentation. There is some geochemical evidence for this (see section 3.4); however, it is not as well defined as the change observed in the upper half of the core.

Below sample 70, the dark laminae, with few exceptions, most notably sample number 56, show higher concentrations of organic carbon than the light layers implying that the greatest input of carbon coincides with winter deposition. It will be shown that this is a false interpretation and that organic carbon values, within the distinct varves, are actually higher in the light layers if allowance is made for dilution by opal.

The carbon to nitrogen ratio of sedimentary organic material has been used to identify the source of sedimentary organic carbon. *Malcolm and Price* (1984) observed C:N ratios of around 17 in particulate material from rivers and *Stuermer et al* (1978) showed a ratio of 13.5 for forest soils. This is thought to be low for the region around Saanich Inlet, where a value of 17-18 might be more

Table VII Carbon, Carbonate, Nitrogen, C:N ratio and %Opal Results.

SAMPLE	%Cl	%Ctot	%Corg	%C(CaCO ₃)	%N	C:N	%OPAL	DEPTH
86	11.3	5.41	4.79	0.62	0.50	9.56	21.2	0
85	11.0	5.86	5.03	0.83	0.53	9.56	14.7	3.8
84	11.1	5.44	4.61	0.83	0.48	9.50	13.9	4.2
83	11.2	5.17	4.53	0.63	0.43	10.45	16.4	6.4
82	12.3	5.05	4.33	0.72	0.43	10.14	17.3	7.5
81	12.6	4.94	4.42	0.52	0.50	8.82	20.0	7.7
80	14.2	5.01	4.55	0.47	0.49	9.26	23.7	9.5
79	13.9	4.82	4.41	0.41	0.47	9.44	24.7	9.8
78	15.1	4.46	4.18	0.28	0.42	9.91	27.3	10.9
77	15.1	4.88	4.57	0.31	0.47	9.70	26.7	11.3
76	15.3	4.59	4.29	0.30	0.47	9.07	27.4	11.5
75	14.5	4.59	4.25	0.33	0.45	9.41	29.7	11.8
74	16.7	4.08	3.76	0.32	0.40	9.49	30.2	12.7
73	16.3	4.52	4.23	0.29	0.44	9.58	29.8	13.3
72	16.5	4.32	4.04	0.28	0.41	9.91	34.5	14.1
71	15.4	3.74	3.46	0.28	0.38	9.00	34.1	15.4
70	17.2	4.22	3.97	0.26	0.43	9.15	36.9	16.2
69	16.4	3.93	3.67	0.27	0.42	8.63	36.5	17.1
68	20.2	4.14	3.86	0.28	0.43	9.04	45.2	18.3
67	16.2	4.22	3.93	0.29	0.43	9.06	32.9	18.7
66	18.3	3.67	3.44	0.22	0.38	8.95	33.9	18.9
65	14.9	3.98	3.67	0.31	0.41	9.00	27.2	19.5
64	18.8	3.64	3.36	0.29	0.36	9.22	39.7	19.7
63	16.4	3.79	3.55	0.24	0.38	9.24	36.1	19.9
62	16.5	3.99	3.75	0.23	0.40	9.33	31.4	20.6
61	14.4	4.01	3.76	0.25	0.40	9.40	27.3	21.1
60	18.0	3.76	3.53	0.22	0.36	9.82	43.1	22.4
59	17.3	4.28	3.92	0.35	0.41	9.56	31.4	22.6
58	19.0	4.01	3.78	0.23	0.42	8.96	46.5	23.2
57	13.9	4.40	4.12	0.27	0.47	8.83	27.5	24.3
56	15.6	5.37	5.15	0.22	0.54	9.48	35.2	27.2
55	12.8	4.49	4.21	0.27	0.44	9.66	21.7	27.7
54	14.4	4.23	3.97	0.26	0.44	9.01	28.5	28.4
53	13.1	4.70	4.42	0.28	0.48	9.30	21.5	29.7
52	15.0	4.25	4.04	0.22	0.43	9.49	31.4	30.6
51	12.4	5.27	4.95	0.33	0.55	9.07	20.3	31.6
50	15.4	4.44	4.23	0.21	0.47	8.94	27.9	32.2

* ALL VALUES ARE SALT CORRECTED * Corg. = C(tot) - C(CaCO₃)

Fig: 3.2.1 % ORGANIC CARBON

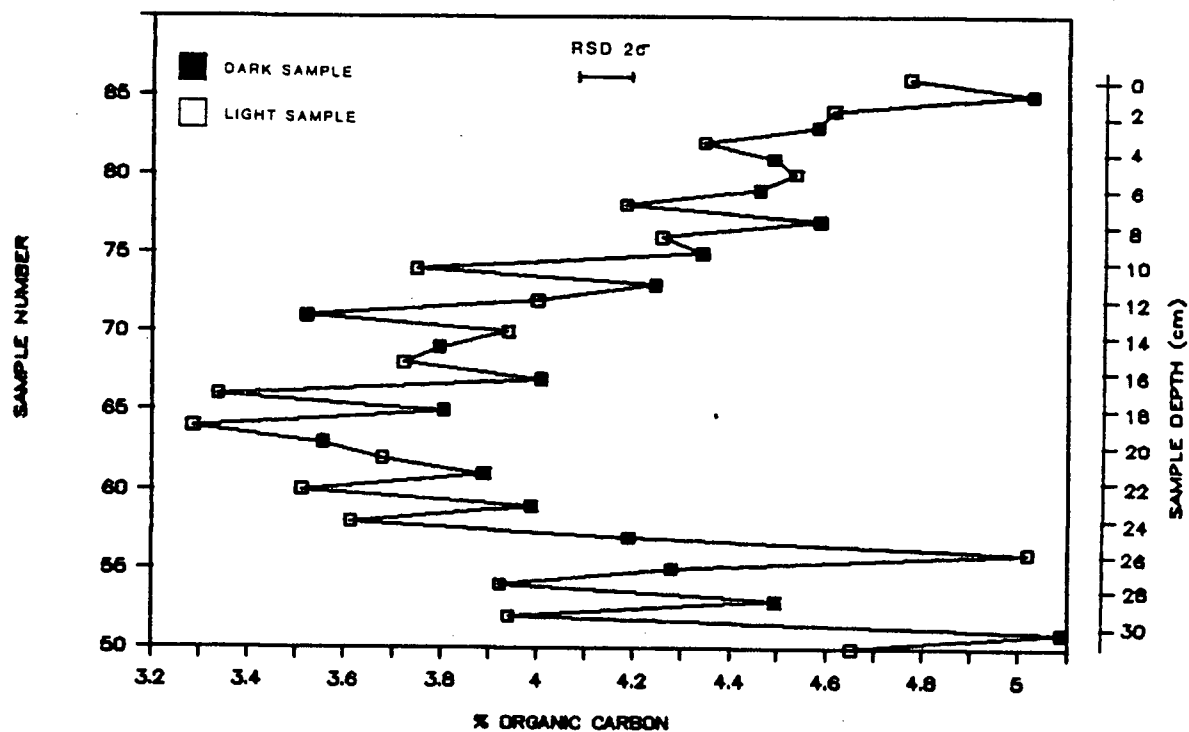
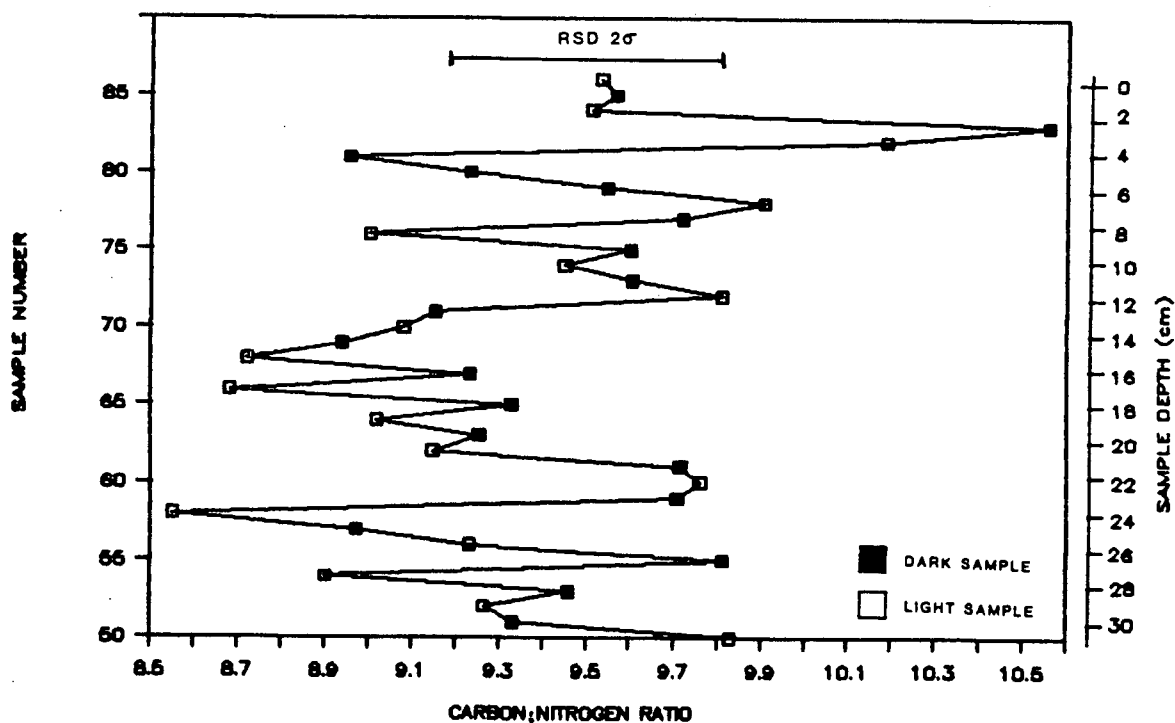


Fig: 3.2.2 CARBON:NITROGEN RATIO



appropriate (Dr. Lowe, Soil Science, UBC. pers. comm). Redfield et al (1963) showed a C:N ratio for marine plankton of around 6. Sholkovitz (1973) discussed the C:N ratio in anoxic sediments from the Santa Barbara basin and pointed out that the loss of labile nitrogen during sedimentation will increase the C:N ratio of marine organic matter reaching the seafloor. The plot of the C:N ratio in core CPIV (Fig.3.2.2) reveals a mean value of around 9.4, which indicates that the major source of carbon is marine. It also shows that most of the differences between samples are not significant when the 2σ error is considered; the size of the error is due to the relatively poor precision of the nitrogen analysis ($\pm 2.1\%$).

The profile of organic carbon is approximately mirrored by that of the Si:Al ratio (Fig.3.2.3), which is controlled by the relationship between silicon derived from diatom opal, aluminosilicates and quartz, and aluminium contained in aluminosilicates. The ratio is low at the top and bottom of the profile and increases in the central part of the section where the organic carbon content is low. It will be shown in the section on the major elements that the decrease in the Si:Al ratio at the top of the core might be caused by a change in mineralogy; however, the higher Si:Al ratio in the centre of the core must either reflect an increase in the amount of silica reaching the sediments or a decrease in the amount of aluminium. Major and minor element data (see next sections) do not provide evidence for a

concomitant decrease in the input of clay minerals nor an increase in the amount of quartz in this part of the core; thus the increased Si:Al ratio, which is always higher in the light layers, must be accounted for by an increase in the input of opal. It follows that low organic carbon values can be accounted for by dilution.

An estimate of the opal content of the sediments can be derived using the following formula;

$$\%opal = [\%Si_{sample} - (\%Al_{sample} \times Si:Al_{lith})] \times 2.14 \quad (4)$$

Where: $Si:Al_{lith} = 3.5$ which is an intermediate value between 3.1, the Si:Al ratio for the Saanich granodiorite (Clapp, 1913) and 3.9, the Si:Al ratio found in winter deposition caught in sediment traps deployed in Saanich Inlet (Francois, 1987). $2.14 =$ the atomic weight ratio of opal, (SiO_2), to Si. Opal is taken as SiO_2 since the quantity of water associated with opal ($SiO_2 \cdot n H_2O$) is poorly defined and the error associated with the assumption of this calculation will mask the error associated with this definition.

The distribution of opal calculated in this manner is shown in Fig.3.2.4. Values range from 14% in the top of the core to around 45% in some light layers lower in the section. In all layers below sample 70 there are higher opal contents in the light layers and this is to be expected if these layers are annual varves.

The decrease in organic carbon in the central section of the core (Fig.3.2.1) is matched by an increase in the opal content of the sediments and this implies that the carbon decrease is caused by the dilution of sedimentary carbon by increased inputs of opal. The profile of organic

Fig: 3.2.3 SILICON:ALUMINIUM RATIO.

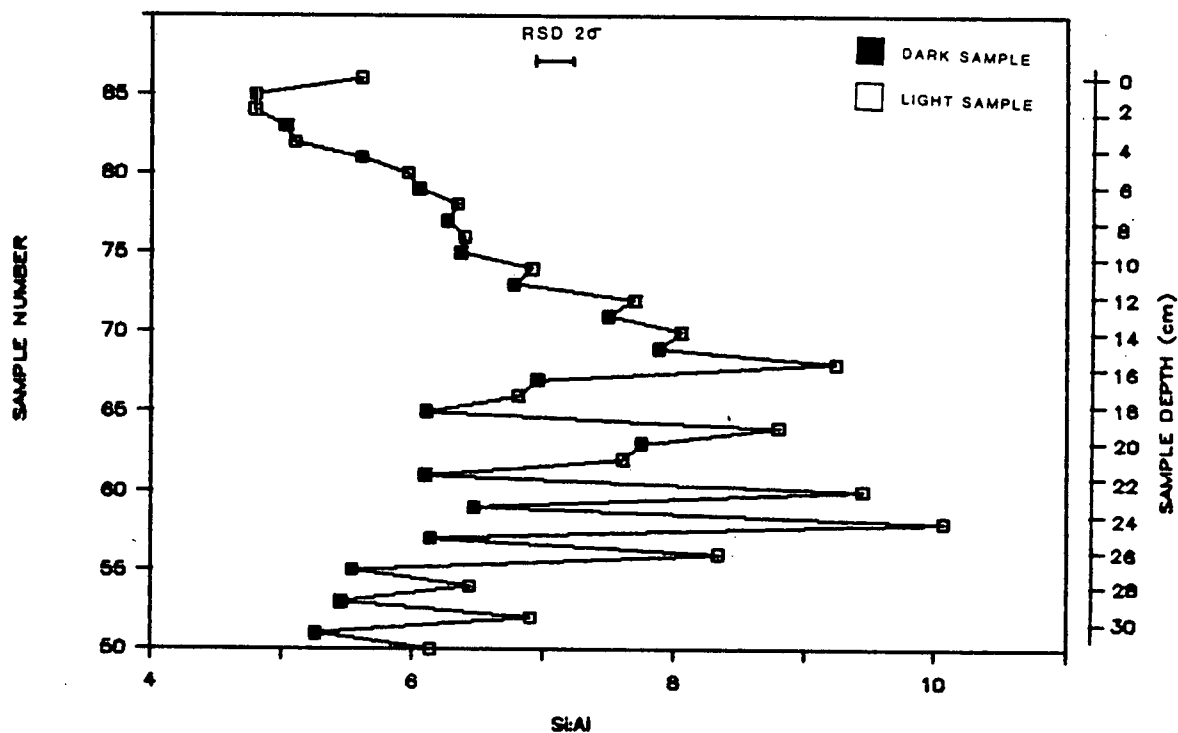
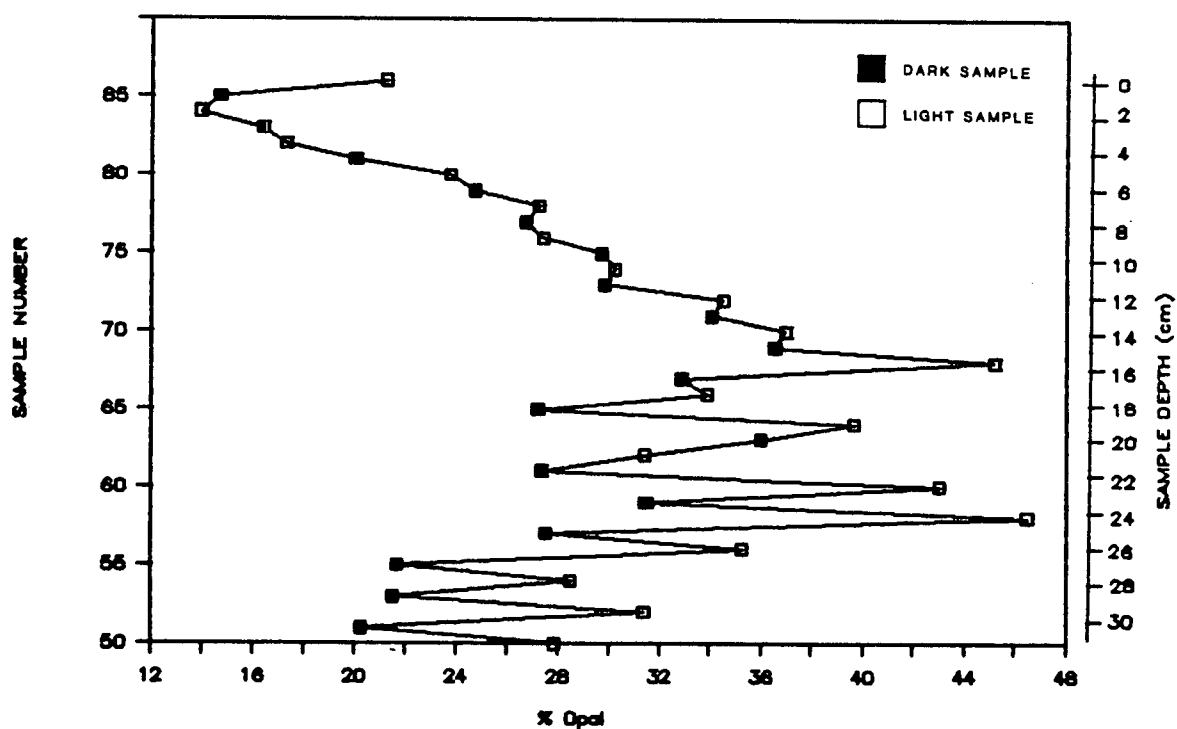


Fig: 3.2.4 % OPAL.



carbon can be corrected for this dilution by calculating %C on an opal-free basis using;

$$\%C_{\text{opal free}} = \%C_{\text{sample}} \times \frac{100}{100 - \%opal} \quad (5)$$

A profile of opal-free carbon is presented in Fig.3.2.5 and the relatively low values in the central section are indeed removed.

The plot of opal-free carbon can be taken as a rough estimate of carbon flux into the sediments thereby indicating relative differences in primary production on the assumption that the main input of carbon is derived from this source. Hence, the variation between layers in this profile may provide an insight into past production in this part of the Inlet. However, on the basis of the evidence presented so far, the interpretation of this profile is not straightforward. A comparison between the diatom valve counts (Fig.3.2.6) and the opal-free carbon profile (Fig.3.2.5) reveals some similarities but also contains some major discrepancies. The most noticeable difference is the high cell counts in sample 64 which has a low organic carbon content. This sample does have a high opal content (see Fig.3.2.4), and it will be shown in section 3.6 that it also contains relatively high counts of both Skeletonema costatum and Chaetoceros spp., both of which are generally small cells and might easily lose their carbon during sedimentation.

Fig: 3.2.5 ORGANIC CARBON OPAL-FREE.

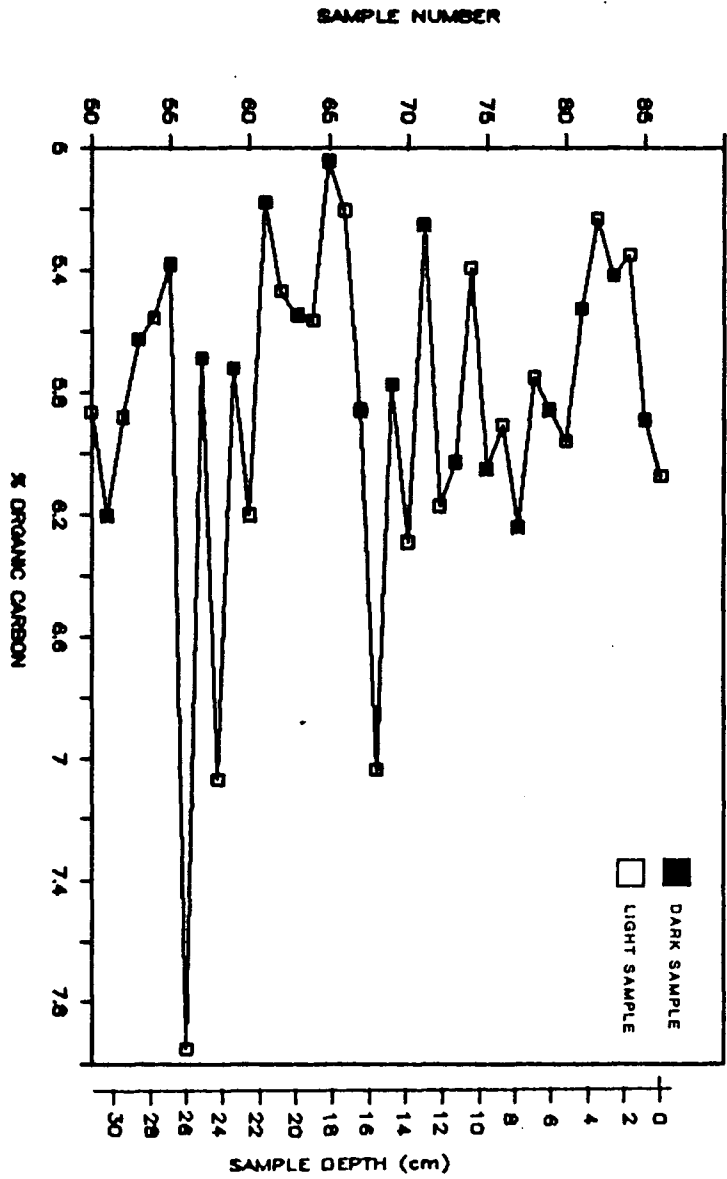
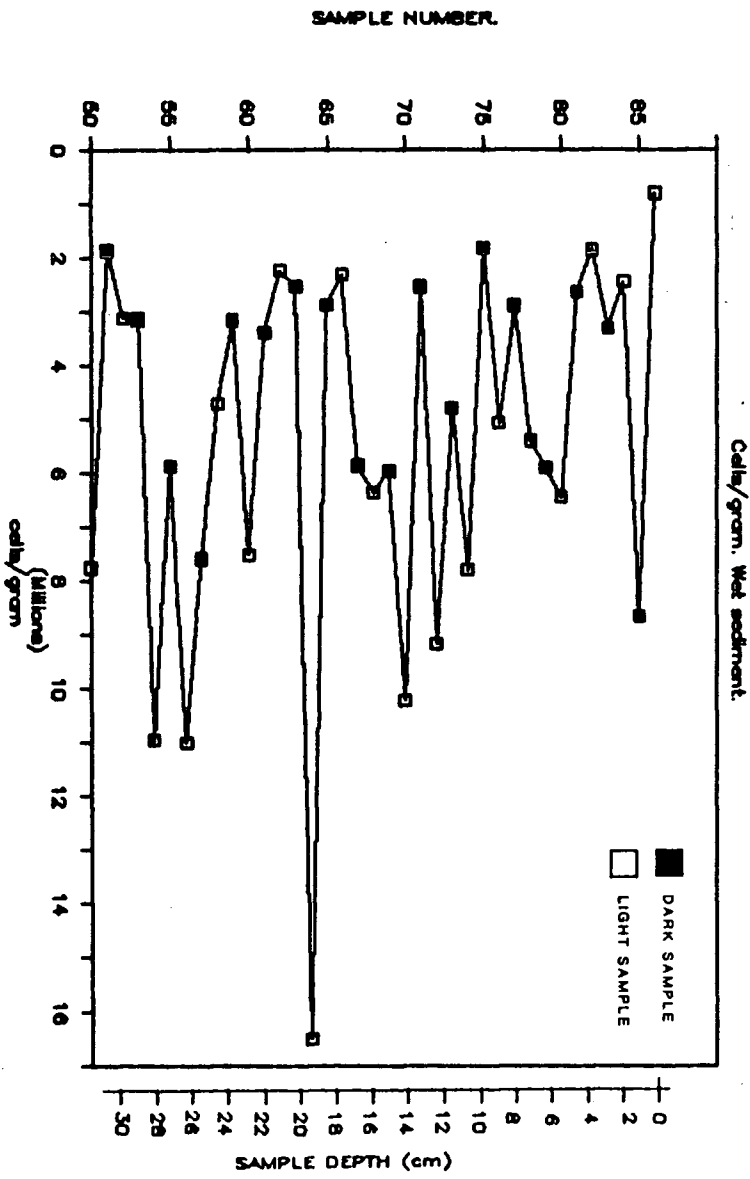


Fig: 3.2.6 DIATOM COUNTS.



One possible explanation for the difference between these profiles is a variation in the amount of grazing to which a diatom bloom is exposed. Heavy grazing will destroy the cells and release their contents while less grazing might be expected to generate sediments with a higher carbon content. Variation in predation on the grazers might also be a significant factor in determining the amount of carbon sedimented.

The carbon content of diatom cells, as shown by the Si:C ratio, will depend on a wide range of variables (see *Spencer* (1983) for a review). *Brzezinski* (1985) discusses the variation in this ratio within cultures of a number of common diatom species subjected to different light and photoperiod conditions. He also cites work where temperature and nutrient limitation have also been shown to change significantly the Si:C ratio. Variations seen in controlled laboratory cultures are even more likely in a natural system such as Saanich Inlet. Changes in the climatic patterns and oceanographic conditions affecting the Inlet will in turn affect the plankton dynamics, nutrient cycles and species succession, which will, in turn, affect the Si:C ratio in living cells. In addition, dissolution of the silica frustules, grazing by zooplankton and bacterial oxidation will affect the ratio of biogenous silica to carbon in settling particulates and therefore in the remains that become preserved in the sediments. Finally, the natural system and all its component variables will also show

interannual, seasonal and even weekly variations. These considerations are thought to account for the seemingly poor relationship between opal and organic carbon.

In addition to the variations which occur that directly affect the diatom population and the carbon they represent, there are also indirect effects and other sources of organic carbon. Photosynthetic flagellates such as dinophytes, cryptophytes, chlorophytes and prasinophytes, form an important part of the phytoplankton within the Strait of Georgia system and have been shown to be particularly important in the inlets (*Takahashi et al.*, 1977, 1978; *Harrison et al.*, 1983). Nanno and picoplankton are also beginning to be considered as important components of the planktonic flora. It is not likely that these soft-walled algae would contribute significant amounts of carbon to the sediments since their cell walls would probably be quickly broken down and the carbon released to the seawater; however, variations in the size of their populations might have a significant effect on that of the diatoms by way of competition for nutrients. Only dinoflagellates produce any remains which might become preserved in the sediments, although studies of raw sediments as smear slides showed no evidence of their cysts in this core.

The laminae below sample 70 are thought to have a higher sedimentation rate and this section of the core contains a record of annual production as varves. Based on these assumptions, the profile of opal-free organic carbon

reveals that variation between the carbon content of the light (summer) and dark (winter) layers is preserved in the sediments. Between samples 52-62 and from 67-72 the light layers have consistently higher carbon contents implying that the major carbon source is the summer production in surface waters.

3.3 Carbonate.

The carbonate profile of core CPIV shown in Fig.3.3.1 is characterised by a distinct peak at the top of the core. The data are presented in Table VII (see section 3.2). Planktonic organisms which produce tests of calcium carbonate (calcite and aragonite) are not thought to be major components of the plankton in the Strait of Georgia system since no reference can be found to them in the papers by *Takahashi et al* (1978), *Hobson* (1980) and *Harrison et al.* (1983). The steep bathymetry of the Inlet, especially around the site from which this core was collected, greatly restricts areas of mud flats in which benthic bivalves, such as clams, thrive, and it is therefore a reasonable assumption that the input of carbonate derived from biogenic sources is small.

Past studies of the sediments within the Inlet have shown that the highest concentration of carbonate is found closely associated with the cement production facility at Bamberton (see Fig.3.3.2) (*Gross and Gucluer*, 1964; *Francois*, 1987). This factory produced cement using a local

Fig: 3.3.1 CARBONATE PROFILE.

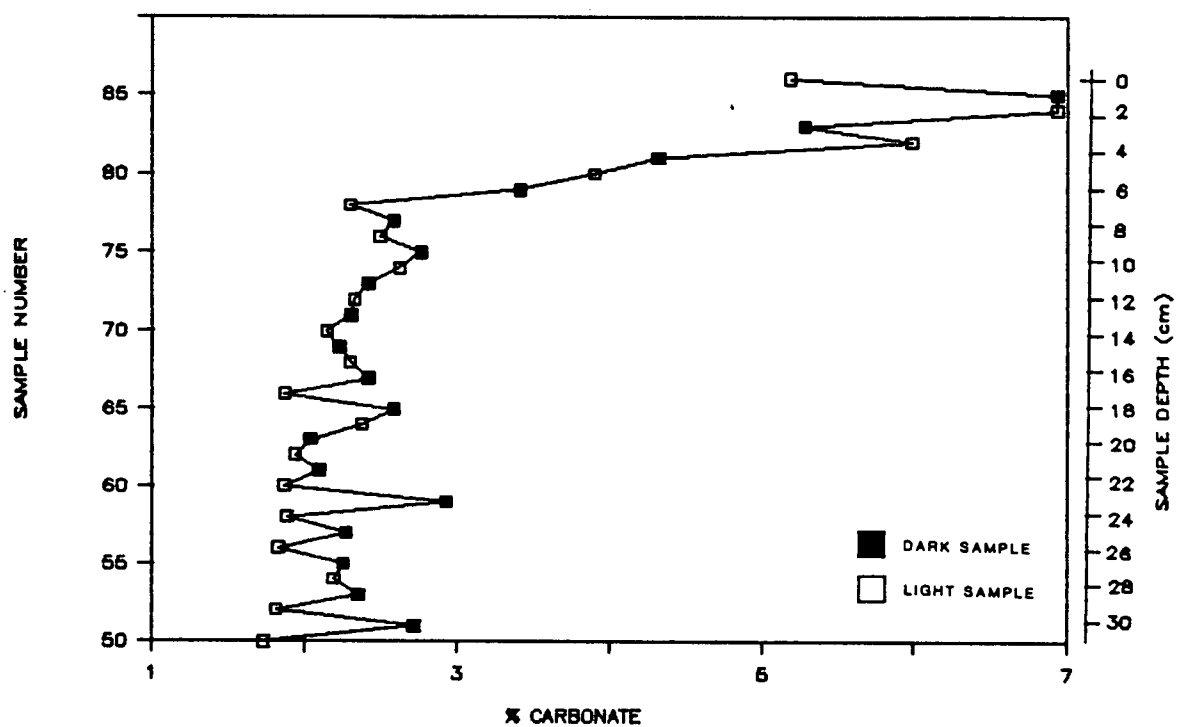
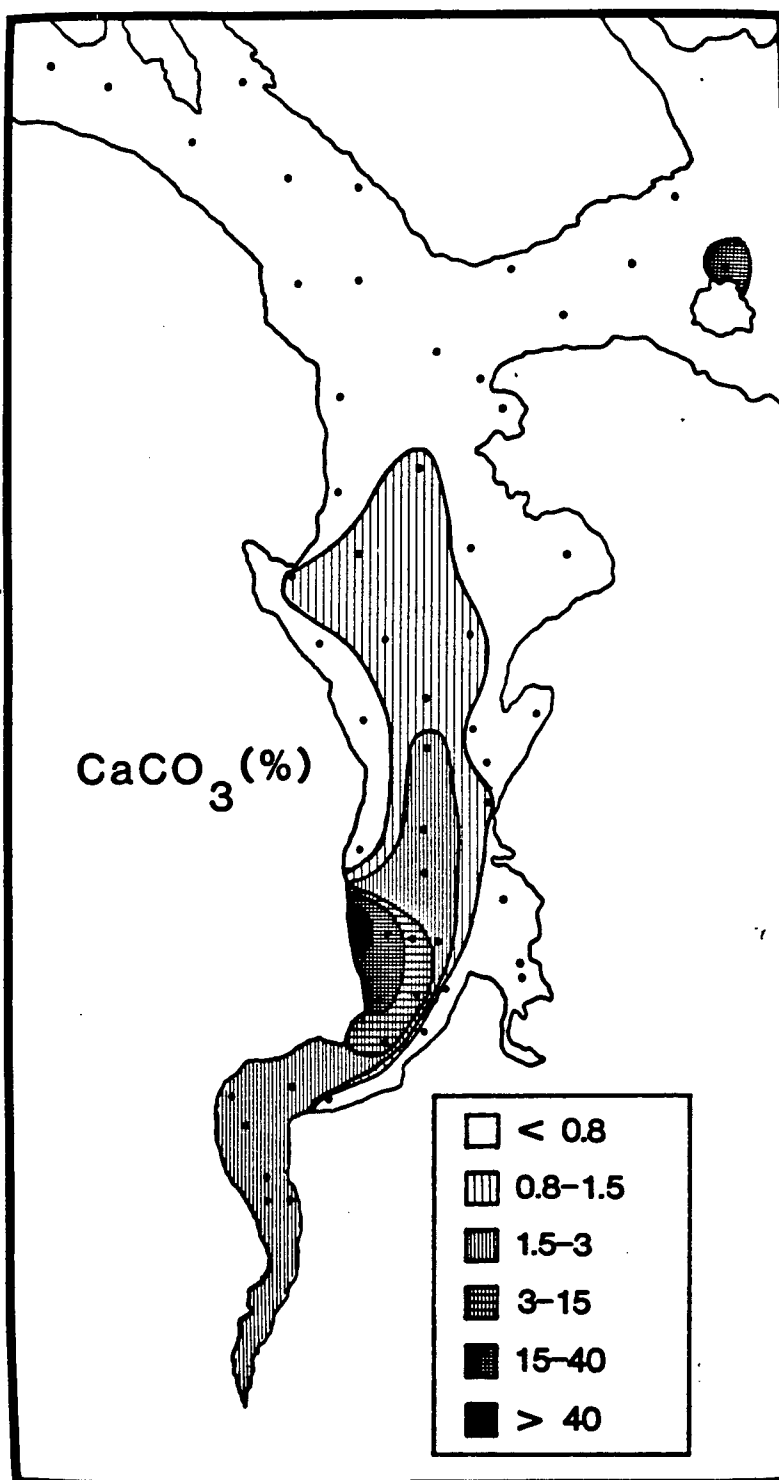


Fig: 3.3.2 Distribution of carbonate
in surface sediments of Saanich Inlet.
(after Francois, 1987)



limestone deposit from 1912 to 1980 (Tilbury Cement, Cobble Hill. pers comm.). The input of carbonate to the inlet from this facility has been shown to contain high concentrations of zinc and lead (Francois, 1987). These are probably pollutants derived from production processes. A comparison between the carbonate profile (Fig. 3.3.1) and that of Zn (Fig. 3.5.14) and of Pb (Fig. 3.5.16) shows that there are indeed increased concentrations of both these elements coincident with the rise in carbonate values, although the match is closer between Pb and carbonate. Calcium (Fig. 3.4.14), is also seen to increase in association with the carbonate profile. Further discussion of these element profiles is given in sections 3.4 and 3.5. Figure 3.3.2 shows that there is a transport of carbonate from the point source at Bamberton towards Finlayson Arm, and it is probable that the carbonate and calcium profiles are reflecting the influence of input from cement production.

Finished Portland cement is composed of calcium aluminates and calcium silicates. Four major mineral phases are present: Ca_3SiO_5 , Ca_2SiO_4 , $\text{Ca}_3\text{Al}_2\text{O}_6$ and $\text{Ca}_2(\text{Al},\text{Fe})\text{O}_5$ (Regourd, 1979). The proportion of these depends upon the initial raw mix, but a cement generally contains 60–65% CaO , 22–24% SiO_2 , 4–7% Al_2O_3 , 2–4% Fe_2O_3 and MgO , NaO and K_2O together totalling around 2–4% by weight (Glasser, 1979).

A raw mix of limestone, clay and a number of accessory minerals, which provide the required amounts of Fe and Al, is homogenised and burnt in a kiln at around 1200°C

to drive water out of the clays and reduce the carbonate to lime. This produces 'clinker' which is subsequently ground to finished cement. Burning of the raw mix results in the production of volatile gases and waste dust that has a high alkali content (Hawkins, 1979). Some dust is returned to the kiln but most is removed in order to control the alkali content of the final 'clinker'. Since extracted dust generally comes from early in the kiln process when the reduction of carbonate to lime has not yet occurred, the dust contains a lot of CaCO_3 (Dr. S Mindess. Dept. Civil Eng. U.B.C. pers comm).

Estimates of sedimentation rate derived from the ^{210}Pb data, although somewhat uncertain, imply that the sediments at the top of the core (down to sample 70) were deposited over a period of about 45 years. However, the activity of ^{210}Pb is still high at the top of the core (10 dpm/g) and it is considered a reasonable assumption that the increase in carbonate does not correspond to the start of production in 1912.

Studies using alkalinity models in the anoxic Santa Barbara basin off southern California have shown that carbonate will certainly be preserved and may even be authigenically produced under the diagenetic conditions prevailing in such sediments (Sholkovitz 1973). However, the amount of carbonate at the core-top, on the order of a 4% increase, is too large to be accounted for by authigenic production, nor does it seem likely that a change in carbonate

preservation has occurred. Personnel at Tilbury Cement, Cobble Hill state that between 1960 and 1963, inefficient extraction of the kiln dust at the plant resulted in the production of a lot of limestone dust which could not be used for the production of cement, and that this was disposed of by dumping it into a disused quarry pit. This practice was halted in 1963 because runoff from the dust dump was found to be entering the Inlet via Hollins Creek, running adjacent to the plant, and the lime content of water drawn from that creek by local cottages was very high. The increase in carbonate seen in this core (Fig.3.3.1) may be attributed to this dump and can thereby be used as a time marker representing the period 1960-63.

Three explanations are possible for the discrepancy between the ^{210}Pb -derived time interval for the upper section of the core ($\approx 45\text{yrs}$) and the date of around 1960 at the base of the carbonate peak. Firstly, the carbonate peak does not represent the dust-dump but rather is the record of increased production at Bamberton and thus represents a longer period of deposition. Secondly, the peak does represent the dust-dump and some mixing has occurred in the top-most sediments. Thirdly, the carbonate peak is preserved within a changed sedimentation regime characterised by a slower sedimentation rate and that this, together with dilution effects of a changed mineralogy, accounts for the observed ^{210}Pb activity.

These possibilities are all supported by the available ^{137}Cs data (Table III, Section 3.1) which show that there is more ^{137}Cs in the core-top; there is no clear definition of the 1963 fallout peak. If the carbonate peak represents the 1960-63 dust-dump then the ^{137}Cs can be used to support this. Sample 83, thought to be 1968 sedimentation on the basis of ^{210}Pb , has a higher ^{137}Cs concentration (190 ± 50 dpm/kg) than sample 80 (150 ± 50 dpm/kg). Since sample 85 is the observed maximum of carbonate (between 1960-63) then it should have higher values of ^{137}Cs . It might also be expected that the decreased carbonate concentration in sample 86 would show decreased ^{137}Cs activity since atmospheric ^{137}Cs fallout is known to decrease sharply after 1963 (*Robbins and Edgington, 1975*). Radioactive caesium is measurable as atmospheric fallout from 1945 until the present although there is a clear decrease associated with the cessation of atmospheric testing in 1963, and thus the two points measured might be anywhere within that time. However, the values in this core (CPIV) are high, although not as high as those (≈ 400 dpm/kg) reported by *Carpenter and Beasley (1981)* in Finlayson Arm. They are thought to be higher than post-1963 background; a value for this of around 50 dpm/kg is reported by *Robbins and Edgington (1975)* in Lake Michigan. Measurement of more samples for ^{137}Cs would be required to define clearly the 1963 peak.

The fact that distinctions between samples within this section are preserved (see major element data on sample

75 for example) supports the idea that little mixing of the upper sediments has occurred during coring.

It is concluded that the ^{137}Cs data supports the correlation of the carbonate peak with the dust-dump. This implies that some 20 years of sediments have been lost during coring, presumably because of the fluid nature of the unconsolidated Saanich sediments.

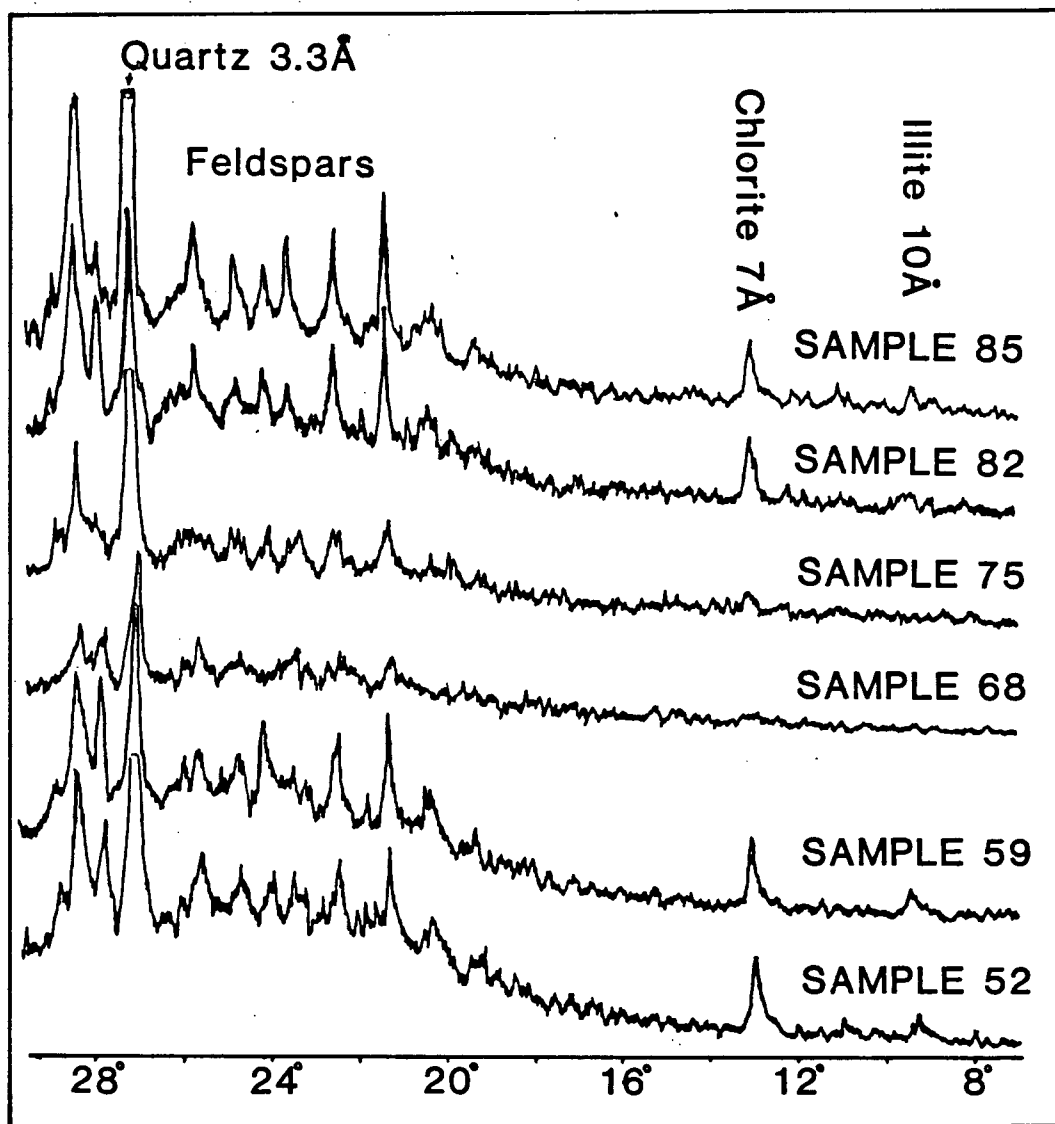
3.4 Bulk mineralogy and the major elements.

The results presented in the previous two sections have shown that there is a significant dilution of the lithogenous components of these sediments by biogenous opal. For this reason, the element profiles reported here are shown as uncorrected profiles and, with the exception of Si and the Si:Al ratio, are presented on an opal-free basis (see section 3.2). Distinction between Si in biogenous opal and lithogenous Si would require the chemical determination of opal rather than a calculation based on an assumed Si:Al ratio of pure lithogenous input.

3.4.1 Mineralogy.

Analysis of untreated bulk samples by X-ray diffraction showed that, in general, there was little mineralogical difference between the samples. Examples of the spectra obtained are presented in Fig. 3.4.1. Some variation in the height of the peaks was observed, but no sample could

Fig:3.4.1 Examples of XRD spectra



be distinguished as having a clearly different bulk mineralogy.

The main XRD peaks seen in these samples were quartz, feldspar, chlorite and occasionally minor illite. The small amounts of illite in these samples is contrary to the assertions of *Gross and Gucluer*(1964) and *Carpenter and Beasley* (1981) that the main source of sediments to the central basin of the Inlet is the Fraser River plume. While this may be the case in the main part of the Inlet and closer to the sill (*Francois*, 1987), it does not appear to be the case in Finlayson Arm. Profiles of the quartz:feldspar ratio, indicating changes in the bulk composition of the lithogenous input to the Inlet, and of the quartz:chlorite ratio, indicating a comparison between coarse and fine-grained input, are shown in Fig. 3.4.2 and Fig. 3.4.3. These data were derived from a comparison of the XRD peak heights and are semi-quantitative.

The quartz:chlorite ratio is highly variable; samples 75 and 62 are seen to have particularly high ratios implying that these samples are coarser-grained layers. There does not appear to be any distinction between the upper and lower sediment types on the basis of this ratio. However, there does seem to be higher ratios in the light layers, which, if it means relatively more quartz, implies a summer input of lithogenous material; this would not be consistent with a pulsed input of this material as a result of winter runoff. It is thought unlikely that the summer contribution

Fig: 3.4.2 QUARTZ:CHLORITE RATIO

PEAK HEIGHTS FROM XRD DATA

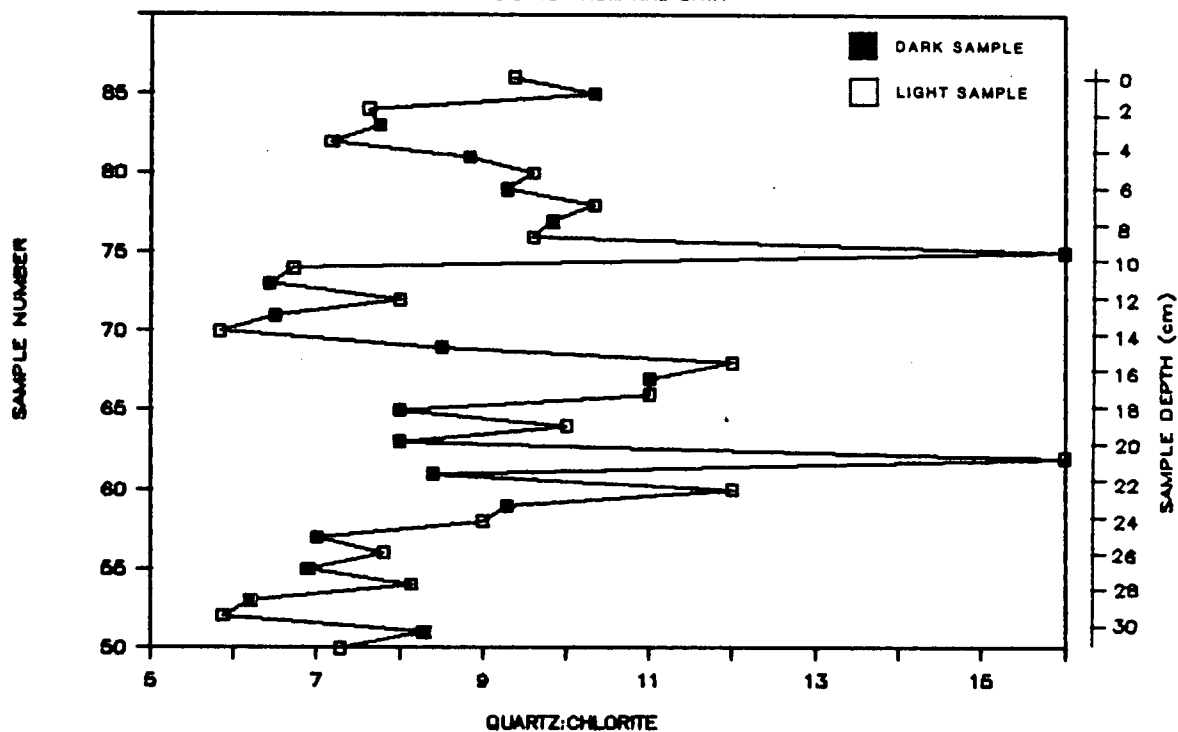
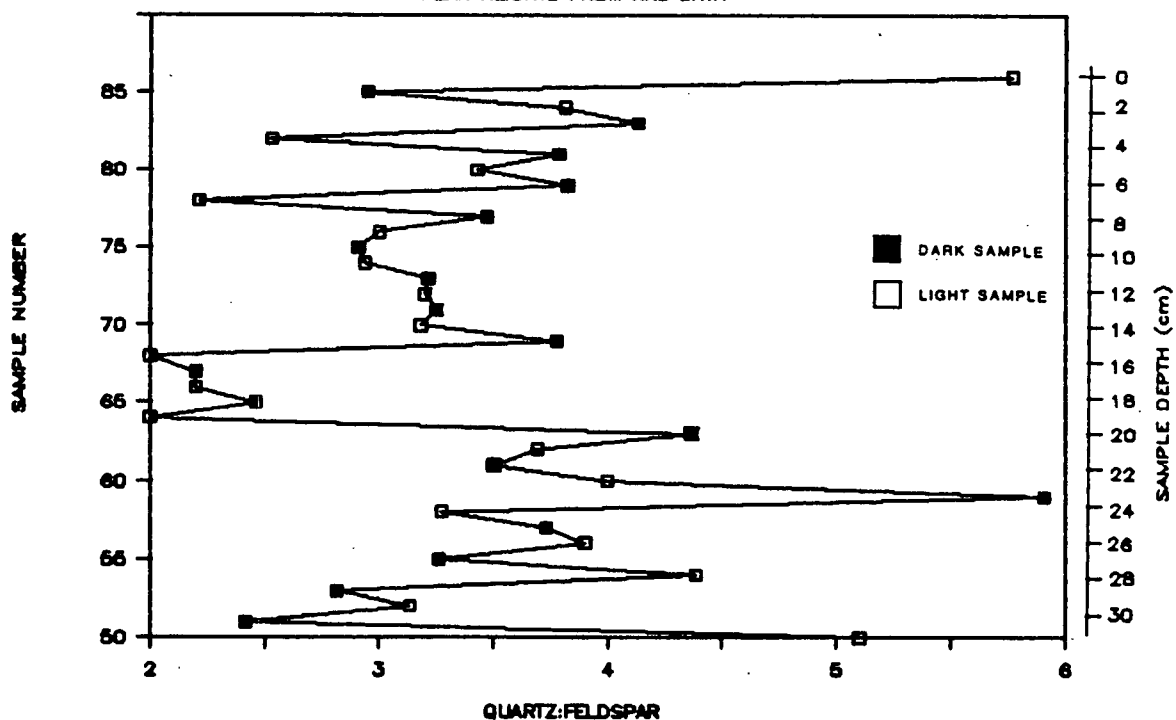


Fig: 3.4.3 QUARTZ:FELDSPAR RATIO

PEAK HEIGHTS FROM XRD DATA



of the Fraser River plume to the sediments of Saanich Inlet would contain much quartz after its passage across the Strait of Georgia. On the other hand, the high ratios might indicate proportionately lower chlorite and this would be in keeping with a seasonal deposition, implying a pulsed input of this mineral. This interpretation does, however, require a steady input of quartz. One other notable feature of this profile is the lower ratios between samples 70-75 as compared with the generally higher ratios in the central section of the core. This is approximately coincident with the proposed change in sediment type but is not seen to continue to the core-top.

Fig. 3.4.3 shows the quartz:feldspar ratio and this too shows some significant variations. Samples 50, 59 and 86 are seen to have high ratios which must indicate, since they show no distinction in the quartz:chlorite ratio, that these samples contain less feldspar. There appear to be little consistent differences between the light and dark layers. At the top of the core the dark layers appear to have higher ratios, but at the base of the core, between samples 50-56, this trend is reversed. Samples 70-75, seen to have low quartz:chlorite ratios, are distinguished here by being quite homogeneous, while samples 64-68 are characterised by low quartz:feldspar ratios.

3.4.2 Major elements.

The major element concentrations are presented in Table VIII. It will be shown in this section that in the middle section of this core, between samples 55-70, many of the major elements appear to indicate a seasonal input of lithogenous material to the sediments. This lends support to interpretation of the laminae as varves. It will also be shown that there appears to be a change in sediment type above sample 70-75. This is indicated by several elements and element ratios (Ti, Fe, and Si for example), although there appears to be no evidence of a change in bulk mineralogy (see Fig. 3.4.1). It can only be assumed that the core top sediment contains amorphous or poorly-crystalline mineral phases which cannot be detected by XRD. It has been suggested in section 3.1 that this change in mineralogy was probably accompanied by a change in sedimentation rate, meaning that sedimentation in the top of the core cannot be assumed to be steady-state. However, the presence of distinct varves in the bottom half of the core implies that sedimentation within this section may have been steady state.

Silicon (Fig. 3.4.4) and Al (Fig. 3.4.6) are both strongly associated with detrital input; Si is present in quartz, feldspar and clay minerals and Al is associated with feldspar and clays. The Si:Al ratio is presented in Fig. 3.4.5. In Saanich Inlet sediments, it has been shown that

Table VIII Concentrations of Major Elements. % by Weight

SAMPLE	%Si	%Al	%Fe	%Ca	%Mg	%K	%P	%Ti	Sanox	Sox
86	26.40	4.71	3.37	2.54	1.94	0.82	0.115	0.28	866	679
85	25.35	5.28	3.80	3.18	1.99	0.89	0.131	0.31	531	347
84	24.18	5.05	3.59	3.11	1.98	0.83	0.126	0.29	701	518
83	25.23	5.02	3.45	2.73	2.02	0.92	0.115	0.29	523	337
82	25.81	5.07	3.41	2.84	2.11	0.88	0.118	0.29	649	445
81	24.91	4.45	3.03	2.23	1.94	0.83	0.108	0.27	727	517
80	26.88	4.51	3.03	2.31	2.13	0.77	0.106	0.27	658	422
79	27.44	4.54	2.90	1.79	2.09	0.73	0.105	0.27	552	321
78	28.43	4.48	2.89	1.31	2.22	0.68	0.090	0.27	502	251
77	28.28	4.51	2.90	1.45	2.25	0.68	0.108	0.27	551	301
76	28.29	4.42	2.93	1.40	2.35	0.65	0.097	0.27	455	200
75	30.85	4.85	3.23	1.76	2.50	0.63	0.112	0.28	766	525
74	28.62	4.14	2.59	1.19	2.42	0.74	0.094	0.22	701	424
73	28.81	4.25	2.67	1.38	2.26	0.81	0.105	0.23	579	310
72	29.57	3.84	2.27	1.13	2.20	0.69	0.087	0.21	400	126
71	29.85	3.98	2.39	0.98	2.16	0.68	0.085	0.21	439	184
70	30.52	3.79	2.40	0.98	2.45	0.64	0.095	0.21	536	250
69	30.68	3.89	2.49	1.03	2.47	0.69	0.112	0.21	581	309
68	33.97	3.68	2.31	0.92	2.87	0.61	0.097	0.17	589	253
67	30.89	4.44	2.66	1.06	2.37	0.77	0.099	0.22	460	190
66	32.56	4.78	2.96	1.09	2.52	0.77	0.105	0.18	533	230
65	29.79	4.88	2.88	1.22	2.38	0.71	0.090	0.27	505	258
64	30.77	3.50	2.14	0.95	2.45	0.55	0.093	0.18	474	162
63	30.66	3.95	2.49	0.98	2.23	0.67	0.093	0.22	616	344
62	27.18	3.57	2.02	0.74	1.90	0.52	0.081	0.09	481	206
61	29.97	4.91	3.13	1.19	2.18	0.83	0.094	0.29	574	336
60	31.93	3.38	2.09	0.75	2.40	0.55	0.084	0.18	487	189
59	31.95	4.93	2.87	1.28	2.53	0.82	0.108	0.27	514	227
58	33.29	3.31	1.92	0.76	2.61	0.55	0.120	0.17	452	137
57	29.94	4.88	3.21	1.32	2.35	0.76	0.105	0.27	584	353
56	28.37	3.40	2.18	0.82	2.20	0.63	0.091	0.20	542	283
55	27.49	4.96	3.36	2.88	2.15	0.84	0.102	0.27	594	382
54	29.17	4.53	3.08	1.11	2.14	0.82	0.095	0.26	591	352
53	28.05	5.14	3.43	1.37	2.15	0.88	0.109	0.30	552	334
52	29.73	4.30	2.84	1.08	2.15	0.80	0.096	0.24	462	213
51	28.31	5.38	3.50	1.58	2.13	0.95	0.118	0.29	760	554
50	30.27	4.93	3.61	1.17	2.25	0.86	0.115	0.22	456	200

* All values are salt-corrected.

* Sulphur values are in ppm. Sanox assumes total SO₄ reduction.

Sox includes the second correction required for oxalic seawater.

Sample sulphur values are between these two values.

Fig: 3.4.4 MAJOR ELEMENTS. % BY WEIGHT Si

Element Concentration, Salt Corrected.

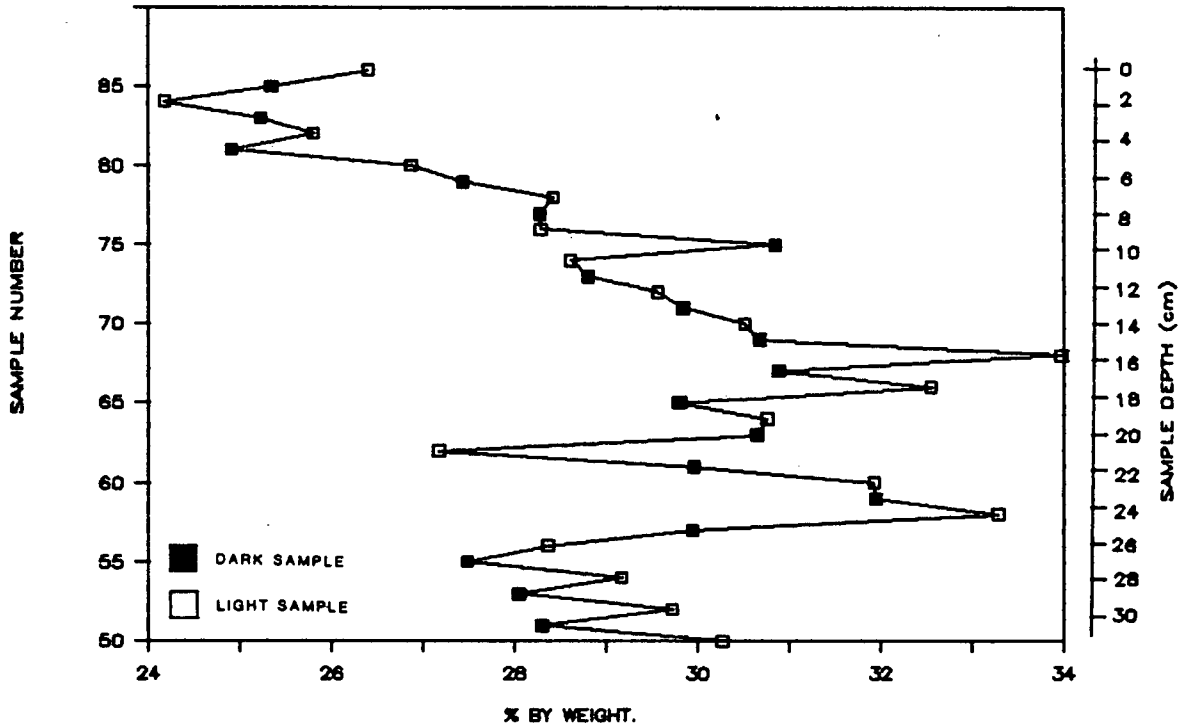
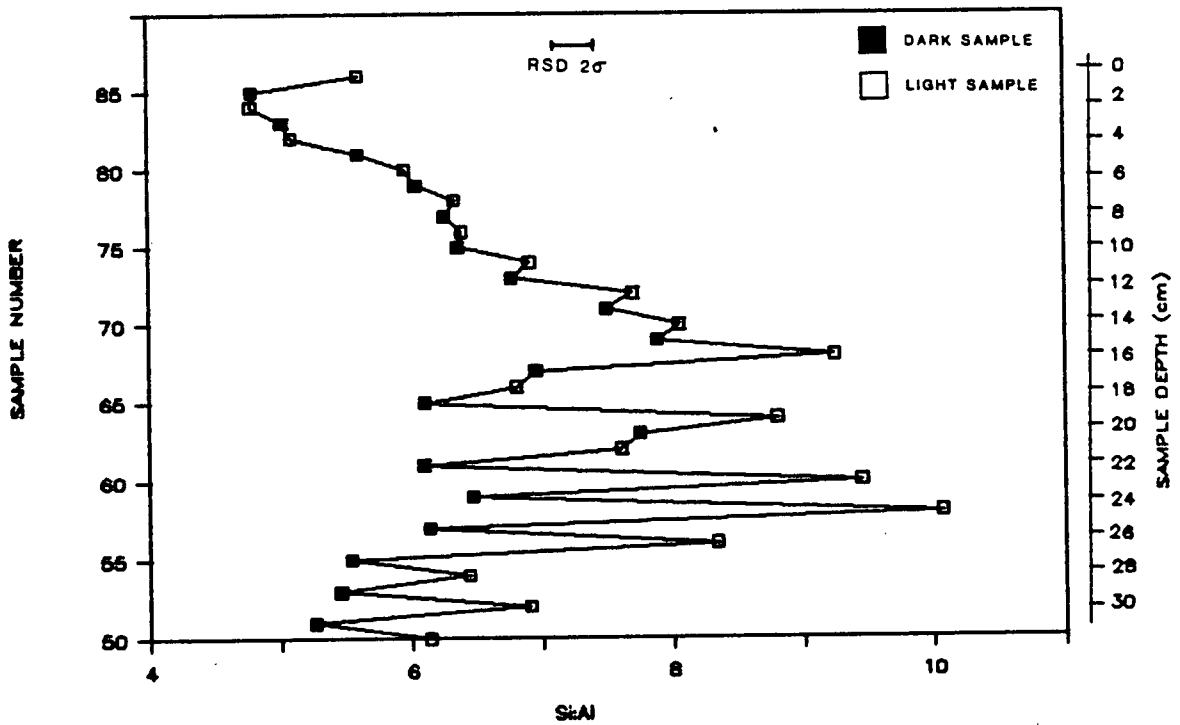


Fig: 3.4.5 SILICON:ALUMINIUM RATIO.



opal is an important component, and below sample 70 both Si and the Si:Al ratio are higher in the light layers which is consistent with a summer input of opal. Clapp (1913) reports Si and Al values of the Saanich granodiorite with a ratio of 3.1 and of the Wark gniess, part of the Jurassic metamorphic complex outcropping along Squally Reach, of 2.4. The significantly higher average ratio in the Saanich Inlet sediments (Fig. 3.4.5) indicates the contribution of opal to these sediments. An interesting feature of this ratio is the significant decrease above sample 70. The fall is caused by decreasing Si content of the sediment which might reflect a decrease in production or a change in the mineralogy of the detrital lithogenous input.

Aluminium (Fig. 3.4.6) is generally present in higher concentration in the dark layers, with the exception of sample 66. The opal-free profile shows that light/dark variation is most noticeable between samples 55-65 and that above sample 70, with the exception of 75, there appears to be much less variation between samples and the Al concentration in the top of the core appears to be fairly constant.

Iron-bearing mafic minerals, such as hornblende, have been recognised in XRD spectra of sediments from other parts of the Inlet (Francois 1987); however, no evidence of them was found in the sediments from this core. The profile of Fe is presented in Fig. 3.4.7. The main iron-bearing mineral seen in the XRD data is chlorite. Iron is also known to be present in anoxic sediments as iron monosulphides and

Fig. 3.4.6 MAJOR ELEMENTS. % BY WEIGHT Al.

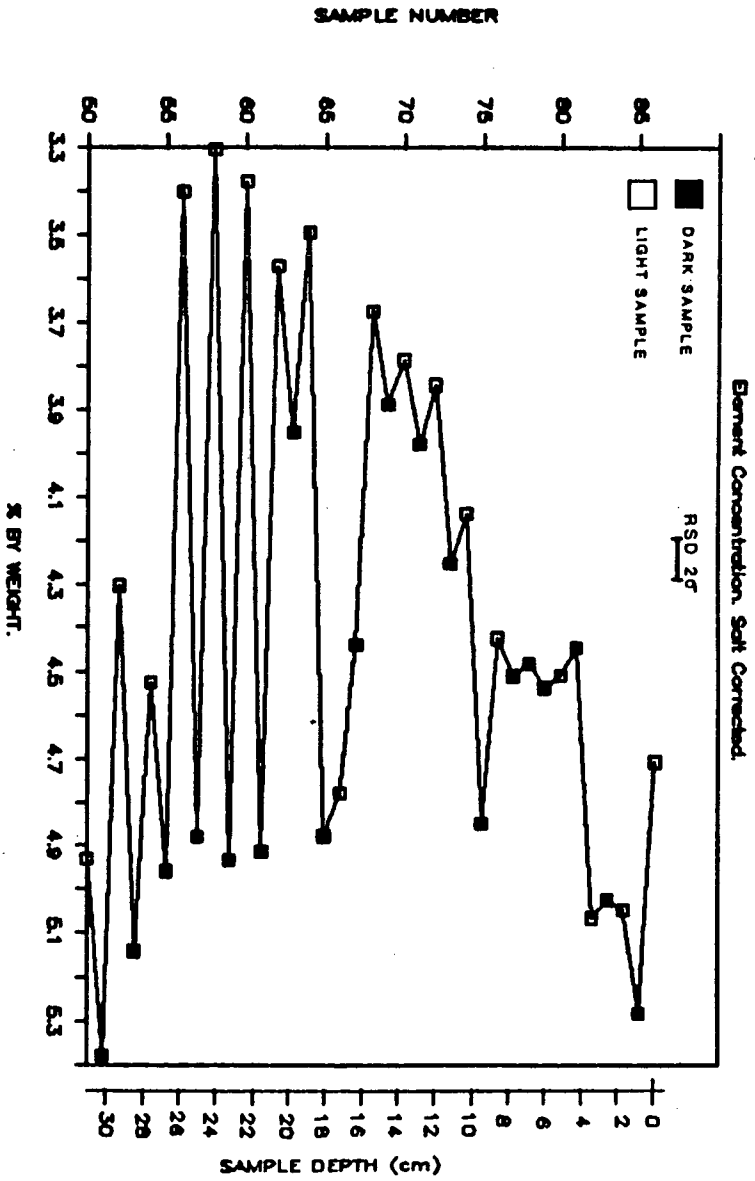


Fig. 3.4.6b ALUMINIUM, OPAL-FREE

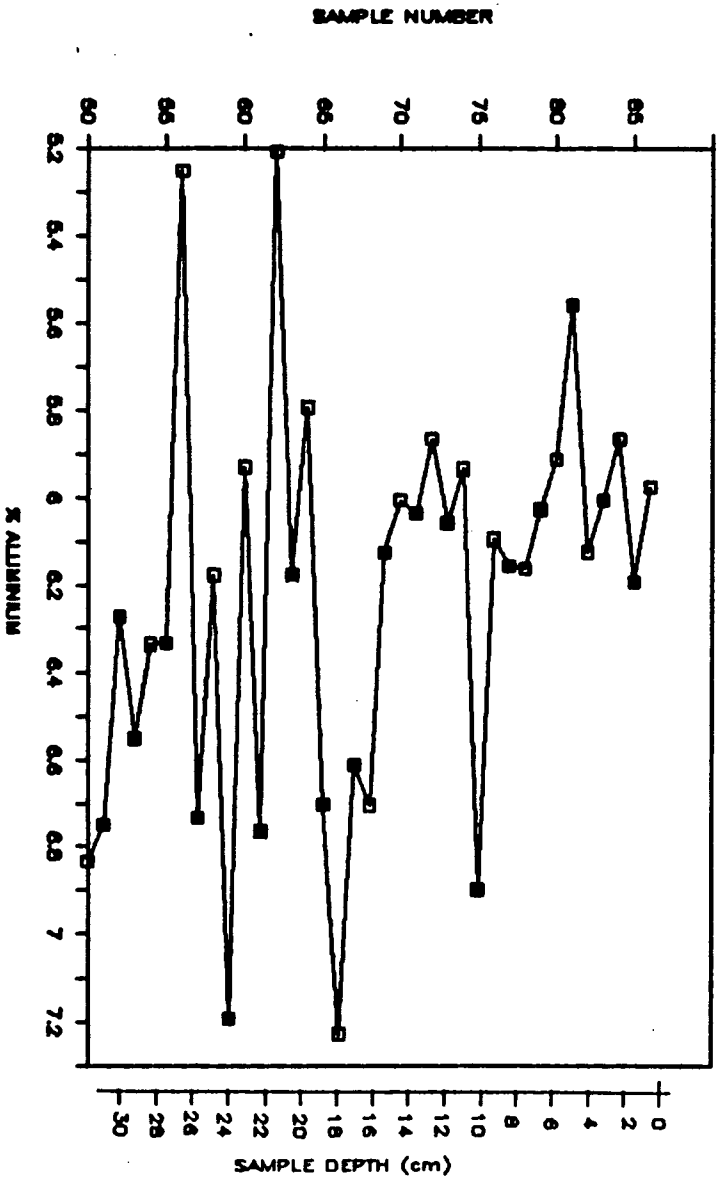


Fig: 3.4.7 MAJOR ELEMENTS. % BY WEIGHT Fe.

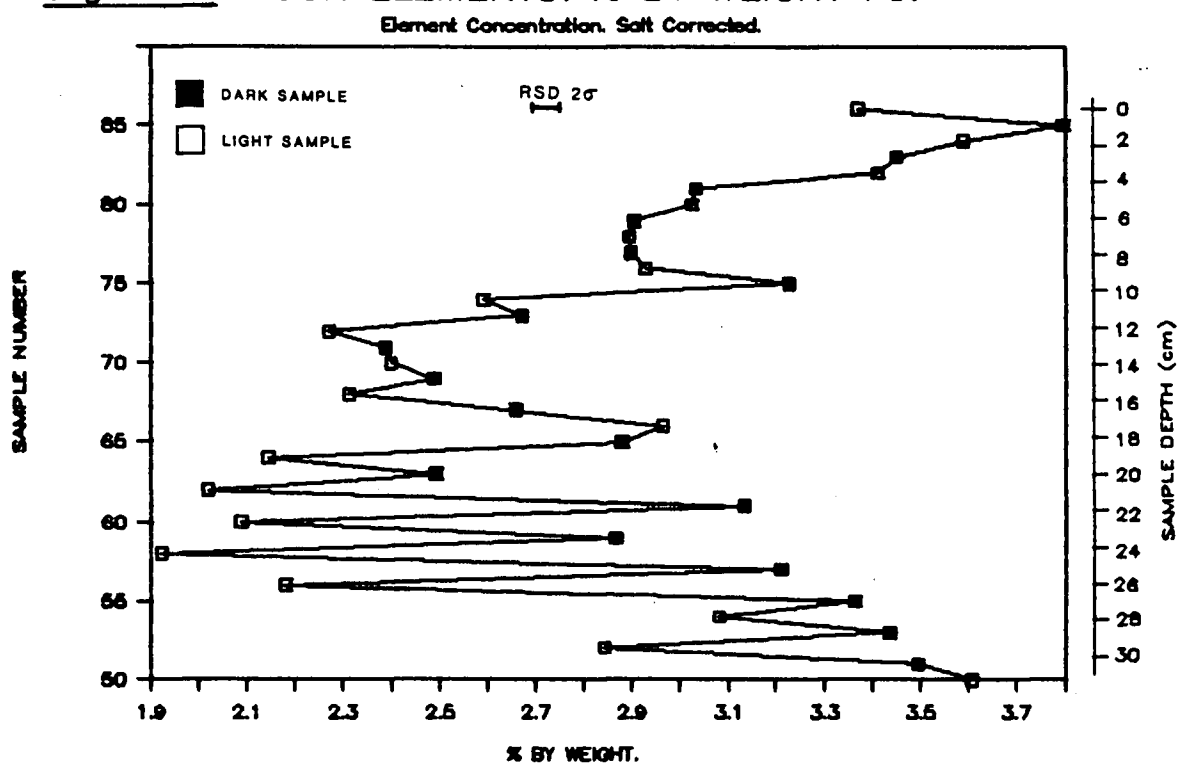


Fig: 3.4.7b IRON, OPAL-FREE

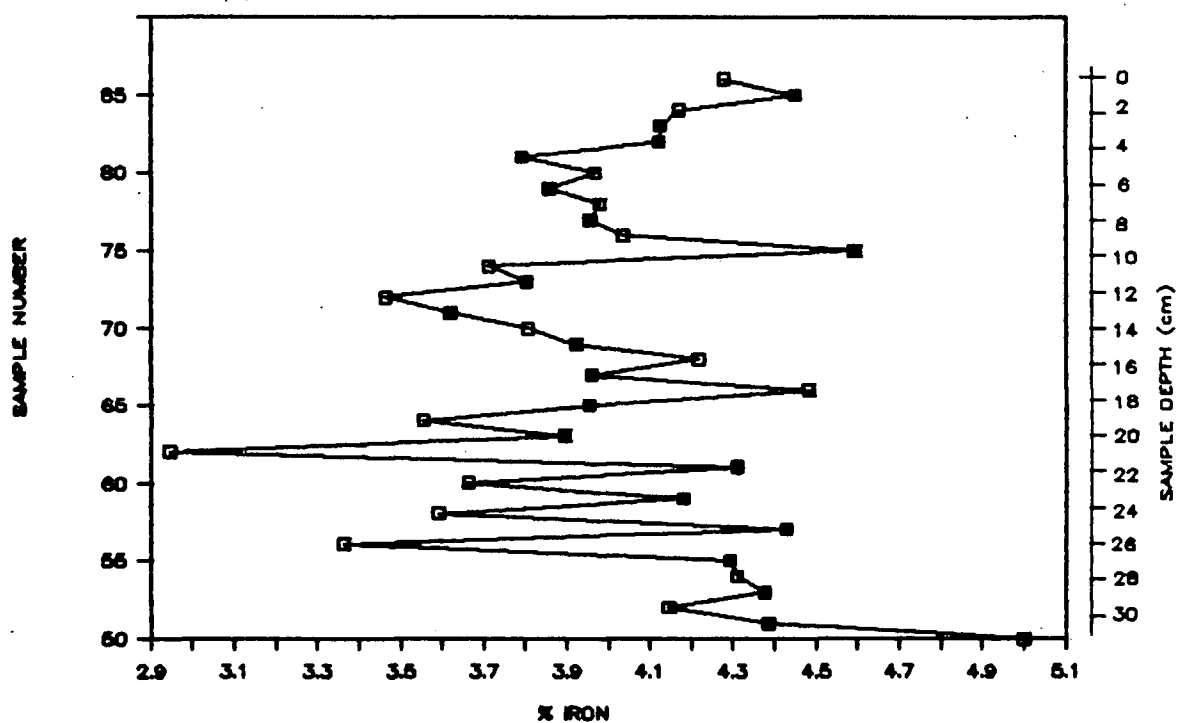


Fig: 3.4.8 IRON:ALUMINIUM RATIO

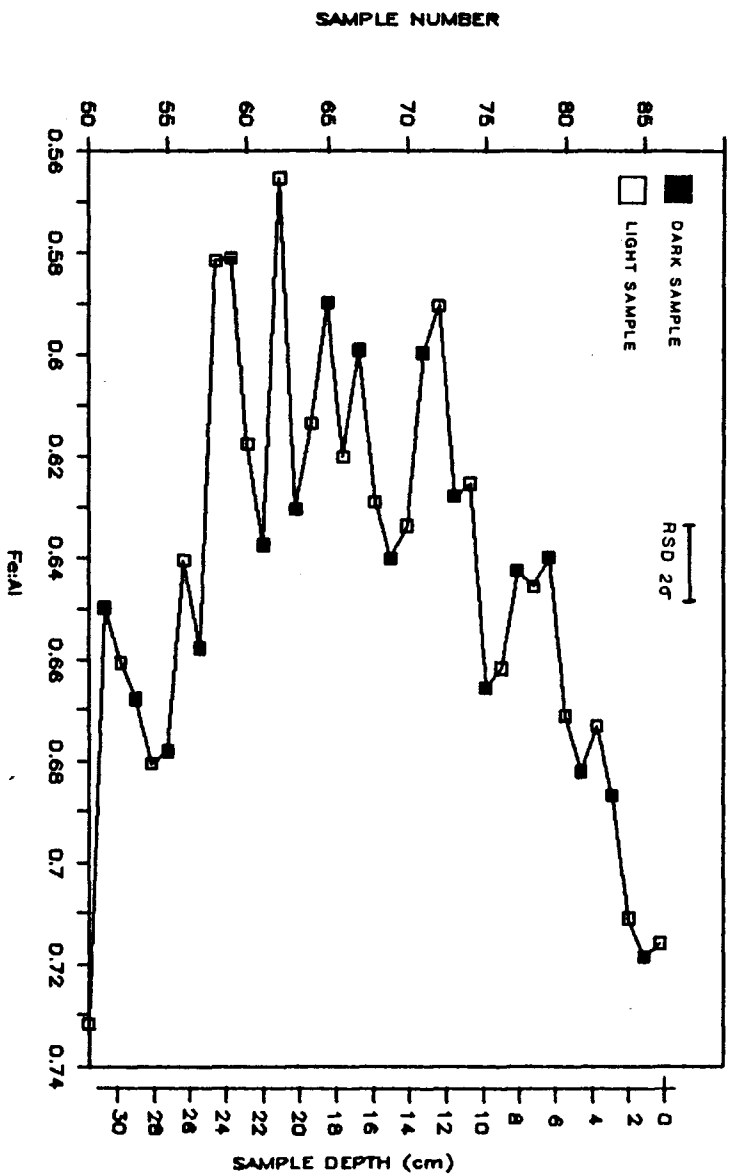
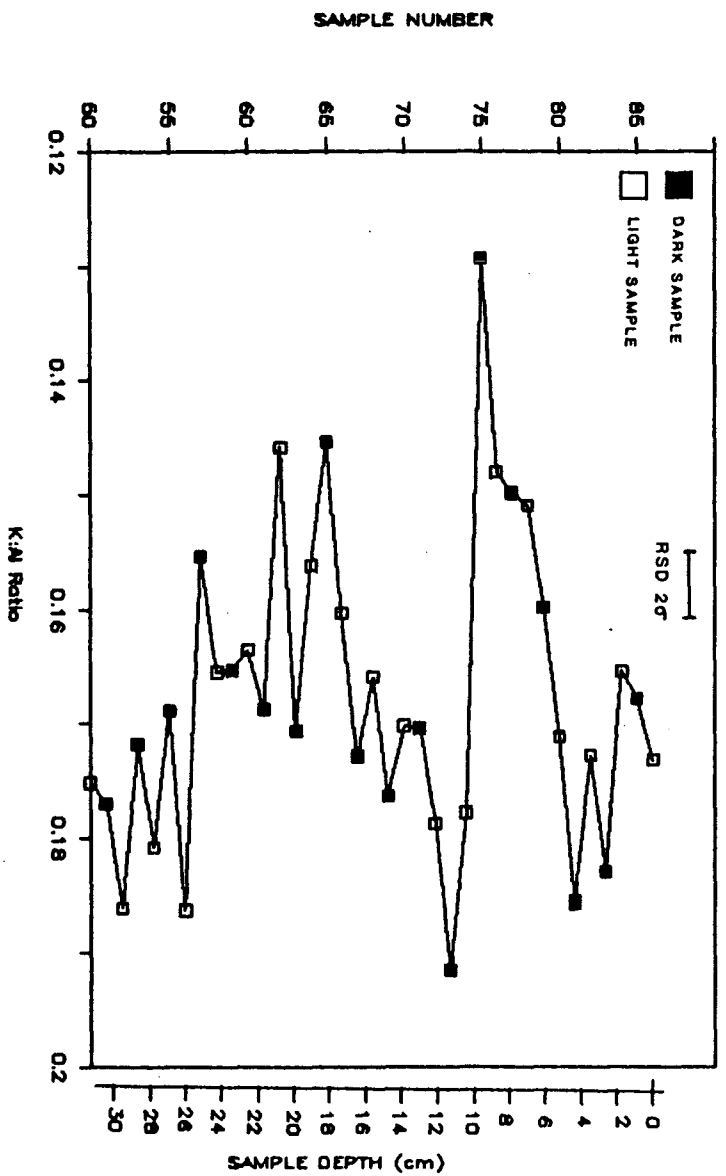


Fig: 3.4.9 K:Al ratio



pyrite; however, no relationship was observed between Fe and S and it seems that the major control on Fe in these sediments is its association with aluminosilicates. The Fe:Al ratio of the sediments has a mean value of 0.64 (Fig. 3.4.8). Clapp (1913) reports Fe and Al values in the rocks cropping out around Finlayson Arm with ratios of between 0.4 and 0.7; thus the sediment values are close to those of the local source rocks. There is, however, a noticeable trend in the profile of the Fe:Al ratio and this indicates that there was a decrease in the input of Fe not associated with clay minerals between samples 55-75 compared to the values at the top and bottom of the core. This indicates that there is an extra input of Fe at the top and bottom of the core. At the top of the core, the increase appears to begin between samples 70-75 and this is coincident with the decreased Si:Al ratio and lower water contents (see section 3.1.2). These observations all lead to the conclusion that there is a change in sediment type at this point and that the younger sediment contains higher amounts of Fe, lower Si and has a lower porosity. The point at which these changes are seen is coincident with the point at which layers became difficult to sample. The increased Fe at the base of this core may also indicate a change in sediment type.

The K content of the sediments will be mainly linked to the amount of alkali feldspar and illite. The amount of illite in the XRD data was small and in most samples a distinct peak could not be measured. However, the

Fig: 3.4.10 MAJOR ELEMENTS. % BY WEIGHT K.

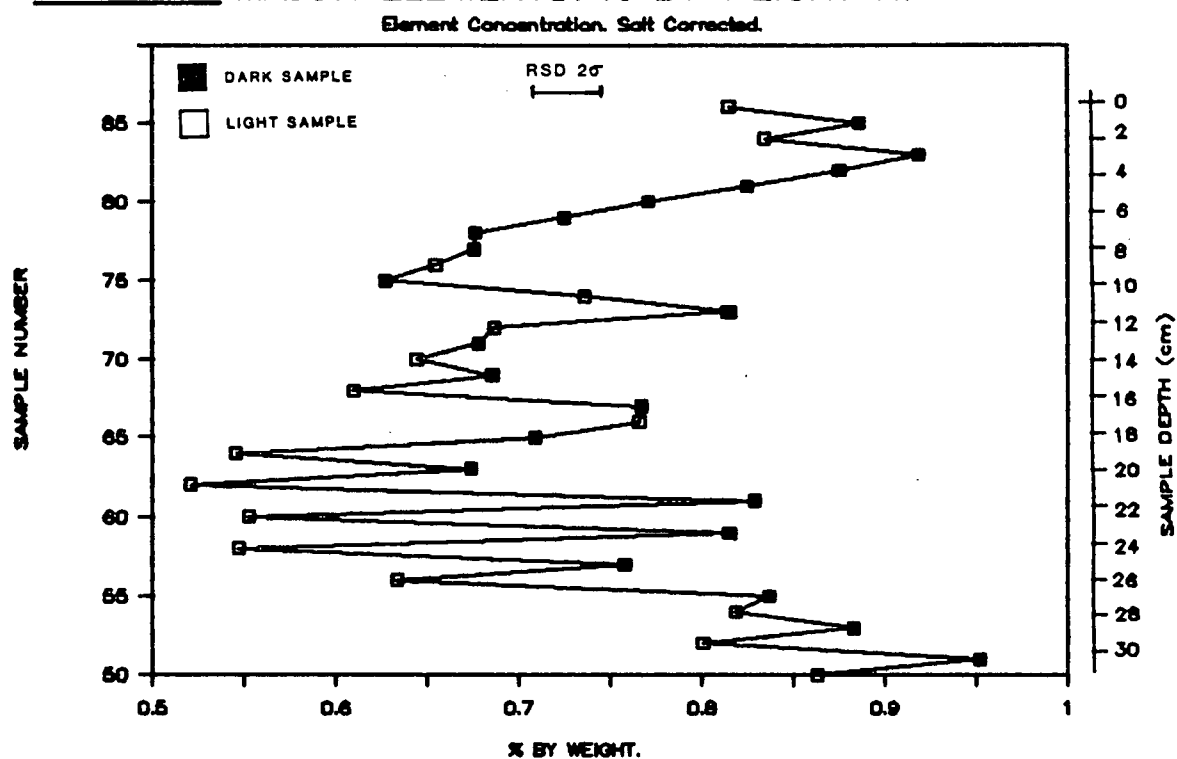


Fig: 3.4.10b POTASSIUM, OPAL-FREE

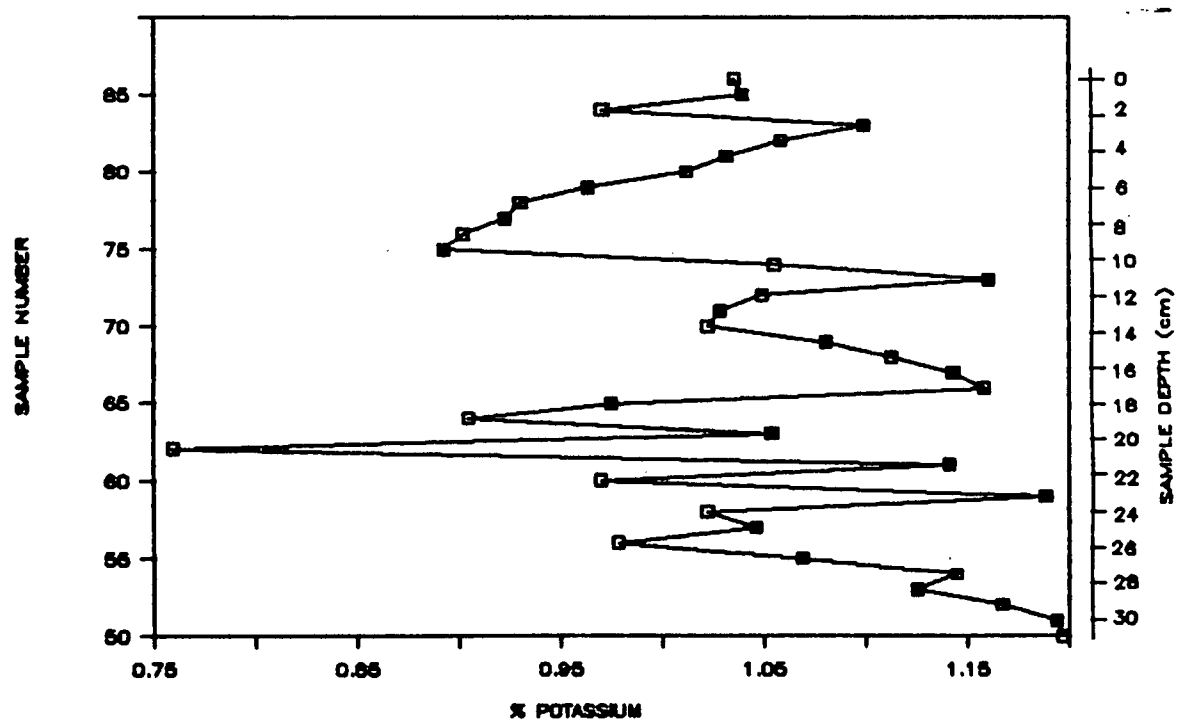


Fig. 3.4.11 % BY WEIGHT OF TI.
 Element concentration. Self Corrected.

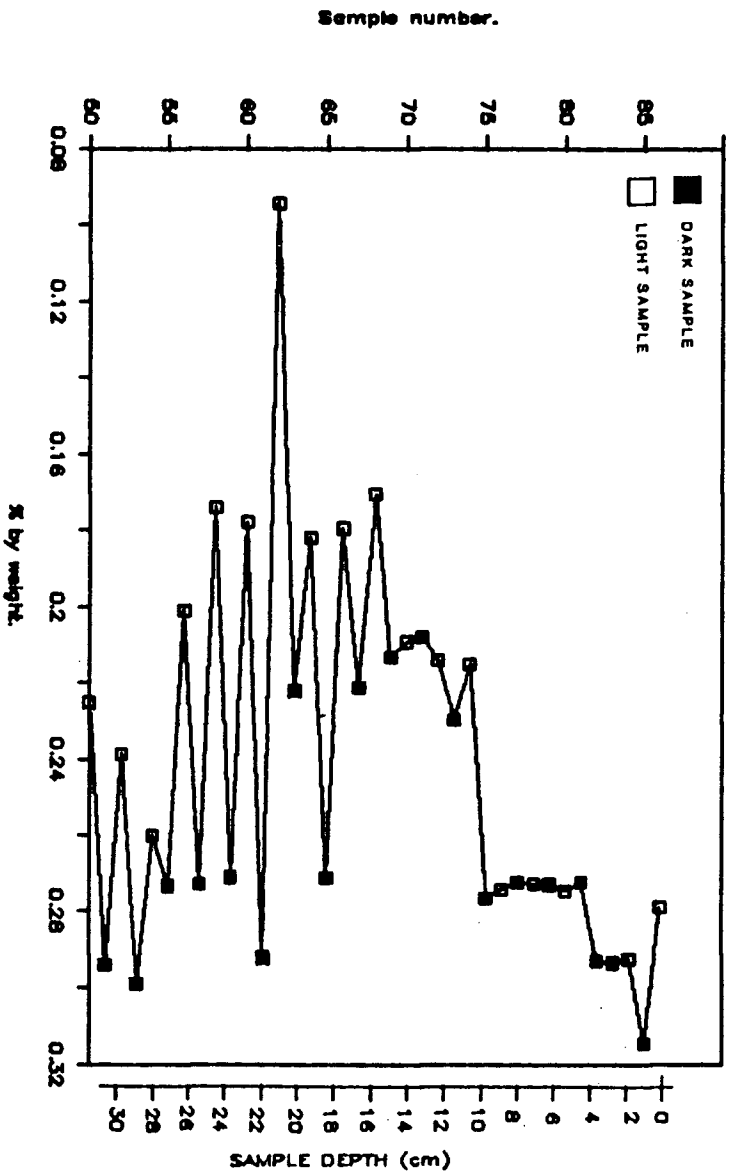
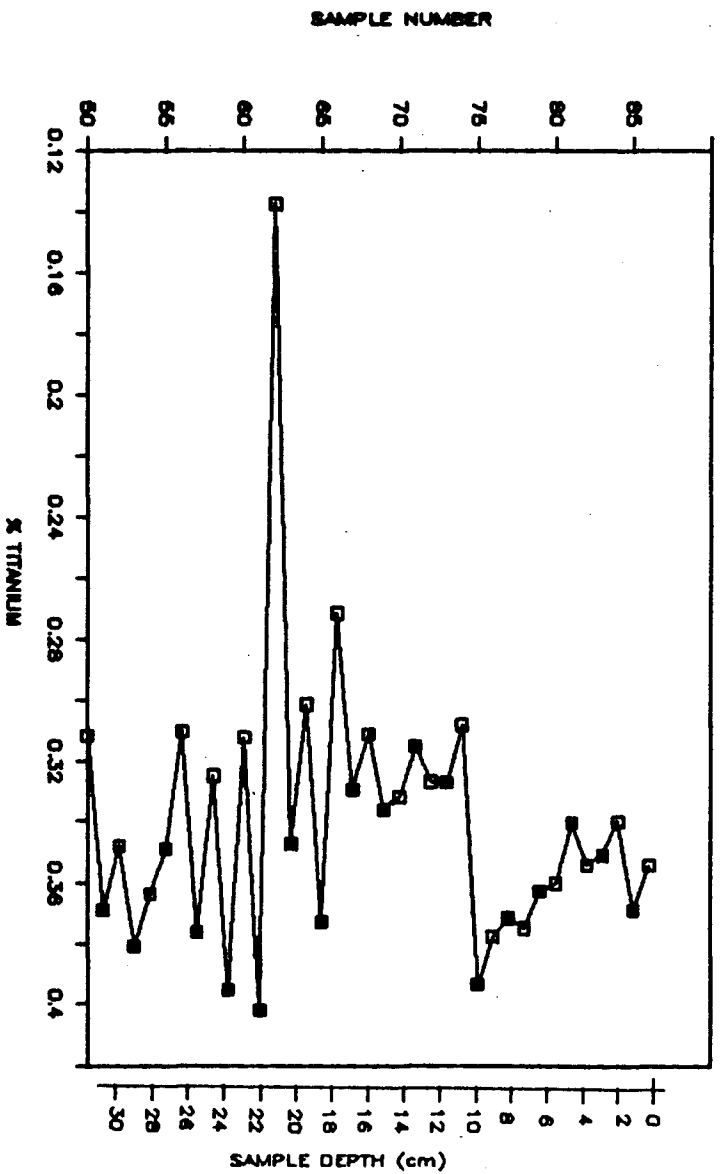


Fig. 3.4.11b TITANIUM, OPAL-FREE



profile of K (Fig. 3.4.9) shows that there are some large changes in K and the peaks do correspond with those samples in which a stronger illite peak was present (samples 85,83,73,64,59,52,50). Sediment trap data collected in the Inlet reported by *Francois* (1987) showed that the input of illite is concurrent with the entrainment of the Fraser River plume during the summer months and it may be that illite peaks at this end of the Inlet are the result of particularly strong incursions of Fraser River water into Saanich Inlet or of particularly strong flushing events transporting the illite from the sill. Variation between light and dark layers is generally random; however, there is a section between samples 55-64 in which there does appear to be a seasonal signal. Neither the K profile nor that of the K:Al ratio (Fig.3.4.10) shows any distinct trend that can be linked to a different sediment type in the core-top, although there is a sharp drop in the K:Al ratio between samples 73-75. Otherwise, K:Al values are generally within the range of the local rocks (*Clapp*, 1913). The decreased K:Al ratio is at a minimum in sample 75. Aluminium, Fe and Ti all show increased values in this sample and it is also seen to have a high quartz:chlorite ratio which is taken to indicate a coarse-grained sediment. The drop in the K:Al ratio must indicate that this sample is low in illite.

Titanium is known to be associated with detrital clays (*Spears and Kanaris-Sotiriou*, 1976) and with some heavy minerals, such as rutile. The profile of this element

Fig: 3.4.12 TITANIUM:ALUMINIUM RATIO

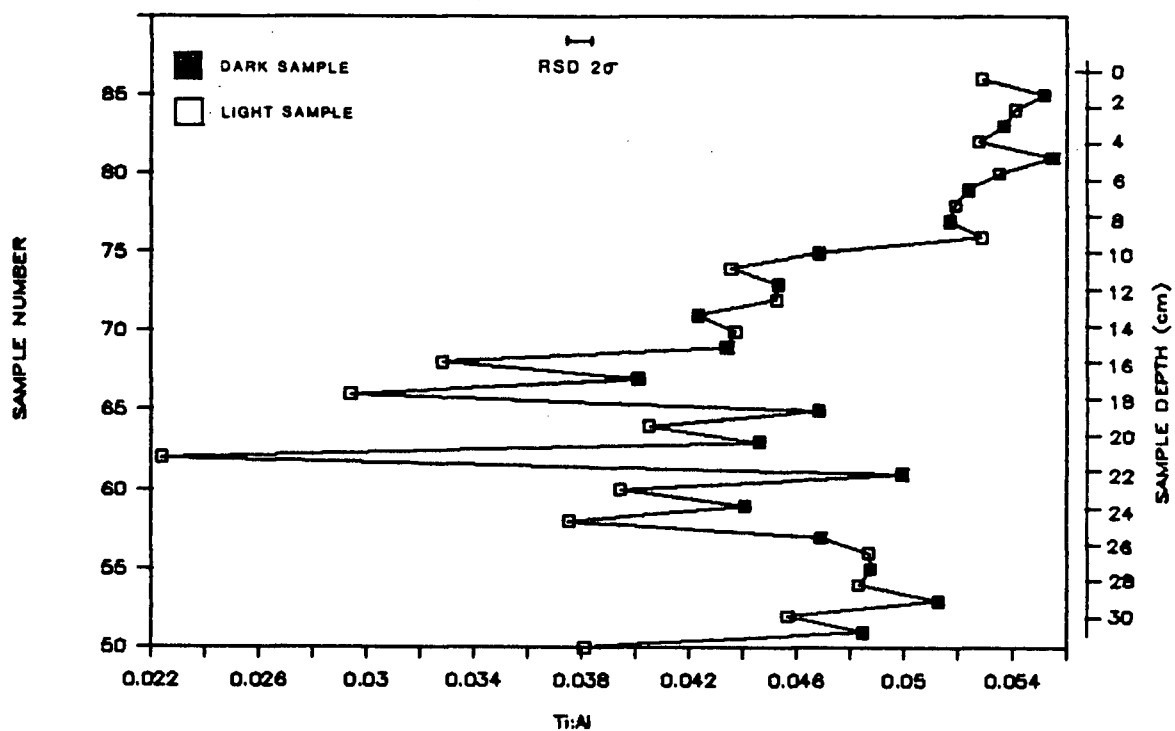
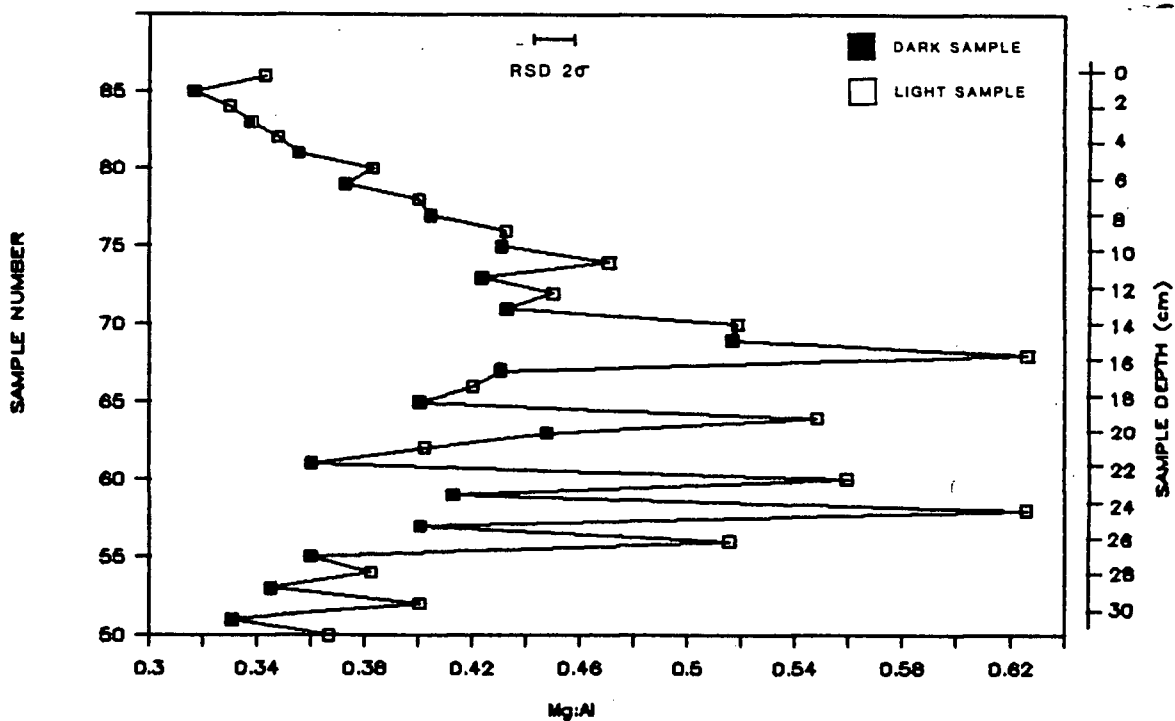


Fig: 3.4.13 MAGNESIUM:ALUMINIUM RATIO



(Fig. 3.4.11) shows relatively small variation with a marked change at sample 75. Below this sample, Ti concentrations are seen to be higher in the dark layers, which is consistent with their formation as a result of winter runoff. Above this level this distinction is no longer evident, and the Ti concentrations are generally higher and much more homogeneous than the samples lower in the core. The increased input of Ti in the top of the core is clearly seen in the Ti:Al ratio (Fig. 3.4.12), which shows values ranging from 0.022 to 0.054. These are in agreement with the values for the local rocks, 0.02 for the Colquitz gniess, part of the Jurassic metamorphic complex cropping out along Finlayson Arm, and 0.05 for the Wark gniess (Clapp, 1913). However, the increasing ratio at the core-top implies an addition of Ti in association with the proposed change in sediment type. *Spears and Kanaris-Sotiriou* (1976) have shown a positive relationship between the Ti:Al ratio and quartz content of shales and argue that this is related to grain-size. However, the low value of this ratio in sample 62 is matched by a high quartz:chlorite ratio indicating high quartz, and the increased Ti:Al ratio at the core-top is matched by a decreasing Si:Al ratio. The increased input of Ti is seen to begin at sample 70, although the largest increase occurs in the coarse-grained sediment in sample 75.

The opal-free Ca profile (Fig. 3.4.13) shows that there does not appear to be any regular pattern of variation between light and dark layers. The profile is characterised

Fig: 3.4.14 MAJOR ELEMENTS. % BY WEIGHT Ca

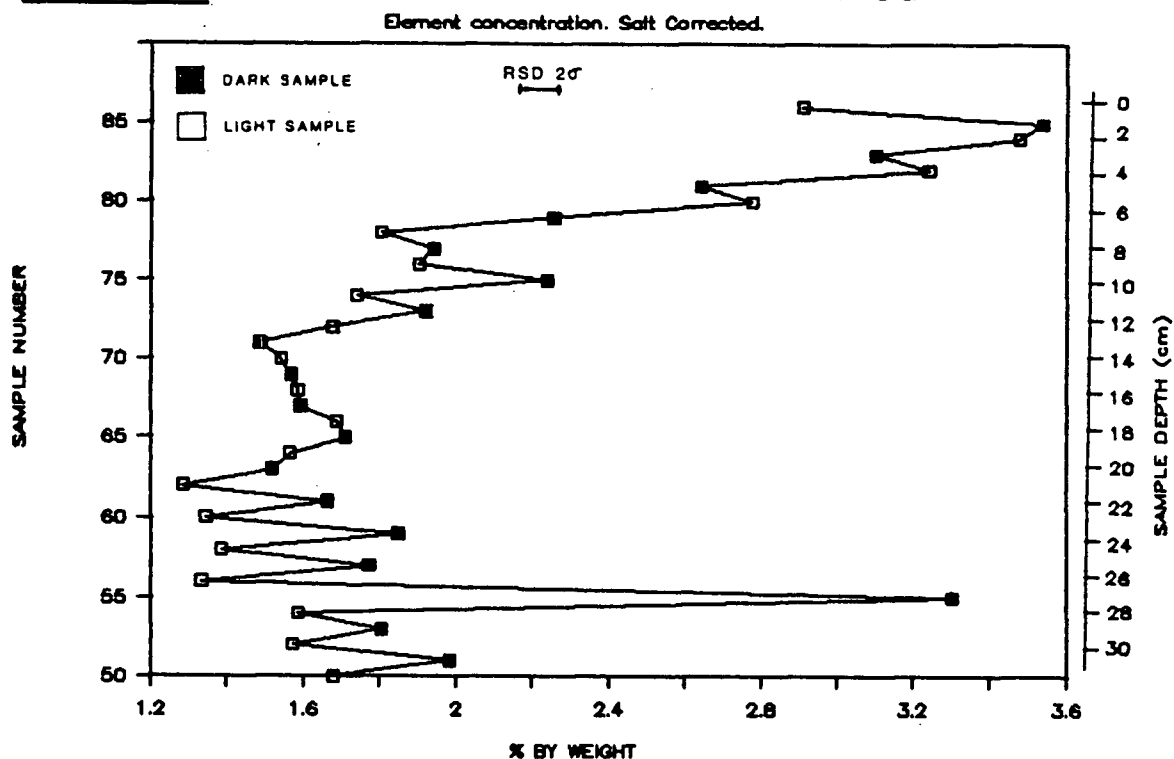


Fig: 3.4.14b CALCIUM, OPAL-FREE

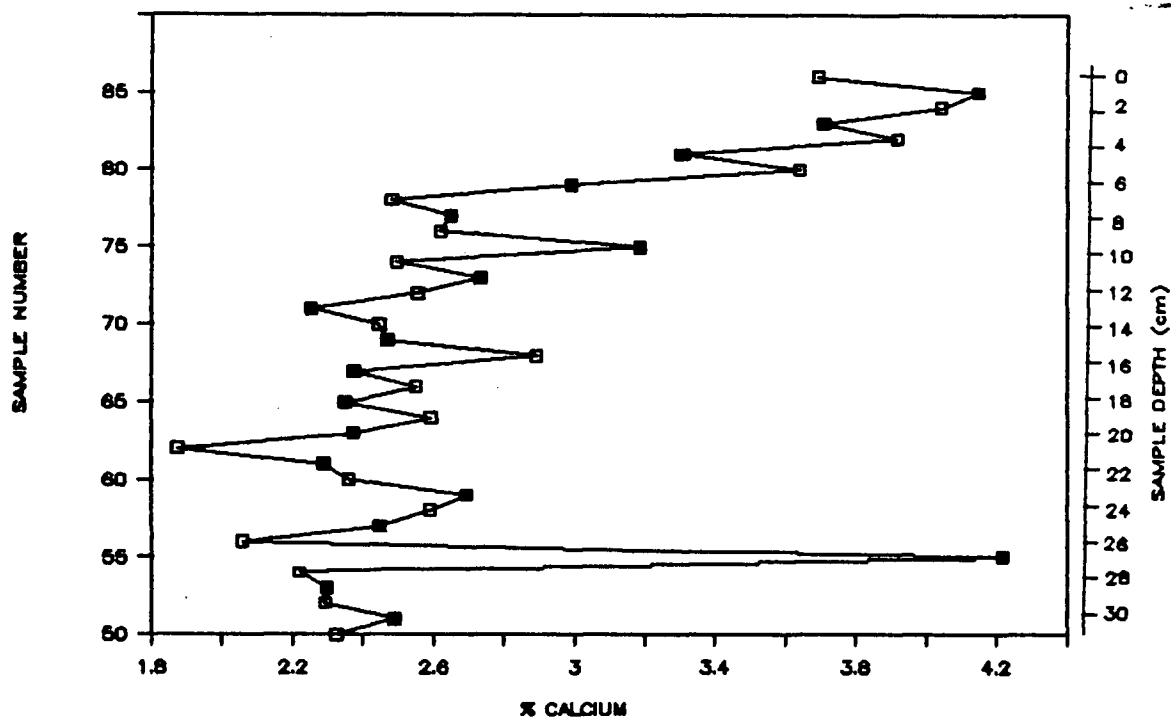


Fig: 3.4.15 MAJOR ELEMENTS. % BY WEIGHT Mg.

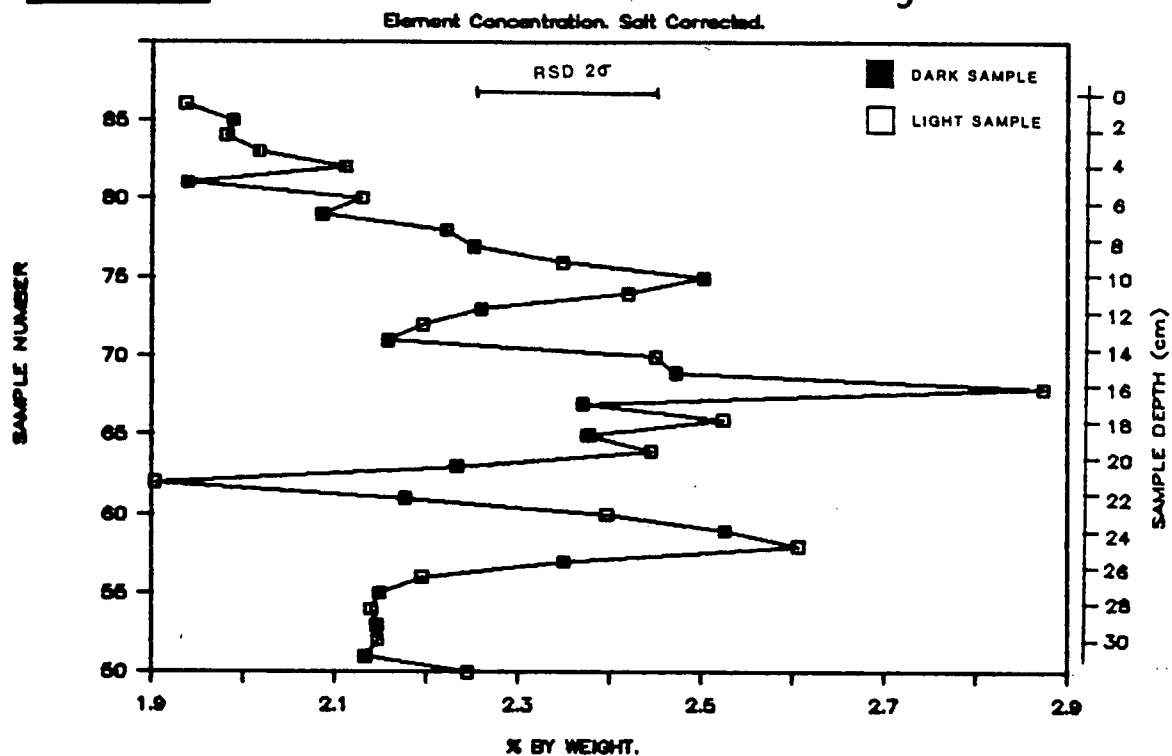
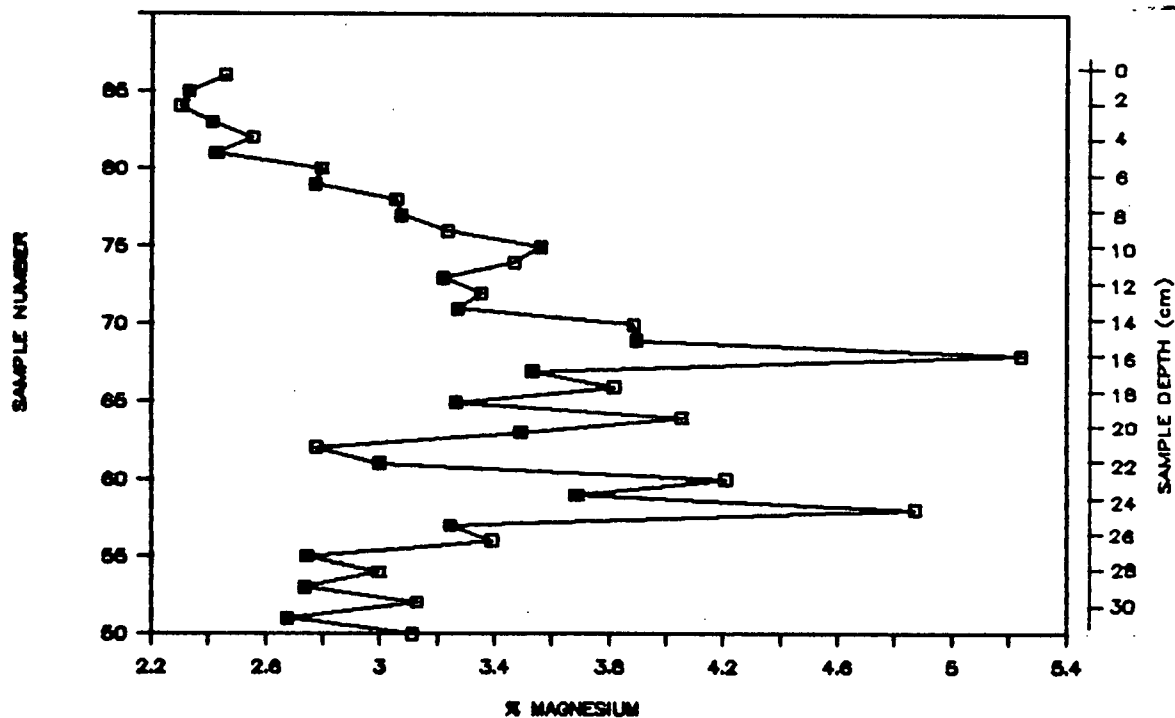


Fig: 3.4.15b MAGNESIUM, OPAL-FREE



by a very high peak in sample 55, which is not matched by an increase in carbonate, and the increased values at the core-top which are thought to be associated with carbonate. It seems that below sample 70, the Ca input is fairly constant, with the exception of sample 55, and it is likely that this element is controlled by its association with plagioclase feldspar.

Magnesium is subject to a large correction because of the content of this element in salt. The Mg profile (Fig. 3.4.14) does have some similarities with the chlorine profile in section 3.1. However, chlorine was determined with reasonably good precision by wet chemistry (see Appendix D) so that the numbers are considered to be reliable. The values are seen to decrease coincident with the decrease in Si and the increased values of Fe and Ti. This decrease is also reflected in the Mg:Al ratio shown in Fig. 3.4.15.

The profile of P is shown in Fig. 3.4.16. The precision of measurement of this element is poor because of its low content in these sediments. Phosphorus is generally associated with organic carbon since it is an essential nutrient for life processes. Samples 68, 69 and 58 do show high values of P and these are matched by high organic carbon content. However, other samples with high carbon do not show peaks in P and the correlation between P and organic carbon was very poor. The C:P weight ratio is around 41, which is the value ascribed to average plankton but higher than the value of 24 ascribed to diatomaceous plankton

Fig: 3.4.16 MAJOR ELEMENTS. % BY WEIGHT P.

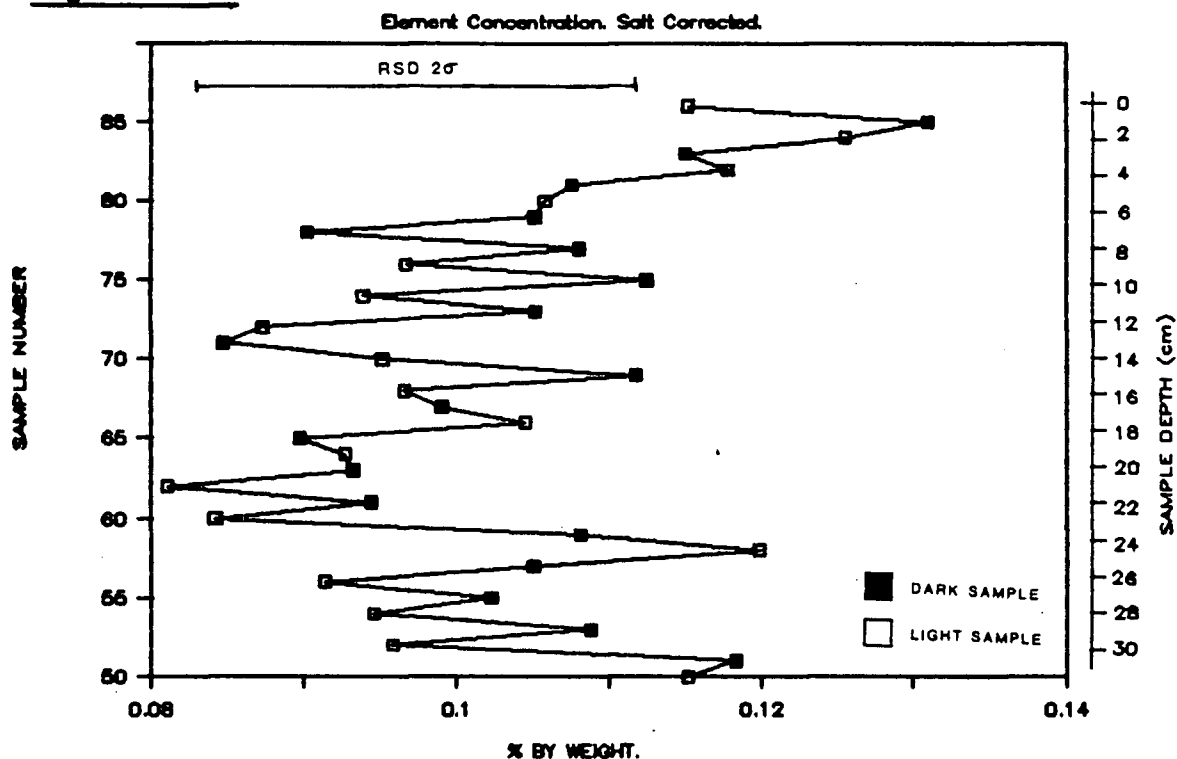


Fig: 3.4.16b PHOSPHORUS, OPAL-FREE

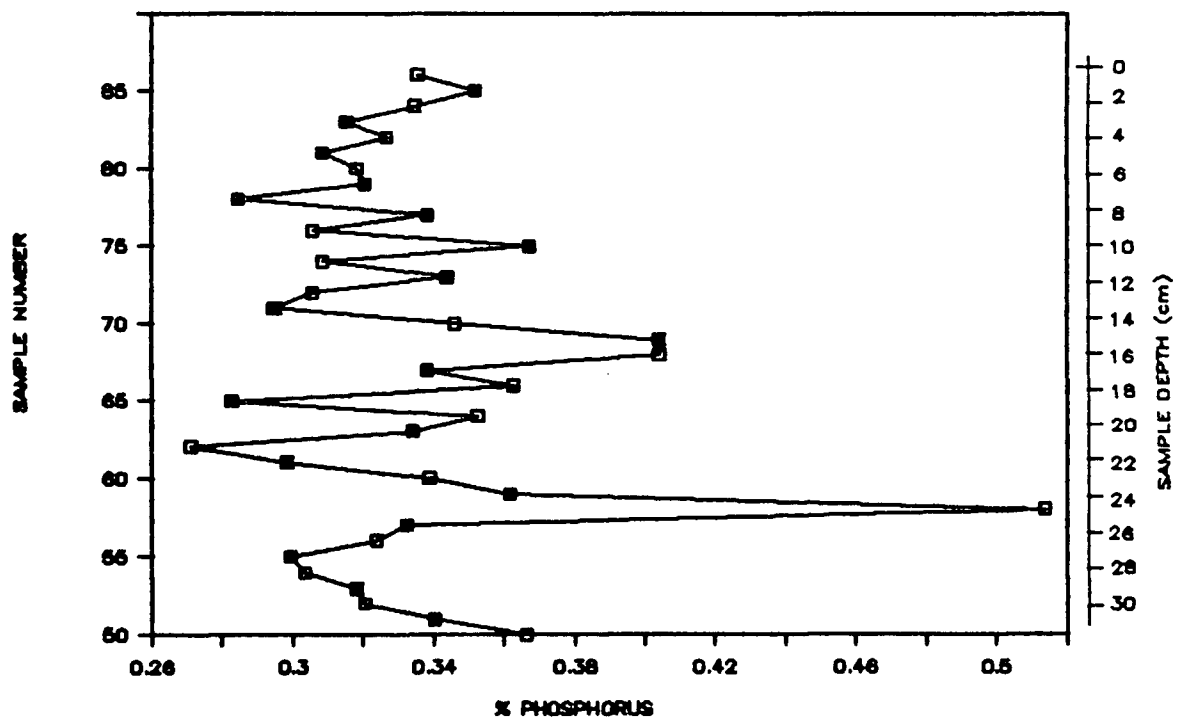
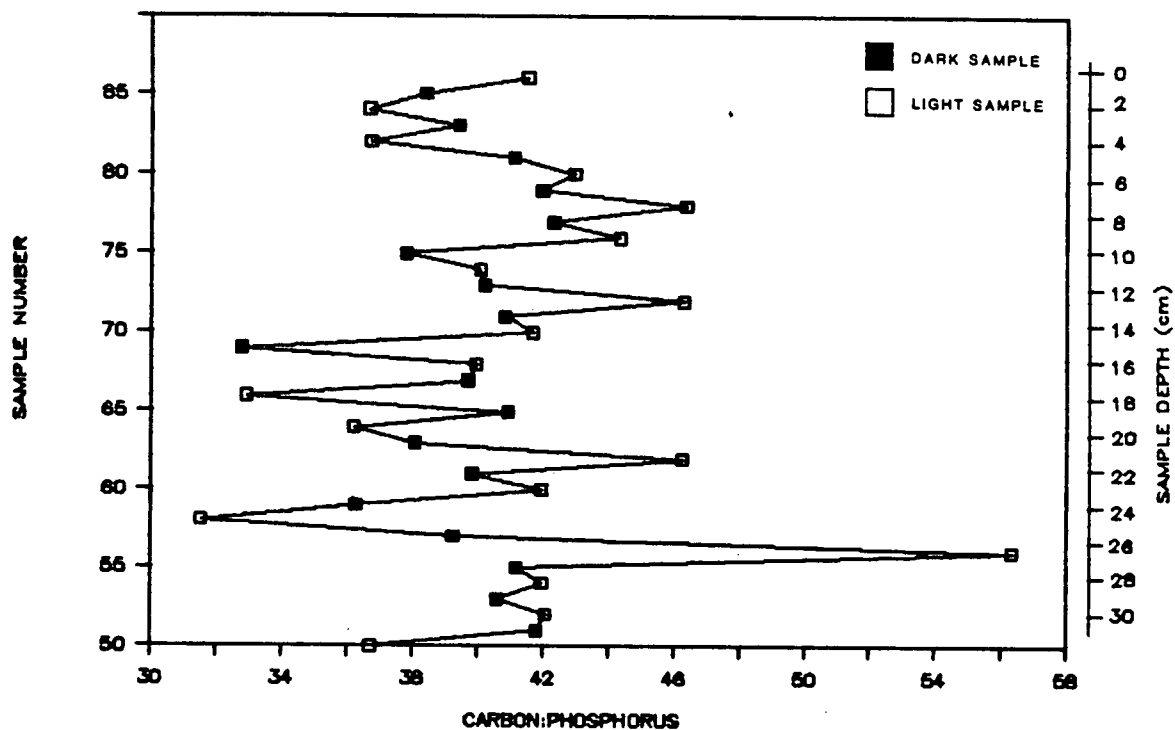


Fig: 3.4.17 ORGANIC CARBON:PHOSPHORUS RATIO



(Calvert, 1976). The profile of this ratio is shown in Fig. 3.4.17 and is seen to be fairly constant with higher ratios being found in the light layers. Sample 56 stands out in this profile with a very high ratio. This sample contains the highest organic carbon content found in this core. This ratio is subject to a number of variables, such as grazing and bacterial decomposition, which will affect the regeneration of these elements. Phosphorus is generally recycled faster than carbon (Calvert, 1976) and thus the high ratios in this core might simply reflect the rapid recycling of P within the water column.

In summary, the profiles of Al, Fe, Ti and K show some interesting features if the light and dark layers are compared. In all cases there appears to be a change in the variation between the layers at around sample 70. Below this sample, all these elements tend to have higher values in the dark layers which is consistent with their deposition during the winter maxima in land runoff, although this distinction is most noticable above sample 55. In the same section, Si and the Si:Al ratio are higher in the light layers which is taken to reflect higher concentrations of opal in these samples and supports the idea that they represent summer deposition. It therefore appears that the geochemical variation of the major elements in the lower part of the core is the sort expected if the samples are reflecting seasonal differences and if pairs of laminae represent annual sedimentation. This observation supports the two

Table IX Minor Element concentrations. Values in ppm.

SMPL	DEPTH	Ba	Cr	Cu	Mn	Mo	Ni	Pb	Rb	Sr	V	Y	Zn	Zr
86	0	307	84	38	5273	74	24	42	28	143	68	16	154	73
85	3.8	370	86	56	8398	93	31	59	31	160	78	15	218	74
84	4.2	381	80	55	7990	81	33	43	29	161	79	19	214	76
83	6.4	361	79	50	4206	82	26	39	31	146	77	14	181	69
82	7.5	338	76	46	6000	77	46	24	26	141	63	15	163	67
81	7.7	357	82	55	1880	95	26	27	29	152	69	17	173	73
80	9.5	384	81	47	1137	101	23	18	31	146	63	13	159	71
79	9.8	402	78	40	772	98	23	24	24	121	63	11	154	64
78	10.9	382	73	59	795	93	25	18	29	132	62	15	149	69
77	11.3	427	84	51	789	103	23	10	33	146	66	15	152	72
76	11.5	409	76	54	753	85	26	14	32	128	58	14	143	169
75	11.8	421	76	53	835	90	31	7	29	152	64	15	134	72
74	12.7	392	72	42	732	85	24	16	23	118	52	13	122	67
73	13.3	439	85	60	851	107	33	16	27	161	70	17	158	74
72	14.1	345	72	43	513	97	20	9	24	102	46	13	106	61
71	15.4	401	64	36	541	91	21	10	28	106	50	12	104	64
70	16.2	454	76	47	626	97	28	7	25	139	61	13	116	68
69	17.1	407	68	36	531	100	23	5	27	128	54	14	108	70
68	18.3	331	57	16	391	96	19	3	21	92	36	13	84	60
67	18.7	433	75	45	535	102	23	10	27	129	60	14	106	70
66	18.9	441	72	40	466	103	21	2	27	109	60	13	103	69
65	19.5	445	73	43	612	115	26	2	34	147	67	15	108	74
64	19.7	371	56	27	401	104	18	6	23	108	38	11	85	74
63	19.9	401	61	34	502	96	24	13	21	136	54	16	108	70
62	20.6	326	62	21	458	77	21	4	24	92	49	10	89	60
61	21.1	455	74	37	636	101	27	18	27	129	66	19	107	68
60	22.4	340	56	19	368	109	12	3	22	71	33	10	77	58
59	22.6	449	76	39	556	146	23	13	34	136	63	13	105	73
58	23.2	304	60	21	341	120	11	12	23	87	31	11	70	53
57	24.3	423	86	40	582	110	29	13	28	131	66	15	98	67
56	27.2	316	67	31	373	86	18	10	24	102	48	14	78	61
55	27.7	412	77	43	614	93	27	8	31	132	72	17	95	69
54	28.4	391	72	41	518	78	24	2	24	107	62	16	87	66
53	29.7	432	74	41	571	93	29	5	30	126	71	14	93	70
52	30.6	356	66	32	504	82	26	8	25	124	55	15	81	69
51	31.6	430	80	34	573	97	32	10	35	137	72	16	96	75
50	32.2	399	71	42	440	86	29	8	21	117	50	15	92	65

* All values are salt corrected.

* Values shown are the mean of three measuring cycles.

sediment models proposed to explain the measured ^{210}Pb activity in these sediments (see section 3.1). The seasonal nature of the lamina samples, at least within the lower half of the reported section, is also supported by both the minor element data (section 3.5) and by the diatom data (section 3.6). Note also that the regular variation between the samples breaks down at the bottom of the core, and that samples 55-50 do not show such clear differences between light and dark layers. This implies that a clear seasonal signal is only present in the middle section of the core. There was an enrichment of iron in this section but, unlike the core-top, no increase in Ti or decrease in Si was seen.

Above sample 70 the lithogenous elements Al, Fe, Ti and K show distinctly different profiles and the Si and Mg contents of the sediment decrease. The distinction between light and dark samples is no longer obvious and the concentration differences between samples are reduced. Potassium is an exception in that there are some large variations in its concentration within this section. Silicon, Al, Fe, and Ti all show higher concentrations in sample 75 and the quartz:chlorite ratio is exceptionally high in this sample. Potassium does not show higher concentrations in sample 75 and the K:Al ratio shows the lowest value in the core indicating that there was perhaps little illite in this coarse-grained sample.

This change in the profiles around samples 70-75 coincides with the point at which the layers were seen to

become indistinct during sampling and it is proposed that there is a change in sediment type and sedimentation rate (see section 3.1) at this point. The new sediment is thought to have lower concentrations of Si and Mg while Fe and Ti are enriched. The chlorinity profile appears to indicate that this sediment also has a lower porosity and, since no distinction can be made from the XRD spectra, the new sediment components are poorly crystalline. The most likely source for such a sediment is the Bamberton cement works; however, the increase in Fe and Ti begins lower in the sediment column than the observed increase in carbonate. Finished cement is likely to be poorly crystalline and is known to contain Fe. However, it also contains Si and Al in much larger quantities and these elements do not show the increase that an input of cement would cause.

3.5 The geochemistry of minor elements.

The geochemistry of trace or minor elements in Saanich Inlet was first examined by Gross (1967) and has recently been studied in detail by Francois (1987). The concentrations of any minor element such as Ba, Cr, Cu, Ni, Pb, Rb, Sr, V, Y, Zr and Zn have been shown in past studies of nearshore sediments to be strongly correlated with the input of detrital lithogenous material (Hirst, 1962b; Calvert, 1976). The reason for this correlation is that they substitute for major elements within the lattices of aluminosilicate minerals (Krauskopf, 1979). In Saanich

Inlet, *Francois* (1987) has shown that some of these elements are also enriched in the diatomaceous anoxic muds of the central basin. He showed that V, Ni, Cr and perhaps Cu are enriched because of diagenetic processes, while Zn, Ni and Cu are also probably enriched because of their chalcophile nature and the deposition of sulphides within these anoxic sediments. He also found that the enrichments were much greater in the sediments of Finlayson Arm. This is probably attributable to the strong reducing conditions in these sediments (*Gross and Gucluer, 1964*) and to lower sedimentation rates at this end of the Inlet, which causes less dilution of diagenetically mobile elements by lithogenous and biogenous components.

The study of the distribution of these minor elements in this core is hampered by a number of factors. Firstly, the range of concentrations observed is generally small, making the determination of any relationships between elements difficult. *Francois* (1987) studied the full range of sediment types within the Inlet so that a much wider range of variation was observed. Secondly, no data were available for the minor element concentrations of the purely lithogenous input into the Inlet and thus changes in the contribution of terrigenous material to the laminae could not be definitively identified. The nature of the laminae themselves is also questionable (see section 3.1) and differences in the concentration of most minor elements between the light and dark layers is generally within the 2

Fig: 3.5.1 BARIUM

Opal Corrected

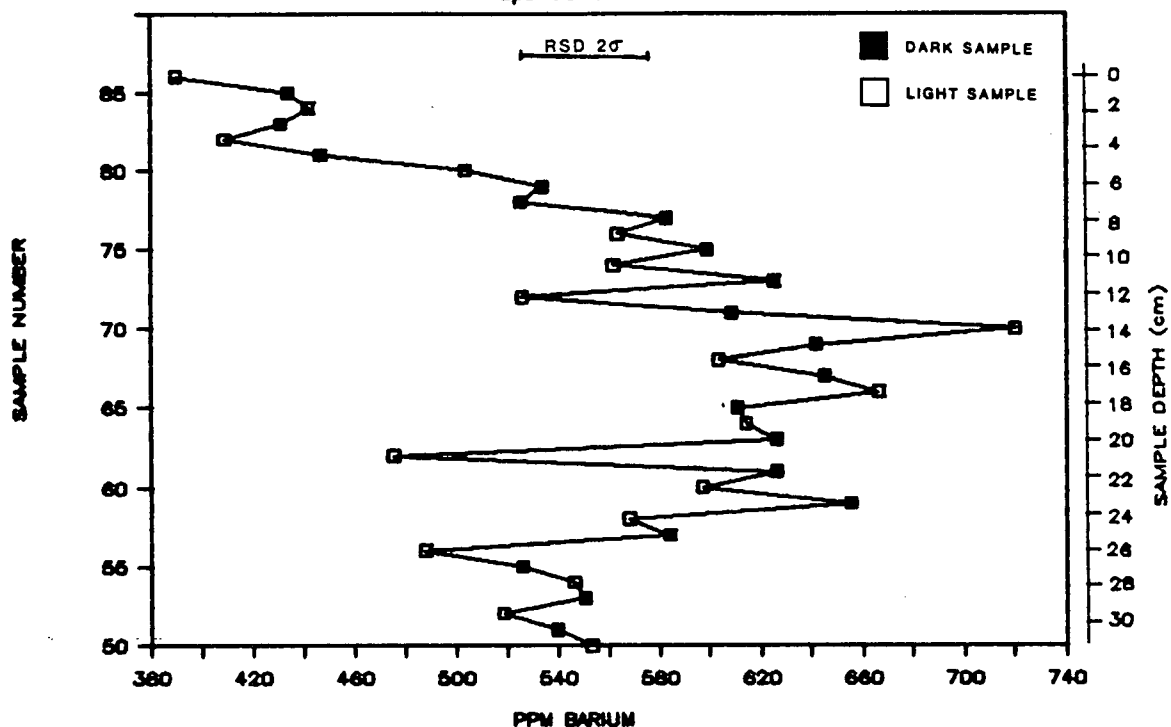
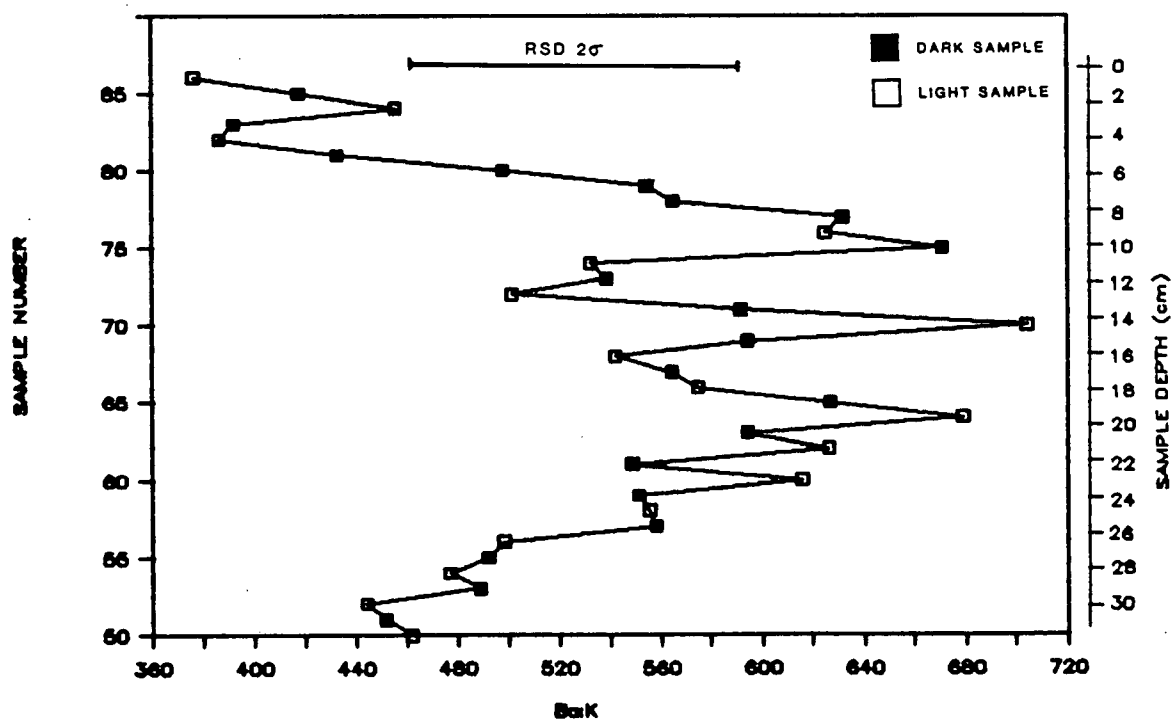


Fig: 3.5.2 BARIUM : POTASSIUM RATIO



error. However, it will be shown that there does appear to be a seasonal signal in the profiles of some elements and that the minor elements generally support the proposition that there are two different sediment regimes within the reported section of this core.

The minor element data are presented in Table IX. Many of the elements (Cr, Ni, Rb, Sr, V and Y) had profiles which decreased to minimum values coincident with high concentrations of opal and therefore the profiles presented here have been corrected for dilution by opal. The first section discusses the absolute abundances of the trace elements and is followed by a section describing their ratios to Al.

3.5.1 Absolute abundances of minor elements.

Barium is known to substitute for K in K-feldspars and micas. The profile of this element (Fig. 3.5.1) shows that values are generally higher in the dark layers, with the exception of samples 70 and 66. Values are seen to show variations between light and dark samples until sample 79, when the seasonal signal appears to break down. There is a significant drop in the Ba content of the sediments in the top of the core which is coincident with the increase in carbonate described in section 3.3. Sample 70 has the highest Ba concentration which appears to be unusual for a light layer.

Fig: 3.5.3 CHROMIUM
Opd Corrected

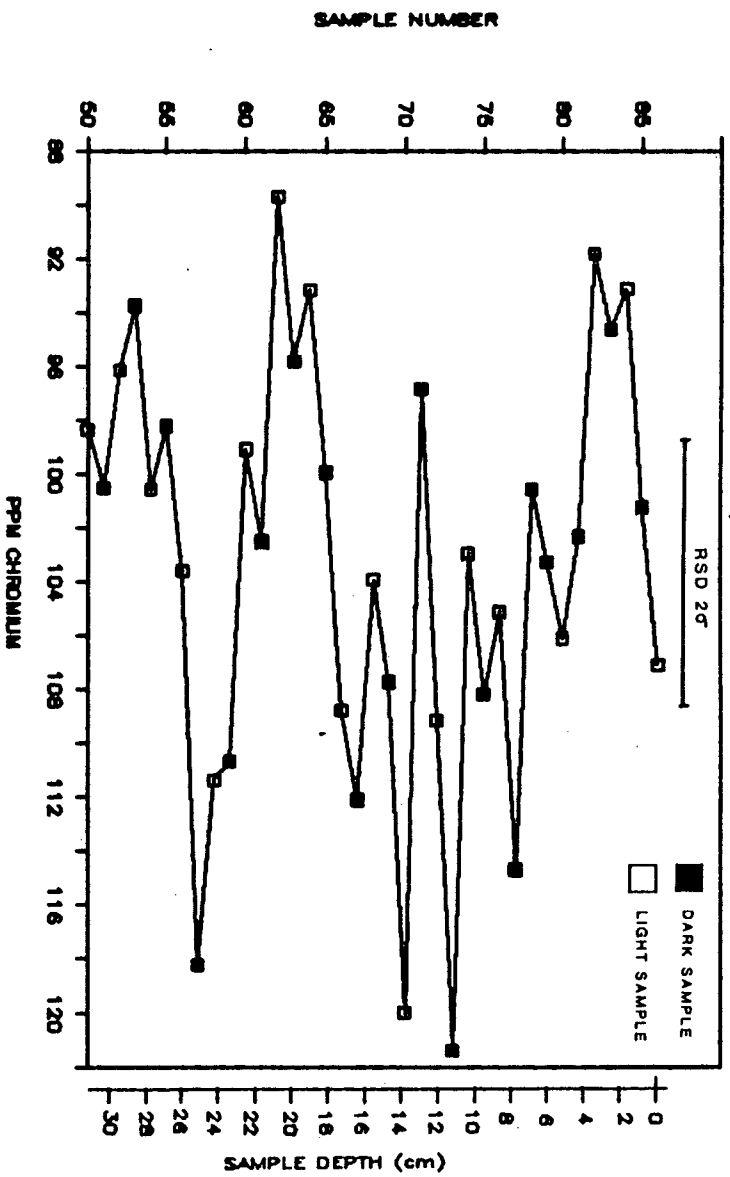
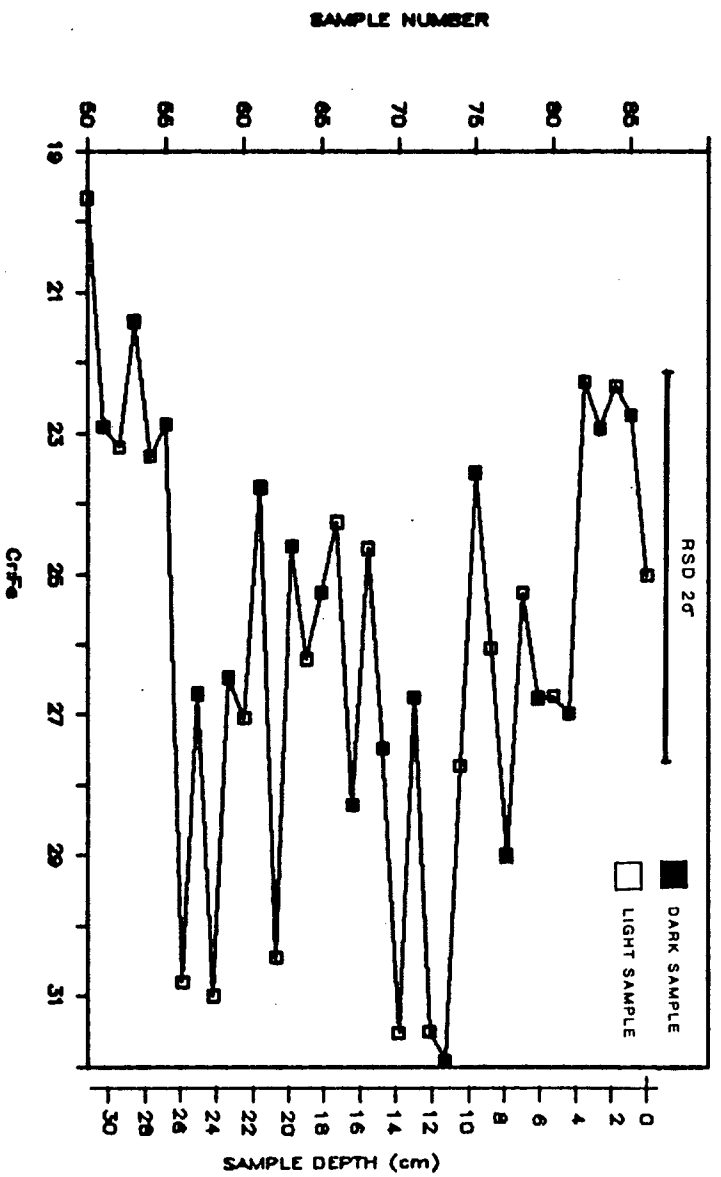


Fig: 3.5.4 CHROMIUM : IRON RATIO



Previous work has indicated a possible link between Ba and the opal content of sediments (Goldberg and Arrhenius, 1958; Brongersma-Sanders et al. 1980), although whether the Ba was directly associated with the opal or if barite was produced in the soft tissues of the diatoms was not known. Calvert and Price (1983) saw no correlation between high opal contents and Ba in the inshore areas of the Namibian shelf, the highest Ba concentrations being located at the outer edge of the shelf. Fresnel et al. (1979) have shown that Ba is concentrated by prymnesiophyte flagellates and culture studies on the genus Pavlova have confirmed this (Calvert, unpublished data). Schmitz (1987) has argued that Ba enrichments in equatorial regions is associated with zones of high production. The plot of the Ba:K ratio (Fig. 3.5.2) shows a maximum in the middle section of the core coincident with the opal maximum (Fig. 3.2.4). This should not, however, be taken as indicative of enrichment by diatoms since flagellates are thought to be important contributors to primary production in BC inlets (Harrison et al. 1983) and it is proposed that the Ba enrichment simply indicates a time of higher production. The Ba:K profile also shows variation between light and dark layers in samples 59-65 with the light layers having the higher ratio expected if Ba is indeed linked to primary production. Sample 70, which has unusual concentrations of a number of minor elements, also has a high Ba:K ratio. With the exception of sample 75, which showed peaks in some of

the major elements, the upper sediment is characterised by a steady decrease in the Ba:K ratio and this might be indicative of decreasing primary production. Lower ratios are also observed in the bottom of the core, which might mean that longer term production cycles occur at this end of Saanich Inlet, lending support to a further change in sedimentation within the last few samples at the base of the core.

Chromium substitutes for Fe and Mg in mineral lattices. *Hirst* (1962b) argued that the substitution is most noticeable in illite but that substitution in montmorillonite also occurs; however, both these minerals are minor components of Saanich Inlet sediments. The profile of Cr is shown in Fig. 3.5.3 and the Cr:Fe ratio is presented in Fig. 3.5.4. Chromium values are generally higher in the dark layers, although sample 70 is again seen to be unusual in that it has a high Cr concentration. Since the Fe profile shows no systematic variation, the increased Cr:Fe ratio in the centre of the core indicates that this element is also enriched where opal values are higher. Higher Cr:Fe ratios are seen in the light layers between samples 55-65, and the ratio is seen to fall at the base of the core. *Francois* (1987) has shown through a correlation between the Cr:Mg ratio and organic carbon that this element is indeed enriched in sediments containing high carbon.

Copper is thought to be added to anoxic sediments by precipitation of CuS or by association with organic matter (*Doff*, 1969; *Calvert*, 1976). The profile of Cu (Fig.

Fig: 3.5.5 COPPER

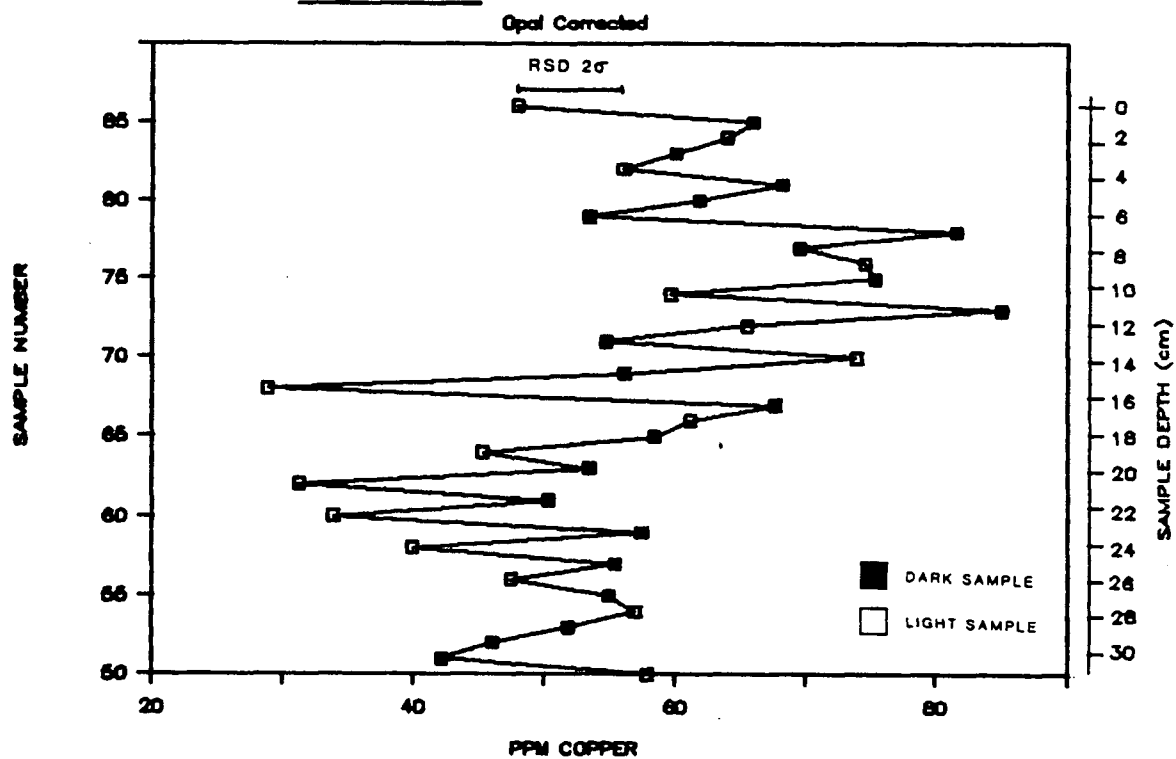


Fig: 3.5.6 MANGANESE

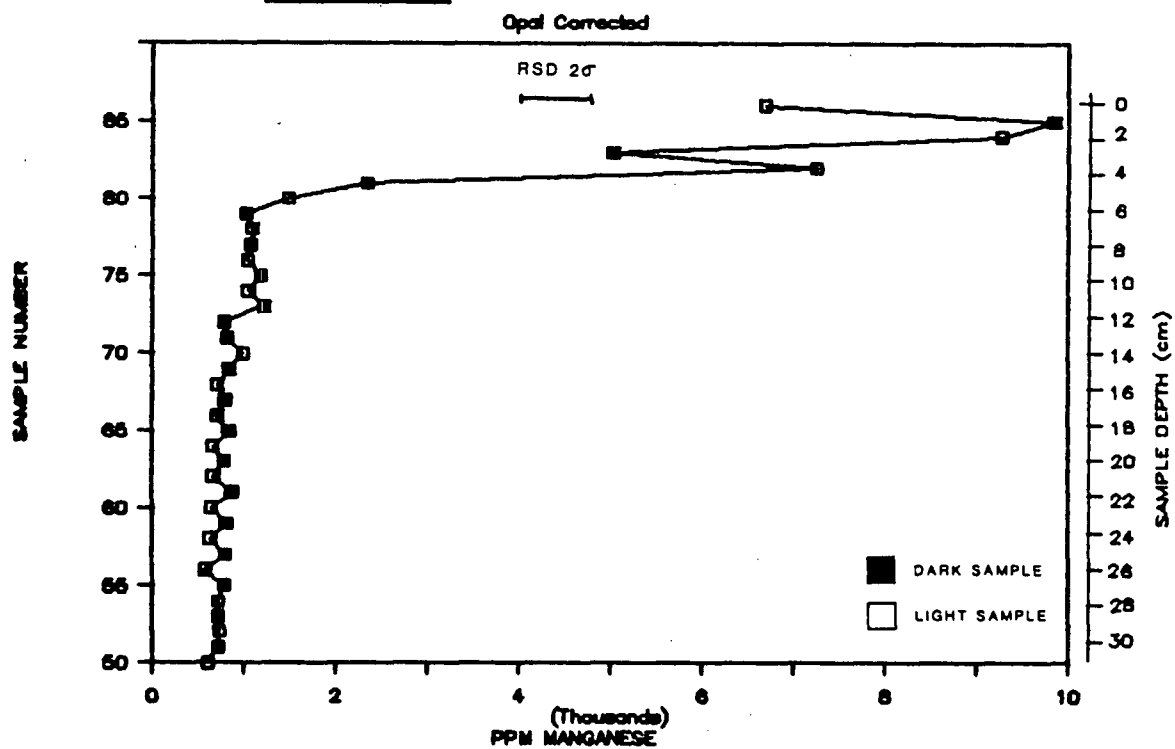


Fig: 3.5.7 MOLYBDENUM

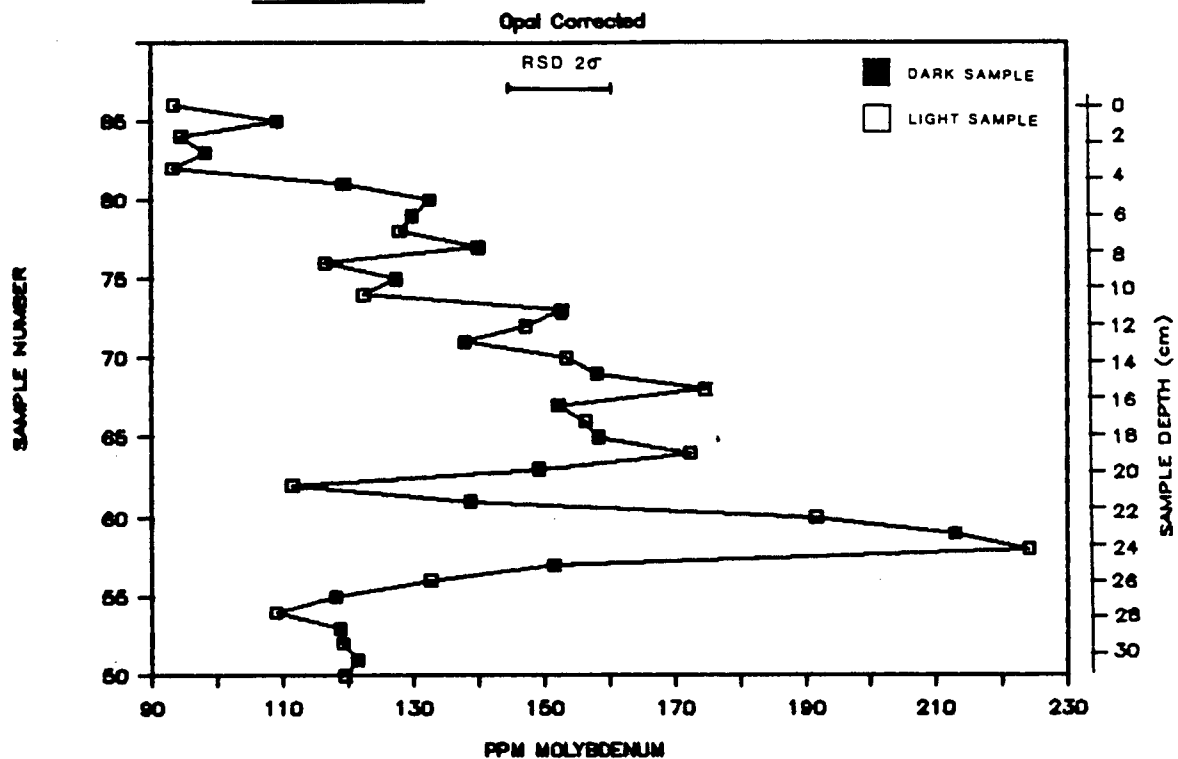
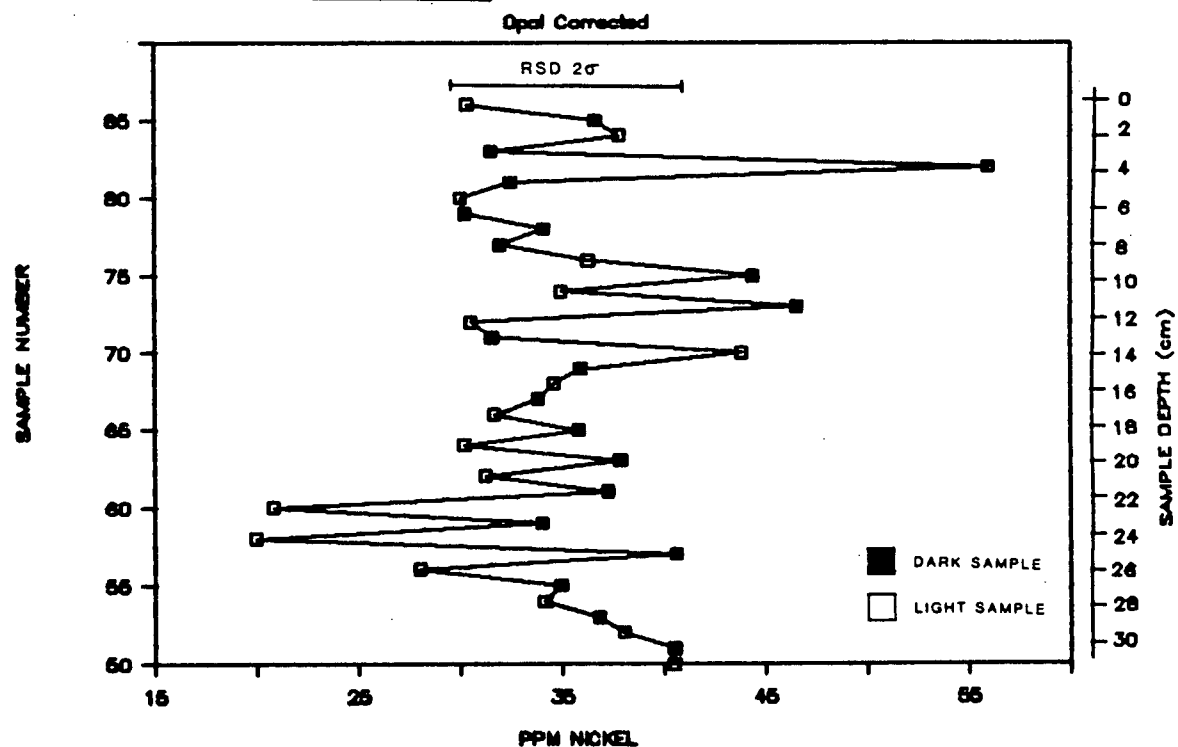


Fig: 3.5.8 NICKEL



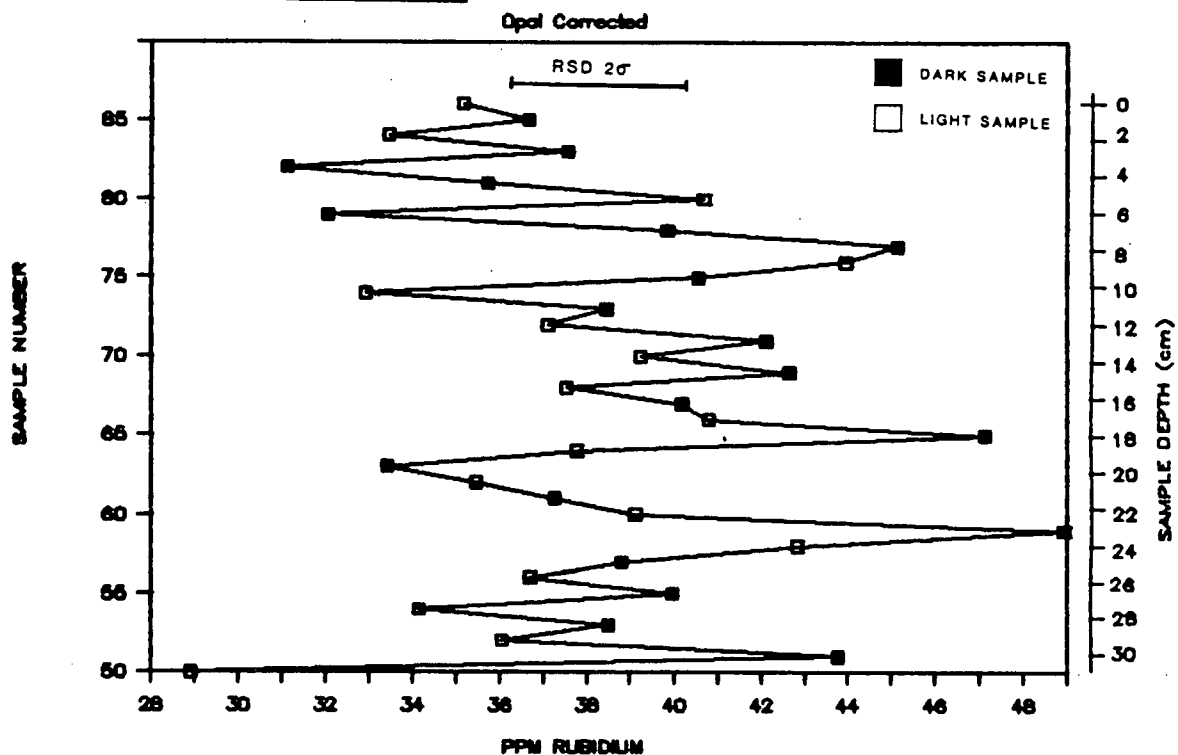
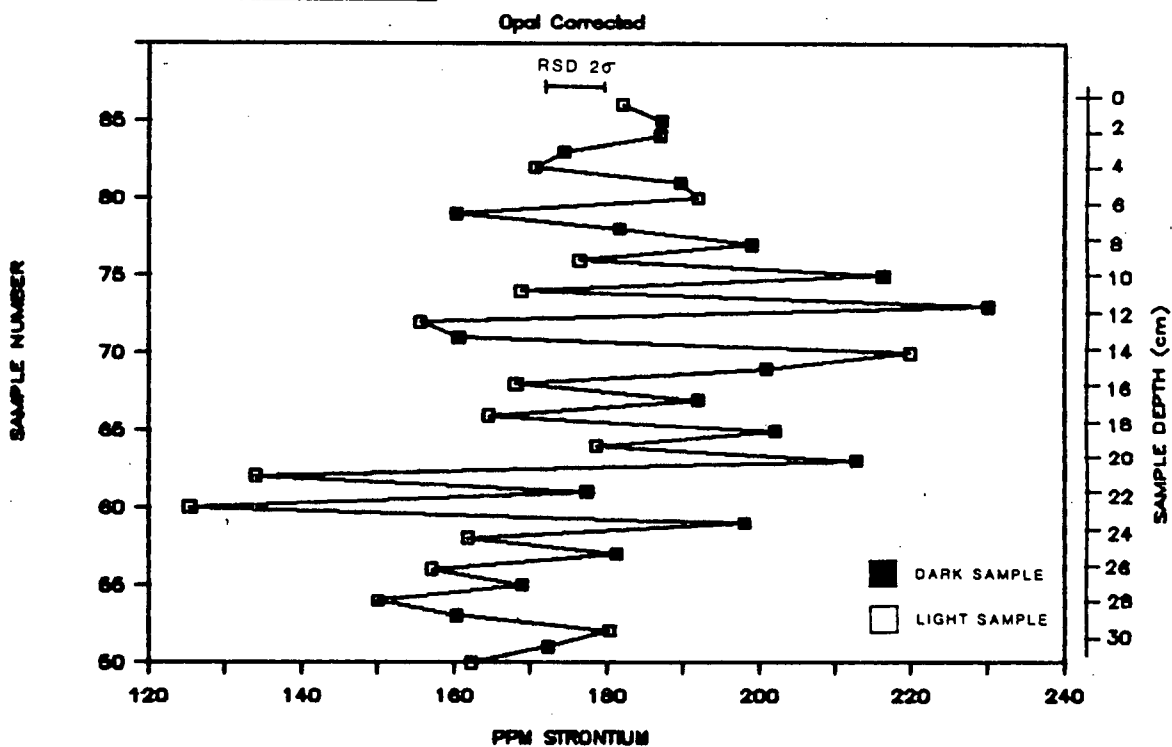
3.5.5) shows that there appears to be an increase towards the top of the core starting at sample 70. Variation between samples appears to show no trend, although there are generally higher values in dark layers indicating that Cu might not be associated with carbon derived from production. No correlation was found between this element and organic carbon.

Manganese, although often considered to be a major element in rocks and sediments, is considered a trace element in this study because of its low concentration compared to other major elements. The profile of Mn is shown in in Fig. 3.5.6; a strong enrichment of this element is present in the surface sediments of the core. Mn oxides are generally reduced to Mn^{2+} under anoxic conditions and this dissolved species is retained in the bottom waters (Grill, 1982). This normally means that characteristic concentrations of Mn in anoxic sediments, unless precipitation of manganoan carbonate ($Mn_{n-}Ca_{n-}CO_{3-}$) occurs, are those typical of aluminosilicates. In Saanich Inlet, this appears to be approximately 500 ppm. The Mn peak in this core may be accounted for if the top of the core is considered to be oxic as the result of a flushing event which has been seen to generate flocs of MnO_2 (Grill, 1982; Francois, 1987). However, no oxygen was measured in water samples of the Inlet bottom waters collected from water casts taken during the same cruise as this core was collected. There is also no evidence, given the profile of Mn lower in the core, that

high Mn values, due to Mn oxides precipitated during flushing events, are preserved upon burial in these anoxic sediments and it has been argued that the recovered interface consists of sediments 20 years old.

Another explanation for the high Mn values in the core-top is that Mn has been fixed in the sediments by the precipitation of Mn carbonate (*Doff, 1969; Calvert, 1976; Pedersen and Price, 1982*). The Mn peak is coincident with the increase in carbonate (Fig. 3.3.1); however, the precipitation of Mn carbonate requires an oxic top to the sediments in order for Mn to be 'pumped' into the pore-waters where high concentration causes the carbonate precipitation. High pore water concentrations of Mn are reported in outer fjord sediments in Norway where rhodochrosite is observed (*Hamilton-Taylor and Price, 1983*). This is not thought to be the case in these sediments because of the anoxic nature of the bottom waters and since no evidence of a long term change in these conditions can be found. This leaves the possibility that the enrichments are caused by high Mn values associated with the dust-dump from the Bamberton works. Manganese has been recognised as an anthropogenic pollutant in sediments of California by *Bruland et al. (1974)*. It is also interesting to note that Mn increases slightly between sample 72-73, close to the point at which there is a proposed change in the sediment type.

The profile of Mo is shown in Fig. 3.5.11. This is an incompatible element and its large degree of enrichment

Fig: 3.5.9 RUBIDIUM**Fig: 3.5.10 STRONTIUM**

in anoxic sediments (a typical crustal value is 1.5 ppm Krauskopf, 1979) is the result of diagenetic enrichment (Gross, 1967; Doff, 1969; Calvert, 1976; Francois, 1987). Berrang and Grill (1974) have suggested that Mo is transported into the anoxic bottom water of Saanich Inlet in association with Mn oxide flocs which are redissolved in the bottom waters. However, the enrichment in the sediments is brought about either through coprecipitation with FeS or through a scavenging process involving organic carbon Calvert (1976). An interesting feature of the Mo profile is the peak between samples 55 and 60. Since Mo is thought to be a good indicator of reducing anoxic conditions, it may be that this peak reflects stronger anoxic conditions in Finlayson Arm at that time. The Mo maximum does, however, match the highest amounts of organic carbon in the core, and no correlation between Mo and carbon or S could be found using all the data points.

The profile of Ni (Fig. 3.5.8) shows that the concentration of this element varies only slightly through the section. Hirst (1962b) has shown that there is a correlation between Ni and heavy minerals in coarse-grained sediments; however, the main influence on this element in fine-grained, organic-rich sediments appears to be its association with organic carbon (Calvert, 1976; Francois, 1987). Doff (1969) showed that there is no significant enrichment of Ni and little difference in concentration when oxic and anoxic sediments in Oslo Fjord are compared. No

correlation was found between Ni and organic carbon in this core and those samples with high organic content, 56, 58 and 60 (see Fig. 3.2.6) are seen to have low Ni concentrations.

Rubidium is closely related to the K content of sediments because of its substitution for that element in K-feldspar and micas and is generally higher in the dark layers of this core. The profile of Rb (Fig. 3.5.9) is, however, quite unlike that of K (Fig. 3.4.7) and a poor correlation was found between these elements, suggesting that they reside in different phases. It is likely, however, that this poor correlation is a result of the narrow ranges of values observed in CPIV. *Francois* (1987) has shown a good relationship between K and Rb in sediments throughout Saanich Inlet.

Strontium is mainly held in plagioclase feldspars and calcium carbonate where it substitutes for Ca. However, *Hawkesworth and Elderfield* (1978) have shown that the Sr content is greatly reduced in the recrystallisation of biogenous carbonate to limestone. Since the main source of carbonate to these sediments is limestone or cement dust from the Bamberton works, an observation supported by the fact that Sr does not show any increase in association with the carbonate peak in samples 80-86, and since there is little input of biogenic carbonate, the Sr concentration in these sediments is probably controlled by feldspar. The profile of Sr is shown in Fig. 3.5.10 and concentrations are seen to be higher in the dark layers which is consistent

Fig: 3.5.11 VANADIUM

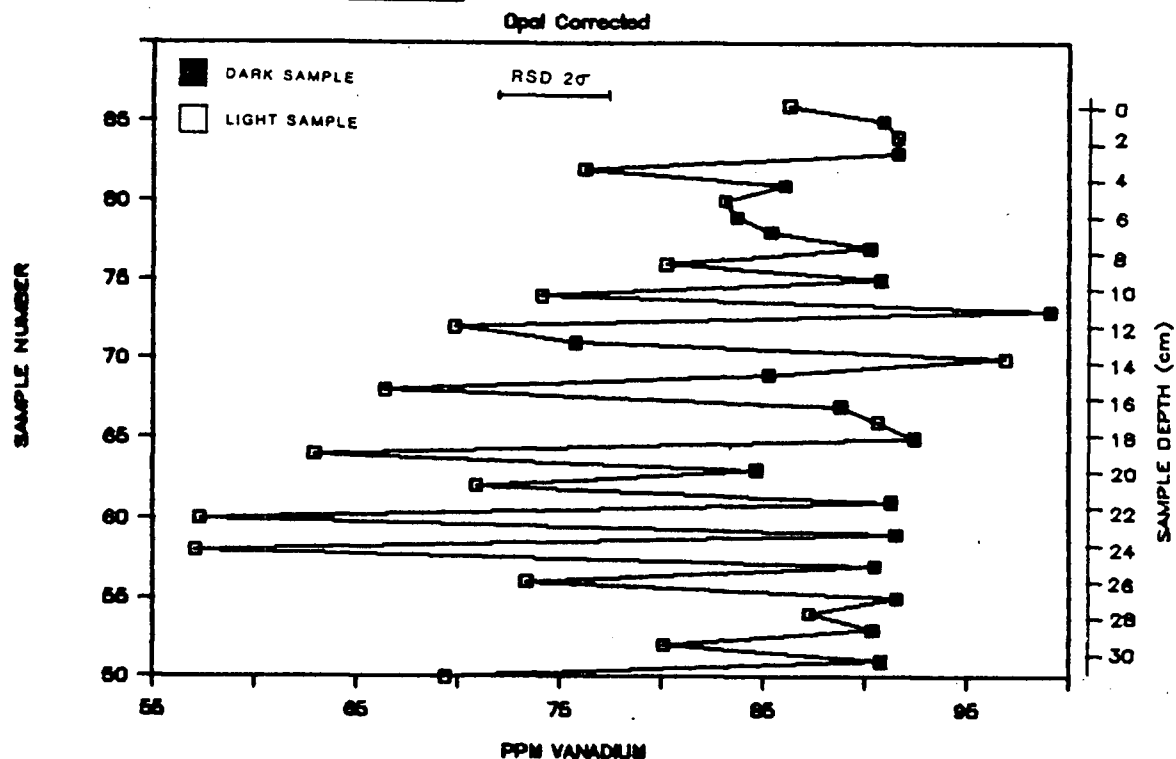
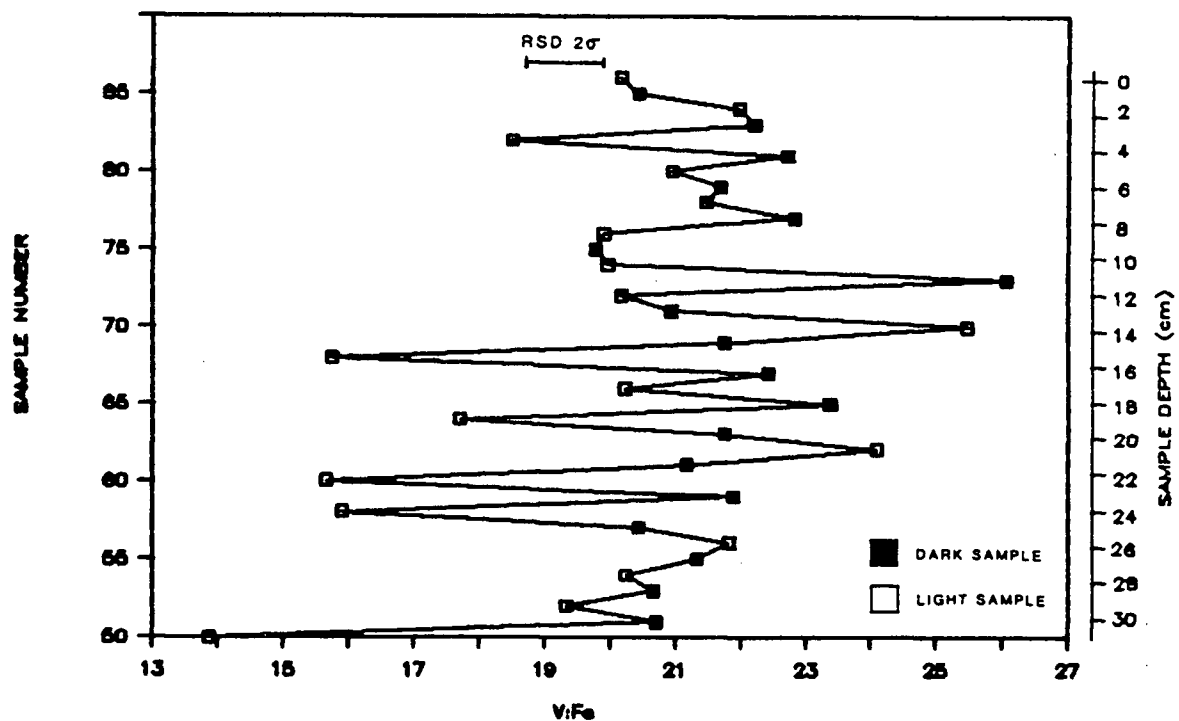


Fig: 3.5.12 VANADIUM:IRON RATIO



with input derived from runoff. This variation breaks down above sample 76 and below sample 53 and sample 70 is again seen to stand out as a light layer with high amounts of elements derived from lithogenous input. This profile, together with that of V (see following section) supports the idea that the laminae are reflecting seasonal input of lithogenous detritus to the Inlet.

Vanadium shows the largest variation between samples of any of the minor elements. The V profile (Fig. 3.5.11) shows consistently higher values in the dark samples, with the exception of samples 66,70 and those above sample 78. This is similar to the variation seen in the profile of Sr. Calvert (1976) states that V is enriched in anoxic sediments and Francois (1987) showed that there is an enrichment of V in the anoxic sediments of Saanich Inlet, particularly in Finlayson Arm and a strong correlation between V and organic carbon in the central basin, however, there is a poor relationship between these components in this core. Doff (1969), shows that there is no distinction between anoxic and oxic sediments of Oslo Fjord on the basis of their V content. Vanadium readily substitutes for Fe in chlorite; a plot of V:Fe (Fig. 3.5.13) shows that the seasonal signal is preserved, with the exception of samples 56,62 and 70 which are light layers with a high ratio. This implies that some of the seasonal V signal must be produced by an association between V and another sediment component.

Fig: 3.5.13 YTTRIUM

Opal Corrected

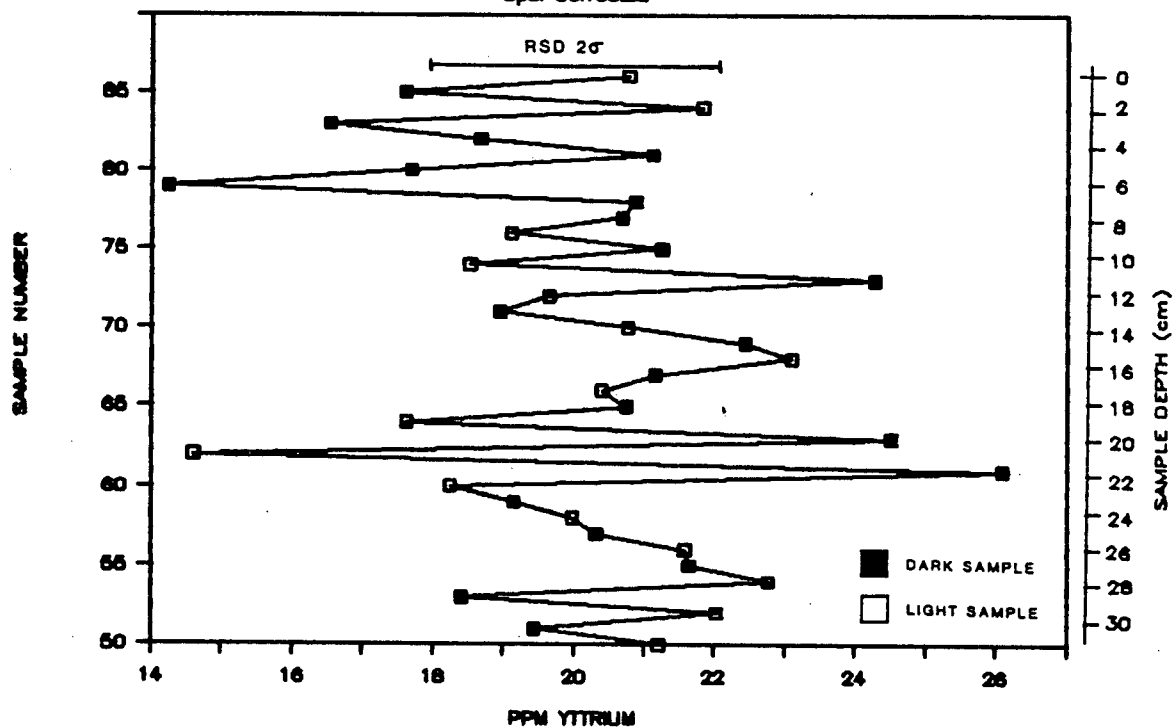


Fig: 3.5.14 ZINC

Opal Corrected

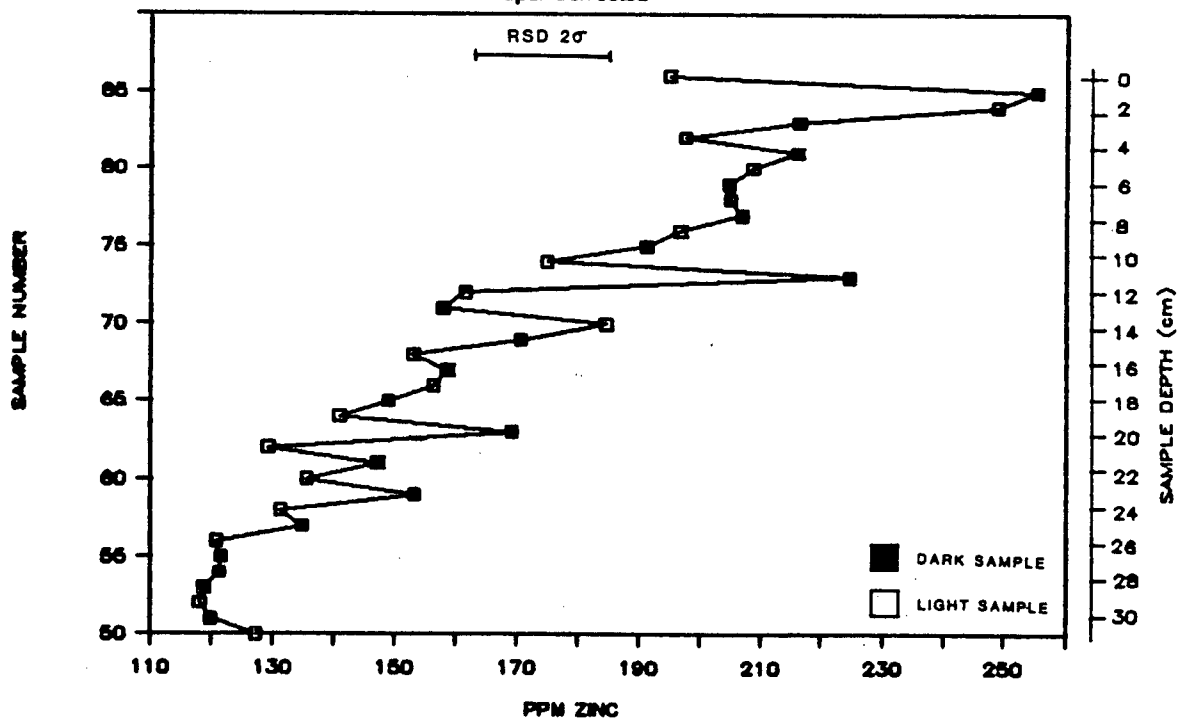


Fig: 3.5.15 ZINC:IRON RATIO

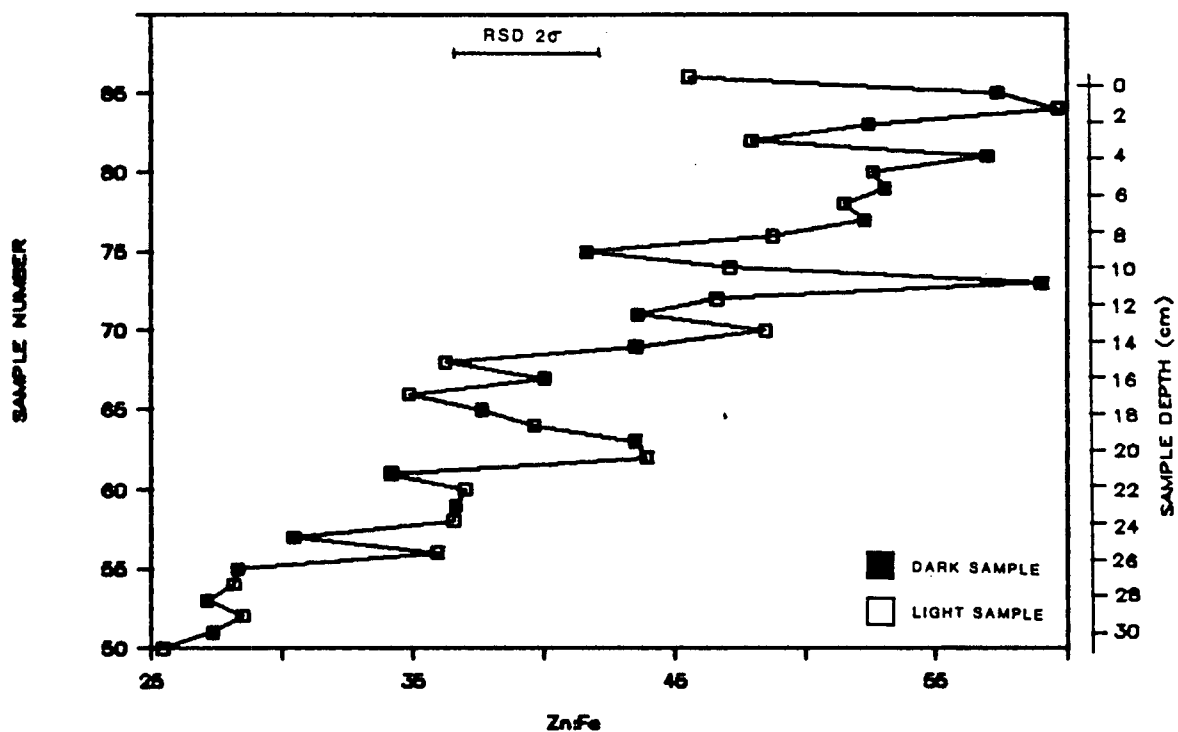
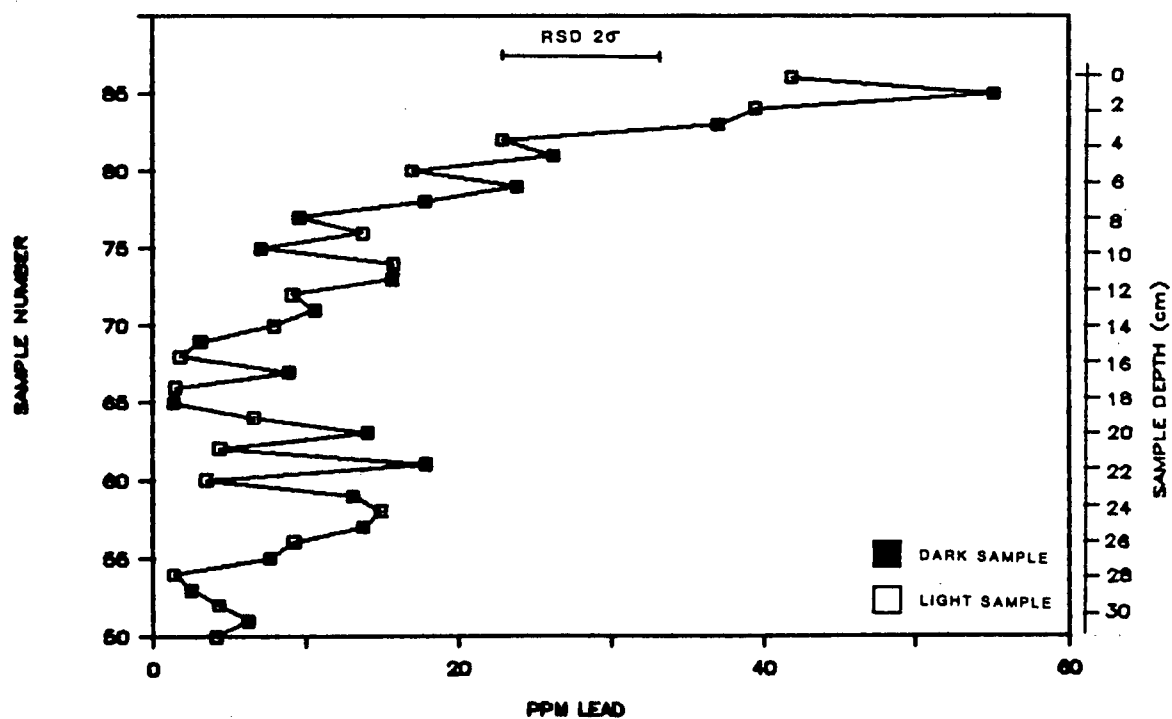


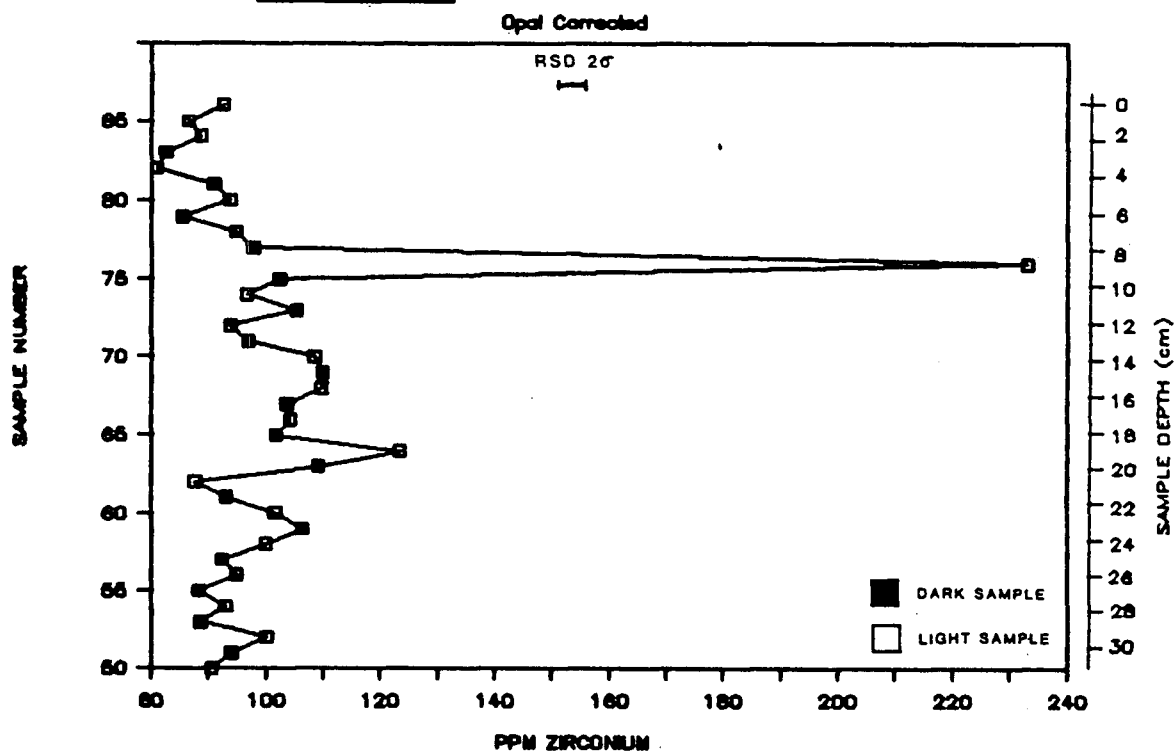
Fig: 3.5.16 LEAD, OPAL-FREE



The profile of Y is shown in Fig. 3.5.14. This element is known to be associated with heavy minerals where it replaces Ca. An interesting feature of the Y profile is that it tends to show seasonal variation in sections of the core where light/dark variation in organic carbon is reduced. This relationship appears to hold below sample 70 and is most noticeable between samples 50-55 and 60-65 where large variations in the Y content are seen and where there is little variation in organic carbon between adjacent samples. In these sections, the Y content of the dark layers is higher and this observation leads to the suggestion that the Y signal, derived from lithogenous material, is very sensitive to dilution by organic carbon. This pattern breaks down above sample 70 where variation between light and dark layers is more random, indicating that the change in sedimentation disturbed the variation between Y and carbon.

Zinc concentrations (Fig. 3.5.15) have been linked to the input of carbonate from the Bamberton Works. However, Zn is also thought to replace Fe in chlorite and can also be diagenetically enriched in organic-rich sediments (Calvert, 1976) because of its association with organic matter (Doff, 1969). No relationship was seen between Zn and carbon in these sediments and the plot of the Zn:Fe ratio (Fig. 3.5.16) clearly shows increased values from sample 55 to the core top, indicating an extra source of Zn to the sediments. This source is thought to be the Bamberton Quarry, since a

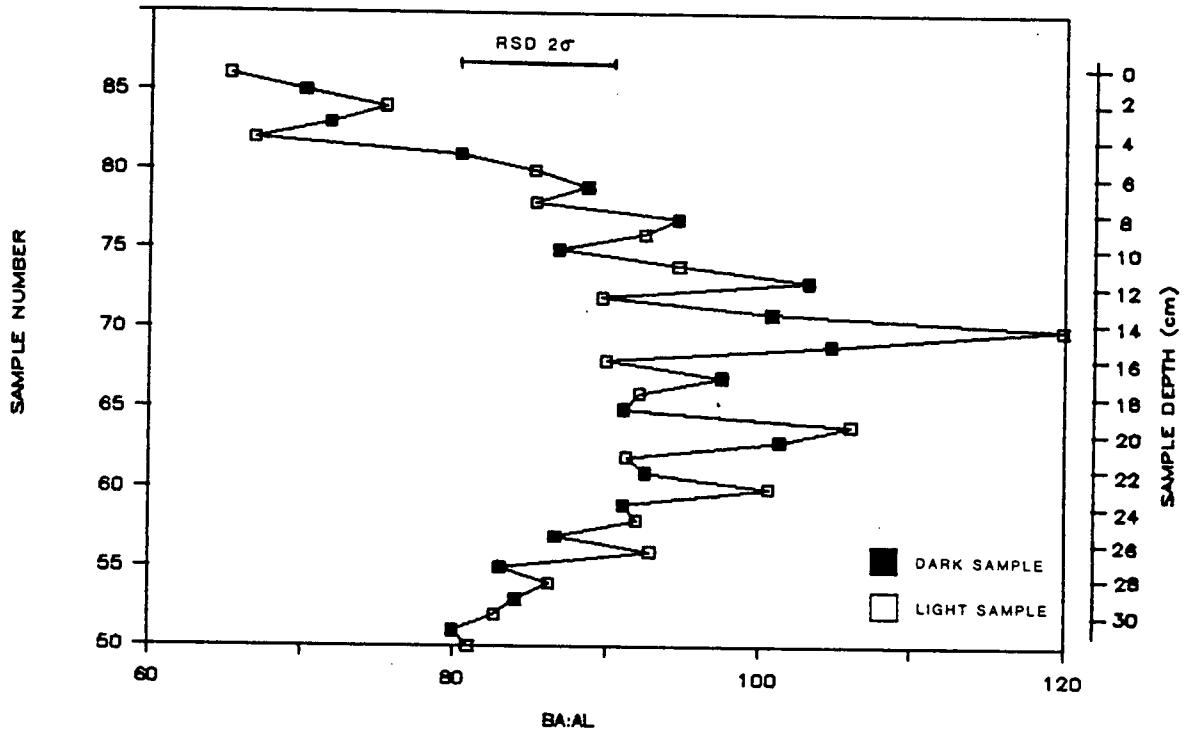
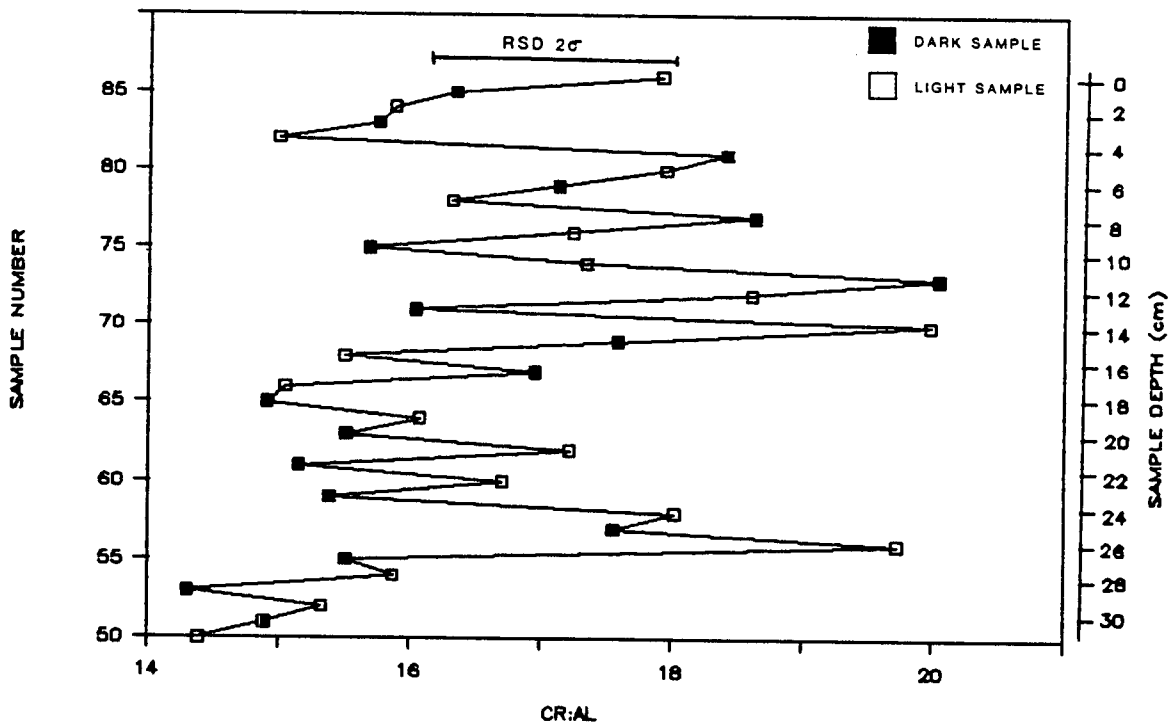
Fig: 3.5.17 ZIRCONIUM



peak is seen in association with the carbonate maximum at the top of the core.

Alternatively, the Zn profile might be reflecting increasing atmospheric pollution since the World War Two. *Bruland et al.* (1974) showed such increases in Zn concentrations in sediments off California. However, the beginning of the Zn increase at sample 55 is not matched by that of Pb (Fig. 3.5.16) which is also known to be an atmospheric pollutant. The Pb increase coincides with the carbonate peak, but shows low and almost constant values lower in the core. However, there is some evidence that the increases in concentration of these two metals in the atmosphere are not coincident and that Zn shows an earlier increase. In the sediments of the San Pedro basin, for example, Pb increases dramatically in 1960, while Zn increases in 1940 (*Bruland et al.*, 1974).

Zirconium occurs in the mineral zircon which is generally associated with coarse-grained sediments. The profile of this element (Fig. 3.5.18) shows low values with the exception of the dramatic increase in sample 76. This peak is not matched by any other element and there is no indication in the Si:Al or quartz:chlorite ratios that this sample is coarser grained; consequently no clear explanation can be given for this peak.

Fig: 3.5.18 BARIUM:ALUMINIUM RATIO**Fig: 3.5.19** CHROMIUM:ALUMINIUM RATIO

3.5.2 Ratios of the trace elements to aluminium.

All of the minor elements were ratioed to the Al concentration of the samples so that any enrichments or depletions relative to the trace element composition of the lithogenous aluminosilicate input to Saanich Inlet might be seen.

The data are shown in Fig. 3.6.19-3.6.28; the profiles largely corroborate the information derived from the profiles of absolute abundance. Barium:aluminium (Fig. 3.6.19) reflects an enrichment of Ba that is coincident with higher Si:Al ratios and decreases above sample 70 in conjunction with the increase in organic carbon and the proposed change in sedimentation rate. The decrease lower in the core is coincident with a change in sedimentation. There is some evidence (see the discussion of Fe in section 3.4 and of Chaetoceros counts section 3.6) that there may also be a disturbance to the sedimentary regime evident at the base of the core. The observed profile seems to support a relationship between Ba and primary production and implies greater production in the middle of this core. This observation supports the possibility that there is long term variation (on the order of 10-15 years, based on the best estimate of sedimentation rate) in production within Saanich Inlet.

The ratios of Ba:Al, Cr:Al, V:Al, Sr:Al and Ni:Al (Fig. 3.6.20, Fig. 3.6.25, Fig. 3.6.24, Fig. 3.6.22)

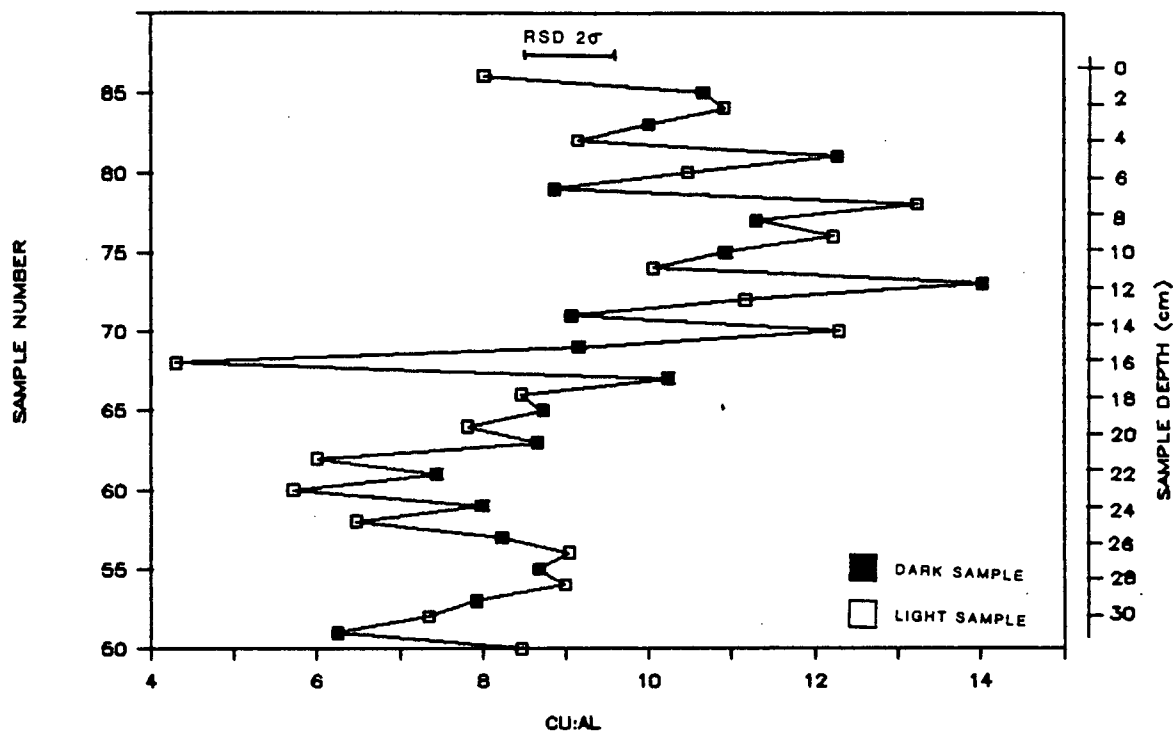
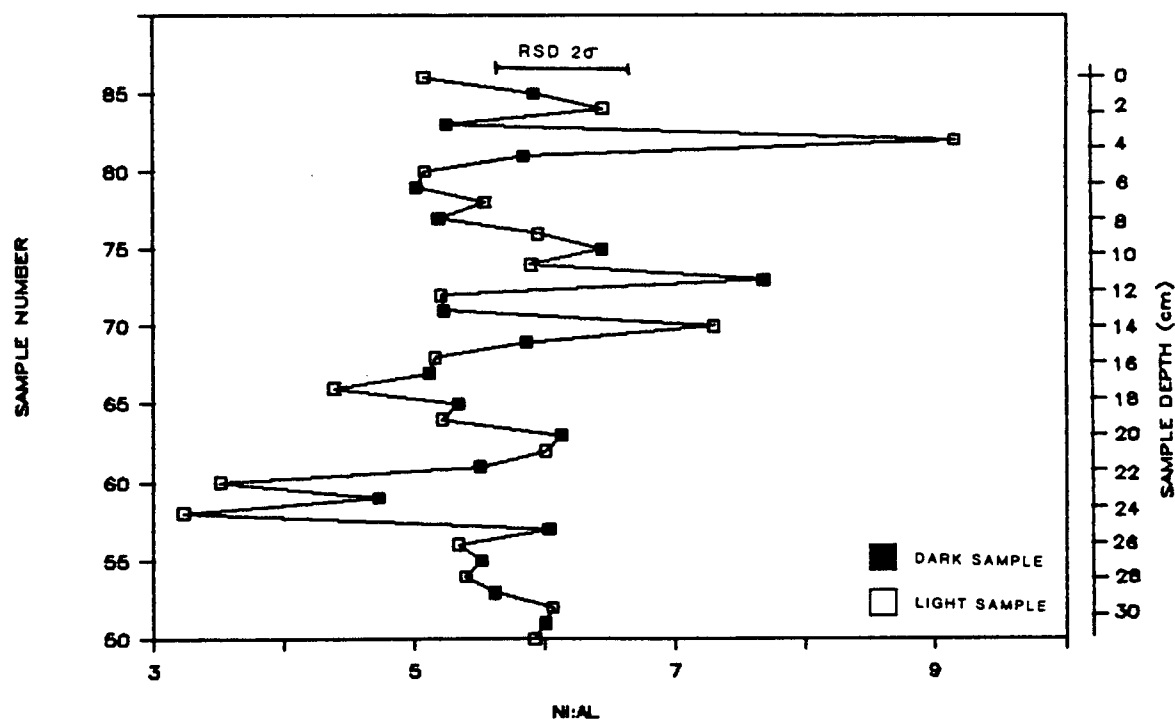
Fig: 3.5.20 COPPER:ALUMINIUM RATIO**Fig: 3.5.21** NICKEL:ALUMINIUM RATIO

Fig: 3.5.22 RUBIDIUM:ALUMINIUM RATIO

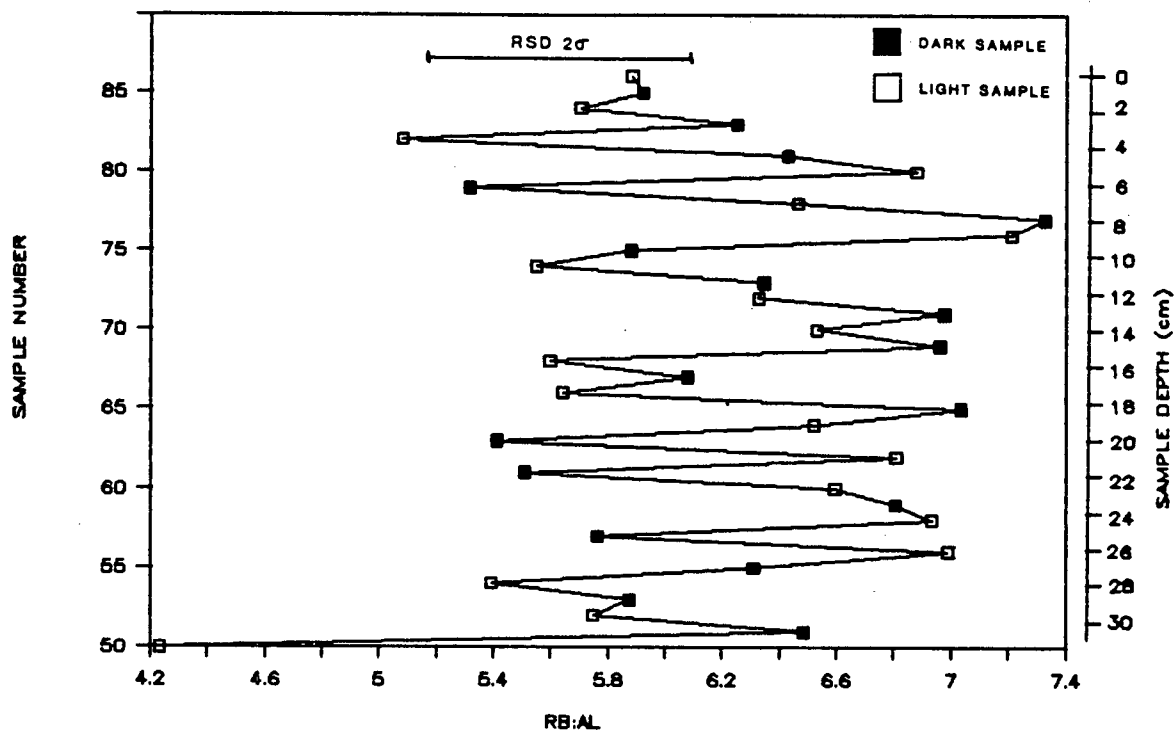


Fig: 3.5.23 STRONTIUM:ALUMINIUM RATIO

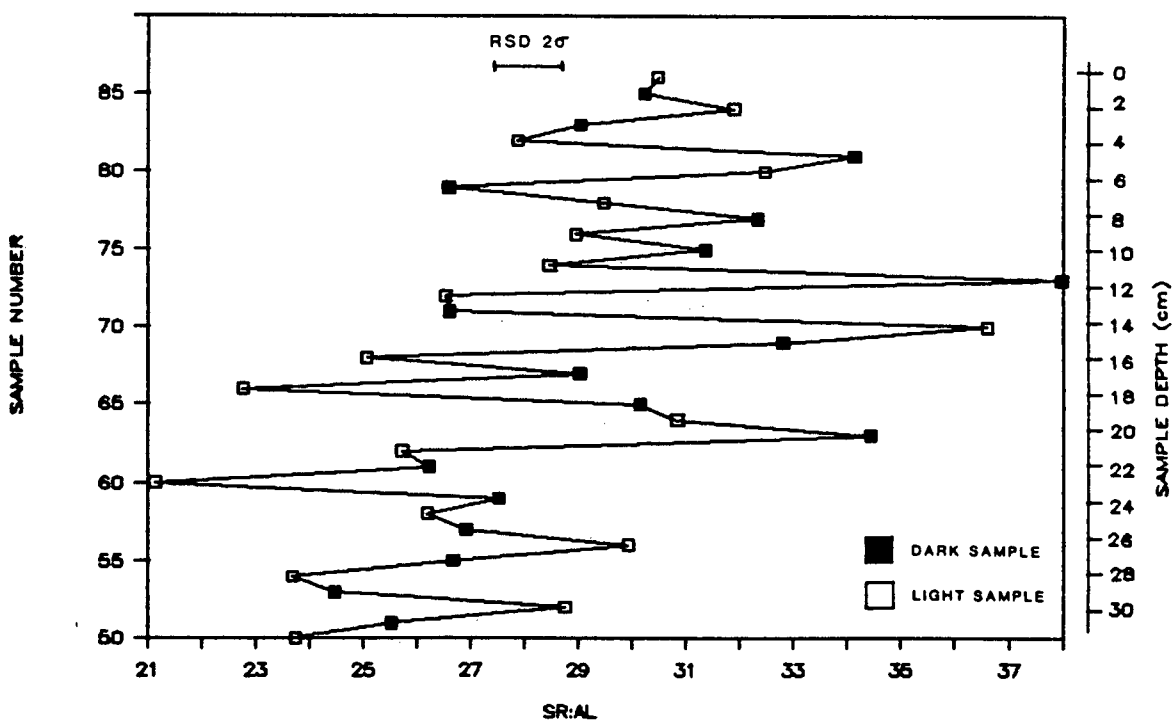


Fig: 3.5.24 VANADIUM:ALUMINIUM RATIO

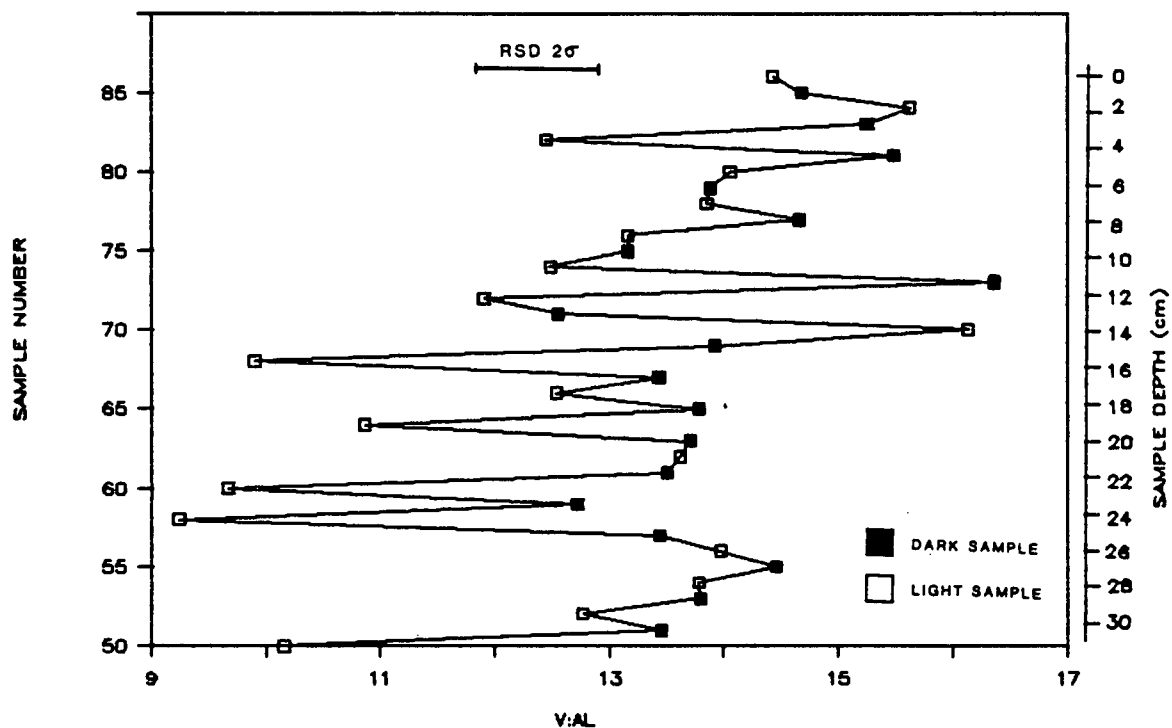
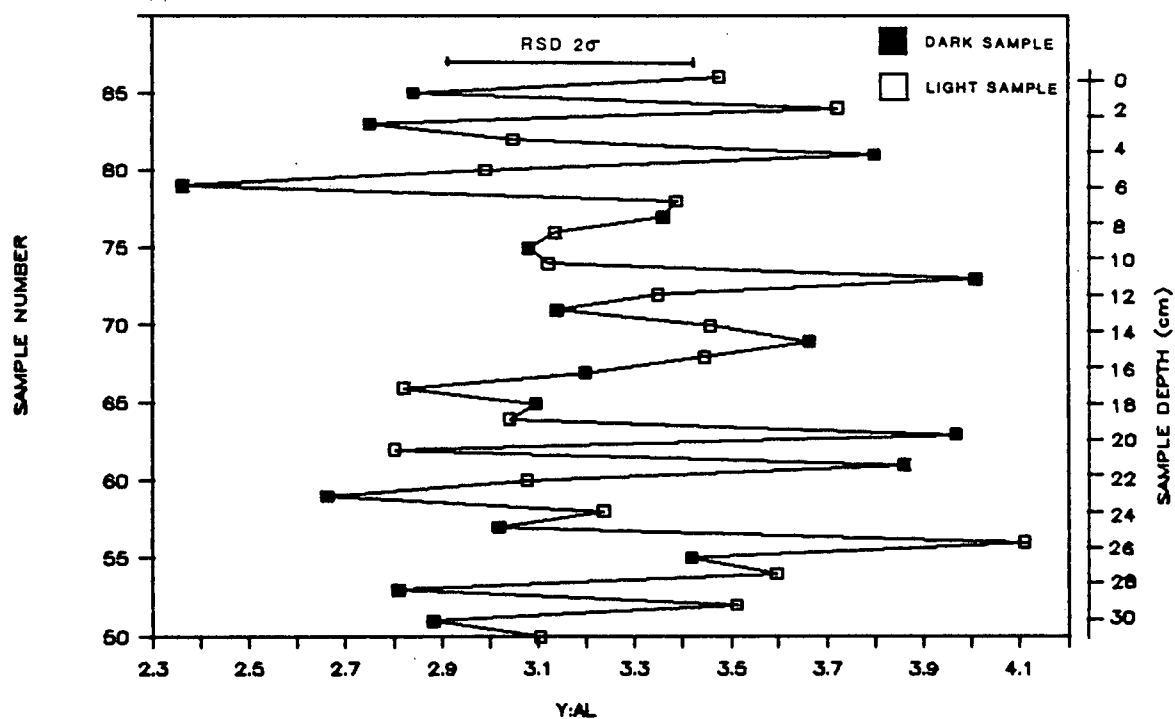


Fig: 3.5.25 YTTRIUM:ALUMINIUM RATIO



are all higher in sample 70 compared with the dark layers above and below. The seasonal signal is not clear in plots of these ratios, whereas in the absolute abundance profiles of V and Sr, for example, do show a clear seasonal variation below sample 70. This implies that the seasonal signal in these elements is derived from their association with aluminosilicates and not from any other source. Those elements which are known to be closely associated with aluminosilicate input, Rb (Fig. 3.6.23) and Y (Fig. 3.6.26) show random variations and an essentially vertical trend in the profiles of their ratios to Al.

Sample 70 thus appears to be the point at which a change in the profiles occurs. This has also been observed in the porosity data and in the major element geochemistry and is thought to be coincident with a change both in mineralogy and sedimentation rate.

Zinc:aluminium and Pb:Al (Fig. 3.6.27 and Fig. 3.6.28 respectively) both show increases coincident with the dump of carbonate from Bamberton and also to atmospheric pollution. These profiles confirm this, and support the idea that Zn increases because of anthropogenic input before those of Pb (*Bruland et al.*, 1974).

The minor elements show some clear distinctions between light and dark layers. This is especially evident in the bottom half of the core and is most clear in the case of V and Sr. Barium is enriched in a section of the profile thought to be coincident with higher primary production.

Fig. 3.5.26 ZINC:ALUMINIUM RATIO

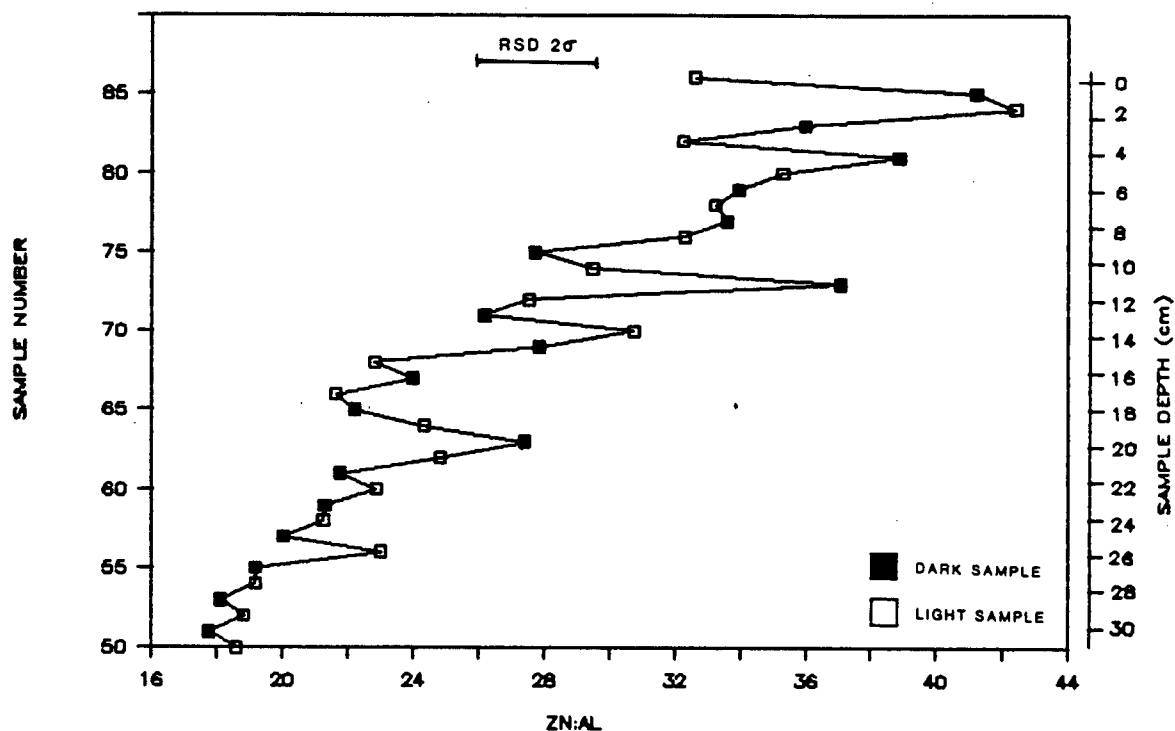
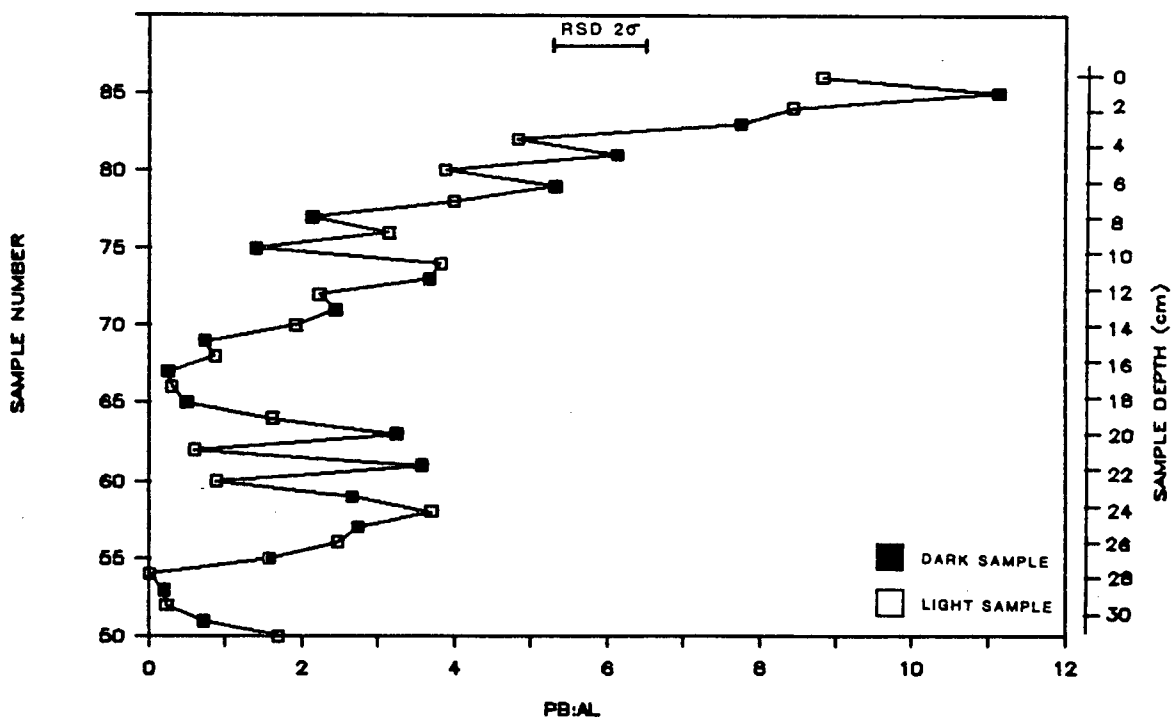


Fig. 3.5.27 LEAD:ALUMINIUM RATIO



Manganese reflects an input in association with the carbonate, possibly as a pollutant, and this observation together with decreased Ba:K ratios and a decreased Mo content also support the proposed change in sediment above sample 70. The elements which do appear to show a strong seasonal signal, V and Sr, seem to show that such a signal continues above sample 70 and is still apparent in samples 77 and 78, which supports the idea that the top sediment may indeed contain laminae but that they are on such a fine scale that they could not be sampled discretely.

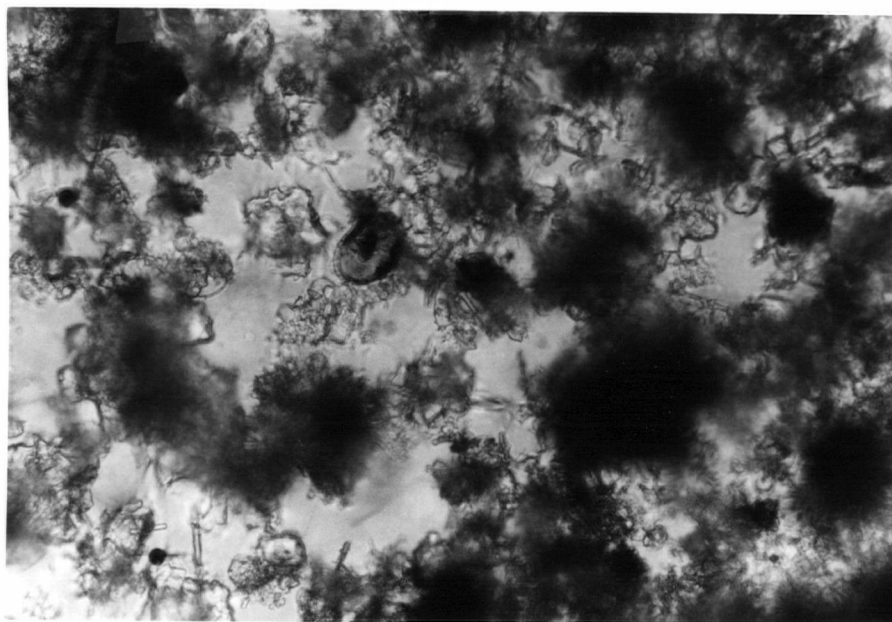
3.6 The diatom record.

3.6.1 Preparation of a peel slide of the varves.

Once the ^{210}Pb dates for core CPIV became known, it was necessary to verify the assumption that the sediment laminae represented true seasonal varves since their discrepancy with the ^{210}Pb chronology meant that they might represent longer cycles of deposition.

To do this, a section of the archive material from the base of core CPIV where the laminae were distinct was chosen for study. A section of this material was freeze-dried, which was found to preserve the sediment laminae, and a peel of the sediment taken by touching the surface of the dried sediment with Scotch-tape. The tape was then mounted

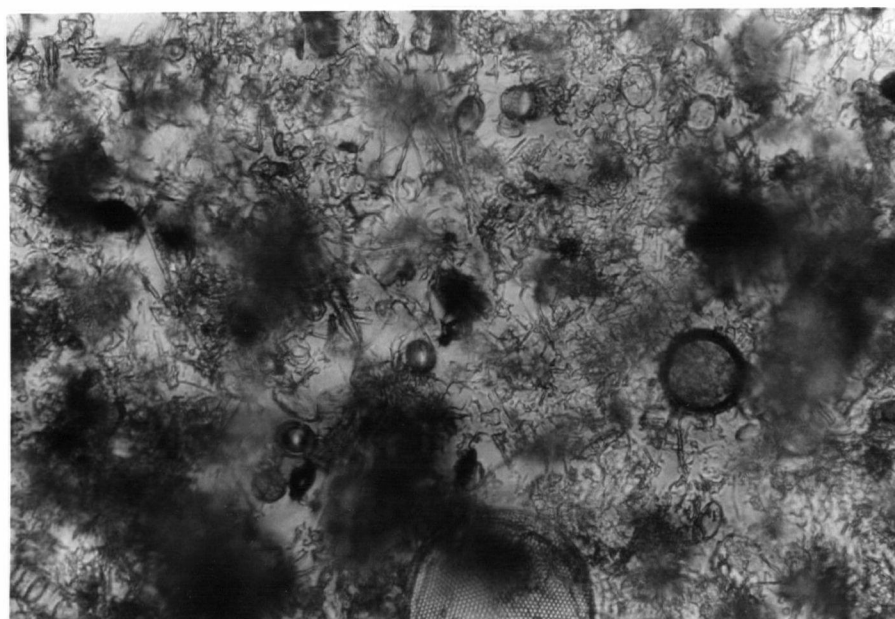
PLATE II An example of a dark lamina.



X400

SCALE 0.1mm

PLATE III Example of a dark lamina containing some centric diatoms.



X400

SCALE 0.1mm

on a microscope slide using Hyrax and examined under the microscope.

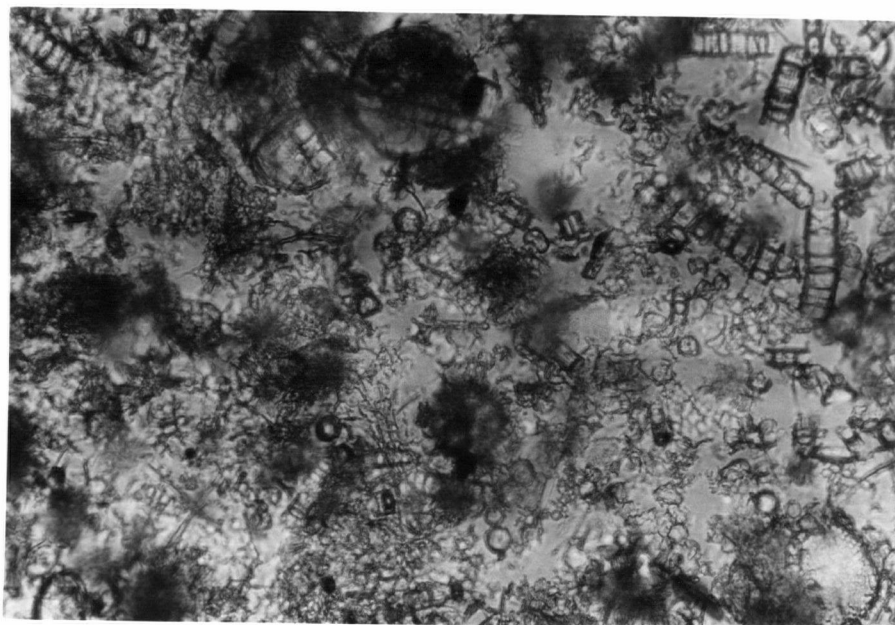
The material on the slide was too thick to allow quantitative counts to be made, but the diatom frustules seen showed distinct layers reflecting a seasonal signal in their species succession (*C. Sancetta*. pers comm).

The seasonal succession that was observed in these laminae is illustrated in Plates II-IX. Plates II and III show typical dark layers. These layers generally contain amorphous aggregates of material and contain few easily recognisable diatoms. This distinction was not always so clear-cut and some dark layers were found which contained spores, large Coscinodiscus and Thalassiosira, as shown in Plate III.

Plate IV shows the junction between a dark layer and the light layer above it (core-top is always to the left in these photographs). Skeletonema costatum was seen to become more prominent in the light layers and increased numbers of Thalassiosira sp were also seen.

Skeletonema costatum sometimes becomes completely dominant and Plate V is a good example of a clear bloom of this species. S. costatum, although it is common throughout the year, is generally thought to bloom in the spring (Takahashi et al. 1977). This has been shown by Stockner et al. (1979) in the Strait of Georgia and in sediment trap data in Saanich Inlet by Sancetta and Calvert (1987 in press). However, S. costatum did not always show a clear

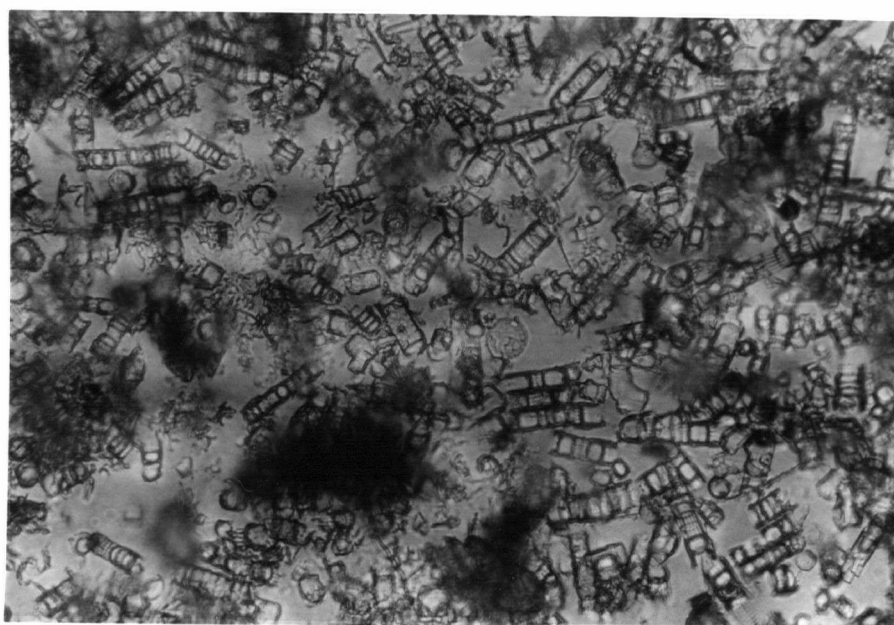
PLATE IV Junction between a dark lamina(right)
and a light lamina(left).



X400

SCALE 0.1mm

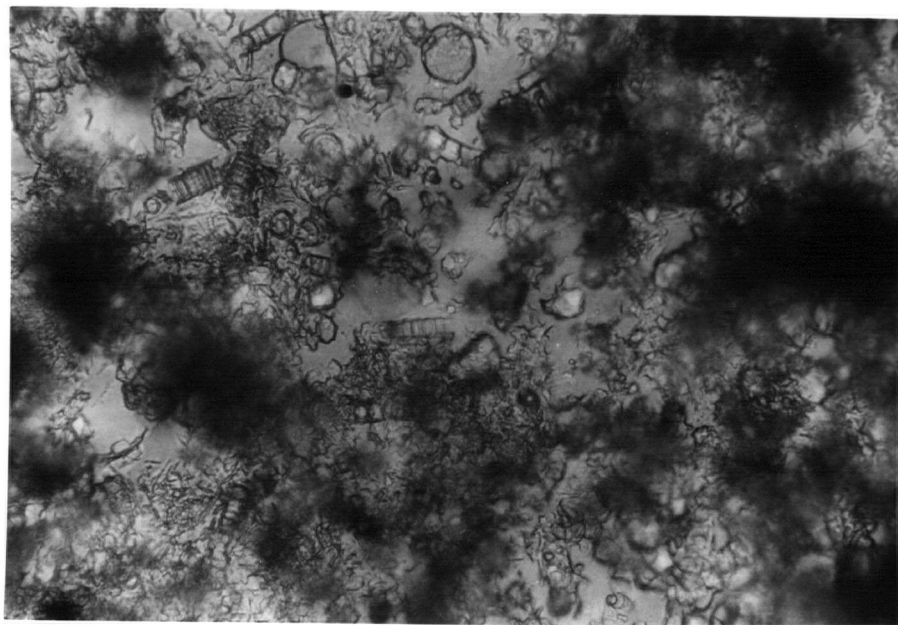
PLATE V An example of a distinct bloom
of S.costatum.



X400

SCALE 0.1mm

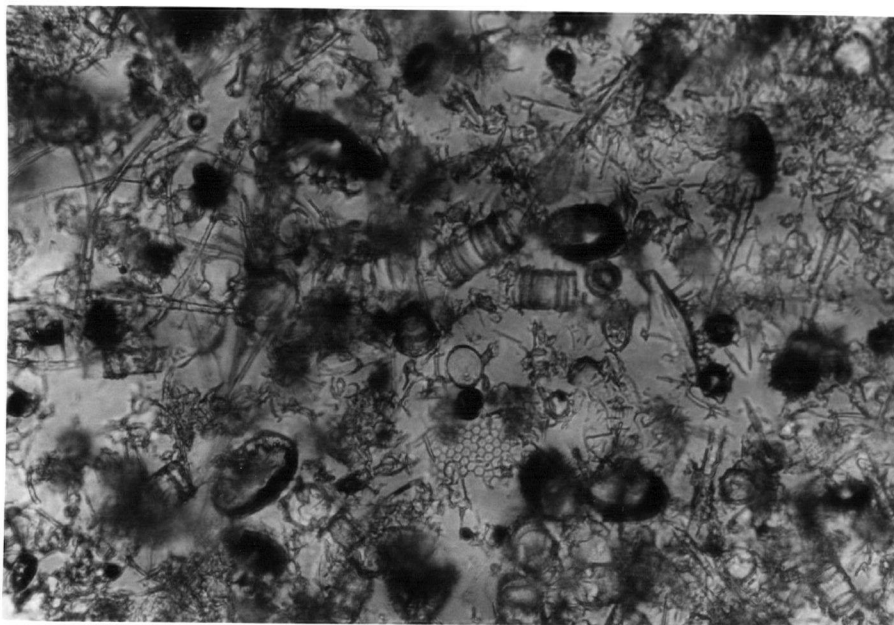
PLATE VI An example of a poorly defined bloom of S. costatum.



X400

SCALE 0.1mm

PLATE VII A characteristic assemblage within a light lamina



X400

SCALE 0.1mm

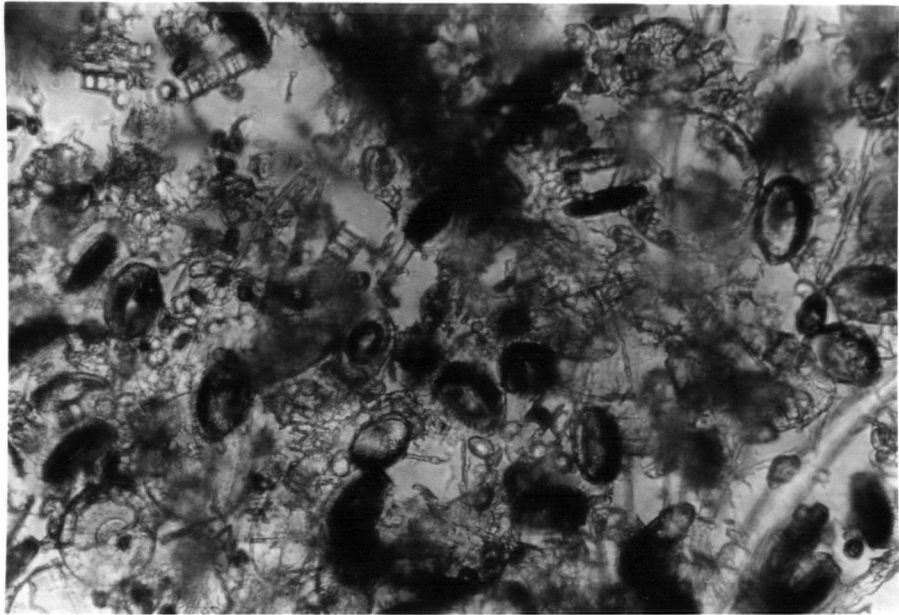
bloom at the edge of a dark layer. Plate VI shows such a junction between a dark layer on the right with S.costatum in the center/left together with some Thalassiosira sp. If this can be taken as the spring bloom, then there is clearly some variation in its intensity when compared with Plate IV.

Plate VII is an example of a light layer. It is characterised by a mixture of larger S.costatum, numerous Chaetoceros species and their spores (the black features in this picture) and Thalassiosira.

Junctions between a light layer and the dark layer following it appeared to be characterised by a large number of Chaetoceros spores, as seen in Plate VIII. This is expected since the succession through the summer bloom in Saanich Inlet is such that Chaetoceros becomes dominant later in the summer (Takahashi et al. 1977). The collapse of this population would be accompanied by the production of a large number of spores.

Blooms of the silicoflagellate Distephanus speculum were occasionally seen at the junction of a light and the dark layer, as shown in Plate XI. Since this is thought to be a cool-water species (Polechau, 1974), such blooms might indicate the start of winter.

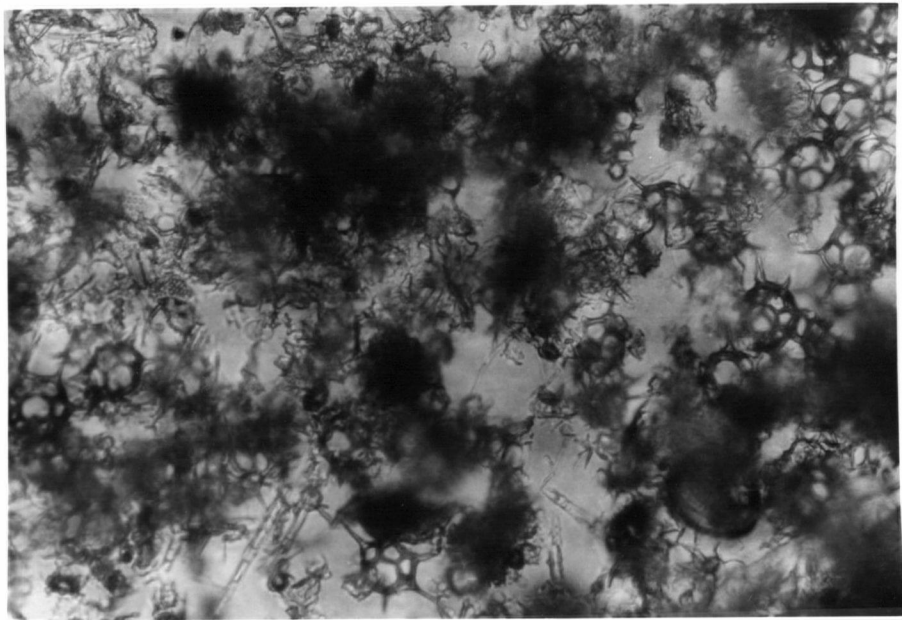
PLATE VIII Junction between a light(left) and a dark(right) lamina.



X400

SCALE 0.1mm

PLATE IX A bloom of the silicoflagellate D.speculum.



X400

SCALE 0.1mm

Table X Results of Diatom counts.

Sample	Wt.(mg)	Area counted	Tot.cells counted	Cells/g	COUNTS											
					I	Σ	II	Σ	III	Σ	IV	Σ	V	Σ		
86	364	24.6	415	8.11E+05	66	15.9	172	41.4	87	21.0	58	14.0	6	1.45		
85	122	8.2	495	8.66E+06	56	11.3	287	58.0	63	12.7	72	14.5	4	0.81		
84	88	32.8	405	2.45E+06	65	16.0	174	43.0	93	23.0	57	14.1	3	0.74		
83	99	24.6	460	3.30E+06	100	21.7	189	41.1	80	17.4	81	17.6	15	3.26		
82	270	16.4	467	1.85E+06	46	9.9	159	34.0	138	29.6	85	18.2	13	2.78		
81	117	24.6	434	2.64E+06	82	18.9	103	23.7	150	34.6	76	17.5	8	1.84		
80	109	16.4	659	6.45E+06	54	8.2	199	30.2	278	42.2	83	12.6	19	2.88		
79	106	16.4	587	5.91E+06	58	9.9	253	43.1	164	27.9	74	12.6	11	1.87		
78	95	16.4	481	5.40E+06	62	12.9	207	43.0	88	18.3	79	16.4	11	2.29		
77	157	16.4	425	2.89E+06	37	8.7	162	38.1	63	14.8	93	21.9	35	8.24		
76	116	16.4	551	5.07E+06	28	5.1	311	56.4	74	13.4	115	20.9	10	1.81		
75	158	24.6	405	1.82E+06	58	14.3	192	47.4	51	12.6	82	20.2	12	2.96		
74	112	8.2	409	7.79E+06	11	2.7	233	57.0	40	9.8	77	18.8	6	1.47		
73	136	16.4	610	4.79E+06	37	6.1	324	53.1	65	10.7	143	23.4	26	4.26		
72	94	8.2	404	9.17E+06	26	6.4	228	56.4	46	11.4	84	20.8	7	1.73		
71	118	24.6	422	2.54E+06	46	10.9	188	44.5	55	13.0	78	18.5	20	4.74		
70	109	8.2	522	1.02E+07	41	7.9	307	58.8	57	10.9	92	17.6	5	0.96		
69	147	8.2	410	5.95E+06	52	12.7	206	50.2	104	25.4	23	5.6	10	2.44		
68	134	8.2	400	6.37E+06	35	8.8	95	23.8	133	33.3	129	32.3	1	0.25		
67	78	16.4	429	5.87E+06	46	10.7	138	32.2	137	31.9	84	19.6	9	2.10		
66	103	32.8	447	2.31E+06	16	3.6	145	32.4	97	21.7	158	35.3	4	0.89		
65	110	24.6	446	2.88E+06	48	10.8	94	21.1	110	24.7	174	39.0	9	2.02		
64	94	8.2	727	1.65E+07	19	2.6	346	47.6	61	8.4	289	39.8	2	0.28		
63	87	32.8	412	2.53E+06	159	38.6	64	15.5	97	23.5	53	12.9	15	3.64		
62	98	32.8	411	2.24E+06	103	25.1	56	13.6	63	15.3	164	39.9	7	1.70		
61	116	24.6	553	3.39E+06	61	11.0	160	28.9	116	21.0	182	32.9	4	0.72		
60	70	16.4	493	7.51E+06	58	11.8	94	19.1	95	19.3	208	42.2	4	0.81		
59	119	24.6	529	3.16E+06	95	18.0	115	21.7	81	15.3	196	37.1	2	0.38		
58	104	16.4	459	4.71E+06	18	3.9	56	12.2	47	10.2	328	71.5	2	0.44		
57	118	8.2	420	7.59E+06	36	8.6	244	58.1	49	11.7	66	15.7	0	0.00		
56	193	8.2	995	1.10E+07	32	3.2	666	66.9	20	2.0	251	25.2	3	0.30		
55	166	8.2	457	5.87E+06	68	14.9	257	56.2	60	13.1	47	10.3	4	0.88		
54	166	8.2	852	1.10E+07	27	3.2	488	57.3	151	17.7	179	21.0	0	0.00		
53	137	16.4	402	3.13E+06	59	14.7	131	32.6	76	18.9	115	28.6	5	1.24		
52	141	16.4	412	3.12E+06	109	26.5	33	8.0	48	11.7	206	50.0	5	1.21		
51	167	24.6	437	1.86E+06	140	32.0	78	17.8	61	14.0	112	25.6	20	4.58		
50	114	8.2	414	7.75E+06	20	4.8	309	74.6	10	2.4	67	16.2	2	0.48		

* Area counted in mm².

* Cells/g. calculated using sample wt. dilution to 13.5ml. and aliquots of 250ul.

* Cells/cm²/6months calculated from sedimentation rate of 45mg/cm²/yr. Assumes each layer is 6 months deposition

* Counts show the number of cells counted in each group together with the Σ they represent of the total count
COUNTED GROUPS: I=Benthics and Pennates. II= *Skeletonema costatum*. III= *Thalassiosira* spp. IV= *Chaetoceros* spp.
V= *Silicoflagellates*. (D.speculum)

3.6.2 Diatom counting.

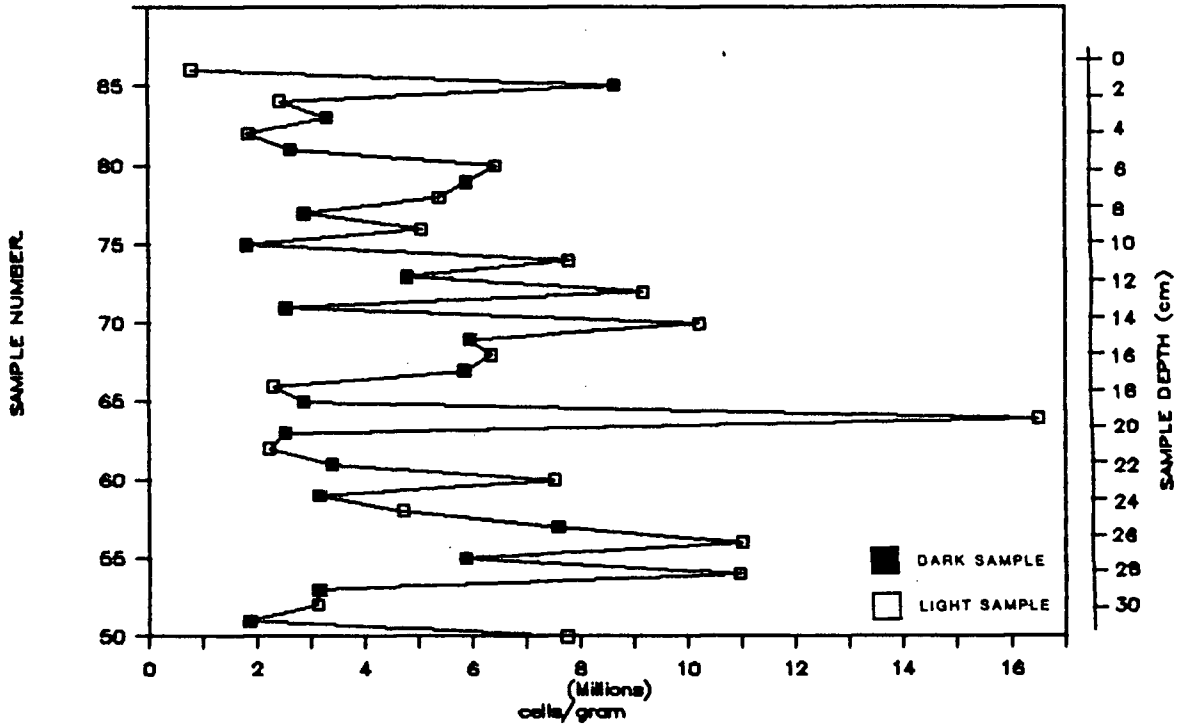
The geochemical data indicates that there are possibly two types of sediment; an upper type in which seasonal signals appear to be lost or on a very fine-scale, and a section with a higher sedimentation rate in the lower half of the core in which varves appear to be preserved. In this section, many elements show clear variations between the light and dark samples. These observations imply that the laminae below sample 75 are true varves, where variation in the lithogenous input to the Inlet is preserved and where variations in the diatom assemblages may also be recorded. This conclusion means that the discrepancy between varve counts and the ^{210}Pb data is the result of variation in the sedimentation rate and the mineralogy at this site.

In order to corroborate the geochemical observations, diatom groups that show seasonal signals in sediment traps moored in Saanich Inlet (*Sancetta and Calvert, 1987 in press*) were counted. Table X is a summary of the results obtained.

Fig. 3.6.1 shows the total numbers of diatom cells per gram of wet sediment. Cell counts, with the exception of the core-top above sample 80 and samples 62-63 and 66-67, are higher in the light layers, which is consistent with the preservation of a signal reflecting the known summer maximum of production in Saanich Inlet. This seasonal signal seems to continue above sample 70, which is the point at which

Fig: 3.6.1 DIATOM COUNTS.

Cells/gram. Wet sediment.

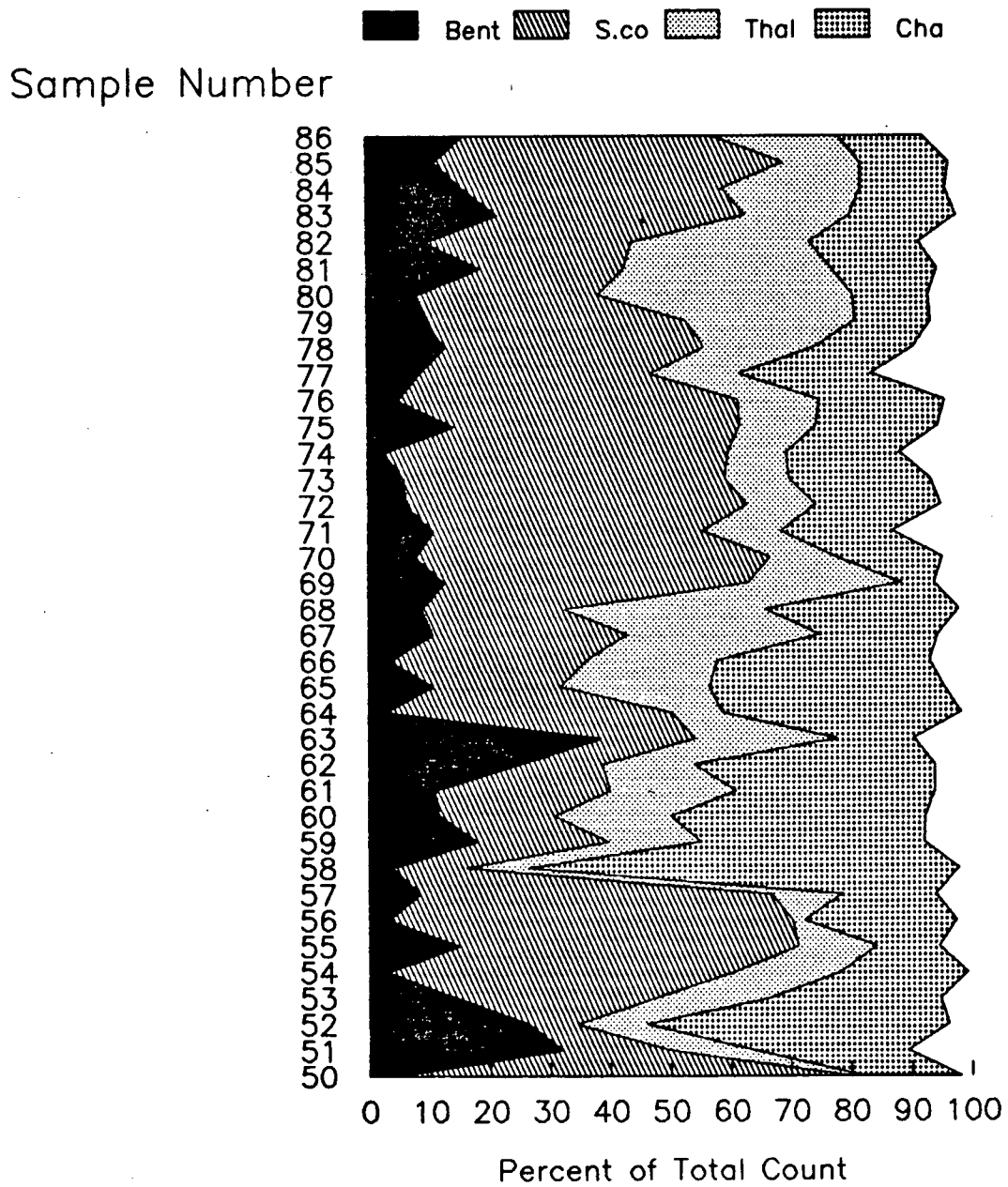


geochemical data indicate a change in sediment type. It breaks down only in the samples which contain the high carbonate values thought to be associated with the dust-dump from Bamberton.

Variation in the preservation of diatom frustules during their passage through the water column to the sediments is the subject of great uncertainty and debate (Sancetta and Calvert, 1987 in press). Grazing, interspecific competition for nutrients, illumination and temperature are all variables which will affect the preservation of diatoms either directly, such as grazing, or indirectly through competition for nutrients resulting in variations of the thickness of frustule walls and thus of their ability to withstand sedimentation processes. Many of the comparisons made in this section are based on the assumption that preservation is constant, as there appears to be no significant change in the species composition between surface and bottom water sediment traps near the site of core CPIV (Sancetta pers comm).

However, preservation problems are not ignored. For example, interspecific variation in the frustule thicknesses within the groups counted, without the additional differences caused by factors such as nutrients, temperature and grazing which show temporal variation, must be considered. S.costatum is a small, often weakly silicified diatom. The Chaetoceros group contains species which are much more heavily silicified, although the

Fig: 3.6.2 Relative Abundance of Diatom Groups.
Core CPIV. Finlayson Arm.



dominant species found in this study, C. radicans and C. didymus are small and thin walled. The centric diatoms in the Thalassiosira group generally have thick frustules. Although the appearance of the sediments when studied under the microscope indicated that preservation was good, these points cannot be ignored in these types of comparisons.

Figure 3.6.2 shows the relative abundances of the groups counted. It can be seen that the largest variations occur at the base of the core section. All four groups show changes in abundance that are on a longer timescale, assuming the laminae are varves, than would be expected from a seasonal signal. Above sample 70, the changes in relative abundance become less obvious, although variation in the abundance of benthic species is less marked above sample 65. A transition at this point is in keeping with geochemical observations and with the laminae becoming harder to follow during sampling.

It is expected that the benthic species would be indicative of turbulence and resuspension of sediments within the Inlet since they are not likely to be indigenous to the anoxic sediments of the central basin. The count of benthic species, which includes Paralia sulcata, and species of Navicula, Nitzschia, Cocconeis and Grammatophora, is shown in Fig. 3.6.3. The variation between samples is seen to be random. No consistent relationship is obvious between counts of benthic species and the light or dark nature of the layers, although where a seasonal signal is seen, as for

Fig: 3.6.3 BENTHIC GROUP

CELLS/GRAM WET SEDIMENT.

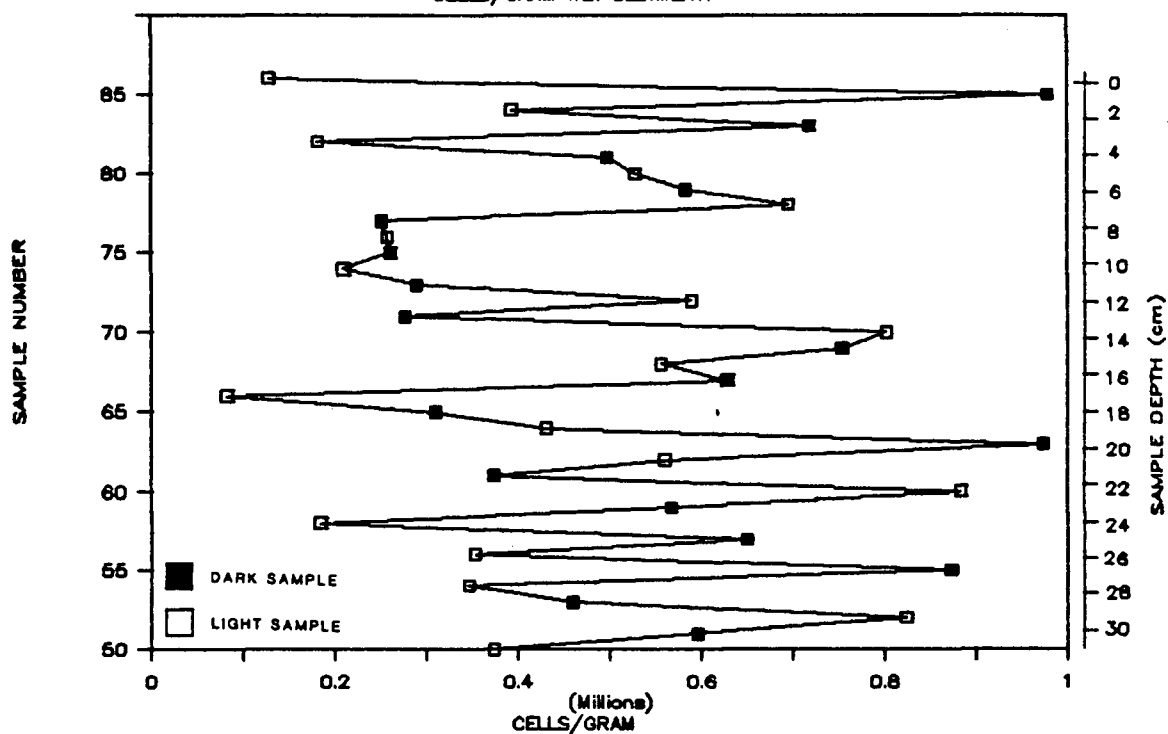
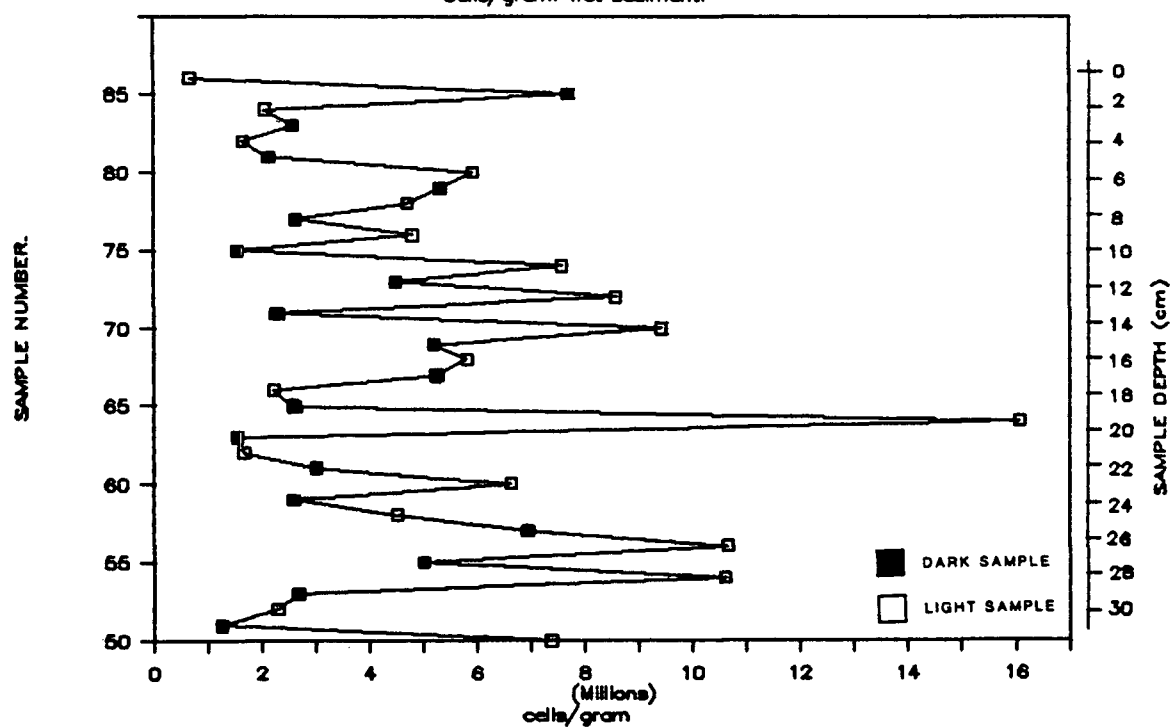


Fig: 3.6.4 PLANKTONIC DIATOM COUNTS.

Cells/gram. Wet sediment.



example between samples 54-59, the dark layers do contain higher cell numbers.

An estimate of the contribution of planktonic species, represented by the other three groups counted, was made by subtracting the benthic count from the total count. The result is shown in Fig. 3.6.4. As expected, these species generally have higher counts in the light layers, implying that these samples are indeed coincident with summer deposition.

Counts of Chaetoceros are presented in Fig. 3.6.5. This group shows the clearest seasonal signal of any group counted. With only two exceptions, samples 62 and 66, the light layers show higher counts up to number 80, where the seasonal signal breaks down. This profile, while it corroborates the presence of varves in the bottom half of the core, does not suggest that a seasonal signal is absent in the upper section. Although intersample variations are seen to decrease above sample 75, two explanations for the continued seasonal signal, in light of the measured ^{210}Pb activity (see section 3.1.2), are possible. Firstly, the seasonal counts might simply be chance and that the variations seen in the core-top sediment type are insignificant when the error involved in the calculation of cells/g is considered. The second explanation is that the top layer of sediment does contain a seasonal signal, that the laminae are finer because of the decreased sedimentation rate, and that it was not possible to sample them

Fig: 3.6.5 **CHAETOCEROS**
CELLS/GRAM WET SEDIMENT.

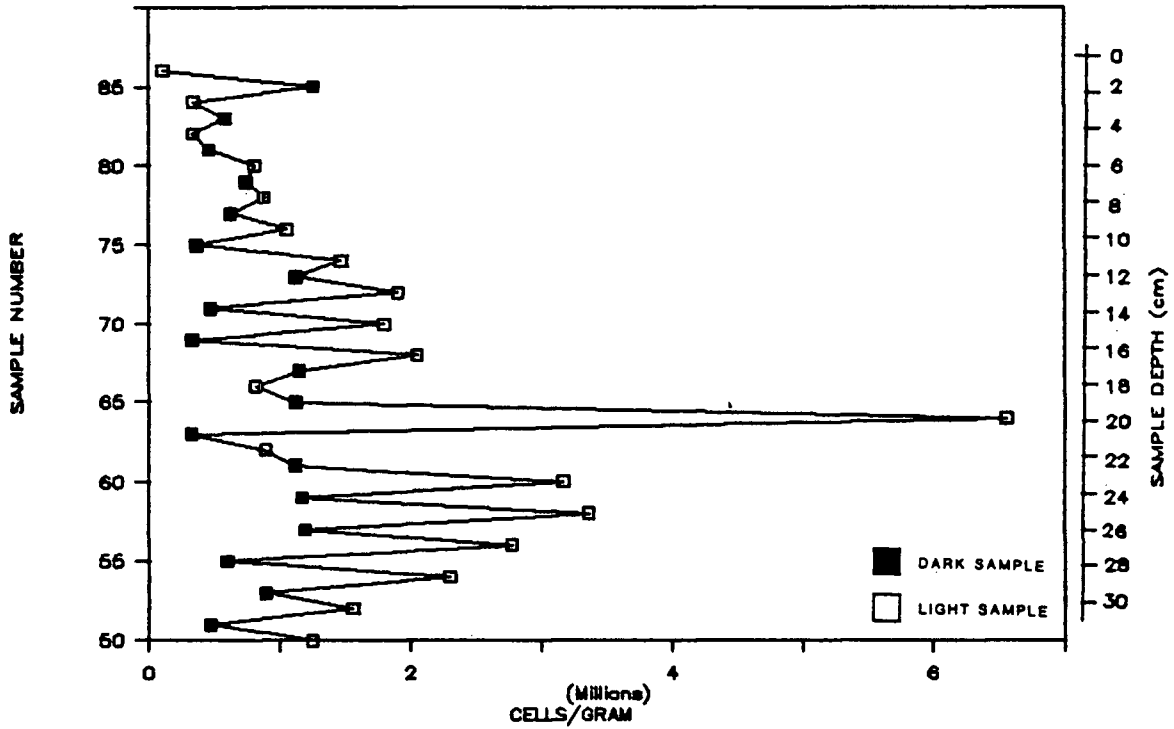
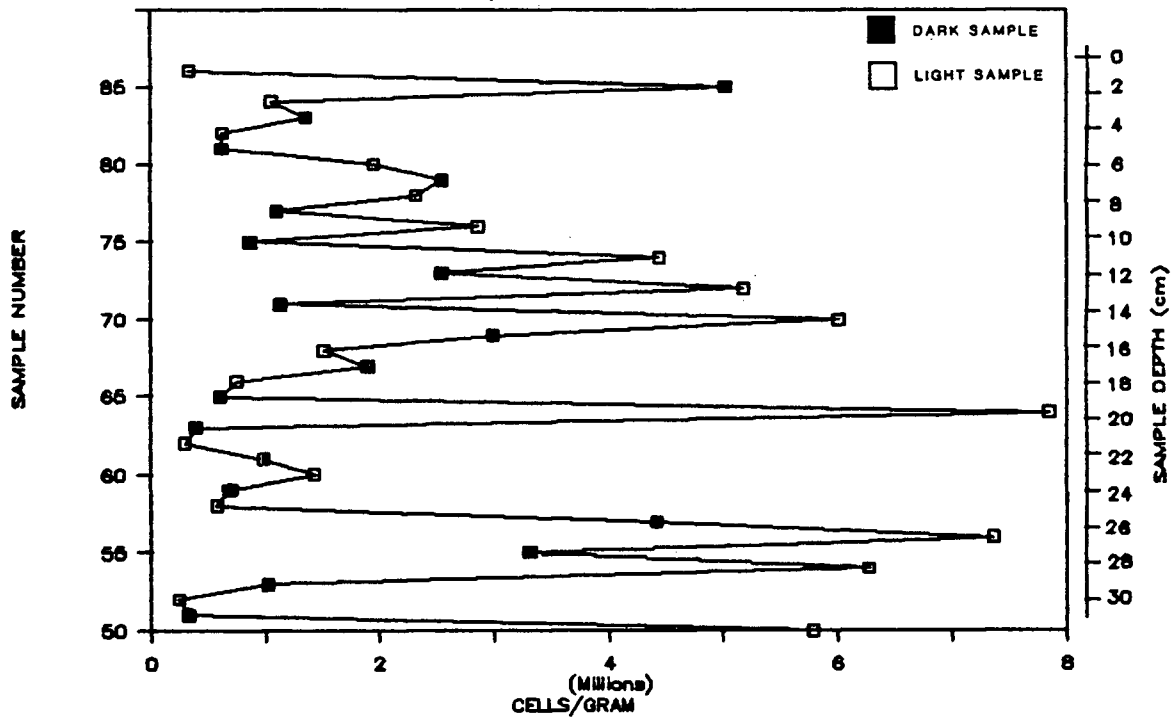


Fig: 3.6.6 **SKELETONEMA COSTATUM**
CELLS/GRAM WET SEDIMENT.



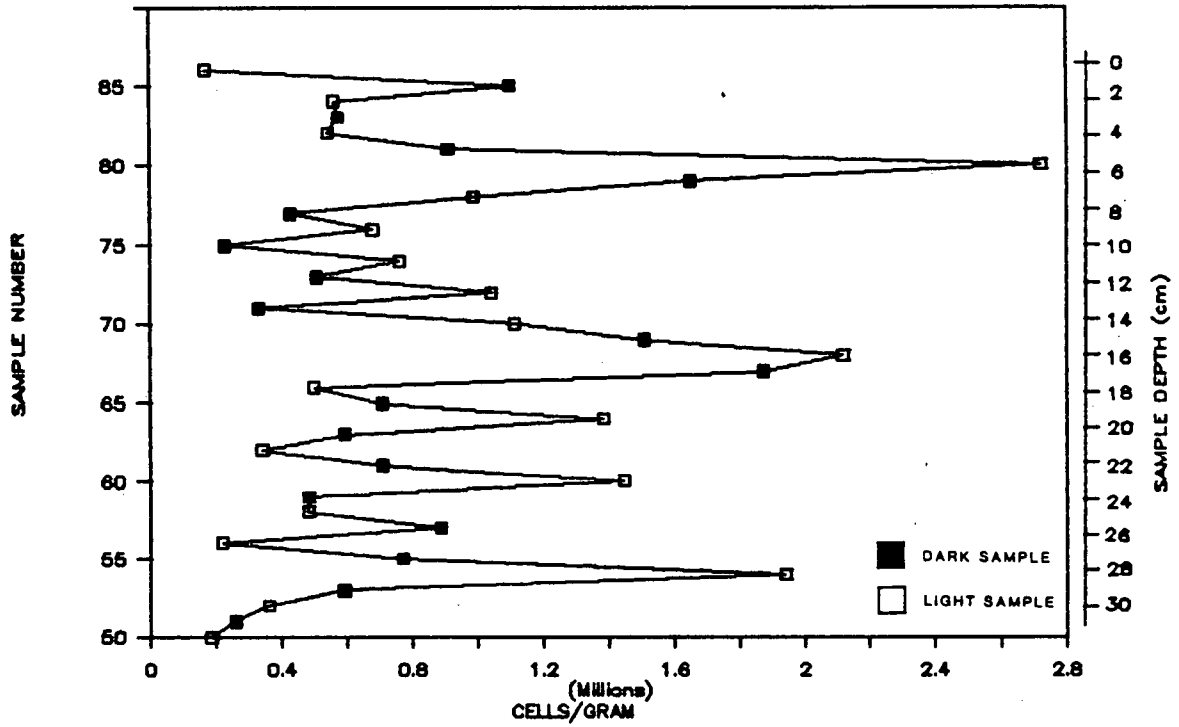
discretely because of their fine-scale. Perhaps those samples within the transition zone which are distinct are indeed varves and represent periods of particularly high production, producing a more distinct layer to be deposited.

Within the clearly defined laminae, Chaetoceros counts are higher in the light layers. This is expected since these diatoms are characteristic of summer production in the Saanich Inlet (Takahashi et al. 1977). Sample 64 stands out in this profile as having very high counts, although it does not contain any unusual chemical signal.

Skeletonema costatum was counted as a single species since it is easily recognised and is a characteristic species of the spring bloom in the Inlet (Sancetta and Calvert 1987). It is one of the most widespread neritic species in the plankton of the eastern Pacific and is particularly common in the spring bloom (Cupp, 1943). Its widespread occurrence indicates that this species has broad environmental tolerances. However, Stockner et al. (1979) have shown that marked annual variations in the abundance of this species are observed in the Strait of Georgia. The data on this species is presented in Fig. 3.6.6. Counts are seen to be higher in the light layers; however, a clear and consistent seasonal signal is not evident. This supports the idea, presented in section 3.6.1 that S.costatum numbers appear to vary quite considerably between consecutive years.

The abundance of Thalassiosira species shows no clear distinction between light and dark layers (Fig.3.6.7).

Fig: 3.6.7 THALASSIOSIRA
CELLS/GRAM WET SEDIMENT.



This might be expected, since this group is thought to be associated with the cooler conditions of early spring and late autumn (*Takahashi et al.* 1977; *Sancetta and Calvert*, 1987 in press). If this is the case, then they may well become incorporated in dark samples during sampling since they would occur close to the junction between light and dark layers. This might lead to the samples showing a random variation.

In summary, the diatom data lends support to the proposition that there are varves preserved in the bottom half of the core. This is particularly clear in the counts of Chaetoceros. This observation is taken to mean that this group is either less susceptible to environmental variation and therefore better able to survive in various environmental conditions, or that they are less affected by processes in the water column, such as grazing. Chaetoceros counts have a distinct and consistent light/dark up to sample 80, and this reveals that the upper sediment type contains seasonal signals, albeit reduced, and that the discrepancy between the ^{210}Pb data and the varve counts is because of dilution of the ^{210}Pb activity.

CHAPTER 4 DISCUSSION.

This study has concentrated on the upper 32.5 cm of a core collected in Finlayson Arm, Saanich Inlet. The core has been found to contain two types of sediment. The upper 15cm of the section contains a sediment with indistinct laminae and a distinct geochemistry, while the bottom half of the core contains sediments in which seasonal signals are preserved as varves. The ^{210}Pb data and the porosity derived from chlorine concentrations indicate that these two sediments were deposited at different sedimentation rates.

Major element geochemistry indicates that the two sediments are chemically distinct. The upper type contains higher concentrations of Fe, Ti and lower amounts of Si and Mg. Potassium shows no clear difference between the sediment types. Within the varved section, the major elements show some indication of seasonal variation; however, no consistent pattern for any element has emerged.

The minor elements show less clear distinctions between the two sediment types; however, a number of these elements do show a consistent seasonal signal within the varved section. Vanadium and Sr are particularly good examples, while a number of other elements show shorter sequences of light/dark variation. Barium decreases at the top and bottom of the core and is at a maximum where the opal content of these sediments is highest. This appears to indicate that there has been a change in primary production

within Finlayson Arm and the decrease at the top and bottom of the section implies a a production change in a cyclical fashion.

Analysis of the diatom assemblages generally do not show clear seasonal signals. The exception to this is the cell counts of the Chaetoceros group, which does show a clear and consistent seasonal variation that continues out of the varved section and into the upper sediment type. Total Chaetoceros counts also decrease where other evidence suggests that primary production decreases.

The activity of ^{210}Pb does not appear to show any signs of disruption caused by mixing; however, it has been shown that the change in sedimentation rate has distorted the activity profile of this isotope making it impossible to derive a chronology for this core.

Despite the lack of a well defined chronology, this study has identified distinct changes in the sediment record which may be attributed to oceanographic and sedimentation changes. A number of conclusions can be derived from this study which will prove useful to any such research contemplated in the future.

Many of these conclusions are best presented in a review of the sediment history revealed by core CPIV. It is proposed that the true sediment/water interface has been lost and that the surface of the core in fact represents sediments approximately 20 years old. This observation is supported by lower ^{210}Pb activities in the surface sediments

than those found in other studies in Saanich Inlet (although *Carpenter and Beasley* (1981) do show low values in Finlayson Arm which they also attribute to sediment loss). It is also supported by high ^{137}Cs activity in the top few samples of the core which, although the profile of ^{137}Cs is not well defined, indicate that these horizons are pre-1963 since higher values close to the expected maximum of around 400 dpm/kg are not seen in samples from lower in the core. The peak in carbonate within the top few samples is thought to be associated with a dump of limestone dust which occurred between 1960-1963. This is unlikely to be recent biogenic carbonate because the Sr profile does not show a similar increase. The loss of sediments from the core-top is probably due to the very high water content of surface sediments in the central basin of Saanich Inlet.

The measured activity of ^{210}Pb revealed a large discrepancy between varve counts (the section studied contains 36 sampled laminae representing 18 years of summer/winter deposition) and the assigned ages based on the 22.2 yrs half-life of ^{210}Pb . The measured surface activity of 10dpm/g decreases to 1.1dpm/g at 32.5cm depth, implying that the section contains sediments deposited over approximately three half-lives, or 65-70 years. This mismatch means that the original goal of the study could not be attained.

Geochemical data on the major and minor element concentrations in the samples revealed that there appeared

to be a change in mineralogy and perhaps a change in the proportion of marine vs terrestrial material, reflected in a decrease in production within the top 10-15cm of the core. The boundary between sediment types is not well defined, but is thought to lie between samples 70-80. The sediment type in the upper core is not distinguished by the XRD spectra, and this implies that the additional material is an amorphous or poorly crystalline phase. Possible candidates include detritus from the Bamberton plant and an increased input of soil clays; however, a better definition of this mineral phase is not possible.

On the basis of the geochemical evidence, supported by the observation that light/dark variation in water contents were preserved, the chlorine profile is a true indication of the porosity of the samples. When porosity was calculated from the water contents, there was seen to be lower porosity at the top of the core rising to a maximum in sample 68 and then decreasing again to sample 50.

The diatom data do clearly support the boundary between the two sediment types being placed at sample 70. While most of the groups counted do not show a consistent variation between light and dark samples, counts of Chaetoceros do appear to indicate a clear and consistent seasonal signal showing higher counts in the light (summer) laminae. This signal, although the difference in counts between adjacent laminae are reduced above sample 70, nevertheless continues to show light/dark variation up to

sample 80. This is almost coincident with the increase in carbonate that starts in sample 78.

This observation is inconsistent with the measured decrease in ^{210}Pb activity. Excess ^{210}Pb decreases from 10dpm/g in sample 86 and 12dpm/g in sample 85 to 3.8dpm/g in sample 75 (thought to be coarser-grained and shown to contain higher amounts of lithogenous elements such as Fe, Ti and Mg) and 1.7dpm/g in sample 70. There is a smaller change from here to the base of the section, from 1.7dpm/g to 1.1dpm/g. By far the greatest decrease in ^{210}Pb activity occurs above sample 70.

Interpretation of the ^{210}Pb data, using a steady-state sedimentation model implies that the core section covers a time period of 65-70 years. However, the observation of a mineralogically different sediment in the top half of the core throws doubt on this chronology and suggests that the sedimentation rate has also changed and that, given a change in mineralogy, the relative proportions of ^{210}Pb -depleted terrestrial material to ^{210}Pb -rich marine detritus might also have changed.

Although the observed porosities based on the chlorine data and the non steady-state sedimentation implied by the geochemistry meant that good estimates of sedimentation rate based on ^{210}Pb decay could not be calculated, a calculation was performed using the observed porosities. This indicated that the upper sediment type had a sedimentation rate of 0.31 cm/year while the lower half of

the section, below sample 70, had a rate of 1.03 cm/year. While these results are somewhat questionable, they do indicate that sedimentation rates in the top 15cm of the core were substantially lower than in the lower half.

If there has been a change in sediment type and in the proportions of terrestrial and marine sediment components together with a change in sedimentation rate, the ^{210}Pb activity decrease measured in this section is not a reflection of radioactive decay. The sediment in the upper core is not the product of a sudden input of terrestrial or nearshore sediment because this would be reflected in an anomalously low ^{210}Pb activity. Moreover, features such as the peak in carbonate, Mn and Pb would not likely be preserved in such a rapid depositional event. In contrast to the ^{210}Pb data, the carbonate peak probably coincides with a dump of carbonate dust from Bamberton which took place between 1960-1963. A clear definition of this would require a much more detailed ^{137}Cs profile. A change in the primary production during this period might also have an effect on the flux of ^{210}Pb into the sediments. Robbins (1978) stated that variations of primary production are a major influence on the relationship between ^{210}Pb delivery and the measured activity in surface waters and thus, presumably, at the sediment interface. Although coastal waters are generally thought to be particle-rich and thus provide a ready source of vectors to transport ^{210}Pb to the sediments, it may be that the quiet conditions in Finlayson Arm do allow large

variation in the particulate load of the water column to occur.

One problem with this explanation is the increasing contents of organic carbon in the surface sediment. Carbon, without the opal correction, is seen to increase from sample 70 upwards, coincident with the decrease in Ba and Si and lower Chaetoceros counts that are thought to indicate decreased production. However, if the decrease in sedimentation rate was more significant than the dilution of carbon by the terrestrial material, then an increased carbon content might be expected.

Below this change in sedimentation, the laminae appear to be varves. Vanadium, Sr, and counts of Chaetoceros show consistent light/dark variations which are indicative of seasonal input. Many of the other major and minor elements do not show consistent variations, but there are sections of some profiles where clear light/dark variations are observed which conform to pulses of lithogenous input to the Inlet. These variations are consistent with those proposed by Gross and Gucluer (1964) to account for the varves in Saanich Inlet. They suggested that the light layers represent summer production, and indeed the Chaetoceros counts are all higher in the light layers in this core. They also suggested that the dark layers contain higher amounts of lithogenous material and this too is consistent with the observations in this core. It is interesting to note, however, that Gross and Gucluer (1964)

distinguish the laminae they sampled partly on the basis of counts of Paralia sulcata, a benthic diatom, and counts of S.costatum, both of which do not show any clear distinction in this core. The reason that these two diatoms do not show a seasonal signal in this core, but that Chaetoceros does, is thought to be linked to grazing. It is possible that the major factor affecting the diatom remains reaching the sediments in Finlayson Arm is the extent to which they are grazed by zooplankton. *Stockner and Cliff* (1979) state that grazing is the prime control on phytoplankton populations in the Strait of Georgia. Chaetoceros species are characterised by long, often spiny chaetae and it is conceivable that these will afford the cells some degree of protection from grazing.

In order to develop a chronology for the core section studied, it would be necessary to assign a fixed date to a point and to derive the chronology by varve counting. This is complicated by the apparently gradual change in sediment type and the uncertainty as to how many years the change represents. The only point for which there is some good evidence available which would allow it to be fixed in time is the carbonate dump from the Bamberton Plant. If the base of the carbonate peak, at sample 78, is taken to represent 1960, then the ^{210}Pb activity is seen to decrease from around 4.0dpm/g to 1.1dpm/g in sample 50. This represents two half-lives of decay (approximately 45 yrs) compared with only 14 years of varve record.

If, on the other hand, the change in sedimentation is taken to occur at sample 75, and the small variations in the Chaetoceros counts above this are taken to be insignificant and not representative of seasonal sedimentation, then there is approximately one half-life of ^{210}Pb (22.5yrs) between this point and the base of the core. This still means that there should be twice the number of varves actually counted (12.5 years between samples 75-50), although the difference is not so discrepant. If the breakdown of the seasonal signal is taken to occur at sample 70, where the geochemical data indicates a change in sedimentation, then there is a decrease in ^{210}Pb activity equal to a little over one half a half-life (around 14 years). This matches reasonably well with 10 years of counted varves. These last two possibilities do not, however, allow a chronology to be adopted for the whole section, since there is no other time marker within the varved section and since the time represented by the sediments between the onset of the sediment change and the carbonate peak is unknown. The only conclusion possible is that a time-scale cannot be assigned to the sediment section and we are unable to examine floral and geochemical changes with respect to climatic and runoff records for the local area.

The possible change in production is, however interesting from a palaeoceanographic viewpoint. Above sample 70, and to a lesser extent within the five lowest

samples in the core, Ba contents decreases. Together with the decrease in Si, this might indicate lower production within Finlayson Arm. Large variations in annual production and the success of the common species of diatoms have been shown to occur in the Strait of Georgia (Stockner et al. 1979). If such variation is possible within the physically mixed environment which the Strait represents, then it might be expected that in Saanich Inlet, and especially Finlayson Arm where the mixing processes are thought to be much weaker, large variations in primary production might also occur. Although this might explain between-layer variations in the diatom counts, the change implied by the Ba data, and possibly by the Chaetoceros data, indicate a change in production on a 10-15 year cycle, with the top and bottom of the core being characterised by lower productivity. This is a cycle derived using the best estimate of a chronology for this core and assumes that the less well defined change in sedimentation at the bottom of the core also represents a change in production. There does appear to be an increase in Fe between sample 50-55, and Ba, organic carbon and the Si:Al ratio all indicate that there is a further change in sedimentation here. Chaetoceros counts, which have been shown to indicate clear seasonal fluctuations, are highest in the middle of the core and decrease at the top and bottom.

The reason for such long-term fluctuations in the production is not known; however, such variability has been

recognised in other studies. *Colebrook* (1982) has shown seasonal and annual variation in the plankton of the North Atlantic, sampled with a Hardy plankton recorder, although he concentrated his analysis on change due to geographic variation. *Gieskes and Kraay* (1977) used records from the same equipment to provide a data series of plankton in the North Sea from 1948-1975. This data set clearly shows large fluctuations on both short (monthly/interannual) and longer (multi-annual) time-scales in both phyto- and zooplankton populations. They showed that the long-term fluctuations are not thought to be the result of anthropogenic influence, but argue that they are caused by variation in seawater temperature, fluctuations in solar radiation and gradual change in the atmospheric patterns over the North Atlantic, and therefore in circulation.

Salmon migration routes in the Northeast Pacific show that they are influenced by long-term variability in climatic patterns (*Hamilton, 1980; Mysak et al., 1986*), and this implies that there is reason to believe changes in the atmosphere, and thus in the oceanographic regime of this region, are influencing the biological oceanography. It is therefore reasonable to argue that such influences might have a long-term effect on phytoplankton populations and thus on primary production.

A review of variability on both short and long time scales and of the implications of such change on our understanding of plankton dynamics, is provided by *Harris*

(1980), although his analysis concentrates on short term fluctuations. Variability on timescales of years or decades are likely to become even more significant in the light of current research aimed at the study of global variability in climatic, oceanographic and geochemical data.

CHAPTER 5: SUMMARY AND CONCLUSIONS.

5.1 Summary.

Cores of varved sediments were collected from Finlayson Arm in Saanich Inlet. This part of the Inlet was chosen because it was thought that cores of undisturbed sediments could be obtained. The initial objectives of the study called for the development of a well defined chronology that would allow the interpretation of the geochemical and diatom record preserved in the sediments.

On the condition that they can be successfully sampled, the varves themselves would provide such a chronology; however, the objectives of the study called for confirmation of such a varve chronology with measurements ^{210}Pb and the development of a timescale based on the 22.2 half-life of this isotope.

Samples collected from the varve laminae of a core that was thought to have a preserved interface revealed a large discrepancy between the varve counts and the measured decay of ^{210}Pb . Varve counts indicated that there were 18 years of deposition in the top 35cm of core CPIV, while the decay of ^{210}Pb indicated that the same section should contain the record of 65-70 years.

This raised the possibility that the laminae seen might not be true annual varves, but that they recorded longer cycles of accumulation. However, microscopic studies

of well-preserved laminae from lower in the same core, and of varves preserved within the sampled section, revealed that a seasonal signal could be determined from the laminae and that they appeared to clearly reflect the seasonal succession of diatoms known to occur in Saanich Inlet. Measurement of the ^{137}Cs content of some samples, while far from providing a complete profile of the core, did, however, tend to support the ^{210}Pb data in that higher ^{137}Cs contents were found around the section at which ^{210}Pb indicated that the sediments were deposited around 1960. The ^{137}Cs values obtained from the top of this core are high enough that they must lie within the time zone 1945-1963.

This information forced the focus of the study to be changed so that this discrepancy could be investigated in detail. A geochemical analysis and the determination of diatom assemblages, based on counts of the major diatom groups which show seasonal signals in sediment traps within Saanich Inlet, was carried out on samples taken from individual laminae within the top 32.5cm of one core.

The observations gathered from this study indicate that sedimentation within Finlayson Arm is not steady and that fluctuations seem to occur in sedimentation rate, bulk mineralogy and primary production. Thus, the relative proportions of marine and terrestrial detritus are subject to change. It is proposed that this affects the observed ^{210}Pb profile and that this is the cause of the discrepancy between varve counts and the ^{210}Pb profile in this core.

Two clearly defined sediment types and sedimentation regimes were seen in this section. There also appears to be a change in sediment within the lowest five samples from the base of the section, although this change is not so well defined.

The top 15cm of the core contains sediments which are characterised by lower sedimentation rates and an increased amount of an undefined, poorly crystalline mineral phase or phases that are probably of terrestrial origin. Preserved within this section is a peak in carbonate which has been linked to a dump of carbonate dust from the cement production plant at Bamberton between 1960-1963; however, this cannot be used to define a chronology because of the uncertainty in the time represented by the sediments between the base of the carbonate peak and the clearly defined varves lower in the core. The upper section of the sediment also appears to coincide with decreased primary production and, together with what appears to be another decrease in production at the base of the core, might indicate that primary productivity in this part of Saanich Inlet, and perhaps in the Inlet as a whole, is subject to some unknown influence which generates long-term cycles. Such a cycle would have a periodicity of between 10-15 years based on the decay of ^{210}Pb and its best fit with the varve counts.

The original observation of a large discrepancy between the varve counts and the measured ^{210}Pb activities is explained by the dilution of the isotope by increased

proportions of ^{210}Pb -depleted terrestrial material relative to marine detritus, and by the proposed change in production which might result in a decreased flux of ^{210}Pb to the sediments. Both of these possibilities would result in decreased concentrations of the isotope and thus the observed decay would not reflect the true activity decrease but would contain a signal imposed by the nonsteady sedimentation rates and dilution.

Below the upper anomalous section of the core, annual varves appear to be well preserved. A number of elements show clear indications of pulsed lithogenous input within this section. However, it seems that the transition between the two sediment types is a gradual one occurring between samples 70 and 80, and because of this it is not possible to define a chronology for the core. Counts of Chaetoceros show the clearest seasonal signal and, although decreased, this is seen to continue through the mineralogical change. It may be that a seasonal signal is preserved within this section on a scale which was too fine to be sampled.

The lack of a chronology means that palaeoceanographic interpretations cannot be developed from the data contained in this core. However a number of useful conclusions can be drawn from this study.

5.2 Conclusions.

- 1: The varves observed within the sediments of Saanich Inlet do reflect a seasonal signal with the light layers containing the record of summer production and the dark layers containing increased amounts of terrestrial material. This is consistent with previous explanations of varve production in Saanich Inlet by *Gucluer and Gross (1964)*.
- 2: Sedimentation in Finlayson Arm is characterised by variable sedimentation rates and mineralogical composition. This has disturbed the activity profile of ^{210}Pb . This site is not considered to be suitable for further palaeoceanographic studies.
- 3: The discrepancy between the number of varves and the ^{210}Pb activity is explained by the dilution of the isotope within the upper section of this core and by the non steady-state sedimentation.
- 4: A carbonate dust dump from the Bamberton cement plant between 1960-1963 appears to be useful as a time marker within the Inlet. At this locality this dump was defined by an increase of around 4 wt% CaCO_3 .
- 5: It appears that the pre-compaction water contents of the sediments in the central basin makes the identification of the true sediment/water interface

very difficult. In this core it appears that some 20-25 years of surface sediment has been lost, and that the interface recovered represents sediments deposited in the early 1960's.

6: Major element concentrations in the individual laminae do not show clear and consistent seasonal signals. The clearest indication of pulsed inputs of terrigenous material is seen in the absolute abundances of some minor elements, especially V and Sr.

7: Barium concentrations appear to be linked to changes in the primary production of the Inlet and variations in the ratio of this element to Al might indicate that there are 10-15 year cycles of production. Detailed analysis of Ba, sterols (to try and pinpoint the true nature of the Ba-production association) and well defined opal determinations on a longer core with a known chronology might provide some interesting information on the palaeoceanography of Saanich Inlet. Long-term data sets on phytoplankton, and variability of their populations, would be useful and may be particularly enlightening in view of the climatic and oceanographic variability known to affect this region.

8: High Mn concentrations in the core top are not thought to indicate that the core-top was oxic but rather that this metal is associated as a pollutant with the carbonate dump.

- 9: Most groups of diatoms preserved in the sediments do not appear to show clear seasonal signals in the samples collected. The exception to this is the Chaetoceros group which shows a clear and consistent seasonal pattern. The proposed reason for this is that the chateae, which are characteristic of this group, afford them some protection from grazing by zooplankton. Because of this, future studies should consider this group in more detail.
- 10: The variation seen in the other diatom groups counted may reflect grazing although there is evidence that even the major diatom groups undergo large annual fluctuations in their abundances within the Strait of Georgia and probably, therefore, in Saanich Inlet.
- 11: Future studies of diatom sedimentation in Saanich Inlet should be supplemented by studies of fresh plankton material in order to quantify the effect of grazing on the thanatocoenoses.

BIBLIOGRAPHY.

- Abbey S. 1980. Studies in "Standard Samples" for use in the general analysis of silicate rocks and minerals. Part 6. Geol. Surv. Canada. Paper 80-14.
- Anderson J.J and Devol A.H. 1973. Deep water renewal in Saanich Inlet, an intermittantly anoxic basin. Est. Cos. Mar. Sci. 1 pp 1-10.
- Baumgartner T, Ferrera-Bertina V, Schrader H. and Soutar A. 1985 A 20-year varve record of silicious phytoplankton variability in the Central Gulf of California. Mar. Geol. 64 pp 113-129.
- Berrang P.G and Grill E.V 1974. The effect of manganeseoxide scavenging on molybdenum in Saanich Inlet B.C. Mar. Chem. 2 pp 125-148.
- Brongersma-Sanders M, Stephen K.M, Kwee T.G and Debrun M. 1980. Distribution of minor elements in cores from the south-west African shelf with notes on plankton and fish mortality. Mar. Geol. 37 pp 91-132.
- Bruland K.W 1974. Pb-²¹⁰ geochronology in the coastal marine environment. Phd Thesis. University of California, San Diego. 102p.
- Bruland K.W, Bertine K, Koide M and Goldberg E.D 1974. History of metal pollution in Southern California coastal zone. Environ. Sci. Technol. 8 pp 425-432.
- Brzezinski M.A 1985. The Si:C:N ratio of marine diatoms: Interspecific variability and the effect of some environmental variables. J. Phycol. 21 pp 347-357.
- Calvert S.E 1964. Factors affecting distribution of laminated diatomaceous sediments in the Gulf of California. In Marine Geology of the Gulf of California- A Symposium. Am. Ass. Pet. Geol. Memoir 3 pp 311-330.

- Calvert S.E 1966a. Accumulation of diatomaceous silica in the sediments of the Gulf of California. Geol. Soc. Am. Bull. 77 pp 569-596.
- Calvert S.E 1966b. Origin of diatom-rich varved sediments from the Gulf of California. Journ. Geol. 74 pp 546-565.
- Calvert S.E 1976. Mineralogy and geochemistry of near-shore sediments. In Chemical Oceanography 6 Riley J.P, Chester R. (eds) pp 187-280.
- Calvert S.E and Price N.B. 1983. Geochemistry of Namibian shelf sediments. In Coastal Upwelling: Its sediment record. Pt.A Responses of the sedimentary regime to present coastal upwelling. Suess E., Thiede J. (eds). Nato Conf. Series pp 337-375.
- Carpenter R. and Beasley T.M 1981. Plutonium and americium in anoxic marine sediments: evidence against remobilization. Geochim. Cosmochim. Acta 45 pp 1917-1930.
- Clapp C.H 1912 Southern Vancouver Island. Geol. Surv. Canada. Memoir 13.
- Clapp C.H 1913 Geology of Victoria and Saanich map-area, Vancouver Island. Geol. Surv. Canada. Memoir 36.
- Colebrook J.M. 1982. Continuous plankton records: Seasonal variations in the distribution and abundance of plankton in the North Atlantic Ocean and the North Sea. J. Plank. Res. 4 pp 435-462.
- Cupp E.E 1943. Marine plankton diatoms of the west coast of North America. Bull. Scripps Inst. Oceanog. 5(1) pp 1-238.
- Curry J.R and Moore D.G 1982. Geologic and tectonic history of the Gulf of California. Initial Reports of the Deep Sea Drilling Project. LXIV(A) pp 1279-1295.

- Doff D.H 1969. The geochemistry of recent oxic and anoxic sediments of Oslo Fjord, Norway. Phd Thesis. University of Edinburgh. 245p.
- De Geer G. 1912. A geochronology of the last 12,000 years: Cong. Geol. Internat. 11th. Stockholm 1910. Comptes Rendus. pp 241-253.
- Donegan D and Schrader H 1981. Modern analogues of the Miocene diatomaceous Monterey Shale of California: Evidence from sedimentologic and micropalaeontologic study. In The Monterey Formation and Related Siliceous Rocks of California. Soc. Econ. Palaeo. Mineral. pp 159-179.
- Donegan D and Shrader H 1982. Biogenic and abiogenic components of laminated hemipelagic sediments in the Central Gulf of California. Mar. Geol. 48 pp 215-237.
- Flynn W.W. 1968. The determination of low levels of polonium ²¹⁰ in environmental materials. Anal. Chimica. Acta. 33 pp 221-227.
- Francois R. 1987. Some aspects of the geochemistry of sulphur and iodine in marine humic substances and transition metal enrichment in anoxic sediments. Phd Thesis. U.B.C. 461 p.
- Fresnel J, Galle P. and Gayral P. 1979. Resultats de la microanalyse des cristeaux vaucolaires chez deux chromophytes unicellulaires marines: Exanthemachirysis gavralliae, Pavlova sp. (Prymnesiophycees, Pavlovacees) Comptes Rendu de l'Academie des Sciences de Paris. 288 pp 823-825.
- Gieskes W.W.C and Kraay G.W. 1977. Continuous plankton records: Changes in plankton of the North Sea and its eutrophic southern bight from 1948-1975. Neth. J. Sea Res. 11(3/4) pp334-364.

- Glasser F.P. 1979. Fundamentals of cement chemistry. The clinkering process. In Cement Production and Use. Skalny J. (ed) Engineering Foundation, New York.
- Goldberg E.O and Arrenhius G.O.S 1958. Chemistry of Pacific pelagic sediments. Geochim. Cosmochim. Acta 13 pp 153-212.
- Grill E.V. 1982. Kinetic and thermodynamic factors controlling manganese concentrations in oceanic waters. Geochim. Cosmochim. Acta 46 pp 2435-2446.
- Gross M.G and Gucluer S.M 1963. Varved marine sediments in a stagnant fjord. Science 141 pp 918-919.
- Gross M.G 1967. Concentrations of minor elements in diatomaceous sediments of a stagnant fjord. In Estuaries. Lauff G.H (ed) Am. Ass. Adv. Sci. Publication 83. pp 273-282.
- Gucluer S.M and Gross M.G 1964. Recent marine sediments in Saanich Inlet, a stagnant marine basin. Limnol. Oceanogr. 9 pp 359-376.
- Hamilton K. 1985. A study of the variability of the return migration route of Fraser River sockeye salmon (Oncorhynchus nerka). Can. J. Zool. 63(8) pp. 1930-1943.
- Hamilton-Taylor J and Price N.B 1983. The geochemistry of iron and manganese in waters and sediments of Bolstadfjord, S.W Norway. Est. Coas. Shelf. Sci. 17 pp 1-19.
- Harris G.P 1980. Temporal and spatial scales in phytoplankton ecology. Mechanisms, methods, models and management. Can. J. Fish. Aquat. Sci. 37 pp 877-900.
- Harrison P.T , Parsons T.R and Tylor F.J.R 1983. Review of the biological oceanography of the Strait of Georgia: Pelagic environment. Can. J. Fish. Aqu. Sci. 40(7) pp 1064-1094.

- Harvey P.K, Taylor S.M, Hendry R.D and Bancroft F. 1973. An accurate fusion method for the analysis of rocks and chemically related materials by X-ray fluorescence spectrometry. *X-Ray Spectrometry* 2 pp 33-44.
- Hasle G.R and Fryxell G.A 1970. Diatoms: Cleaning and mounting for light and electron microscopy. *Trans. Amer. Microsc. Soc.* 89(4) pp 496-474.
- Hawkesworth C.J and Elderfield H. 1978. The strontium isotopic composition of interstitial waters from sites 245 and 336 of the Deep Sea Drilling Project. *Earth. Planet. Sci. Let.* 40 pp 423-432.
- Hawkins P. 1979. Effect of manufacturing parameters on clinker quality: Overall considerations. In *Cement Production and Use*. Skalny J. (ed). Engineering Foundation, New York.
- Hendey N.I 1974. The permanganate method for cleaning freshly gathered diatoms. *Microscopy* 32 pp 423-426.
- Herlinveaux R.H 1962. Oceanography of Saanich Inlet in Vancouver Island, British Columbia. *J. Fish. Res. Bd. Canada* 19 pp 1-37.
- Heusser L.E. 1983. Palynology and palaeoecology of postglacial sediments in an anoxic basin; Saanich Inlet, B.C. *Can. J. Earth Sci.* 20 pp 873-885.
- Hirst D.M 1962a. The geochemistry of modern sediments from the Gulf of Paria- I. The relationship between the mineralogy and the distribution of major elements. *Geochim. Cosmochim. Acta* 26 pp 309-334.
- Hirst D.M 1962b. The geochemistry of modern sediments from the Gulf of Paria-II. The location and distribution of trace elements. *Geochim. Cosmochim. Acta* 26 pp 1147-1187.

- Hobson L.A 1980. Phytoplankton biology of Saanich Inlet BC. In Fjord Oceanography. Freeland H.J, Farmer D.M Levings C.D (eds) NATO Conf. Ser. Mar. Sci. 4 pp 423-427.
- Hollibaugh J.T, Seibert D.L.R and Thomas W.H 1981. Observations on the survival and germination of resting spores of three Chaetoceros (Bacillariophyceae) Species. J. Phycol. 17 pp 1-9.
- Huntley M.E and Hobson L.A 1978. Medusa predation and plankton dynamics in a temperate fjord, British Columbia. J. Fish. Res. Bd. Canada 35(2) pp 257-261.
- Ingle J.C 1981. Origin of Neogene diatomites around the Northe Pacific Rim. In The Monterey Formation and Related Siliceous rocks of California. Soc. Econ. Paleo. and Min. pp 159-179.
- Krauskopf K.B. 1979. Introduction to geochemistry. McGraw Hill. 617 p.
- Lund J.W.G, Kipling C and LeCren E.D 1958. The inverted microscope method of estimating algal numbers and the statistical basis of estimations by counting. Hydrobiologia. 11(2) pp 143-178.
- Ma J.C.W and Jefferey L.M 1978. Description and comparison of a new cleaning method of diatom frustules for light and electron microscope studies. J. Microsc. 112(2) pp 225-238.
- Malcolm S.J and Price N.B 1984. The behaviour of iodine and bromine in esturine surface sediments. Mar. Chem. 15 pp 263-271.
- Matsumoto E and Wong C.S 1977. Heavy metal sedimentation in Saanich Inlet measured with ²¹⁰Pb technique. J. Geoph. Res. 82(34) pp 5477- 5482.
- Muller J.E 1980. The Paleozoic Sicker Group of Vancouver Island, B.C. Geol. Surv. Canada Paper 79-30. 29p.

- Mysak L.A, Groot C. and Hamilton K. 1986. A study of climate and fisheries: Interannual variability of the Northeast Pacific Ocean and its influence on the homing migration routes of sockeye salmon. *Climatological Bulletin*. 20(1) pp. 26-35.
- Murray D.W 1982. Palaeoceanography of the Gulf of California based on silicoflagellates from marine varved sediments. Msc Thesis. Oregon State University. 187 p.
- Murray D.W and Schrader H. 1982/83. Distribution of silicoflagellates in plankton and core top samples from the Gulf of California. *Mar. Micropalaeo.* 7 pp 517-539.
- Norrish K. and Hutton J.T 1969. An accurate X-ray spectrographic method for the analysis of a wide range of geological samples. *Geochim. Cosmochim. Acta* 33 pp 431-453.
- Parsons T.R, Stronach J, Borstad G.A, Louttit G. and Perry R.I. 1981. Biological fronts in the Strait of Georgia, British Columbia, and their relation to recent measurements of primary production. *Mar. Ecol. Prog. Ser.* 6 pp 237-242.
- Parsons T.R, Perry R.I, Nutbrown E.D, Hsieh W. and Lalli C.M. 1983. Frontal analysis at the mouth of Saanich Inlet, British Columbia, Canada. *Mar. Biol.* 73 pp 1-5.
- Pedersen T.F, and Price N.B. 1982. the geochemistry of manganese carbonate in Panama Basin sediments. *Geochim. Cosmochim. Acta* 46 pp 59-68.
- Pella E. and Colombo B. 1973. Study of carbon, hydrogen and nitrogen determination by combustion-gas chromatography. *Mikrochimica Acta.* 3 pp 697-719.
- Poelchau H.S 1976. Distribution of Holocene silicoflagellates in North Pacific sediments. *Micropalontology.* 22(2) pp. 164-193.

Redfield A.C, Ketchum B.A and Richards F.A 1963. The influence of organics on the composition of seawater. In *The Sea*. Hill M.N (ed) John Wiley and Sons. pp 26-77.

Regourd M. 1979. Fundamentals of cement production: The crystal chemistry of Portland cement minerals. New data. In *Cement Production and Use*. Skalny J.(ed) Engineering Foundation, New York.

Reynolds R.C 1963. Matrix corrections in trace element analysis by X-ray fluorescence: Estimation of the mass absorbtion coefficient by Compton scattering. *Amer. Mineral.* 48 p 1133.

Reynolds R.C 1967. Estimation of mass absorbtion coefficients by Compton scattering: Improvements and extensions of the method. *Amer. Mineral.* 52 pp 1493-1502.

Riley J.P and Skirrow G. 1965. *Chemical Oceanography* Vol: 2. Academic Press.

Robbins J.A and Edgington D.N 1975. Determination of recent sedimentation rates in Lake Michigan using ^{210}Pb and ^{137}Cs . *Geochim. Cosmochim. Acta* 39 pp 285-304.

Robbins J.A 1978. Geochemical and geophysical applications of radioactive lead. In *The Biogeochemistry of Lead in the Environment*. Nriagu J. (ed) pp 285-393.

Sancetta C. and Calvert S.E 1987. Vertical flux of diatom assemblages in Saanich Inlet, British Columbia. *Deep Sea. Res.*(in press).

Schmitz B. 1987. Barium, equatorial high productivity and the northward wandering of the Indian continent. *Paleoceanography* 2 pp 63-77.

- Schrader H. 1973. Proposal for a standardised method of cleaning diatom-bearing deepsea and land exposed marine sediments. In Second Symposium on Recent and Fossil Marine Diatoms. Simonsen R. (ed) Beihefte Nova Hedwigia 45. pp 403-409.
- Schrader H. and Baumgartner T. 1983. Decadal variation of upwelling in the central Gulf of California. In Coastal Upwelling (Pt.B) Thiede J, Seuss E. (eds) pp 247-276.
- Sholkovitz E. 1973. Interstitial water chemistry of the Santa Barbara Basin sediments. Geochim. Cosmochim. Acta 37 pp 2043-2073.
- Smith J.N and Walton A. 1980. Sediment accumulation rates and geochronologies measured in the Saquenay Fjord using the ^{210}Pb dating method. Geochim. Cosmochim Acta 44 pp 225-240.
- Soutar A. 1966. The accumulation of fish debris in certain California coastal sediments. Cal. COFI XI pp 136-139.
- Soutar A. and Isaacs J.D 1974. Abundance of pelagic fish during the 19th and 20th centuries as recorded in anaerobic sediment of the Californias. Fish. Bull. 72(2) pp 257-273.
- Soutar A. and Crill P.A 1977. Sedimentation and climatic patterns in the Santa Barbara Basin during the 19th and 20th centuries. Geol. Soc. Am. Bull. 88 pp 1161-1172.
- Soutar A, Johnson S.R and Baumgartner T.R 1981. In search of modern depositional analogs to the Monterey Formation. In The Monterey Formation and Related Siliceous Rocks of California. Soc. Econ. Paleo. Minerol. pp 123-147.
- Spears D.A and Kanaris-Sotiriou R. 1976. Titanium in some Carboniferous sediments from Great Britain. Geochim. Cosmochim. Acta 40 pp 345-351.

Spencer C.P. 1983. Marine biogeochemistry of silicon.
In Silicon Geochemistry and Biogeochemistry.
Ashton S.R. (ed). Academic Press. pp101-144.

Stockner J.G, Cliff D.D and Shortreed K.R.S 1979.
Phytoplankton ecology of the Strait of Georgia,
British Columbia. J. Fish. Res. Bd. Canada 36(6)
pp 657-666.

Strickland J.D.H and Parsons T.R 1968. A Practical
Handbook of Seawater Analysis. Bull. 167 Fish.
Res. Bd. Canada.

Takahashi M, Siebert D.L and Thomas W.H 1977.
Occasional blooms of phytoplankton during summer
in Saanich Inlet B.C. Canada. Deep Sea Res. 24(8)
pp 775-780.

Takahashi M, and Hoskins K.D. 1978. Winter conditions
of marine plankton populations in Saanich Inlet
B.C I: Phytoplankton and its surrounding
environment. J. Exp. Mar. Biol. Ecol. 31 pp 283-
301.

APPENDIX A.

Determination of ^{210}Pb in Sediments.

The method used was taken from *Smith and Walton* (1980) and is based on *Flynn* (1968).

Sample preparation.

Approximately 1 gram of ground sediment was weighed accurately and placed in a clean teflon bomb. The sample was then digested with concentrated nitric (6ml) and hydrofluoric acids (6ml). If foaming occurred, a few drops of n-octanol was added.

The sediment/acid mixture was then spiked with a known amount of ^{208}Po as a yield tracer. A solution of ^{208}Po was prepared by dilution from a stock solution with 0.5N HCl to give a working concentration of 9.32 dpm/ml. when fresh. The half life of ^{208}Po is 1035 days; the samples for this study were processed before any significant decrease in activity occurred.

The sealed teflon bomb was heated in a water bath at 90°C for 6 hours. After removing excess water from around the join between the lid and the base with a tissue, the bomb was partially immersed in a cold water bath and allowed to cool overnight. The water level reached well

below the lid, thereby avoiding any contamination of the sample.

The contents the bomb were transferred to a clean teflon beaker using washes of 0.5N HCl from a squeeze bottle. A final rinse was performed with around 20ml. of concentrated HCl. The beaker was placed on a hot plate and the contents reduced to near dryness. 20ml of conc. HCl were then added, swirled and boiled down. This was repeated twice. The residue was transferred to a pyrex centrifuge tube with washes of 0.5N HCl, each wash being well mixed and heated on the hot plate before being poured into the centrifuge tube. Four or five washes were used.

This solution was centrifuged at 3000rpm. for 20 min. after which the supernatant was carefully poured into a 150 ml. pyrex beaker. Centrifuging was repeated twice more with enough 0.5N HCl being added and swirled to give about 100 ml. as the final volume of plating solution. The beaker was kept covered until plating. The solid residue was transferred to plastic bottles and stored.

Plating method.

The polonium in solution was plated onto nickel discs. These were made from 1.5mm thick BDH Assured sheet nickel. The discs were cut by hand to approximately 1 1/4 inches and then turned on a lathe to exactly 1 inch (2.2 cm) to fit the ORTEC sample holders. The discs were cleaned with methanol and then with distilled water. They were then

placed into teflon holders following a design in Flynn (1968). These are designed so that the plating solution is prevented by an O-ring from coming into contact with the back of the disc. The holders form a lid to the plating beaker and hold a thermometer and the disc which is suspended in the solution.

0.2g. of ascorbic acid and around 0.5g. of hydroxylammonium chloride were added to the plating solution to reduce any Fe^{3+} which causes a significant decrease in plating efficiency (Flynn, 1968).

The beaker, containing the plating solution, a teflon coated stir bar and holder was placed onto a hot plate/stirrer. The solution was maintained at 85 °C for 6 hrs. Air bubbles were removed from the disc surface by wiggling the holder. The minimum stirring rate was used to avoid excess evaporation.

The beaker was then removed from the hotplate and the disc removed. It was rinsed in methanol and then in distilled water and allowed to air dry. The discs were stored in a petrie dish until counting. The date of plating was recorded.

All equipment used in the digestion and plating was dedicated and kept clean by rinsing with distilled water after use and stored in 10% HCl which was changed regularly. Blank tests were run occasionally; no counts were ever recorded over 24h. periods.

Alpha spectrometry.

The discs were counted over 24 hours on an ORTEC 576a Alpha spectrometer.

The energy scale of the spectrometer was calibrated using its internal test peak (5.0 mev) and an ^{241}Am source (5.49 mev) obtained from the TRIUMF Facility at U.B.C.

Both polonium peaks (^{208}Po = 5.11 Mev, ^{210}Po = 5.305 Mev) were integrated over 250 channels by using the ORTEC 'Region of Interest' storage and recall facility. The total counts in these peaks were recorded. These counts were converted into ^{210}Po and thereby ^{210}Pb activity using the program PB-CALC (S.E Calvert) stored on the boot disc of the ORTEC system.

This calculates the ^{210}Po activity using the formula;

$$A^{210}\text{Po} = \frac{A^{208}\text{Po}}{\text{sample wt.}} \times \frac{^{210}\text{Po counts}}{^{208}\text{Po counts}}$$

where A = Activity in dpm/g.

An error estimate based on counting statistics was calculated by;

$$Z^{210}\text{Po} = \frac{\sqrt{((V1 \times V1) + (V2 \times V2))} \times A^{210}\text{Po}}{100}$$

where V1 = error estimate as a % of ^{208}Po counts.
V2 = error estimate as a % of ^{210}Po counts

A test of instrument precision was also carried out and the results are given in Table A.1. A 2σ value of 0.1 dpm/g. is reported.

TABLE A.1: Estimate of ORTEC Instrument Precision.

SAMPLE	WEIGHT	COUNTS/24hrs	DPM/G ^{210}Po
I	1.007	1300 \pm 36	6.61 \pm .24
II	1.008	1262 \pm 35	6.72 \pm .25
III	1.009	1369 \pm 37	6.72 \pm .25
IV	1.003	1468 \pm 38	6.28 \pm .21

Mean 6.58 dpm/g. $2\sigma = 0.42$. RSD (2σ) = $\pm 6.33\%$

A well-mixed bulk sample of Core CPIII was used. This was shaken for 30min. in a mechanical shaker, reground and shaken again. Four sub-samples were run together with a blank. The blank recorded no counts.

Sediment solutions were plated twice and no counts were measured on the second disc.

APPENDIX B.

X-ray fluorescence methods.

All analyses were carried out on an automated Philips PW 1400 spectrometer controlled by a DEC PDT 11 microcomputer. A rhodium target x-ray tube was used for excitation.

Samples for x-ray analysis were the dried and ground samples taken from core CPIV. All reported values have been corrected for dilution by seasalt and, where appropriate, for the elemental composition of that salt. The formulae used for these corrections are found in Appendix C.

Sample preparation: Major elements.

The major elements were determined using a fusion method based on *Norrish and Hutton* (1969), using a sample preparation technique very similar to that published by *Harvey et al.* (1972).

0.4g. of ground, dried sample was fused in a Pt/Au crucible in a muffle furnace at 1100 °C with 3.6g. of Spectroflux 105 (Johnson and Matthey Ltd.). The flux consists of lithium tetraborate(47.03%), lithium carbonate(36.63%) and lanthanum oxide(16.34%), the recipe recommended by *Norrish and Hutton* (1969). The two lithium compounds reduce the melting temperature of the flux to 700

°C with full fluidity at 1000 °C. Lanthanum oxide is used as a heavy absorber to produce high mass absorption of the matrix and reducing matrix differences between samples and standards. Its addition avoids the use of a high sample dilution and the consequent loss of precision that would otherwise be required to ensure a linear relationship between fluorescent intensity and concentration.

Weight loss on fusion was made up with Spectroflux 100 (100% Lithium tetraborate, Johnson and Matthey Ltd.) This maintained the lanthanum/sample ratio. Both fluxes were kiln dried and stored in sealed containers before use. The cooled melt with added $\text{La}_2\text{B}_4\text{O}_7$ was reheated to fluidity over a flame burner, poured into an aluminium mold, quenched and pressed into discs by the application of a brass weight. This process was carried out on a hot-plate at 400 °C.

Sample preparation: Minor elements.

Trace or minor elements were determined using 0.5g. subsamples of sediment. The ground, dried sample was pressed into a boric acid backed pellet at 10 tons pressure in a hydraulic press.

For elements with wavelengths shorter than the Fe absorption edge, matrix correction was carried out using the Compton Ratio method of Reynolds (1963;1967).

Sample analyte lines, corrected for background, are ratioed to the Compton peak of the Rh $K\alpha$ line. This

ratio plotted against the ppm. values of international standards provides the calibration for each element.

Elements with wavelengths longer than the iron absorption edge (Ba,V,Cr,Mn) were matrix-corrected by ratioing the peak to a convenient background measured either adjacent to the element peak or in a section of the spectrum where there is no interference by the peaks from other elements.

No matrix corrections were applied to the sodium intensities. For this light element, there is a close correlation between uncorrected concentrations and those published for international rock standards.

Spectral interferences of Ti on V and Ba, Rb on Y, Ni, Sr on Zr and V on Cr were corrected in a conventional manner by determining the ratios between $K\alpha$ and $K\beta$ intensities on pure interfering element standards and by applying the appropriate corrections to the net intensities of the affected elements.

Instrument conditions.

The instrument conditions used are listed in Table B.I. Sulphur and Mo, which were measured using dedicated measuring programs, calibrations and standards, are included with the major and minor elements, respectively.

Instrument drift was corrected by running a monitor before each set of samples and standards. Sample intensities are then ratioed to the monitor intensities.

Standards used in the calibrations were run as unknowns together with the samples in order to check for instrument performance during the analyses of groups of samples. The results of these analyses are reported in Tables B.III, B.VIII, B.X and B.XII. It was found that no further corrections were necessary.

Instrument calibration.

The spectrometer was calibrated using international geochemical reference standards whose element concentrations are found in Abbey (1980). Table B.II lists those used for the determination of the major elements and shows a comparison between measured values and the published values of the standards.

Instrument calibration for the minor elements was carried out using 1.0g. standards. A comparison of 1.0g. and 0.5g. pellets using bulk Saanich sediment (Table B.VI) shows satisfactory agreement.

Since the international standards used do not contain high enough concentrations of S and Mo, calibrations for these two elements were carried out using standards made from bulk basalt spiked with a known amount of the element concerned and converted into a dilution series to provide a calibration covering concentrations expected in the samples.

Molybdenum standards were made by spiking the basalt with Specpure MoO_3 while the sulphur standards were made with both sulphide (FeS_2) and sulphate (Na_2SO_4) spikes

to make sure that any difference in the calibration due to the oxidation state of the sulphur was accounted for.

Estimates of accuracy and precision.

The mean differences between published and measured concentrations of each element in the standards run as unknowns were used as an estimate of the accuracy of the method. It must be noted, however, that the standards were also used for calibration so that this method is not an unbiased estimate of accuracy.

These estimates are given as MDV (Mean difference between published and measured values) in Table B.III for major elements, Table B.VIII for the minor elements, Table B.X for sulphur and Table B.XII for molybdenum.

Estimates of instrument precision and between sample precision for the major elements are reported in Tables B.IV and B.V, respectively.

Instrument precision was determined by running one sample of well mixed bulk Saanich sediment six times and reporting the 2σ relative standard deviation from the mean of these six values. Between sample precision was determined by running five samples of the same sediment, prepared using the same method as that used for the core samples. These estimates were determined on a sample of well mixed bulk Saanich central basin sediment since the core samples did not provide enough material.

Instrument precision for the determination of the minor elements was estimated using the same method except that the bulk Saanich sample was run ten times. 2σ RSD values from this test are reported in Table B.VI.

Table B.1 XRF Instrument Conditions.

	Si	Al	Fe	Mg	Ca	K	P	Ti	S
Tube kV	80	60	60	30	30	60	30	60	60
Tube mA	20	40	40	60	10	40	60	40	40
Crystal	2	2	1	4	1	1	3	1	3
Counter	F	F	F	F	F	F	F	F	F
Peak $^{\circ}2\theta$	109.36	45.35	57.66	45.34	113.29	136.76	141.17	86.24	110.77
Background $^{\circ}2\theta$	+1.6				+1.4	+2.0		+3.0	+1.0
		-1.3	-1.6	-1.2			-1.5		
Collimator	C	C	C	C	C	F	C	C	C
Count Time	40	40	20	100	20	20	100	40	80
Peak									
Count Time	20	20	10	50	10	10	50	10	40
Background									

	Zr	Y	Sr	Rb	Zn	Cu	Ni	Mn	V	Cr	Ba	Na	Mo
Tube kV	60	60	60	60	60	60	60	60	60	60	60	30	60
Tube mA	40	40	40	40	40	40	40	40	40	40	40	60	40
Crystal	1	1	1	1	1	1	1	1	1	1	1	4	5
Counter	S	S	S	S	FS	FS	FS	F	F	F	F	F	S
Peak $^{\circ}2\theta$	22.49	23.78	25.15	26.60	41.73	44.98	48.60	63.11	77.37	69.49	87.21	55.26	28.85
Background $^{\circ}2\theta$	+0.74	+0.6	+0.6	+0.6	+0.72		+1.2	+1.5	+4.0	+1.0	+1.2		+0.7
	-0.74	-0.6	-0.6	-0.6		-0.62	-0.6					-1.7	-0.7
Collimator	F	F	F	F	F	F	F	C	C	C	F	C	F
Count Time	100	100	100	100	100	100	100	100	100	100	200	100	200
Peak													
Count Time	40/40	40/40	40/40	40/40	40	40	40	40	40	40	100	40	20/20
Background													

* RHODIUM TUBE

* All elements measured on the Kalpha line except Ba on Lbeta.

* Counters: F = flow using 90% Ar & 10% CH₄. S = scintillation counter.

* Collimators: C = coarse; 480um. F = fine; 160um.

* Cu- Aluminium filter over the x-ray tube.

* CRYSTALS: 1 = Lithium fluoride (200 cut). 2 = Pentaerythritol. 3 = Germanium.

4 = Thallium acid phthalate. 5 = Lithium fluoride (220 cut)

* Vacuum path used throughout.

* Count time in Seconds.

Table B.II Standards used for the Calibration of Major Elements.

Name		Si	Al	Fe	Mg	Ca	K	P	Ti
AGV-1	P	59.61	17.19	6.8	1.52	4.94	2.92	0.51	1.06
	M	59.27	17.07	6.83	1.58	4.94	2.94	0.5	1.05
G-2	P	69.22	15.4	2.68	0.75	1.96	4.46	0.13	0.48
	M	67.17	15.41	2.73	0.75	1.95	4.42	0.13	0.5
GSP	P	67.32	15.28	4.29	0.97	2.03	5.51	0.28	0.66
	M	67.63	15.3	4.31	0.99	2.03	5.59	0.26	0.67
BCR	P		13.72	13.42	3.48	6.97	1.7	0.36	2.26
	M		13.96	13.43	3.71	6.93	1.75	0.37	2.22
GA	P			2.8	0.95	2.45	4.03	0.12	0.38
	M			2.73	0.91	2.42	4	0.12	0.38
NIM-S	P	63.63	17.34	1.4	0.46	0.68	15.35	0.12	0.04
	M	63.97	17.14	1.4	0.43	0.67	15.24	0.11	0.03
SY-2	P	60.1	12.12	6.28	2.7	7.98	4.48	0.43	0.14
	M	59.81	12.14	6.28	2.67	7.92	4.51	0.44	0.14
MRG-1	P	39.32	8.5	17.83	13.49	14.77	0.18	0.06	3.69
	M	39.23	8.37	17.8	13.06	14.79	0.17	0.06	3.68
DR-N	P	52.88	17.56	9.69	4.47	7.09	1.73	0.25	1.1
	M	52.17	17.52	9.66	4.55	7	1.74	0.23	1.06
NIM-G	P	75.7	12.08	2.01	0.06	0.78	4.99		0.09
	M	75.44	12.23	1.99	0.05	0.8	4.96		0.1
BHVO	P	49			7.31	11.33	0.54	0.28	2.69
	M	49.95			7.37	11.48	0.52	0.27	2.72

M= MEASURED VALUES. P= PUBLISHED VALUES.

* Blanks indicate that the standard was not used in calibration.

Table B.III Standards run as unknowns during Major Element Analysis.

NAME	Si	Al	Fe	Mg	Ca	K	P	Ti	
GSP-1	68.16	15.55	4.34	1.05	2.04	5.49	0.3	0.66	M
	67.32	15.28	4.29	0.97	2.03	5.51	0.28	0.66	P
SY-2	60.03	12.16	6.3	2.76	7.9	4.47	0.45	0.13	M
	60.1	12.12	6.28	2.7	7.98	4.48	0.43	0.14	P
AGV-1	59.13	17.21	6.83	1.53	4.92	2.91	0.5	1.07	M
	59.61	17.19	6.8	1.52	4.94	2.92	0.51	1.06	P
GA	68.61	14.67	2.73	0.92	2.24	4.03	0.12	0.37	M
	68.96	14.51	2.8	0.95	2.45	4.03	0.12	0.38	P
BCR-1	54.48	13.81	13.47	3.66	6.92	1.75	0.37	2.23	M
	54.53	13.72	13.42	3.48	6.97	1.7	0.36	2.26	P
MDV	0.4%	0.12%	0.04%	0.07%	0.07%	0.02%	0.01%	0.01%	

MDV= Mean Difference between values for each element.

Can be taken as an estimate of absolute accuracy

M = Measured values. P = Published values.

Table B.IV Instrument Precision Estimate for Major Elements

Cycle	%Si	%Al	%Fe	%Ca	%K	%Mg	%P	%Ti	%S
1	59.33	11.97	5.90	2.03	1.55	2.47	0.18	0.7	1.27
2	59.44	11.77	5.96	2.04	1.53	2.47	0.18	0.7	1.29
3	59.21	11.88	5.95	2.05	1.53	2.48	0.19	0.69	1.28
4	59.23	11.89	5.96	2.11	1.54	2.54	0.2	0.7	1.29
5	59.23	11.89	5.97	2.08	1.50	2.51	0.21	0.7	1.28
6	59.26	11.95	5.97	2.08	1.55	2.39	0.21	0.69	1.29
MEAN	59.28	11.89	5.95	2.07	1.53	2.48	0.19	0.696	1.28
2sigma	0.18	0.14	0.05	0.06	0.04	0.1	0.03	0.01	0.02
RSD	2s0.03%	1.18%	0.89%	2.91%	2.43%	4.07%	14.51%	1.48%	1.28%

* Analysis run on one sample of bulk Saanich sediment.

Table B.V Between Sample Precision estimate for the Major Elements.

SAMPLE	%Si	%Al	%Fe	%Ca	%Mg	%K	%P	%Ti
SAN 1	60.08	12.06	5.97	2.08	2.58	1.57	0.19	0.7
SAN 2	60.37	12.1	6.05	2.11	2.5	1.62	0.2	0.7
SAN 3	60.01	12.21	6.06	2.07	2.46	1.53	0.19	0.7
SAN 4	60.7	11.9	6.09	2.15	2.57	1.63	0.2	0.69
SAN 5	61.38	12.16	6.24	2.12	2.6	1.64	0.19	0.7
MEAN	60.50	12.08	6.08	2.11	2.54	1.60	0.19	0.697
RSD 2s	1.7	2.0	3.3	3.0	4.5	5.9	5.3	0.005

* RSD 2sigma can be taken as an estimate of precision.

* Test run on five samples of bulk Saanich central basin sediment using the same preparation method as that used for the core samples.

Table B.VI Minor Element Comparison between 1.0g. and 0.5g. pellets and an Estimate of Instrument Precision.

ELMT.	Precision.	1.0 g.*	0.5 g.*
Ba	5±10%	438±38	440±34
Cr	5±10%	85±10	83±6
Cu	10±20% 4.5±9%	29±10	29±10
Mn	4±8%	565±38	557±24
Ni	15±30% 8±16%	25±6	26±6
Pb	18±36%	19±10	20±10
Rb	6±12%	51±8	51±8
Sr	2±4%	196±26	194±24
V	3±6%	105±8	105±6
Y	10±20%	20±4	21±4
Zn	6±12%	114±18	115±16
Zr	±13%	109±14	109±14
Na	1±2%	2.2±.1	2.2±.08
Mo	±8%	42±3	41±3

* All samples were made from Bulk Saanich central basin sediment. Each sample was measured 6 times. Errors are two standard deviations on 30 measurements.

* Precision estimates from a one gram pellet run 10 times. Values show ± 2sigma RSD. Ni 1st value <20ppm, 2nd value >30ppm. Cu 1st value <25ppm, 2nd value >50ppm. (R.Francois. pers.comm).

Table B.VII Standards used for the Calibration of Minor Elements.
1.0g. Pellets. Values in ppm. Na in % by weight

Name		Zr	Y	Sr	Rb	Zn	Cu	Ni	Mn	V	Cr	Ba	XNa
AGV-1	M	230	19	660	67	86	59	15	728	125		1200	
	P	223	22	666	67	86	60	16	758	132		1145	
GSP-1	M	500	29					9	326			1300	2.81
	P	510	38					13	310			1326	2.78
G-2	M	300			170	84	10		265		8		4.06
	P	293			167	83	8		244		5		4.22
BCR	M	185	40		47	125	16	10	1350			680	3.3
	P	189	35		48	129	16	10	1307			698	3.13
GA	M	150	21		175	80		7	700	38	12		3.55
	P	134	26		181	84		6	679	46	10		3.33
SY2	M		130	275	220	250						460	
	P		125	270	213	241						445	
MR6	M	105	16		8							50	0.71
	P	96	12		8							46	0.71
DR-M	M		30										3
	P		26										2.95
BM	M	105	26	230						180	120	260	
	P	110	24	225						156	157	240	
BR	M						72					1050	3.07
	P						65					1087	3.31
BHVD	M	180	27	420	10		140		1316			135	
	P	181	24	424	9		139		1379			132	
BEN	M		30			120	72		1548			1050	
	P		27			115	77		1511			1038	
NIM-D	M										2900	10	
	P										2875	10	
NIM-N	M					68	14		1393			100	2.46
	P					70	13		1415			114	2.62
NIM-6	M		145	10	320					2	12		3.36
	P		143	10	316					1.66	15		3.15
NIM-S	M	33			530	10		7	80				
	P	33			534	9		4	88				
ASK-1	M					105	7	110			40		
	P					106	8	105			45		
ASK-2	M			100						220	90		
	P			96						223	70		

M = Measured values. P = Published values.

* Blanks are standards not used in that elements calibration.

Table B.VIII Standards run as Unknowns during Minor Element Analysis.

Name		Zr	Y	Sr	Rb	Zn	Cu	Ni	Mn	V	Cr	Ba	ZNa
AGV-1	cycle1	195	17	601	61	82	55	13	710	126	2	956	3.72
	cycle2	201	20	595	53	66	37	5	748	128	0	975	3.69
	cycle3	201	17	603	60	70	37	8	744	129	0	942	3.69
	Mean	199	18	600	57	73	43	9	734	128	0.6	958	3.7
	S.D	3	1	3	5	7	8	3	17	1		16	0.01
	Pub	223	22	666	67	86	60	16	758	132	10	1145	3.75
GA	cycle1	136	33	340	177	85	11	5	698	48	10	825	3.3
	cycle2	135	35	342	179	93	15	12	665	44	14	799	3.24
	cycle3	139	33	342	183	90	19	9	688	47	12	777	3.23
	Mean	137	34	341	180	89	15	9	684	46	12	800	3.26
	S.D	2	1	1	3	3	3	3	14	2	1	20	0.03
	Pub	134	26	310	181	84	16	6	680	47	11	850	3.33
GSP	cycle1	451	38	222	229	119	31	14	286	79	7	1311	2.7
	cycle2	453	41	228	231	118	32	10	285	78	5	1201	2.67
	cycle3	450	35	225	234	122	33	11	274	76	5	1176	2.65
	Mean	451	38	225	231	120	32	12	282	78	6	1229	2.67
	S.D	1	2	2	2	2	1	2	5	1	1	59	0.02
	Pub	520	38	250	250	105	33	13	310	54	12	1326	2.78
G2	cycle1	265	14	446	157	82	8	1	242	66	5	1789	4.19
	cycle2	268	18	457	159	97	8	0	231	63	2	1651	4.08
	cycle3	275	22	470	158	99	8	7	235	68	5	1825	4.1
	Mean	269	18	458	158	93	8	3	236	66	4	1755	4.12
	S.D	4	3	10	0.5	8		3	5	2	1.5	75	0.05
	Pub	293	11	480	167	83	8	3	244	36	5	1900	4.22
BR	cycle1	181	21	986	39	127	62	152	1256	292	237	948	3.21
	cycle2	183	22	983	34	117	57	140	1315	301	253	1035	3.19
	cycle3	180	26	986	37	115	65	152	1308	297	258	901	3.3
	Mean	181	23	985	37	120	61	148	1293	297	249	961	3.23
	S.D	1	2	1.5	2	5	3	6	26	4	9	55	0.05
	Pub	250	30	1300	47	150	65	142	1548	240	380	1087	3.31
NDV		39	5	91	10	15	9	7	124	23	30	121	0.08

NDV = Mean difference between values. Can be taken as an estimate of absolute accuracy, but still contains error inherent in the calibration.

Table B.IX Calibration Standards for
Sulphur.

NAME	Published	Measured
S I	4.31	4.18
S II	3.23	3.31
S V	0.95	0.96
S VI	0.73	0.78
S VII	0.47	0.38
S VIII	0.36	0.4

Table B.X Standards run as unknowns
during Sulphur Analysis.

NAME	Published	Measured
S V	0.95	0.92
S IV	1.52	1.54
S II	3.23	3.25
S VIII	0.36	0.34
MDV = 0.02% (Mean diff. between M and P)		

S I-S VIII are a synthetic dilution series.

Table B.XI Calibration Standards for
Molybdenum.

NAME	Published	Measured
ASK-2	60	64
TS	130	141
SGR-1	36	30
POMO II	208	194
POMO III	149	152
POMO V	48	42
POMO VI	20	16
POMO VII	11	12

* All are 1.0g. pellets.

* POMO are a dilution series made
from basalt spiked with Specpure Mo.

Table B.XII Standards run as unknowns
during Molybdenum Analysis.

NAME	Published	Measured	1 SD
POMO II	208	205	0.78
POMO IV	92	82	0.91
ASK-2	60	69	2.33
POMO V	48	41	1.18

* Measured values are the Mean of two
measuring cycles. 1 SD reported.

MDV= 7.3ppm. (Mean diff. between M and P)

APPENDIX C

Chlorine analysis.

The amount of chlorine, and thereby the salt content of the dried samples, was determined volumetrically using a method adapted from *Strickland and Parsons* (1968).

Around 100 mg. of sample was accurately weighed into a clean plastic centrifuge tube, 5ml. of distilled water was added and the mixture was stirred on a vortex stirrer for 10 minutes to dissolve the salt. The sample was then centrifuged for 10 minutes at 3000 rpm. The supernatant was collected by pipette and stored in plastic vials.

The amount of solution remaining in the centrifuge tube was estimated by the weight difference between the wet and dry sediment residue. This was done eight times during the analysis of the CPIV samples. The mean weight of water retained was found to be 0.28g. ($2\sigma=0.04$) The volume of water used in the calculations was thus taken as 4.72ml. rather than 5.0ml.

The Cl^- was titrated against AgNO_3 (0.1484 M). in aliquots of 1ml. of the supernatant solution using a Gilmont microburette reading to three decimal places. Potassium dichromate was used as the indicator and the solution was stirred during titration with a teflon coated stir-bar. The titrations were carried out in duplicate and the solution

was stirred quickly on the Vortex stirrer before each aliquot was taken.

%Cl was calculated from the following:

$$[\text{Cl}^-] = \frac{[\text{AgNO}_3] \times \text{vol. AgNO}_3}{\text{sample volume}}$$

$$\text{gCl/l.} = [\text{Cl}^-] \times 35.45 \text{ (atomic wt. of Cl)}$$

$$\text{gCl/sample} = \frac{\text{gCl/l.}}{1000} \times 4.72$$

$$\% \text{Cl} = \frac{\text{gCl/sample}}{\text{sample wt. (g)}} \times 100$$

These values were then used to correct all chemical data for dilution by salt and, where appropriate, for addition of the element concerned because of its concentration in seasalt.

These corrections were performed using the following formulae:

$$[\text{El}]_{\text{salt free}} = [\text{El}] \times \frac{100}{(100 - 1.82(\% \text{Cl}))}$$

$$\% \text{Nacor} = \% \text{Na} - 0.556 (\% \text{Cl})$$

$$\% \text{Mgcor} = \% \text{Mg} - 0.067 (\% \text{Cl})$$

$$\% \text{Cacor} = \% \text{Ca} - 0.021 (\% \text{Cl})$$

$$\% \text{Kcor} = \% \text{K} - 0.02 (\% \text{Cl})$$

$$\text{ppm Br} = \text{Br} - 34.6 (\% \text{Cl})$$

$$\text{ppm Sr} = \text{Sr} - 4.13 (\% \text{Cl})$$

$$*\text{ppm S} = \text{S} - 16.6 (\% \text{Cl})$$

* Sulphur numbers calculated with this correction reflect oxic seawater conditions. In Saanich Inlet the anoxic conditions which predominate will reduce seawater sulphate; thus sulphur numbers reported are shown as Sox

where this correction is employed, and Sanox where no second correction was calculated since the Sulphate:Chlorine ratio of the cores pore waters is unknown. The values of sulphur for CPIV will lie in the range between these numbers.

Table C.I Chloride Calculations.

SMPL	WT.(g)	ml. AgNO3			% Cl.	% WATER
		Run1	Run2	MEAN		
86	0.103	0.444	0.445	0.444	11.3	86.8
85	0.108	0.456	0.455	0.455	11.0	86.6
84	0.108	0.457	0.457	0.457	11.1	86.6
83	0.106	0.453	0.453	0.453	11.2	86.7
82	0.104	0.489	0.485	0.487	12.3	87.7
81	0.104	0.503	0.503	0.503	12.6	88.1
80	0.101	0.546	0.546	0.546	14.2	89.2
79	0.104	0.557	0.556	0.556	13.9	89.1
78	0.104	0.602	0.601	0.601	15.1	89.8
77	0.102	0.589	0.59	0.589	15.1	89.8
76	0.109	0.64	0.639	0.639	15.3	90.0
75	0.108	0.596	0.6	0.598	14.5	89.4
74	0.106	0.679	0.677	0.678	16.7	90.7
73	0.104	0.643	0.642	0.642	16.3	90.5
72	0.106	0.673	0.669	0.671	16.5	90.6
71	0.102	0.598	0.598	0.598	15.4	90.0
70	0.102	0.668	0.667	0.667	17.2	90.9
69	0.102	0.637	0.636	0.636	16.4	90.5
68	0.108	0.836	0.839	0.837	20.2	92.2
67	0.107	0.666	0.662	0.664	16.2	90.5
66	0.104	0.724	0.723	0.723	18.3	91.4
65	0.108	0.617	0.616	0.616	14.9	89.7
64	0.108	0.771	0.774	0.772	18.8	91.6
63	0.101	0.634	0.635	0.634	16.4	90.5
62	0.105	0.662	0.662	0.662	16.5	90.6
61	0.106	0.579	0.58	0.579	14.4	89.3
60	0.104	0.715	0.717	0.716	18.0	91.3
59	0.102	0.673	0.675	0.674	17.3	91.0
58	0.104	0.751	0.751	0.751	19.0	91.7
57	0.103	0.548	0.548	0.548	13.9	89.0
56	0.105	0.627	0.626	0.626	15.6	90.1
55	0.104	0.507	0.508	0.507	12.8	88.2
54	0.106	0.582	0.583	0.582	14.4	89.4
53	0.109	0.547	0.545	0.546	13.1	88.4
52	0.107	0.613	0.613	0.613	15.0	89.7
51	0.111	0.527	0.527	0.527	12.4	87.9
50	0.102	0.6	0.601	0.600	15.4	90.0

* Molarity AgNO3 = 0.1484.

* Water content calculated for 31%.

APPENDIX D.

Carbon, nitrogen and carbonate analysis.

Total carbon and nitrogen were measured by gas chromatography on a Carlo-Erba model 1106 CHN analyser. The basis of the method employed by this equipment is described by *Pella and Colombo* (1973). The sediment samples are packed into tin foil cups and combusted at 1050 °C in a quartz tube flushed by a continuous stream of helium and oxygen.

Flash combustion is primed by the oxidation of the tin container and quantitative combustion, or full oxidation, occurs as the gas passes over Cr_2O_3 . Excess oxygen is removed by passing the gas over heated copper which also reduces nitrous oxides to nitrogen. N_2 , CO_2 and H_2O are separated in that order by a chromatographic column and are measured by a thermal conductivity detector.

The instrument was calibrated and the method standardised using acetanilide ($\text{CH}_3\text{CONHC}_6\text{H}_5$) which contains 71.09% carbon and 10.36% nitrogen.

Each run consisted of three blanks, to assure that the system was flushed before samples were run, six standards and 14 samples.

Approximately 3.0mg. of dried sediment was accurately weighed into a tin foil cup on a Mettler microbalance and pinched closed. Prepared samples were kept in a dessicator if not immediately run. Samples were run in

duplicate and triplicate where the first two runs showed a marked difference in result.

Analytical precision was estimated by running five samples of bulk Saanich sediment. The results are reported in Table D.I. Precision is estimated by the RSD (2σ) of $\pm 0.73\%$ for carbon and $\pm 2.6\%$ for nitrogen.

The results obtained from the analysis of CPIV samples are presented in tables D.II and D.III. Values are salt-corrected and the C_{org} value is $C_{tot.} - C_{carbonate}$.

Determination of carbonate carbon.

Carbonate carbon was determined on the core samples by coulometry.

Approximately 25mg. subsamples of the dried sediment was accurately weighed into clean glass reaction tubes. These were then attached to a Coulometrics Inc. model number 5010 coulometer and flushed in a CO_2 -free air-stream. After two minutes, 2ml. of 10% HCl is added to the reaction cup and the cup is heated to around 60 °C. The CO_2 generated is carried to a titration cell containing a solution of ethanolamine and an indicator. The strong titratable acid produced by the reaction of the CO_2 with the ethanolamine is titrated with OH^- ions produced by a silver electrode. The end point is determined photometrically by the lack of colour change in the solution.

The amount of current required to produce the OH⁻ ions is integrated and converted into ugC. This value is converted into % C_{carb} or %Total inorganic carbon by:

$$\%C_{carb} = \frac{\text{ugC}_{CO_2} - \text{ugC}_{blank}}{\text{sample wt.}} \times 100$$

The samples were run in duplicate and the mean value used for the calculation of %C_{carb}. Blanks were run at intervals during the analysis and showed a maximum value of 5.7ugC while sample values ranged from 40-180 ugC. Corrections were made for these blank values.

A standard of pure CaCO₃ (%C_{carb} = 12.0) was also run four times during measurement. A mean value of 12.12%C_{carb} was determined (2σ = 0.14) Thus an estimate of precision for this analysis is given by the RSD (2σ) = ±1.2%.

The results obtained by this method are presented in Table D.III and are corrected for dilution by salt. %C_{carb}, used in the calculation of %C_{org}, and %CaCO₃ are both presented.

Table D.I Estimate of Precision for the analysis of
Carbon and Nitrogen.

SMPL	WT mg.	%C	%N
I	4.196	2.913	0.314
II	4.931	2.905	0.304
III	4.093	2.934	0.307
IV	4.149	2.921	0.312
V	4.31	2.919	0.309
	MEAN	2.918	0.309
	2sigma	0.02	0.008
	RSD	0.73	2.6

* Analysis performed on a well mixed bulk
Saanich central basin sediment.

Table D.II Results of Nitrogen Analysis.

SMPL	Run1	Run2	Run3	MEAN	%Cl	%N	DEPTH
86	0.47	0.43		0.24	11.3	0.50	0
85	0.46	0.51	0.45	0.32	11.0	0.53	3.8
84	0.45	0.43	0.43	0.29	11.1	0.48	4.2
83	0.38	0.4		0.19	11.2	0.43	6.4
82	0.37	0.39		0.19	12.3	0.43	7.5
81	0.45	0.44		0.23	12.6	0.50	7.7
80	0.43	0.43		0.22	14.2	0.49	9.5
79	0.38	0.39	0.46	0.26	13.9	0.47	9.8
78	0.38	0.4	0.32	0.26	15.1	0.42	10.9
77	0.41	0.41		0.21	15.1	0.47	11.3
76	0.41	0.41		0.21	15.3	0.47	11.5
75	0.4	0.39		0.20	14.5	0.45	11.8
74	0.35	0.33		0.18	16.7	0.40	12.7
73	0.39	0.37		0.20	16.3	0.44	13.3
72	0.36	0.34		0.18	16.5	0.41	14.1
71	0.34	0.35	0.31	0.23	15.4	0.38	15.4
70	0.36	0.38		0.18	17.2	0.43	16.2
69	0.38	0.35		0.19	16.4	0.42	17.1
68	0.36	0.35		0.18	20.2	0.43	18.3
67	0.46	0.35	0.31	0.27	16.2	0.43	18.7
66	0.33	0.32		0.17	18.3	0.38	18.9
65	0.35	0.36		0.18	14.9	0.41	19.5
64	0.29	0.33	0.3	0.21	18.8	0.36	19.7
63	0.34	0.32		0.17	16.4	0.38	19.9
62	0.33	0.36		0.17	16.5	0.40	20.6
61	0.35	0.35		0.18	14.4	0.40	21.1
60	0.31	0.3		0.16	18.0	0.36	22.4
59	0.36	0.34		0.18	17.3	0.41	22.6
58	0.34	0.37		0.17	19.0	0.42	23.2
57	0.41	0.41		0.21	13.9	0.47	24.3
56	0.49	0.48	0.44	0.32	15.6	0.54	27.2
55	0.39	0.41	0.36	0.27	12.8	0.44	27.7
54	0.39	0.38		0.20	14.4	0.44	28.4
53	0.41	0.43		0.21	13.1	0.48	29.7
52	0.36	0.38		0.18	15.0	0.43	30.6
51	0.49	0.48		0.25	12.4	0.55	31.6
50	0.42	0.4		0.21	15.4	0.47	32.2

Table D.III Results of Carbon and Carbonate Analysis.

SMPL	Run1	Run2	Run3	MEAN	%Cl	%Ctot	%Corg.	%Ccarb	%CaCO3	DEPTH
86	4.88	4.84		4.86	11.3	5.41	4.79	0.62	5.19	0
85	5.1	5.51	5.22	5.28	11.0	5.86	5.03	0.83	6.94	3.8
84	5.09	4.74	4.86	4.90	11.1	5.44	4.61	0.83	6.94	4.2
83	4.56	4.73		4.65	11.2	5.17	4.53	0.63	5.28	6.4
82	4.44	4.55		4.50	12.3	5.05	4.33	0.72	5.99	7.5
81	4.33	4.44		4.39	12.6	4.94	4.42	0.52	4.32	7.7
80	4.4	4.38		4.39	14.2	5.01	4.55	0.47	3.90	9.5
79	3.92	4.54		4.23	13.9	4.82	4.41	0.41	3.42	9.8
78	4.01	3.74		3.88	15.1	4.46	4.18	0.28	2.30	10.9
77	4.28	4.21		4.25	15.1	4.88	4.57	0.31	2.59	11.3
76	4	3.96		3.98	15.3	4.59	4.29	0.30	2.50	11.5
75	3.95	4.06		4.01	14.5	4.59	4.25	0.33	2.77	11.8
74	3.62	3.37		3.50	16.7	4.08	3.76	0.32	2.63	12.7
73	3.78	4		3.89	16.3	4.52	4.23	0.29	2.42	13.3
72	3.77	3.65		3.71	16.5	4.32	4.04	0.28	2.33	14.1
71	3.26	3.33	3.13	3.24	15.4	3.74	3.46	0.28	2.31	15.4
70	3.51	3.7		3.61	17.2	4.22	3.97	0.26	2.15	16.2
69	3.3	3.46		3.38	16.4	3.93	3.67	0.27	2.23	17.1
68	3.5	3.38		3.44	20.2	4.14	3.86	0.28	2.30	18.3
67	3.39	4.25	3.26	3.63	16.2	4.22	3.93	0.29	2.42	18.7
66	3.11	3.09		3.10	18.3	3.67	3.44	0.22	1.87	18.9
65	3.43	3.5		3.47	14.9	3.98	3.67	0.31	2.59	19.5
64	3.25	2.85	3.1	3.07	18.8	3.64	3.36	0.29	2.38	19.7
63	3.32	3.2		3.26	16.4	3.79	3.55	0.24	2.04	19.9
62	3.54	3.3		3.42	16.5	3.99	3.75	0.23	1.94	20.6
61	3.46	3.56		3.51	14.4	4.01	3.76	0.25	2.10	21.1
60	3.15	3.22		3.19	18.0	3.76	3.53	0.22	1.87	22.4
59	3.71	3.58		3.65	17.3	4.28	3.92	0.35	2.93	22.6
58	3.46	3.28		3.37	19.0	4.01	3.78	0.23	1.88	23.2
57	3.91	3.81		3.86	13.9	4.40	4.12	0.27	2.28	24.3
56	4.79	4.58	4.56	4.64	15.6	5.37	5.15	0.22	1.83	27.2
55	3.85	4.18	3.9	3.98	12.8	4.49	4.21	0.27	2.26	27.7
54	3.72	3.68		3.70	14.4	4.23	3.97	0.26	2.19	28.4
53	4.24	4.07		4.16	13.1	4.70	4.42	0.28	2.36	29.7
52	3.71	3.69		3.70	15.0	4.25	4.04	0.22	1.82	30.6
51	4.73	4.65		4.69	12.4	5.27	4.95	0.33	2.72	31.6
50	3.87	3.82		3.85	15.4	4.44	4.23	0.21	1.73	32.2

* Corg. = Ctot-Ccarbonate

APPENDIX E

Preparation of samples for enumeration of diatoms.

Subsamples of the sediments were prepared for diatom frustule counting by the use of a method based upon the permanganate method *Hasle and Fryxell* (1970) and *Hendey* (1974), the peroxide/centrifuge method of *Schrader* (1973), and the potassium persulphate method published by *Ma and Jeffrey* (1978).

These methods were all investigated in order to find one that;

a: was time efficient.

b: preserved delicate diatoms, such as many of the *Chaetoceros* species.

c: broke up the organic aggregates found to be common in Saanich Inlet sediments.

d: successfully cleaned the diatom frustules of adhered organic matter facilitating identification of species by frustule areolae patterns.

It was found that the permanganate method of *Hasle and Fryxell* (1970) and *Hendey* (1974) which required boiling each sample in the cleaning solution, was time consuming, while the peroxide/centrifuging method of *Schrader* (1973) tended to break up the more delicate species. The persulphate method of *Ma and Jeffrey* (1978) was found to be the most time efficient, allowing batches of 30 samples to

be processed at one time. The samples were allowed to settle and centrifugation avoided to prevent damaging the frustules. The better parts of these cleaning methods were combined and sample/slide preparation was carried out using the following method.

The frozen samples were allowed to thaw and a small portion was removed with a spatula. Around 100-200mg. of wet sample was found to provide sufficient diatoms. The sample weight was determined by the difference between the original sample weight and that with the diatom subsample removed.

The sample was placed in a clean test-tube and 10-20 ml. of distilled water were added. The suspension was shaken by hand and allowed to settle for 6 hours. The supernatant was then removed using a micro-pipette attached to a Venturi suction pump. This procedure was repeated twice in order to remove most of the salt from the samples.

The rinsed sample was then diluted with 10 ml. of Primary cleaning solution, consisting of 100 ml. hydrogen peroxide, 100 ml. glacial acetic acid and 20 g. of sodium hexametaphosphate made up to 500ml. with distilled water. The sample was shaken and allowed to settle until bubbling stopped. This usually occurred in 24hrs. but the sample was left for another 6hrs. to allow frustules suspended by the bubbles to settle. The cleaning solution was then removed and the sample rinsed with distilled water.

Further organic removal and 'bleaching' of the frustules was done by adding 2 ml. of a solution containing 6mg./ml. potassium persulphate with the samples being placed in an oven overnight at 70 °C.

The samples were cooled to room temperature, allowed to settle and the solution removed. They were then rinsed once more with distilled water and then finally diluted to 13.5 ml. (the volume of the storage vials used) with distilled water containing a few drops of Photoflow. The Photoflow acts as a wetting agent and facilitates the dispersal of the frustules on the cover slip prior to mounting (C. Sancetta. pers.comm.)

The cleaning tubes used were well washed in 10% HCl between uses and rinsed with distilled water before use. Pure water rinses were checked on occasion under the microscope for transference of frustules between samples and no significant contamination was observed.

Three slides were made of each sample: a smear slide of the raw sediment and two dilutions of the cleaned material.

The first dilution was 500ul. of the 13.5ml; the second dilution was 250ul. of the sample together with 250ul. of distilled water. The 250ul. dilution proved to be much easier to count since 500ul. often contained too many frustules. The diluted subsamples were pipetted onto an 18x18 mm coverslip and allowed to dry in air but protected from dust.

Once the dilutions had dried on the coverslip a drop of Hyrax mounting medium (RI=1.63) was placed in the center of the slip and spread out by heating the slip over a hot-plate at low temperature. The coverslip was picked up with a heated microscope slide, tilted and tapped to remove trapped air bubbles and allowed to cool.

Counting of the cleaned material was done on a phase-contrast microscope at 400x magnification. (Field of view =0.46mm. diameter) All complete frustules within the field of view were counted on transects in both the x and y directions over the coverslip. A minimum of 400 cells were counted; if this number was exceeded in the middle of a transect then the transect was completed. Counting 400 cells gives counting statistics of $\pm 10\%$ (Lund et al., 1958).

The results of the counting performed on the cleaned material are presented in Table E.I. Counting was concentrated on certain groups, since the object was simply to establish seasonality in the top of CPIV. However, many of the diatom groups were also identified to genus, and in many cases to species, level. A species list is given in table E.II.

Table E.2. Species list of diatoms observed in core CPIV.

Actinocyclus curvatulus Janish
Actinoptvchus senarius Ehrenberg
Actinoptvchus undulatus (Bailey) Ralfs
Asterionella glacialis Castracane
Asteromphalus heptactis (Brebisson) Ralfs
Chaetoceros affinis Lauder
C. convolutus Castracane or C. concavicornis Mangin
C. decipiens Cleve

C. debilis Cleve
C. diadema (Ehrenberg) Gran
C. didymus Ehrenberg
C. radicans Schutt
C. similis Cleve
C. subsecundus (Grunow) Hustedt
C. vanheurkii Gran
Coscinodiscus gigas Ehrenberg
Coscinodiscus radiatus Ehrenberg
Ditylum brightwellii (West) Grunow
Minidiscus spp. Maybe M. trioculatus or M. chilensis
Odontella aurita (Lyngbye) Agardh
Paralia sulcata (Ehrenberg) Cleve
Pleurosigma strigosum or Pleurosigma angulatum
Pseudoeunotia doliolus (Wallich) Grunow?
Raphoneis surirella
Rhizosolenia setigera Brightwell
Skeletonema costatum (Greville) Cleve
Stephanopyxis turris (Greville and Arnott) Ralfs
Thalassionema nitzschiodes (Grunow) Peragallo
Thalassiosira aestivalis Gran
T. eccentrica (Ehrenberg) Cleve
T. gravis Cleve
T. nordenskoeldii Cleve
T. pacifica Gran and Angst
Thalassiothrix longissima Cleve and Grunow
Thalassiothrix frauenfeldii Grunow

Diatoms from the genres: Cocconeis, Cyclotella, Grammatophora, Navicula and Nitzschia were also recognised but not identified to species.

SILICOFALGELLATES.

Distephanus speculum Ehrenberg

EBRIDIANs.

Ebria tripartita (Schumberg) Lemmermann.

REFERENCES USED TO IDENTIFY SPECIES.

- 1: Cupp E.E 1943 Marine Plankton diatoms of the west coast of North America. Bull. Scripps Inst. Ocgy. Tech. Ser. 5. pp 1-248.
- 2: Gran H.H and Angst E.C 1931 Plankton Diatoms of Puget Sound. Pub. Puget Sound Mar. Biol. Stn. 7. pp 417-519.

- 3: Hendey N.I 1964 An Introductory Account of the smaller Algae of British Coastal Waters. Bacillariophyceae (Diatoms). H.M.S.O London. 317p.
- 4: Hustedt F 1927-1966 Die Kieselalgen Deutschlands, Oesterreichs und der Schweiz. In; Kryptogamen-Flora 7, Part 1,2,3. (ed. L. Rabenhorst) 1927-1966.
- 5: Shim J.H 1976 Distribution and Taxonomy of planktonic marine diatoms in the Strait of Georgia. Ph.D thesis U.B.C Vancouver. 248p.
- 6: Roelofs A.K 1983 The Distribution of Diatoms in the surface sediments of British Columbia Inlets. Ph.D thesis U.B.C Vancouver. 253p.