

THE CHEMICAL, PHYSICAL AND STRUCTURAL CHARACTERISTICS OF
ESTUARINE ICE IN GREAT BAY, NEW HAMPSHIRE:
RESULTS OF A TWO-YEAR PILOT STUDY

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ABSTRACT

To date, most sea ice research has been conducted in polar regions and, therefore, very little information is available on this type of ice at lower latitudes. As such, the purpose of this study is to provide general information on the chemical, physical and structural properties of estuarine ice as found in Great Bay, New Hampshire, and to determine if it can be used as an analog in the study of Arctic sea ice.

The study was conducted during the 1983-1984 and 1984-1985 freezing seasons (late December to late February). Ice cores and surface water samples were taken 1-4 times per week near Adams Point in Great Bay, New Hampshire. Concentrations of chloride, sulfate, nitrite plus nitrate, phosphate, silicate, ammonium and chlorophyll-a were determined for samples chosen on the basis of identifiable stratigraphic layers (i.e. bubble and sediment layers).

Similarities between ice formation in Great Bay and that in the arctic regions include the nature of the freezing process and ice types produced, the nature of incorporation of brine into the crystal structure of the ice and the drainage of brine. In addition, the distribution and concentration of chemical constituents were found to be similar. Factors affecting the chemistry of the ice in Great Bay that may also affect polar ice include rainfall during the freezing season, the presence of sediment layers in the ice and flooding of the ice by sea water.

BACKGROUND

Ice Formation and Crystal Structure

Structurally sea ice may be composed of as many as three types of ice: frazil ice, congelation ice and snow ice (Weeks and Ackley, 1982). The first stage of the freezing process is characterized by fine spicular or platelike crystals, called frazil, which form on the surface

of the water giving it a greasy appearance. Frazil is generally associated with dynamic, turbulent conditions in the water column. These crystals are up to 2 cm in diameter and less than 1 mm thick (Mellor, 1964). Water movement causes this sheet to break-up and as freezing continues, the crystals congeal into circular shaped masses that develop raised rims due to collisions with other masses which are referred to as pancakes. Frazil continues to form between the pancakes until a continuous sheet of ice is formed (Weeks and Ackley, 1982).

Below the frazil a transition to congelation ice may be observed (Weeks and Ackley, 1982). Once a continuous ice layer has formed ice crystals lose a degree of growth freedom and geometric selection of the crystals occurs. Eventually a preferred orientation is developed producing a characteristic growth fabric (Weeks and Ackley, 1982). Congelation ice is characterized by relatively large columnar-grained crystals, that are approximately 1 cm in diameter, that are produced by the slow removal of heat from the water under an existing ice sheet. Closer examination of these crystals show they are composed of closely packed plates with layers of brine inclusions incorporated between them (Weeks and Ackley, 1982).

Chemical Composition of Ice and Water

As sea water freezes, residual brine is concentrated between the crystal platelets and as freezing continues, pockets of brine become trapped in the spaces between the platelets (Anderson, 1960). Air also may be trapped within and between the platelets. If the ice temperature decreases, brine will begin freezing at the edge of a pocket until it is in eutectic equilibrium with the ice at that temperature. If the temperature of the ice increases, the opposite effect occurs (Anderson, 1960). The formation of cryohydrates is the mechanism by which salts are retained and fractionated in the ice (Reeburgh and Springer-Young, 1983). If the eutectic temperature for a specific cryohydrate is not exceeded, it will remain in the brine pockets as a solid. Temperature gradients in sea ice provide a means of selectively mobilizing specific cryohydrates that leads to fractionation and variation in major element ratios (Reeburgh and Springer-Young, 1983). New sea ice may have salinities as high as 20 o/oo. After a few weeks the salinity may drop to 10 o/oo and at the end of the first year it may be as low as 3 o/oo due to brine drainage (Anderson, 1960). The mechanisms of brine drainage are uncertain but Untersteiner (1968) proposed four hypotheses: 1) brine pocket diffusion (drainage along a temperature gradient), 2) gravity drainage, 3) flushing (drainage occurring through interconnected cavities) and 4) brine expulsion (expulsion caused by volume changes as the ice cools). It is believed that flushing and gravity drainage are the primary processes in "freshening" the ice (Reeburgh and Springer-Young, 1983; Weeks and Ackley, 1982).

Clarke and Ackley (1984) have found that rapid ice growth is important in determining the distribution and structure of the biological and chemical components in the ice. They hypothesize that frazil ice can incorporate algal cells by two mechanisms, either by nucleation of a frazil ice crystal or by incidental incorporation of cells as frazil crystals float through the water column. This results in higher initial chlorophyll-a concentrations (measure of the living plant material) in the ice than in the water (Clarke and Ackley, 1984). However, in congelation ice growth algal cells may be rejected by methods similar to salt rejection. For frazil ice correlations were shown between chlorophyll-a and depth, phaeopigment (measure of chlorophyll degradation products) and ice and chlorophyll-a and

phaeopigment, indicating that surface samples are lower in chlorophyll-a than samples at depth, however, does not increase with depth continuously (Clarke and Ackley, 1984). In congelation ice it is believed that the biological community may be enhanced by passive water exchange in the lower ice allowing the nutrients to be cycled continually. This water exchange replenishes the nutrients and enhances biological growth (Clarke and Ackley, 1984).

Sediment Entrainment

When this study began, two mechanisms of sediment incorporation in ice had been previously identified in Great Bay: ice crystal nucleation and grounding (Thompson, 1977). The surface sediments in the area of Great Bay studied consists of very fine-grained (mean grain-size of 0.023 mm) material (Anderson, 1973) and these sediments are easily incorporated into the water column by waves and tidal action producing sediment-rich waters. This particulate matter can provide nucleation sites for crystal growth and generally results in the production of a fine-grained crystal texture in the ice. In the case of grounding during low tide Thompson (1977) found that sediment frozen on to the ice sheet is located inside the crystal structure indicating that the sediment and water within the sediment were incorporated as part of the ice crystal. Sediment incorporation of this variety requires that the ice must be at its coldest, i.e. the early stages of formation (Thompson, 1977). While the ice is in contact with the mud, cold transferred from the ice to the mud begins to freeze the mud to the bottom of the ice. As the tide rises, the buoyant ice sheet rises lifting the incorporated sediment. Repetition of this process yields layers of poorly sorted basal sediments.

Sampling Area

The sampling site used for this study was Adams Point in Great Bay, southeastern New Hampshire (Fig. 1). This site was chosen because of its accessibility and relative assurance of a seasonal ice cover.

In Great Bay ice usually begins to form in late December and may persist into March. The extent of ice cover varies throughout the freezing season and from season to season depending on weather conditions. During a mild season ice may be limited to small inlets and remain relatively thin (1-2 cm) whereas during a harsh winter (i.e. 1969) ice may cover the entire Bay and reach thicknesses of up to 30 cm.

Average January salinity at Furber Strait is 23 o/oo, which is less than that of the Gulf of Maine (32 o/oo) but normal for estuarine conditions (3-32 o/oo) (Loder et al., 1983). Although there appears to be a large influx of freshwater into the Bay from seven major tributaries, which would create a brackish water situation, Loder et al. (1983) find that the combined freshwater discharge of the major tributaries entering Great Bay contributes less than 2% of the total water volume exchanged during each tidal cycle. Accordingly, mixing in the Estuary is predominantly tidal. The tidal currents and the turbulence associated with it produce a well-mixed water column throughout most of the Bay (Loder et al., 1983).

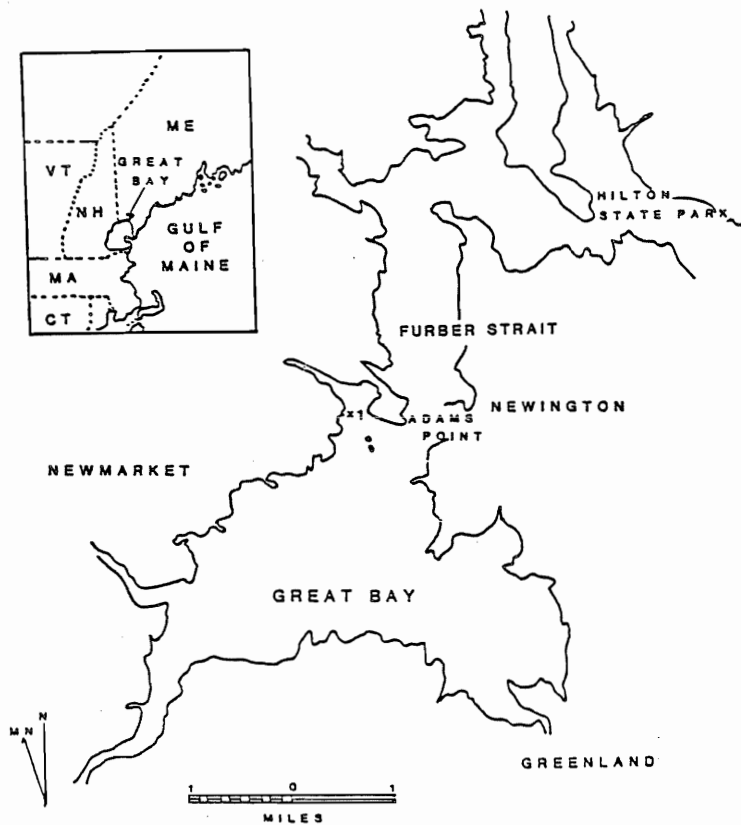


Fig. 1. Great Bay location map.

METHODOLOGY

During the 1983-1984 winter season (WS1) and the 1984-1985 winter season (WS2) samples were collected 1-4 times per week during a 10 week sampling period. During each visit 2 ice cores and 2 water samples taken at the ice/water interface were collected. In addition, weather data, ice thickness, ice temperature and water temperature were measured. A total of 45 ice cores and 74 water samples were collected during WS1 and during WS2, 14 ice cores and 41 water samples were collected. Cores were taken using a teflon coated SIPRE ice auger, double bagged in polyethylene bags, transported in a cooler and stored in a cold room at -20 C in the Glacier Research Group (GRG) Laboratory, University of New Hampshire. Water samples were collected in 30 ml precleaned Nalgene containers and kept frozen until analysis. All containers were precleaned by rinsing 3-4 times with Milli-Q water, filled and soaked overnight. The following day they were rinsed 2-3 times and then sealed with plastic tape until use. Each ice core was described structurally (including observations of bubble size, brine channel characteristics and sediment layers), cut in half vertically and sectioned based on stratigraphic breaks for chemical analysis.

The outer 1 cm of one-half of each core was melted off using Milli-Q water to remove any contaminants introduced during coring and preliminary handling. Each sample was stored in precleaned polystyrene jars and sent frozen to the Water Laboratory, Branch of Exploration

Geochemistry, United States Geological Survey, Denver where chloride, nitrate, phosphate and sulfate were analyzed using a Dionex Model 2120i* ion chromatograph. A standard eluent of 0.003 molar sodium bicarbonate plus 0.0024 molar sodium carbonate was used for analysis. Following analysis at the USGS the samples were returned to the GRG Laboratory and analyzed for nitrate plus nitrite, ammonium, phosphate and silicate by AutoAnalyzer using the techniques of Glibert and Loder (1977). Chlorophyll-a and phaeopigment concentrations were determined on selected samples from WS2 using the techniques of Strickland and Parsons (1972).

Blanks and standards were run in order to determine analytical error in all analyses. An integrater was used on the ion chromatograph and a computerized data aquisition system was used with the AutoAnalyzer for samples from both winter seasons. These methods automatically normalize the concentrations of the samples using the standard runs. Standard deviations ranged from 0-3% and these variations are considered insignificant for this study compared to the estimated lateral variability that occurs in the chemical species contained in the ice. Horizontal variations are a result of variations in brine channel characteristics. Tucker et al. (1984) studying horizontal variations in Arctic sea ice found that large horizontal variations between small segments occur often enough in the vertical direction (down core) that little difference exists in the salintiy content throughout the entire thickness of the ice sheet when averaged. Blanks were created by filling jars and bottles with Milli-Q water when the cores were sectioned. They were frozen and sent to Denver with the samples for ion chromatographic analyses and were returned to the GRG Laboratory for analyses on the AutoAnalyzer. Blanks from both seasons are below the detection limit (<0.5 ppm) for all species analyzed.

Relationships between concentrations of the various chemical species were determined by visual comparison of plots (concentration vs depth) and by statistical analyses. Correlation coefficient matrices and factor analysis were determined for each species analyzed for the following groups of samples: WS1-water, WS1-ice, WS2-water and WS2-ice using the Statistics with Finesse Program (Bolding, 1975). In addition, these statistics were performed on the data from the top, sediment, bottom and remaining interior ice layers for each season. The correlation coefficient matrices were produced in order to determine correlations between chemical species within each grouping of samples. These correlations were then compared between ice and water for each season. Factor analysis was then performed on each group to determine if additional relationships between chemical species exist.

The other half of the sectioned cores were taken to the Cold Regions Research and Engineering Laboratory (CRREL) where horizontal and vertical thin sections (measuring <0.5 mm in thickness) were prepared. Thin sections were photographed in both reflected light and between crossed polarizers in order to determine ice types, sizes, shapes and orientation of crystals and ice/entrapped sediment relationships.

RESULTS AND DISCUSSION

Growth and Structure of Ice

Ice sheet formation in the Bay was identical both seasons (Meese et

*Any use of trade names are for descriptive purposes only and does not imply endorsement by the U.S. Geological Survey.

al., in press) and is very similar to that observed in the Arctic. However, the freezing season in Great Bay is much shorter than in the Arctic. The first stage of the freezing process is characterized by growth of crystals beginning the last week in December. These crystals (max. 2 cm in diam.) coalesced to form the initial ice sheet. Wave action occurring over the first several days of the freezing process caused this sheet to break-up into circular shaped masses (pancakes). Frazil continued to grow between the pancakes until a continuous sheet of ice had formed. By the middle of January (WS1 and WS2) the ice had thickened to a minimum of 12 cm and the sheet extended to the edge of the cove. WS1 maximum thickness was 28 cm and 23 cm for the WS2. Changes in structure of the ice with increasing depth are identical to those observed in the Arctic where frazil ice generally constitutes the top layer and is followed at depth by a transition zone leading into congelation which usually composes 50 to 90% of the thickness of the mature ice sheet. In Great Bay the top 2-4 cm of the ice was fine-grained frazil ice overlain by variable amounts of generally fine-grained snow ice. Below the frazil a fairly short 1-2 cm transition into congelation ice was observed (Fig. 2). The frazil crystals, as observed in thin section, are generally equidimensional and range in diameter from 0.1 to 0.5 cm. In the congelation ice the crystals are long and comprise up to 83% of the ice thickness. Crystal cross-sections increased progressively with depth in the congelation ice and grain diameters of 1 cm were observed near the bottom of the ice.

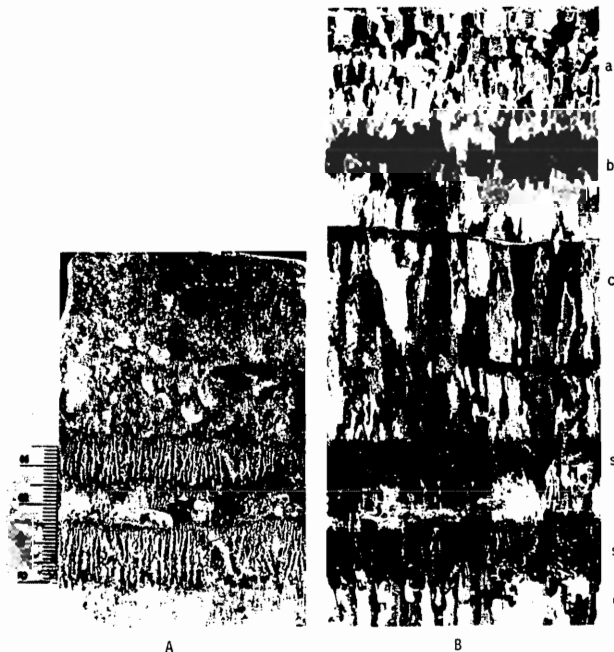


Fig. 2. Photograph of a vertical thin section of core 3, WS1: A) under reflected light; B) under crossed polarizers, showing ice types and sediment layers: a) snow ice, b) transition zone, c) congelation ice, s) sediment layers.

Chemical Composition of Ice and Water

In order to ascertain which chemical fractionation and/or biological processes are active in the ice and water in Great Bay chemical concentration trends and correlations for the data sets were determined. Two types of chemical species were analyzed: conservative species (chloride and sulfate) and nutrients (silicate, phosphate and nitrite plus nitrate-nitrogen). The conservative species are major salts in sea water and their concentration trends are expected to track each other. As a result, correlations between these species should be statistically significant. Nutrients may be used as indicators of biological activity. If the nutrients correlate significantly with conservative species they are salinity dependent, suggesting that biological activity is not affecting chemical species concentration either by enrichment or depletion.

Concentration versus depth plots for each ice core analyzed reveal that, with the exception of silicate for some events, the concentrations of all species track each other (Fig. 3). Concentrations of silicate range from 0.06 to 0.6 ppm in ice layers that are free of sediment. If sediment is present in the ice silicate concentrations are as high as 14.3 ppm due to dissolution of silicate from the sediment into the ice. Generally, an increase in the concentration of chemical constituents is observed in all of the sediment layers. This may be a result of draining brine being trapped and concentrated by the sediment filling the brine channels which would prevent further brine drainage. In several top layers noticeable increases or decreases of several species are often present. Increases in the top layers are a result of flooding of seawater whereas decreases are generally due to either brine drainage or dilution by rainfall. Increases that occur in the bottom layer are due to freezing on of highly saline water during high tide whereas decreases are either due to brine drainage or freezing on of fresher water during low tide. Visual correlations comparing concentration trends within each core were significant for the conservative elements that were analyzed. A concentration trend for the nutrients was not evident.

In order to determine correlations between chemical species the data from each ice core was divided into the following groups: top layers, sediment layers, bottom layers and the remaining interior layers. This was done in order to determine processes that are active in the ice at the various layers and to determine how events such as flooding and precipitation and the presence of sediment affect chemical species concentrations and chemical fractionation processes. A correlation coefficient matrix was produced and factor analysis using varimax rotation was performed on each group of data including the water sample data. Significant correlations between species at the 99% confidence interval are listed in Tables 1 and 2 for WS1 and 2, respectively, for each group of data. Results for the factor analysis appears in Tables 3 and 4 for WS1 and 2, respectively, and groups displaying high and equal loading for a particular species are listed. Underlined values in each table represent significant correlations that occur both seasons.

In general, positive and negative correlations in the ice layers are a function of the concentrations and ratios of the chemical species in the water at the ice/water interface. Exceptions to this are the chemistry of the top layers of the ice since these may be affected by flooding, precipitation and the presence of sediment layers (Meese et al., in press). In addition, variations in the top layers may be due to

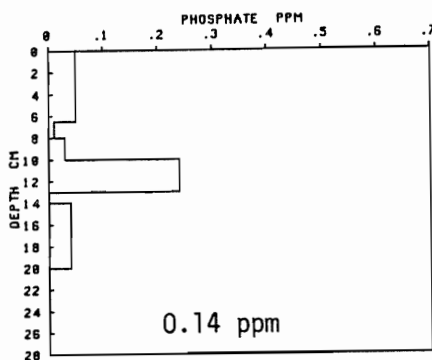
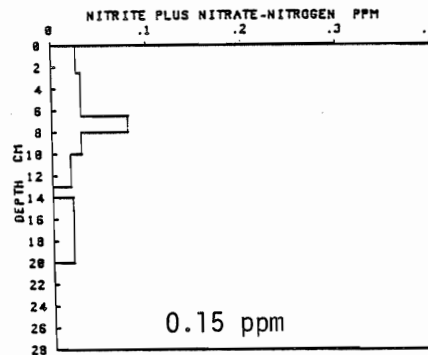
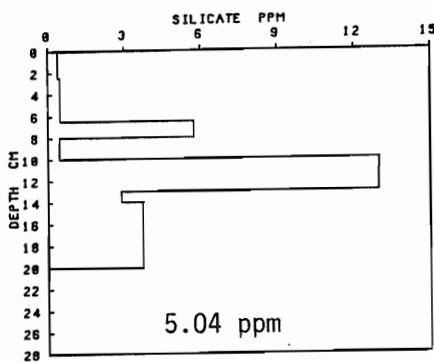
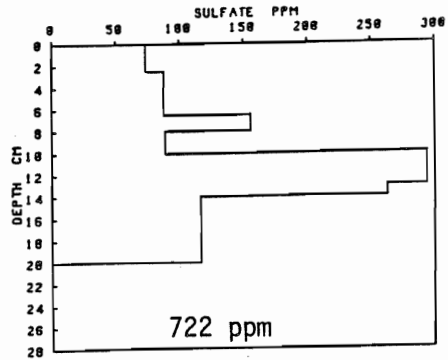
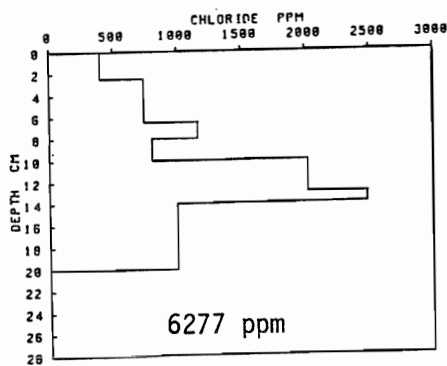


Fig. 3. Chemical profiles of core 7, 7 January 1984 (WS1). The value under each plot is the concentration in ppm for the water sample collected at the ice/water interface. The high concentrations noted at approximately 7 and 12 cm correspond to the locations of sediment layers in this core.

Table 1. Significant correlations at the 99% confidence interval for chemical species from WS1. I=All ice samples, S=sediment layers, T=top layers, B=bottom layers, R=remaining layers, W=water samples. A negative sign indicates a negative correlation. Numbers in parentheses indicate the 99% significance level. Underlined values represent significant correlations that occurred both seasons.

SPECIES	GROUPS					
	I (>.283)	S (>.561)	T (>.590)	B (>.606)	R (>.418)	W (>.549)
Cl-PO4	.29				.8	
Cl-SO4						
Cl-NO3	.83	.97	.59	.99	.96	.95
Cl-SiO2	.37		.60		.8	-.71
PO4-NO3						
PO4-SO4					.77	
PO4-SiO2	.74			.88	.95	
NO3-SO4						
NO3-SiO2						
SO4-SiO2	.44				.76	-.79

Table 2. Significant correlations at the 99% confidence interval for chemical species from WS2.

SPECIES	GROUPS					
	I (>.354)	S (>.735)	T (>.708)	B (>.798)	R (>.496)	W (>.549)
Cl-PO4						
Cl-SO4	.54		.96	.96	.95	.76
Cl-NO3					.67	
Cl-SiO2	.51					
PO4-NO3						
PO4-SO4						-.66
PO4-SiO2						
NO3-SO4	.52				.77	-.84
NO3-SiO2	.39					
SO4-SiO2	.66	.77				

Table 3. Results of factor analysis using varimax rotation and 3 factors for WS1.

	Factor 1	Factor 2	Factor 3
Cl	I, S, B, W		R
SO4	I, S, B, W		-T, R
PO4	R	-I, S, T, -B	W
NO3		R, W	I, S, B
SiO2	T, R, -W	-I, S, -B	

Table 4. Results of factor analysis using varimax rotation and 3 factors for WS2.

	Factor 1	Factor 2	Factor 3
Cl	I, T, B, R, -W	S	
SO4	S, T, B, R, -W		
PO4		I	S, T, B, R, W
NO3	R, -W		I
SiO2	I, S	T, B, R, W	

chemical fractionation and brine drainage that occurs throughout the season.

Significant positive correlations that existed between species for both seasons include: chloride-sulfate for all ice samples, top, bottom and remaining interior ice layers and water samples; chloride-silicate and sulfate-silicate for all ice samples. High positive correlations between chloride-sulfate in most of the groups are expected since both are conservative species. Results from factor analysis indicate that many relationships between species in the various groups are consistent throughout the two seasons (see Tables 1-4).

The results of the statistics for each group of sample data are discussed below detailing significant positive and negative correlations that exist between chemical species, similarities and differences between years and possible explanations for the correlations.

Water

A high negative correlation exists between the conservative species and silicate for the WS1 data (Table 1). WS1 was characterized by high amounts of rainfall (Meese et al., in press) which created high river runoff (silicate in Great Bay may be used as an indicator of freshwater influx (i.e. when river input is high silicate concentrations are high and when tidal influx predominates silicate concentrations are low). The riverine influx of silicate combined with the high concentrations of the conservative species from sea water may explain the negative correlation that exists between them. Factor analysis (Table 3) supports the above correlation and also suggests that phosphate and nitrate plus nitrite-nitrogen are behaving independently of the other species and of each other.

The negative correlations between sulfate and nitrogenous nutrients (WS2) are difficult to explain. They may be indicative of processes occurring within the sediment of the tidal flat (i.e. sulfate reduction and/or nitrification/denitrification).

Ice Chemistry By Stratigraphic Layers

Top Layers

The correlation coefficient matrix for the data from the top layers of the ice reveals few correlations. This is expected since the top layers are affected by rainfall and flooding of sea water during the freezing seasons. Factor analysis indicates that as in the water the nutrients are behaving independently of salinity and each other.

Bottom Layers

A high positive correlation exists between phosphate and silicate during WS1 as revealed by the correlation matrix (Table 1) and factor analysis (Table 2). This relationship is difficult to explain, however, since this relationship exists in several of the data sets (Table 1) it may be result of chemical fractionation that occurred during this season due to the high amounts of rainfall (Meese et al., in press).

Factor analysis for bottom layers in both seasons indicates that the other nutrients are behaving independently of each other and of salinity.

Interior Layers of Ice Exclusive of Ice Containing Sediment

The chemistry of the ice layers that remain after the sediment layers and top and bottom layers have been removed appears to be the most representative of the chemical fractionation processes occurring in the ice unaffected by external variables (i.e. sediment entrainment, flooding of the ice by sea water and precipitation) throughout the freezing season.

Statistics for WS1 display significant positive correlations between several chemical species for the interior sections of the ice sheet (Tables 1 and 3). Many of these correlations are difficult to explain based on typical estuarine and/or oceanic relationships. However, the statistics from WS2 show fewer correlations (Table 2) and factor analysis (Table 4) indicates that this part of the ice correlates well with the other groups of sample data and correlates especially well with the water sample data. The reason for this is most likely the high amount of rain that fell during WS1 which may have caused fractionation of species and influenced the biological activity, whereas WS2 was meteorologically a more "normal" season based on means from 1951-1980 (NOAA, 1980). This indicates that the interior layers of the ice are the most representative of the water column and during a long winter would be excellent indicators of fractionation processes and biological activity that may be occurring in the ice.

Sediment Layers

Sediment layers are found in 75% of the ice cores. Higher concentrations of most chemical species analyzed occur in these layers and, therefore, these layers are also considered separately.

Sulfate does not correlate significantly with chloride in the sediment layers in WS2 but does have a high positive correlation with silicate (Tables 3 and 4). This may be an indication that sulfate is fractionating within the sediment layers or oxidation of iron sulfides to sulfate in the sediment layers is occurring.

Biological Activity

During WS2 selected ice and water samples were analyzed for chlorophyll-a in order to determine if a biological population exists in the ice. Clarke and Ackley (1984) and Sullivan and Palmisano (1984) found a significant positive correlation between chlorophyll-a concentrations and ice type in Antarctica. It was found that chlorophyll-a concentrations are the highest in frazil ice at depth. Concentrations in the surface layers are lower and concentrations in congelation ice are the lowest (Clarke and Ackley, 1984). Clarke and Ackley (1984) found that a threefold difference in chlorophyll-a concentrations may exist between two cores from the same area with similar length and structure. They attribute this difference to formation conditions and the history of the ice. Concentrations in the Great Bay ice ranged from 0.3 to 12.4 mg/l. Concentrations deep within the interior of the Great Bay ice were much greater than the concentrations in the top or bottom layers. The concentrations in the surface water below the ice were higher than the ice which is the reverse of what was found by Clarke and Ackley (1984) in the Weddell Sea. The greatest concentrations of chlorophyll-a occurred in the water in December. There may be several parameters affecting the concentration of chlorophyll-a in the water and ice of Great Bay including the presence or absence of sediment layers and/or ice type.

One of the factors that affects biological activity in water and ice is the amount of light that reaches layers at various depths. Sediment layers reduce the amount of light transmitted through the ice and hence reduce biological activity. Before specific processes that affect the concentration can be identified the effect that these parameters have on the concentrations must be determined. This would involve chlorophyll-a analyses in cores with and without sediment layers throughout the season and also analyses by ice type and not stratigraphic layers.

Sediment Entrainment

In most sediment layers, ice crystal growth continued through the sediment uninterrupted (Fig. 2) indicating that in these instances the ice had not become frozen to the sediment. Closer examination of the thin sections shows that this entrainment of sediment actually occurred within the spaces between the crystal platelets where brine is normally trapped. Weight percentages of the sediment in these layers ranged from 3-25%. It is believed that there are two possible mechanisms of sediment entrapment that may explain this situation: 1) sediment particles were frozen into the ice while freely suspended in the water column or 2) ice grounded at low tide and sediment became incorporated as the pore water froze. In typical situations the latter explanation would not be possible, however, in Great Bay the porosity of the sediment is as high as 70% (Mark Hines, personal communication, 1986). With porosities this high and weight percentages as great as 25% it appears that it would be possible for crystal growth to continue through the sediment.

Our observations of substantial debris entrapment in actively growing crystals of congelation ice appear to be the first ever reported. There are numerous reports of sediment entrapment in arctic sea ice, usually in the top meter of the ice sheet (Osterkamp and Gosink, 1984). This entrainment of sediment invariably occurs in conjunction with frazil ice formation and not in congelation ice as observed in Great Bay. One explanation for the Arctic situation is that early winter storm action causes stirring up of bottom sediments and promotes turbulence in the water column, leading to frazil formation. Suspended sediment then becomes entrained mechanically between the grains of frazil. This explanation together with the Great Bay observations strongly implies that the presence of suspended sediment in the water column is not a necessary condition for generating frazil, i.e., the suspended particles do not actively nucleate growth of frazil crystals in the water column. A similar explanation may also apply to frazil and sediment particles found mixed together in rivers.

In addition to the above mechanism, grounding of ice, resulting in freezing on of sediment, occurred during WS2 leading to thicker more uniform layers of sediment that, in some cases, contained plant material and other debris.

SUMMARY

The structure, chemistry and sediment in the ice and water in Great Bay were studied for 2 winter seasons (1983-1984 (WS1) and 1984-1985 (WS2)) to determine general characteristics of the ice and to determine if the ice in Great Bay can be used as an analog in the study of Arctic sea ice. The following conclusions were made:

- 1) Ice formation in Great Bay occurs by the same processes as those found in the Arctic and crystal structure is identical. In general, three types of ice are found in Great Bay: snow ice, frazil and congelation ice. Congelation ice dominates the thickness of the ice in Great Bay.
- 2) Two mechanisms of sediment entrapment have been identified in Great Bay: adfreezing of debris to the bottom of the ice during grounding and freezing of particles between ice crystal platelets. Sediment freezing between the crystal platelets, at least to the extent observed in Great Bay, has not been previously reported.
- 3) With the exception of snow ice there did not appear to be any correlation between chemical species concentration and ice type and/or bubble structure.
- 4) Statistically significant positive correlations exist between conservative species (chloride and sulfate) and between nutrients (silicate, phosphate and nitrite plus nitrate-nitrogen). An example of this is the positive correlation between sulfate-silicate that exists in the ice. This may be indicative of sulfate oxidation in the sediment layers. Dissolution of silicate occurs in the sediment layers resulting in an increase in silicate concentration. Sulfides contained in the sediment appear to oxidize resulting in an increase in sulfate concentration.
- 5) In general, most of the correlations between the conservative species and the nutrients in the ice are similar to those in the water. The main exception to this is found in the sediment layers where some enrichment of sulfate may have occurred and silicate-sulfate correlations were observed.
- 6) Chlorophyll-a concentrates in the interior of the ice indicating that biological activity is occurring in the ice.

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