Origin of salt in coastal marshes of Hudson and James bays

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The presence of salt in isostatically uplifted coastal marshes well removed from tidal sources suggests that the salt is relict in origin. This was confirmed by the measured downward increase in salinity towards the deeper and older Tyrrell Sea sediments and by the presence of water isotopically heavier than the present-day meteoric or tidal waters. The low permeability of marsh sediments and the vertical distribution of salt indicate that diffusion is transmitting salt toward the surface, where it is subsequently removed by surface flow. Salt concentration decreases with distance inland, where the salt-loss processes have proceeded for a longer time. The chloride concentration of the deep pore water suggests that the total salinity of the postglacial Tyrrell Sea was 21–25 g L^{-1}.

La présence de sel dans les marécages littoraux, jadis soulevés isostatiquement et déplacés à l'abri des effets des marées, indique que le sel doit avoir une origine relictuelle. Cette interprétation est corroborée par l'accroissement de la salinité, de haut en bas, en approchant les sédiments de la mer de Tyrrell, plus anciens et plus profondément enfouis, et par la présence d'une eau isotopiquement plus lourde que les eaux météoriques ou des marées actuelles. La faible perméabilité des sédiments des marécages et la distribution verticale du sel indiquent une ascencion du sel par diffusion vers la surface, où il était subséquemment délavé par les eaux d'écoulement de surface. La concentration en sel diminue avec la distance vers l'intérieur des terres où les processus de dissolution du sel ont agi pendant une plus grande période de temps. La concentration en chlorure dans l'eau des pores à un niveau profond suggère que la salinité totale de la mer de Tyrrell postglaciaire fut de 21 à 25 g L^{-1}.
[Traduit par la revue]

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Introduction

Most coastal salt marshes of the world derive their salt from seawater, which inundates the marshes and from which salt is concentrated by evaporation (Casey *et al.* 1986; Hackney and de la Cruz 1978; Lindberg and Harriss 1973; Mahall and Park 1976). These salt marshes exhibit a decreasing salinity with depth and with distance inland because of the downward and landward decrease in the influence of the tidewater. These processes were assumed to be responsible for the formation of salt marshes in the Hudson Bay Lowland (Glooschenko and Clarke 1982). However, in the James Bay coastal area, we found that salinity increases with depth and that salt occurs in the inland marshes far beyond the extreme limit of high tide. The relatively low salinity of the seawater in Hudson Bay and James Bay, the small tidal range, and the low frequency of storm surges seriously restrict the import of salt from the tidewater. Other processes are required to explain the observed spatial patterns of salt distribution. This note reports the investigation at two coastal sites, the results of which shed light upon the origin of salt marshes in the Hudson Bay and James Bay coasts.

Study site and method

In seeking an explanation for the distribution of salt, we obtained marsh sediment cores and water samples from the coastal zone at the southern end of James Bay, Ontario (51°10′N, 79°47′W), near the mouth of the Harricanaw River. Inflows from this and other rivers reduce the salinity of James Bay to typical values of 0–4 g L^{-1} in shallow coastal areas and estuaries (McCrea *et al.* 1984; McCrea and Wickware 1986) and 25–30 g L^{-1} in deeper waters; the salinity is 30–33 g L^{-1} in Hudson Bay (Pelletier 1969). Hudson Bay and James Bay were preceded by the postglacial Tyrrell Sea, dating back to 7875 ± 200 years BP. In this sea grey–blue marine clays up to 56 m thick were deposited (Lee 1960). Fossil assemblages showing faunal changes (Wagner 1969) suggest that the salinity of the Tyrrell Sea was lower than that of present-day Hudson Bay water. Such conditions must have been brought about by mixing of the salt water with glacial meltwater.

The shoreline is currently prograding at a rate of 1–2 km/100 years, and beach building along the coastal margin has added 1.5–2.0 m of silty sediments onto the Tyrrell Sea clay (Martini 1981). Peat development begins at about 0.5 km inland, increasing to a thickness of 0.7 m at 3.0 km inland. The hydraulic conductivities of the peat, silt, and clay are of the order of 10^{-5}, 10^{-7}, and 10^{-10} m s^{-1}, respectively, and the regional hydraulic gradient is very low, averaging only 0.001.

Pore-water samples were centrifuged from sections of two 8–10 m cores collected in April 1986, approximately 1 and 3 km inland. Tidal water and rain were sampled from April 1984 to August 1985, and a depth-integrated snow sample was taken from the April 1985 snow cover. These waters were analysed for chloride content with a chloride electrode and for ^{18}O and D isotopes by mass spectrometry. Reproducibility for chloride was ±2%; for $\delta^{18}O$, ± 0.2‰; for δD, ±2‰.

Results

The results indicate that pore waters from the marsh sediments are isotopically heavier than the present-day tidal and meteoric waters (Fig. 1) and have a composition closer to that of sea water. The isotopic values of water from the deeper

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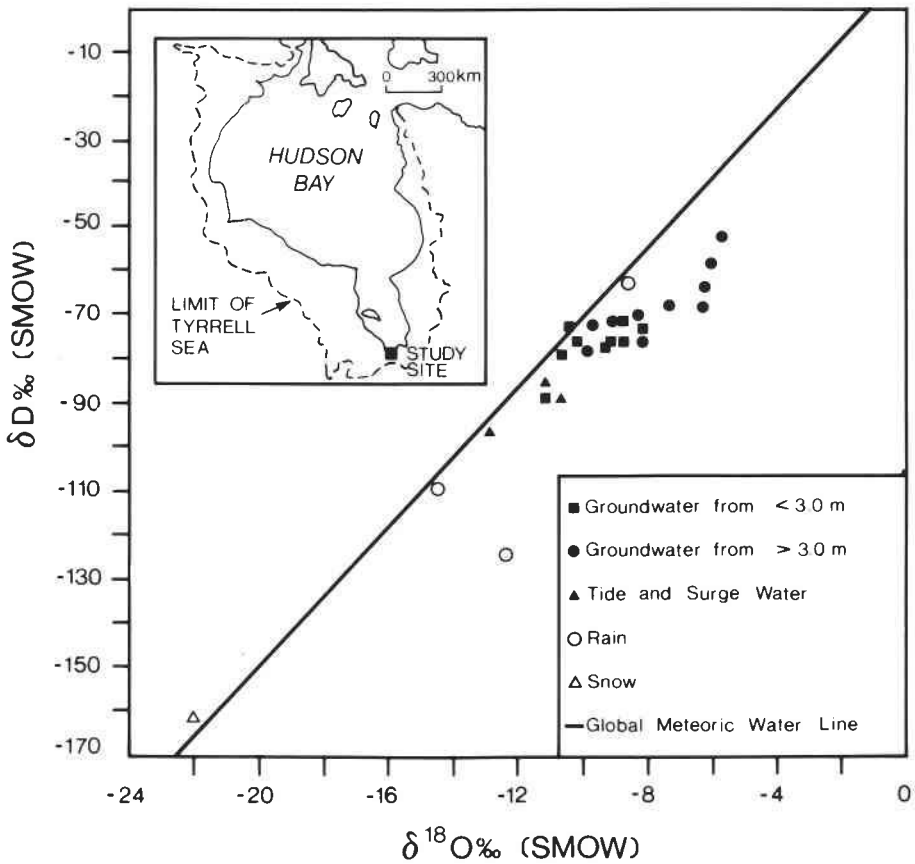

FIG. 1. Deuterium vs. ^{18}O expressed in deviation from standard mean ocean water indicates that groundwater samples trend towards seawater in origin and have not been introduced to the marsh via local tide and meteoric water, which is isotopically lighter. The study area is also shown.

sediments plot closer to the origin (0,0) in Fig. 1, at which point is the isotopic composition of standard mean ocean water (SMOW). The vertical profiles of chloride (Fig. 2) show that more-saline pore water occurs at depth. The increase in salinity with depth is inconsistent with the possibility that tidewater introduced salt at the surface and carried it downward, since the low hydraulic gradient and conductivity limit the probability of advection in the clayey sediments. This is confirmed by the absence of isotopically lighter tide or meteoric water in the deeper sediments. The isotopic composition of pore water in the deeper sediments trends toward that of seawater (Fig. 1), but this water was mixed with isotopically light water of low salinity, probably of glacial origin. It is therefore concluded that the pore water and the salt originated from the Tyrrell Sea and were trapped in the sediments during deposition.

After isostatic emergence, the presence of fresh meteoric water at the surface has produced a strong vertical concentration gradient. This gradient drives the diffusion process, resulting in an upward movement of chloride from the sediment. These processes are relatively recent at coastal locations: they were inoperative until isostatic rebound raises the sediments to the littoral zone, where the water is of low salinity. A comparison of the two core profiles shows a landward decrease in chloride concentration in the near-surface layers. This is due to the longer period of time available for upward diffusion and subsequent removal of salt at the more inland site.

Pore water that is deeper than 3 m has had little loss of chloride, as is indicated by the small or negligible vertical concentration gradient (Fig. 2), and thus is probably representative of the salinity conditions of the Tyrrell Sea. The maximum chloride concentration of 13–15 g L^{-1} indicates the total salinity of these pore waters (thus Tyrrell Sea waters) was 21–25 g L^{-1}. These pore waters were laid down with the sediment during a period of intense glacier melt. The input of glacial meltwater reduced the salinity of the Tyrrell Sea, and the admixture of isotopically lighter glacial meltwater caused the Tyrell Sea water, and thus the pore water, to plot away from the origin in Fig. 1.

Conclusion

Our data suggest that the postglacial Tyrrell Sea had a salinity of 21–25 g L^{-1}, higher than that of the water of southern James Bay but lower than that found in the deeper parts of James Bay and Hudson Bay. The Tyrrell Sea water that was trapped in sediments has become an important source of salt for the coastal marshes. This salt was connate (i.e., entrapped in sediments at the time of deposition), which explains the observed vertical salinity distribution and the presence of salt in marshes well beyond the upper tidal limit.

A higher salt content at depth implies that an upward solute flux by diffusion brings the salt to the surface. A significantly lower salinity at sites farther inland reflects a longer history of salt loss to diffusion and surface removal. This pattern of upward and inland decrease in salt is found at many other James Bay marshes, implying the prevalence of the processes described in this note. The finding pertaining to our study site are therefore applicable to other coastal areas developed above the sediments of the former Tyrrell Sea. These include marshes of the Hudson Bay Lowland and possibly saline lakes in the Canadian Arctic Archipelago (Pagé *et al.* 1984).

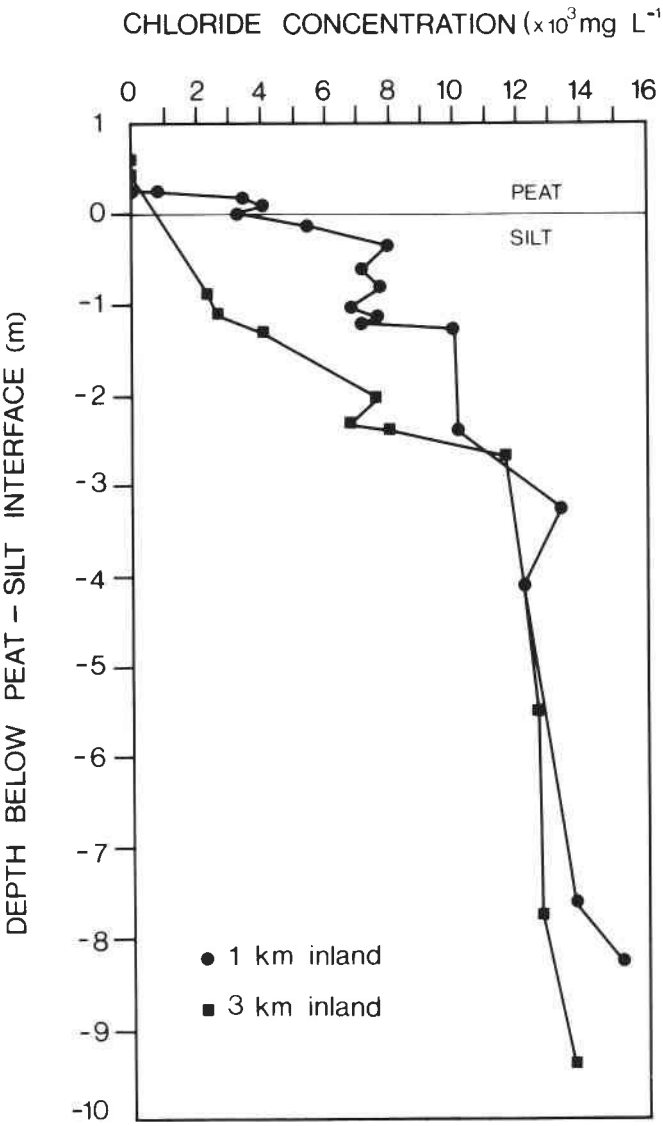

FIG. 2. The Cl^- profile shows a relatively constant concentration with depth, indicative of Cl^- conditions of the Tyrrell Sea. Lower Cl^- occurs at the surface, where increased hydrologic activity has carried away the products of upward diffusion. Sites farther inland have had more time for diffusion.

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