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INTRODUCTION

The potential of the Damariscotta River to provide data on sea-level rise in the central Maine coast area has long been recognized. A bedrock sill, known as Johnny Orr, creates an impediment to tidal flow, so that while tidal range at the Damariscotta-Newcastle bridge is 3.5 m, the range just upstream of the Johnny Orr sill is but 1.1 m (Figure 1). American oysters (Crassostrea virginica) once formed dense colonies upstream of the sill, a feature that attracted Indians who built some of the world's largest shell middens. By historic times, the middens were abandoned by the Indians. The area was also devoid of a breeding population of oysters.

A number of scholars have assessed the available evidence in attempts to reconstruct past sea levels. In the current study, a new technique is added to those already used: sediment coring above the Johnny Orr sill. Since the last major reconstruction attempt by Myers (1965), a great deal has been learned about the prehistory of the area. This has allowed a better evaluation of the old artifact collections.

This report relates a brief history of significant previous research, the coring program, oyster ecology, the archaeological evidence, and conclusions including a plan for further research.

I am grateful for the assistance of Tom Kellogg, Davida Kellogg, Herb Hidu, Mike Dunn, Scott Anderson, George Lichte, Doug Kellogg, and Pat Sanger. Mary Jo Sanger prepared a bibliography of relevant literature, scoured local newspapers for accounts of the mining activities at the shell middens, and worked with the archival documents at the Peabody Museum of Harvard University. The staff of the Peabody was most helpful. Finally, my thanks to Mr. George H. Hart for permission to work at the Glidden site. The map was drawn by Stephen Bicknell.

PREVIOUS WORK

The Damariscotta oyster shell middens have attracted attention for over a century (see Castner, 1956, and Snow, 1972, for general reviews). Two themes have dominated the discussions. First, the size of the structures (one is nearly 9 m deep) places them among the world's largest known middens. Second, the presence of so many oysters in an estuary not currently supporting a breeding population caused a great deal of speculation about changing environments. The remarkable sizes achieved by individual oysters also drew comments from most observers.

Desultory excavations in the mid-19th century resulted in some information on the activities represented by the middens. The major excavation, however, was not inspired by scientific curiosity but rather by a commercial venture. In 1886, the large midden on the east bank (the Whaleback) was systematically mined for chicken "scratch" and for fertilizer. In recognition of this disaster, Professor Putnam, Director

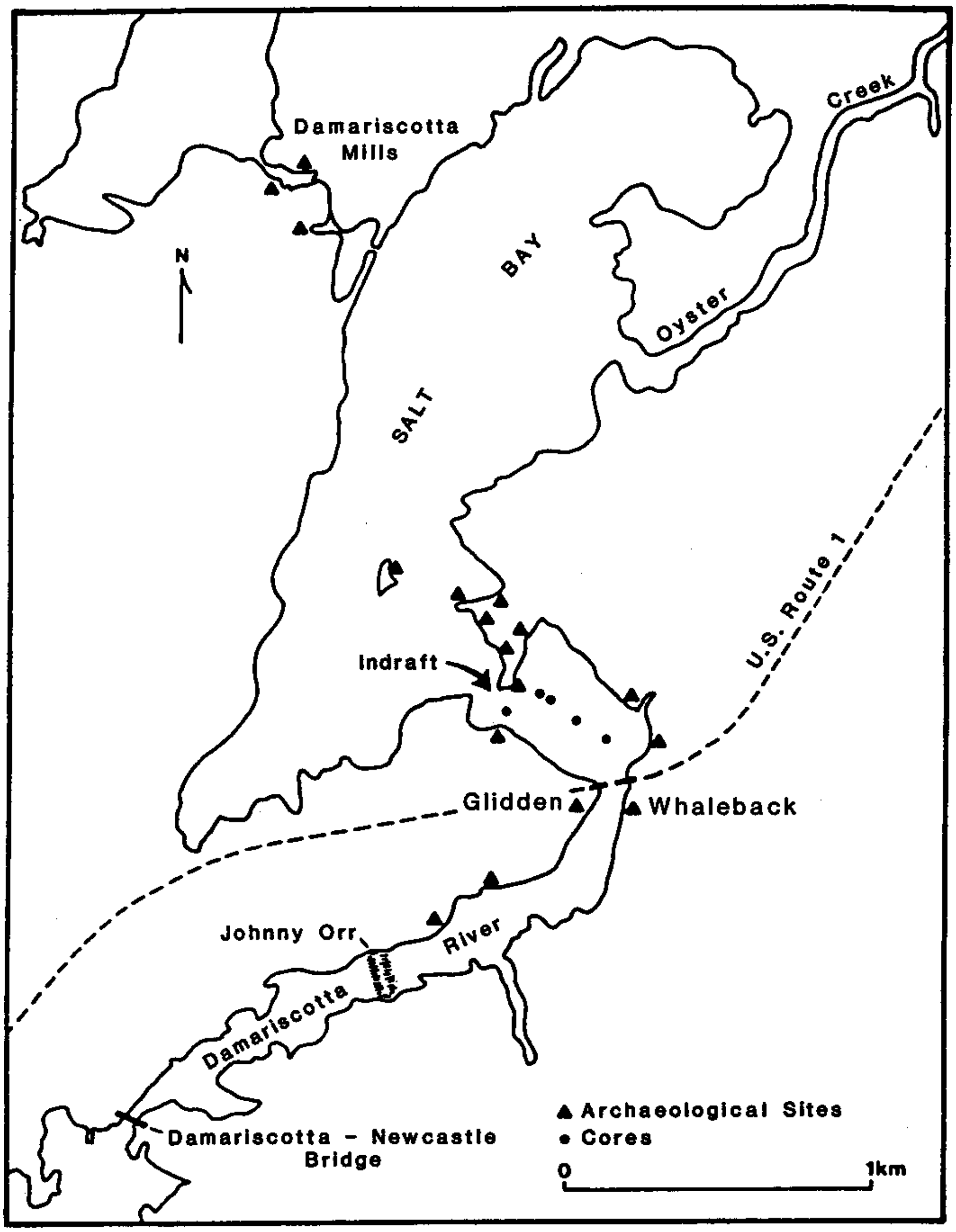

Figure 1. The Damariscotta shell midden area.

of the Peabody Museum at Harvard University, arranged for a local naturalist, A. T. Gamage, to watch over the mining operations and to send artifacts, shells, and bones to the museum.

Gamage gridded the site into 10 foot squares. He recorded the finds by square and the level below the surface to the nearest foot. Finally, he recorded the depth of excavation in each square. Letter reports from Gamage to Putnam provide additional data on stratigraphy and features. It is clear that he undertook his task in a most conscientious manner, and it is only now, nearly 100 years later, that his excellent work can be fully appreciated.

In 1935, Frederick Johnson (n.d.) took a group of Harvard University archaeology students to Newcastle to excavate the Glidden site. Although they excavated impressive quantities of shells, the students recovered few artifacts. Johnson's unpublished account represents the only systematic excavation of the Glidden midden. His description of pottery and stratigraphy can be employed to help reconstruct aboriginal activities at the site.

The implications of once extensive oyster beds in the Damariscotta River were not lost on a number of scientists who recognized that rising sea levels had created suitable conditions for oysters. Speculation on the demise of the oysters has ranged from pollution in historic times to unfavorable conditions created by continued sea-level rise.

In 1932, Richard P. Goldthwait (1935) conducted field work in the Damariscotta-Newcastle area. Much of his effort went into imaginative efforts to calculate the age of the middens based upon the inferred original (pre-erosion and pre-mining) volumes of the sites and accumulation rates of shells by aboriginal inhabitants. On the basis of a series of unfounded assumptions, Goldthwait estimated that the middens began to accumulate between 800 and 1850 years ago.

Next, Goldthwait approached the question of sea-level rise over the bedrock sill at Johnny Orr. A trench dug to examine the intersection of a midden and the fringing salt marsh showed no evidence of marsh overlapping the midden edge. From this and related observations, Goldthwait concluded: "It is almost unavoidable: sea level has been stable here during the 1000 years recorded by the heap." (1935, p. 11).

Myers' (1965) thesis, "The Damariscotta Oyster Shell Heaps: Some Further Considerations", represents the most impressive study of the paleoenvironments to date. Drawing on the previous research, as well as shellfish ecology and some radiocarbon dates on shells from the middens, Myers reevaluated the problem of sea-level rise over the sill at Johnny Orr. He concluded that sea levels have been rising slowly from approximately 3000 years ago. At that time mean high tide was no lower than minus 4 feet (1.2 m). Unlike Goldthwait, who hypothesized sea-level stability, Myers interpreted the demise of the oysters as resulting from a combination of increasingly unfavorable environmental conditions created by a greater influx of salt water, climaxed by pollution due to sawdust and siltation of the river. Recent work tends to support Myer's model of changes in the river.

SHELLFISH ECOLOGY IN THE DAMARISCOTTA RIVER

Oysters no longer maintain a breeding population in the Damariscotta River above Johnny Orr. There are at least three hypotheses to explain this phenomenon. One explanation is that subsequent to European presence in Salt Bay, a number of saw mills dumped large amounts of sawdust in the water, thus causing the extinction. Silt from agricultural activities may also have contributed.

A second explanation is related to sea-level rise. It suggests that as the depth of sea water increased above Johnny Orr, the temperature dropped to a point below which the oysters could not breed.

A third hypothesis is that an increase in sea level in the river has resulted in higher water salinity, thus allowing predators to invade the area above Johnny Orr (Myers, 1965).

The first hypothesis cannot be tested with the available data, although recent scouring has revealed beds of dead oysters once buried under silt (Newell, 1983). The silt covering was not necessarily the cause of death, however. The second and third hypotheses are related to the same event, sea-level rise, and can be tested.

Carter Newell of Maine Shellfish Research and Development Co. was engaged to provide answers to a series of questions relating to the ecology of the Damariscotta River above Johnny Orr. Basically, he was asked if it is environmentally possible for oysters to maintain a breeding population in the area.

Newell employed a "habitat suitability index" developed for oysters by Cake (1983). This methodology assesses a number of critical variables and combines them to produce an index which predicts whether or not oysters could maintain a breeding population. Water temperatures, substrate, salinity, fresh water floods, disease, and predator pressure are considered both for larval and later stages of development.

Newell (1983) found that the proximity of the older shell beds provided adequate cultch for oysters in the larval stages. Water salinity in the area ranged from 23-29 ppt in the summer of 1971, and 21-29 ppt in the summer of 1982. Salinity values of 10-30 ppt are considered suitable, although oysters can survive in levels as low as 6 ppt.

During the attached stage of oyster growth, prevalent annual water salinity values of 10-30 ppt are desirable. Values taken throughout the year ranged from 15-26 ppt. Fresh water killing flood intervals of greater than 5 years are considered suitable. Based on inspections of hard shell clams in the area, Newell suggested no killing floods in the past 10 years. Therefore, salinity is not a factor in the absence of oysters today.

Mean substrate firmness varies from very soft to hard in the high current flow areas. There is adequate firm substrate area. Water temperatures are considered suitable for growth and survival of oysters and cannot be considered unfavorable for reproduction. The mean predator abundance is calculated as numbers of predators per area. Oyster drills (Urosalpinx) and horseshoe crabs (Limulus) are plentiful in the area, and have hindered recent attempts to cultivate oysters. Predator pressure is considered variable and high in certain areas. There are no available data on diseases.

According to the habitation suitability index, the only reason for the lack of a breeding population is the absence of adults as sources for larvae. Oysters cultured in trays in 1971 grew rapidly (Newell, 1983). If, as the data suggest, the local conditions favor oyster presence, then the hypothesis involving a temperature drop due to increased sea water is not correct. However, the hypothesis relating to sawdust and siltation is still possible, as is an increase in predator presence.

The oyster drill is incapable of surviving in salinity levels of less than 20 ppt, the so-called "drill line", whereas oysters can maintain populations in 6 ppt. (H. Hidu, personal communication). Therefore, it is quite likely that while salinities were less than 20 ppt the oysters flourished. As sea-level rose, the salinity exceeded 20 ppt to achieve the modern mean values of about 25 ppt. At that time predator pressure from oyster drills reduced the young oysters.

Myers (1965, p. 45) examined oyster shells from an unspecified midden in the study area. He noted that whereas shells from the bottom showed slight evidence of Polydora and Cliona, both predators, shells from the upper levels were more affected. An increase in water salinity, a consequence of sea-level rise, is suggested.

In conclusion, it seems apparent that a shift in the environment towards an influx of more salt water, presumably a factor of sea-level rise, brought about changes in the Damariscotta River. Oysters, which had previously been able to expand and grow to abnormal sizes, came under increasing pressure from predators. The 20 ppt threshold, the so-called "drill line", may have been achieved quite recently, and marked the onset of the oyster decline. Sawdust and siltation may have polluted the less saline refugia for the larval stage, thus insuring the extirpation of the species from the river.

SEDIMENT CORES IN THE DAMARISCOTTA RIVER

In May, 1982, a series of sediment cores was taken with a piston corer in the river upstream of the Route 1 bridge (Figure 1). The research design involved an examination of the sediment for diatoms in the expectation that as sea-levels rose over Johnny Orr the increasingly saline environment would be reflected in the constitution of the diatom communities. Unfortunately, the high sedimentation rate resulted in too few diatoms for conclusive results. An examination of the same sediment for pollen produced similar negative results. The details of this phase of analysis have been reported (Sanger and Kellogg, 1983).

ARCHAEOLOGICAL INVESTIGATIONS

In the spring and early summer of 1983 the area from Johnny Orr upstream to Damariscotta Mills, including Salt Bay, was surveyed for prehistoric sites. A number of potential site areas were examined for traces of shell middens. Four sites at Damariscotta Mills are non-shell midden sites and therefore unrelated to the sea-level problem, except that artifacts older than 3500 B.P. are present, thereby attesting to the presence of people in the area at that time. The shell midden that is located farthest upstream is a small, eroded, *Mercenaria* and *Mya* midden on an island near the river channel. A group of small shell exposures occur around the east side of the threshold at the Indraft (Figure 1). Downstream of these are the large Whaleback and Glidden middens.

Middens extend from the Glidden site downstream along the west bank for several hundreds of meters, whereas there is currently little shell debris beyond the limits of the Whaleback midden on the east side. Non-shell sites are present below Johnny Orr but above the Damariscotta-Newcastle bridge.

The present distribution of shell middens suggests a concentration around the Glidden Point area and the Indraft. While this distribution might have been affected by the mining described earlier, it points to a relatively restricted area of about 2 km. The general absence of shell middens in Salt Bay is probably due to the very shallow nature of the Bay, which suggests that it might have been drowned by sea-level rise relatively recently.

These shell middens have the potential to play a key role in the history of sea-level rise in the river. Ideally, the sites should be excavated and shell and charcoal samples recovered for radiocarbon dating. A second option is to study archaeological specimens from previous excavations.

The presence of artifacts from the Whaleback Midden has long been known (see Previous Work section above). A. T. Gamage gridded the Whaleback in 10 foot squares and recorded artifacts by square and by 1 foot levels below the midden surface. He also recorded the maximum depth of each square below the surface. Assuming that he was in fact able to obtain every artifact from the shell diggers, and that artifacts have not been lost in the 100 years since they were shipped to Cambridge, the collection represents a documented excavation.

The Whaleback collection was examined on two different occasions in the spring of 1983, courtesy of the Peabody Museum. Certain artifacts have distinctive attributes that allow archaeologists to place them within fairly narrow time boundaries. Other artifacts are less useful for this purpose, because they have quite a wide time range.

The artifacts from the Whaleback proved to be almost all from the Ceramic Period (2500 yr B.P. to 350 yr B.P.). One exception was the presence of several Late Archaic specimens, all from the same square. In order to determine if these artifacts were in primary depositional context and not redeposited, a search was made for artifacts in the same square but at lower levels. Those few found are from the Ceramic Period, suggesting that the Archaic specimens were imported into the site from another area. Possibly the older pieces were lying on the surface and represent pre-midden occupation. The conclusion drawn from two visits to the collection is that the Whaleback was probably formed during the Ceramic Period, and is probably no older than about 2000 yr B.P.

Across the river is the huge Glidden midden that was largely spared destruction due to the foresight of Mr. Glidden. According to Willoughby (1935), Gamage measured the height of this midden at 27 feet, while Willoughby found it to be 22 feet high in 1909. The top of the midden is marked by large depressions that suggest some midden removal. There are large trees growing on the top and the age of these could provide some limiting dates on when the material was removed. Johnson (n.d.) recorded that some of these trees were 6 inches in diameter in 1935, the year he led a Harvard University archaeology class in an excavation of the midden. Although the crew made a 5 m deep cut into the site, they recovered few artifacts. Charcoal from hearths, animal bones, and some pottery were excavated, but the main impression received from the report is the overwhelming quantity of oyster shells.

In the 1950's, W. H. Bradley (n.d.) made collections of soft shell clams from somewhere on the Glidden site. Bradley noted that although clams were rare in the midden, they were selected because "they have been much less affected by weathering" than the oyster shells. Shells from a pit approximately 6 feet above mean high tide produced a date of 1710 $\pm$ 160 yr B.P. (W-337). From another pit, this time 6 feet below the top of the midden, shells dated to 1610 $\pm$ 160 yr B.P. (W-342). Bradley also submitted some oyster shells taken from near the base of the midden for dating at the Lamont laboratory. They dated 1800 $\pm$ 250 yr B.P. (L-160A) and 2100 $\pm$ 250 yr B.P. (L-160B). Two hundred years was added to both of these dates for the "Suess effect". If 200 years is subtracted from the Lamont dates, then the clam and oyster dates are statistically indistinguishable (Bradley, n.d.; Broecker and others, 1956).

The present owner of the Glidden site, Mr. George H. Hart, is currently opposed to any excavation of the site. However, in the fall of 1983 he kindly consented to a series of small tests in the river side of the midden where a shelf has been formed at mean high tide. Oyster shells extend to at least 70 cm below mean high tide. Shell samples gathered from the lowest levels in the test pits on top of the subsoil, as well as just above the high tide mark near the base of the midden, were submitted to the Smithsonian Institution for radiocarbon dating. Seven radiocarbon dates range in age from 1720 $\pm$ 50 yr B.P. to 2330 $\pm$ 50 yr B.P.

Unfortunately, these samples cannot be employed to unequivocally yield either the midden starting date or an earlier sea-level. Preliminary analysis of the dates and their locations suggests that there has been considerable slumping along the river side of the midden. Shells now 70 cm below mean high water were dated at 1780 $\pm$ 65 yr B.P. A systematic excavation will be required to locate intact fire hearths or other features that had to form above high tide level. Johnson's report (n.d.) makes it clear that hearths with charcoal do occur in the midden.

The radiocarbon determinations from the Glidden midden samples, gathered by Bradley 30 years ago, indicate that the midden had grown to a height of 6 feet above current mean high tide by approximately 1600 yr B.P. The actual height of the midden from its base could have been 8-9 feet. There is no known way to estimate how long that would have taken. At this time it would be reasonable to suggest that the Glidden midden, like the Whaleback, began to accumulate no earlier than 2500 years ago.

Archaeological and historical evidence indicates that the middens were abandoned by late prehistoric times. No Iroquois-like pottery has been reported from either the Whaleback or the Glidden middens. Such pottery occurs in very late prehistoric to early historic sites (16th to early 17th centuries) in the Boothbay area at the mouth of the Damariscotta River. In addition, the collections from Whaleback and Glidden lack small triangular projectile points of the very late prehistoric period. The absence of these items could be interpreted as an abandonment of the large oyster middens even prior to the arrival of Europeans in the area.

A local collector, Tim Dinsmore, reported a collection of very late prehistoric artifacts from a soft shell clam midden overlying an oyster deposit. According to Dinsmore, the site is on the west bank, downstream from the Glidden midden and the other smaller oyster middens. A search of the area indicated did not reveal the site.

In conclusion, the available archaeological evidence suggests intensive use of oysters from at least 2300 yr B.P. to 500 yr B.P. Despite the documented presence of earlier Indian populations in the area, they apparently did not partake of oysters. Documented shellfish utilization on the central Maine coast occurred by at least 5200 yr B.P.

(Bourque, 1976). If it is assumed that the extensive use of oysters is purely a function of their availability, a reasonable assumption at this time, then the introduction of the species above Johnny Orr occurred not much earlier than 2500 yr B.P.

CONCLUSIONS

The conclusions presented in this paper are not the final word on sea level changes in the Damariscotta River. In addition to more research above Johnny Orr, there are two other major pieces of research that must be integrated. One of these involves the study of the age and distribution of over 200 shell midden sites in the lower reaches of the Damariscotta and the adjacent Sheepscot River valley. To this should be tied the ongoing program of sub-bottom profiling and coring by project investigators at the University of Maine and the Maine Geological Survey.

The archaeological research in the lower estuaries demonstrates the presence of numerous sites dating from 2000 yr B.P. and younger. A few shell midden sites are in the 2500 yr B.P. range, while older sites are generally eroded away. To the extent that sea-level rise is a factor in the erosion, the archaeology suggests some stability over the past 2000 years, following a period of quite rapid sea-level rise.

Despite the fact that people were in the region making use of the resources of the river, it seems that the heavy use of the oysters did not begin before 2500 yr B.P. Given the fact that the native peoples were fully cognizant of shellfish as a valuable food resource, the most plausible explanation is that sea-levels did not effectively rise over the sill at Johnny Orr so as to raise salinity levels to a minimum of 6 ppt. until about 2500 yr B.P. That would suggest a rise of a little over 1.1 m (the tidal range in Salt Bay) during the past 2500 years.

At this time, the most reasonable approach is to suggest the above as a hypothesis very much in need of testing. Several research tasks should be carried out to test the hypothesis.

First, longer sediment cores will be taken in an attempt to recover sediments that document the change in water salinity. In May, 1984, another coring expedition, this time using a vibracorer, will be undertaken with Daniel Belknap and Craig Shipp. Davida Kellogg will once again examine samples for diatoms.

Second, it is critical that proper excavations be undertaken at the Glidden midden and perhaps at some of the smaller middens nearby. Until we can uncover hearths and other activity areas deep in undisturbed deposits, we cannot date either the onset of shellfish collecting or the level of high tide relative to current mean high tide. As part of the research strategy, a shellfish ecologist should examine the condition of the shells and the associated fauna that might have been brought into the site with the oysters. Many of the associated faunal community have salinity tolerances that are more restrictive than the oysters. In this way, a dated salinity-depth curve could be established. Salinity is a factor of sea water entering over Johnny Orr and fresh water flowing through the Indraft. To the extent that the latter can be calculated utilizing modern discharge rates, the volume of salt water can be deduced. And that, of course, is a function of sea-level in the river.

As desirable as this would be, two obstacles stand in the way. First, and most important, the current landowner, Mr. Hart of Newcastle, is opposed to an excavation, despite his complete cooperation at other levels of research. Second, the depth of the middens would require an expensive excavation and analysis program, a level well beyond the currently available funding.

The final requirement is the systematic integration of the downriver archaeology, seismic profiling, and coring research with the upriver efforts.

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APPENDIX A

TABLE I

ANALYSIS OF CORES FOR DIATOMS

CORE I

TOP (5 cm and 10-11 cm)

Marine Species:		Non-marine Species:	
Nitzschia cylindrus	1	Cyclotella stelligera (marine and fresh water)	2
Cocconeis scultellum var. parva	1	Melosira distans	1
Rhizosolenia hebetata var. semispina	1		
Sponge spicules			

MIDDLE (96 cm)

A few centric fragments		Cyclotella stelligera	1
Sponge spicules			

BOTTOM (136-137 cm)

None		Cyclotella stelligera	2
		Melosira distans	2
		Cyclotella comta	1
		Gyrosigma balticum	1

CORE II

TOP (3 cm)

Cocconeis costata	1	Tabellaria (most of the species of this genus occur in fresh water)	1
Sponge spicules		Cyclotella stelligera	2

MIDDLE (100 cm)

None		Cyclotella stelligera	2
		Tabellaria quadriseptata (dystrophic or oligotrophic waters)	1

BOTTOM (122 cm)

Nitzschia sp.	1	Melosira distans	2
Sponge spicules		Tabellaria	1

TABLE I (cont.)

ANALYSIS OF CORES FOR DIATOMS

CORE III

TOP (7-8 cm)

Marine Species:		Non-marine Species:	
Melosira sol	1	Cyclotella stelligera	1
Navicula directa	1	Amphora ovalis var. affinis (alkaliphil)	1
Cocconeis costata	1		
Nitzschia seriata	1		
Radiolarian spines			
Sponge spicules			

MIDDLE (21-22 cm)

Melosira sol	1	Cyclotella stelligera	4
Trachyneis aspera	3	Melosira distans	3
Sponge spicules		Gyrosigma macrum (mesohalobe)	1

BOTTOM (100 cm)

Centric fragments		Melosira distans	6
Sponge spicules		Cyclotella stelligera	2
Nitzschia sp.	1	Cyclotella comta	1