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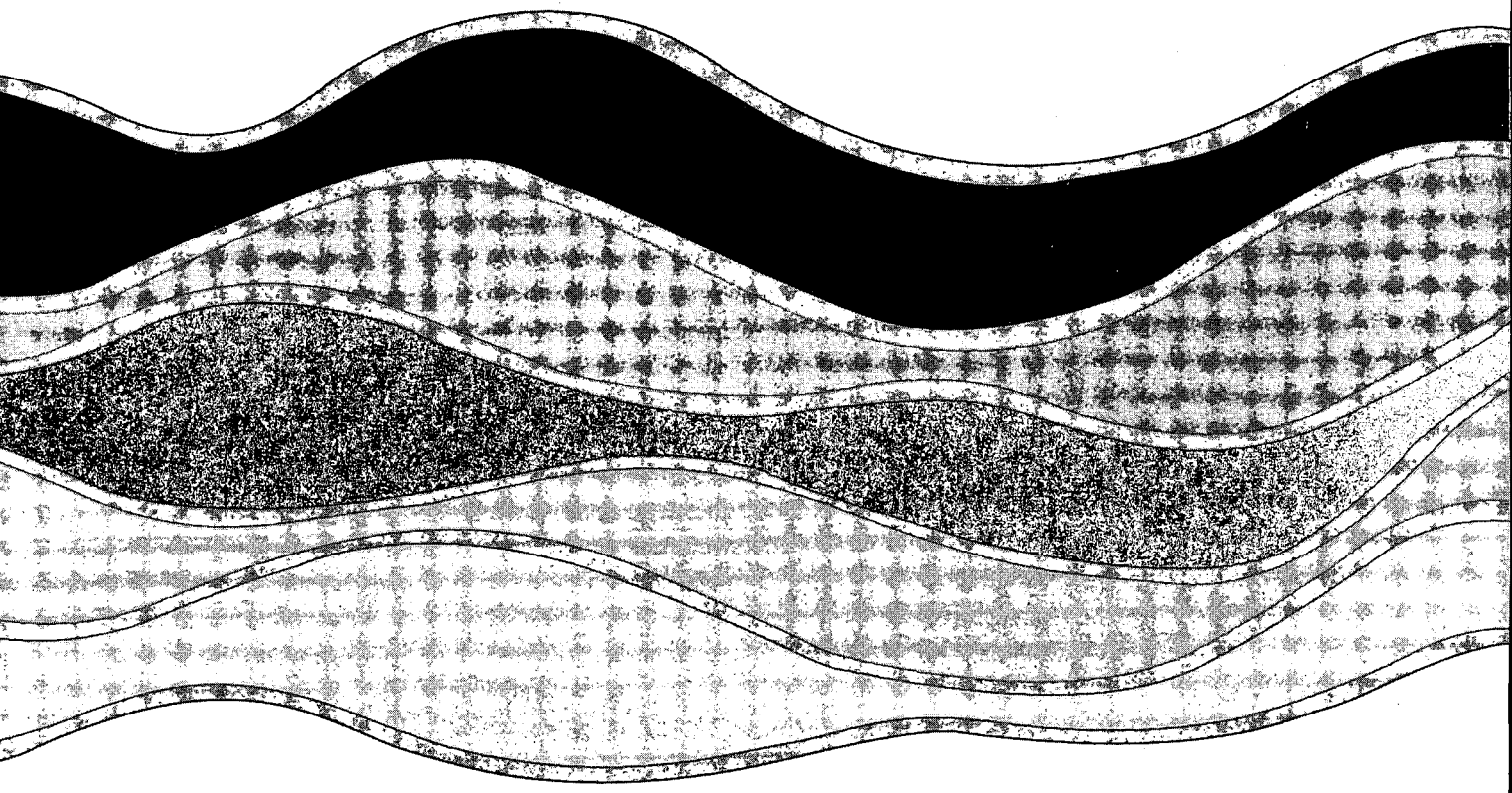

TRACING NEARSHORE SEDIMENT AND CONTAMINANT TRANSPORT IN THE PORT HOPE/PORT GRANBY AREA, LAKE ONTARIO

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NWRI Contribution No. 90-39

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MANAGEMENT PERSPECTIVE

Port Hope harbour has been identified by the International Joint Commission as an Area of Concern because of its severely contaminated state as a result of receiving, over decades, the waste effluents from uranium refining at the CAMECO (formerly El Dorado Nuclear) plant. The Port Hope Remedial Action Plan Committee expressed interest in knowing, prior to the formulation of their plans, the extent of any possible migration from the harbour to the adjacent nearshore zone of Lake Ontario. With partial RAP funding, the study began in 1988 and was aimed at investigating the incidence and distribution of selected contaminants identified in the plant effluent in sediment deposits immediately outside the harbour, and thus to assess the general patterns of contaminated sediment transport in the area. A specific study of mass transfers from the harbour involved the incorporation into the sediments at the harbour entrance of a silt-sized artificial sediment containing the tracer element cesium, whose dispersal was monitored over the summer to identify net transport patterns.

The results indicate that the level of contamination of the nearshore sand-bodies from the harbour sediments is low, at least during the summer months when the study took place. There appears to be some enrichment in uranium and thorium (usually associated with uranium refining wastes) in the deposit off Port Granby, several kilometres to the west of Port Hope, where a landfill for such wastes is located close to the bluff edge.

PERSPECTIVES DE LA DIRECTION

La Commission mixte internationale a classé le havre de Port Hope parmi les secteurs préoccupants, car celui-ci a été fortement pollué, au cours des décennies, par les effluents de la raffinerie d'uranium de la CAMECO (l'ancienne El Dorado Nuclear). Le Comité chargé du Plan de mesures correctives a demandé, avant de procéder à la planification des mesures, qu'on étudie la migration des contaminants du havre dans la zone littorale adjacente du lac Ontario. Partiellement subventionnée dans le cadre du Plan de mesures correctives, l'étude, amorcée en 1988, visait à examiner la fréquence et la répartition de certains contaminants provenant des effluents de l'usine dans les sédiments situés juste à l'extérieur du havre et, par le fait même, à évaluer les configurations générales de la migration des sédiments contaminés dans la région. Au cours d'une étude précise portant sur les transferts de masse dans le havre, on a introduit des sédiments artificiels de type limon contenant le traceur césium dans les sédiments situés à l'entrée du havre. On a pu ainsi surveiller la dispersion des sédiments au cours de l'été afin de déterminer les configurations de la migration nette des contaminants.

D'après les résultats, les dépôts de sable situés près du littoral sont faiblement contaminés par les sédiments pollués du havre, du moins pendant les mois d'été, au moment où l'étude a été réalisée. Il semble se produire un certain enrichissement en uranium et en thorium (provenant habituellement des déchets de raffinage de l'uranium) dans les dépôts situés au large de Port Granby, à plusieurs kilomètres à l'ouest de Port Hope, où se trouve une décharge servant à l'élimination de ces déchets près du rebord de la falaise.

ABSTRACT

Bottom sediment samples from the nearshore zone of Lake Ontario (from east of Port Hope westward to Port Granby) were analyzed for grain-size and selected trace elements in an attempt to determine sources and qualitative transport pathways of contaminants associated with uranium refining and waste management. Median diameters and concentrations of uranium, thorium, and cobalt in the less-than-80-micrometre fraction of the local sand-bodies were compared to each other using a Tukey Honestly Significant Difference HSD test, and showed significant differences that were interpreted in terms of affinities and probable sources. The sand-body at Port Granby was significantly enriched in uranium and thorium, compared to the other two sand-bodies, whereas the median grain-size of the Port Hope deposit significantly higher. This indicates a separate contaminant source at Port Granby, and also the importance of coarser sediment supply from the Ganaraska River. The Port Hope area was the site of a special field experiment using an artificial sediment containing cesium as a fine sediment tracer. The tracer was injected into the local sediments at the entrance of the harbour jetties and its spatial evolution was monitored over a radial pattern centred on the injection site for the period July to September. In addition to cesium, the samples (together with all the other samples) were analyzed for uranium, thorium, and cobalt. Transport patterns resulting from the tracer study at Port Hope were difficult to interpret, and suggested a highly variable transport regime. The strongest trend was associated with predominant littoral transport toward the east. However, less strong trends were associated with westward and southward (offshore) transport. The main conclusion of the tracer study was sediments from Port Hope inner harbour do not appear to be a major source for the contaminants analyzed for, at least during the summer months.

RÉSUMÉ

On a examiné la granulométrie et certains éléments traces dans des échantillons de sédiments de fond prélevés dans la zone littorale du lac Ontario (de l'est, depuis Port Hope, vers l'ouest, jusqu'à Port Granby) afin de déterminer les sources et les voies de migration des contaminants dues au raffinage de l'uranium et aux méthodes de gestion des déchets. On a comparé entre eux les valeurs médianes des diamètres et des concentrations d'uranium, de thorium et de cobalt dans la fraction de moins de 80 micromètres dans les dépôts de sable locaux au moyen de la méthode H.S.D. de Tukey; on a observé des différences significatives en ce qui a trait aux affinités et aux sources probables. Par rapport à deux autres dépôts de sable, celui de Port Granby présentait de fortes concentrations d'uranium et de thorium, tandis que la taille médiane des particules était notablement plus élevée dans le dépôt de Port Hope. Cela révèle qu'il existe une source de contamination distincte à Port Granby et met également en évidence l'importance de l'apport de sédiments à grains plus grossiers de la rivière Ganaraska. Dans la zone de Port Hope, on a procédé à une expérience spéciale sur le terrain au moyen de sédiments artificiels contenant du césium, employé comme traceur des sédiments fins. Le traceur a été injecté dans les sédiments locaux à l'entrée des jetées du port, et on a surveillé son évolution spatiale selon une trajectoire radiale, dont le centre était le lieu d'injection, pendant la période s'échelonnant de juillet à septembre. On a analysé les échantillons (ainsi que tous les autres échantillons prélevés) afin d'y déceler la présence d'uranium, de thorium et de cobalt (outre le césium). Les configurations de migration obtenues au cours de l'étude au traceur à Port Hope ont été difficiles à interpréter et, d'après les résultats obtenus, le régime de migration serait fortement variable. La plus forte tendance observée était une migration littorale prédominante vers l'est. Toutefois, on a également observé une tendance moins marquée de migration vers l'ouest et le sud (au large). La principale conclusion de l'étude réalisée au traceur était que les sédiments du havre intérieur de Port Hope ne semblent pas constituer une importante source des contaminants analysés, du moins pendant les mois d'été.

INTRODUCTION

Contaminated fine sediments are found at several locations along the shore of Lake Ontario. One such site, Port Hope Harbour (Figure 1), has been identified by the Great Lakes Water Quality Board as an Area of Concern because of high levels of contamination by radionuclides. These radionuclides have been discharged for a number of years in the industrial effluent of the El Dorado Nuclear (now CAMECO, Ltd) uranium processing plant (Durham, 1981; IEC Beak Consultants, 1985; Pollock, 1985). Abutting the bluff shoreline several kilometres to the west is the Port Granby nuclear waste management facility, which receives much of the solid low-level radioactive wastes from the plant. This storage site is presently being threatened by ongoing shore erosion and its surface runoff and seepage waters have a ready access to the lake (Bobba and Joshi, 1988). The release and dispersal of contaminated sediments from Port Hope Harbour or the Port Granby waste management site, and the potential impact on the surrounding lake water and clean-water resources such as beaches and drinking water intakes are therefore items of real concern for lake managers.

The present study seeks to address some of these concerns, first, by mapping the overall distribution of nearshore sediments in the Port Granby / Port Hope area. The second task is to investigate whether alleged point-source contaminants such as uranium, thorium, cobalt could be used as tracers in the interpretation of the medium- and long-term transport patterns for contaminated sediments originating at the above two sources. This approach has never been tried before in this context, however, as the adsorption/desorption behaviour of these elements on fine sediments is not well known (Langmuir and Herman, 1980). They are believed to form strong attachments to clays and organic matter (L.J. Evans, University of Guelph, personal communication, 1990), but their stability when adsorbed on sand and silt, the apparently dominant sediment types in the area, is another question. The eventual goal of the study is to indicate how sediments from these sources of

contamination are being dispersed in the lake.

FIELD WORK

The field data-gathering phase took place in the summers of 1988 and 1989. In 1988, the extent of mobile modern sediments, as opposed to the considerable areas of glacial sediments and bedrock in the area, were accurately defined and the sediment types recognized using underwater videotape, echo-sounder, and side-scan sonar techniques. The underwater video was made using a remote-controlled, manoeuvrable camera (MURV) and the side-scan work made use of a Klein 590 system. Later, 38 representative samples of the mobile sediment bodies so defined were obtained using a Shipek grab sampler (Figure 1). Positioning was by Motorola Miniranger, with an estimated accuracy of less than 10 m.

Also in early 1988, an artificial sediment tracer, milled to approximately 62 micrometre (μm) diameter and containing 25% cesium, was injected at Port Hope Harbour entrance, between the two protective jetties (Figure 1). Reasons for the selection of cesium are outlined in Coakley and Long (1989), but the main ones were the low background levels for Cs in the area (less than 1 ppm) and the high analytical resolution possible using Neutron Activation Analysis, or NAA (Attas, 1987). Details on the injection and sampling technique are provided in Coakley and Poulton (1990, in prep.). During the period July to September, three separate bottom sampling surveys were carried out along a closely-spaced radial grid pattern centred on the tracer injection site and extending up to 400 m away, in order to monitor the spatial evolution of the artificial sediment distribution with time. A total of 146 samples were taken over this radial grid.

The representative samples from the sand-bodies, totalling 29 in all, were size-analyzed using standard SediGraph / sieve techniques. Most of the 175 samples were analyzed for U, Th, and Co using NAA. These elements were chosen because they were identified as major contaminants in the harbour sediments, resulting from long-term release of effluent from the CAMECO plant processes (Durham, 1981; IEC Beak Consultants, Ltd, 1985). Prior to NAA analysis, the samples were screened through a 3.5 phi (88 micrometer) sieve to remove all natural particles coarser than the tracer, thus increasing tracer resolution. Appropriate statistical analysis of the data was carried out using programs contained in the SYSTAT[1] and LOTUS 1-2-3[2] software packages. The mean values for parameters from the sand-bodies were compared using Tukey's Honestly Significant Difference (HSD) test (Dowdy and Wearden, 1982). This test is one of the few that did not require equal numbers of samples in each group. Standard regression and correlation testing were also applied to the individual parameters.

RESULTS

Sediment distribution

Figure 2 shows the distribution of sediment types in the nearshore zone in the vicinity of Port Hope / Port Granby. The mobile sediments were restricted almost entirely to three discrete sand-

[1]Registered trademark of SYSTAT, Inc., Evanston IL, U.S.A.

[2]Registered trademark of Lotus Development Corp., Cambridge MA, U.S.A.

bodies of undetermined, but probably minor, thickness. These were located, respectively, at Port Hope (A), several kilometres west of Port Hope (B), and slightly east of Port Granby (C) (Figure 2). The only other mobile sediment type found consisted of extensive pavements of coarse material (granule-to-boulder size), presumably residual deposits formed by differential erosion and removal of finer fractions from the underlying glacial sediments. The immobile "basement" materials consisted of glacial sediments (undifferentiated), whose presence was marked primarily by this coarse pavement, and bedrock in the form of a very dark shale (most likely the mid-Ordovician Collingwood shale). The latter outcropped in the eastern and southern parts of the area. The largest sand-body is located around the Port Hope Harbour entrance. Unlike the other sand-bodies, the one at Port Hope shows a southeastward extension or tongue extending out into greater water depths than elsewhere. Another noteworthy feature in this sand-body is the presence of irregular mounds, very visible on the side-scan sonar records, which appear to represent dump sites of dredged material taken from the harbour entranceway.

The major grain-size statistics are included in Table 1. The samples all consisted of medium-sized, well-sorted sand having a median grain-size ranging from 2.75 to 3.14 phi (Figure 3). Nevertheless, using the multiple comparison procedure, differences in median size between the sand-bodies indicated that sand-body A (Port Hope) was significantly coarser (greater than 95% confidence level) than both sand-bodies B and C; there was no significant difference between B and C.

Visual examination of the contour patterns in Figure 3 shows that the sediments tend to coarsen in an offshore direction, a trend opposite to most nearshore sands. This suggests an offshore source, most likely the glacial materials occurring below, and offshore from, the sand-bodies. Shore erosion and stream inputs appear to be secondary sources. In the Port Hope area, the most likely explanation for the anomalous grain-size character, the relatively large area, and the shore-normal

extension of the Port Hope sand-body is the input of coarser sand from the Ganaraska River. The other sand-bodies, however, show no clear association with inflowing streams, but appear to be all located on the lee (east) side of coastal promontories. This pattern, and the observed preferential accretion of sand on the west side of the Port Hope jetties, add weight to the conclusions of Rukavina (1976) and Brebner and Kennedy (1959) of a net eastward littoral drift in this area.

Distribution of man-made tracer elements, Port Hope / Port Granby

Concentration values determined for U, Th, and Co over the area between Port Granby and Port Hope are presented in Table 1. Prior to further assessment of their potential as sediment tracers, these elements were examined for spatial trends and interrelationships. A number of these interrelationships are presented in Appendix 1. The results show a considerable enrichment in all the above elements compared with values determined elsewhere in the area (see control sample T7, Fig. 1, Table 1; Coakley and Poulton (1990, in prep.)). Variability in the data, however, prevented any clear-cut definition of sources and transport trends to be made. Whether this is because of the predominance of coarse (relatively inert) sediments, or the fact that sources are not as well defined as was initially believed. Therefore, statistical inferences were used to improve our resolution of these sources and trends. The following conclusions can be drawn:

1. There is a clear and significant correlation between U and Th throughout the area (Figure 4, Table 2). The correlation between U and Th, respectively, against Co was less, but still significant (r^2 = 0.54 and 0.48). When only the non-Port Hope area samples are used, the correlation is much weaker (r^2 = ---). This suggests that the U, Th, and Co come from a similar source in the Port Hope area, and U and Th from a similar source elsewhere, while there is

apparently another unidentified source for the Co in the western sand-body.

2. Other correlation testing between the variables showed that the correlations of U and Th against median phi size and percent silt (Table 2) were not significant at the 90% confidence level (r^2 = 0.11 or less). This indicates that grain-size does not play an important role in the above differences, and increases confidence in the presumption that the analysis results as not being skewed by grain-size effects. It also supports the preparation procedure of sieving out the coarser-than-silt-sized fraction of the samples prior to chemical analysis.

The spatial distribution of two of the elements analyzed - U and Co - was examined to identify systematic trends that might aid interpretation of sources and pathways for sediments contaminated by these elements. Th was not included because the correlation results (Table 2 and Figure 4) indicated that U is a close proxy for Th. The concentration data are plotted and contoured in Figures 5 and 6. To obtain insight into whether there was a single source for the various contaminants, and because the concentrations varied considerably over the area (Table 1), it was decided to group the data according to location (sand-body A, B, and C) and the same HSD test as used above for the grain-size data was applied. The objective was to test the hypothesis that there was no significant difference in contaminant concentration between the three sand-bodies. If this null hypothesis was rejected, then any variation noted would thus not be due to chance and could be linked to differences in sources or process.

The test results (Table 2) showed that:

1. U and Th values for sand-body C at Port Granby were both statistically very significantly different from those for A and B near Port Hope (greater than 99% confidence level).

2. There was no statistical difference between A and B.

3. The ratio U/Th showed a similar result, linking A and B, with C distinct from the others. This result confirms the suggestion from the correlation analysis results that the source of U and Th contamination for the Port Granby sand-body is different from that of the two deposits nearer Port Hope. The close relationship of these latter bodies suggests a similar source.

Port Hope Harbour as a contaminant source. In order to investigate further whether the Port Hope inner harbour was a possible contaminant source for sand-bodies A and B, the nearshore trace element data were compared with similar analyses on suspended sediment samples from inside the harbour made available by Rosa and Mudroch (1990, in press), and those on bottom sediments published by Hart et al. (1986). The inner harbour values, included in Table 1, showed U levels up to an order of magnitude higher than those elsewhere in the area; however, these values decline sharply to ambient lake sediment levels before reaching the lake. Comparable U results were noted in bottom sediments in and around Port Hope by Hart et al. (1986). On the other hand, Th values inside the harbour were consistently very much lower than those outside. From these data, there is no clear indication that contaminants from the harbour are being deposited in sand-bodies A and B.

Co content in the samples from the three nearshore sand-bodies between Port Granby and Port Hope were also investigated to see whether they also could indicate contaminant sources. The HSD multiple comparison test, however, indicated no very significant difference in Co levels between any of the sand-bodies (Table 2). Likewise, comparing Co values in sand-body A and B with those inside the harbour was not conclusive in terms of indicating source. Co in the nearshore sediments ranged from 7 to 29 µg/g, i.e., much lower than the average of 57 µg/g noted in bottom sediments

collected inside the harbour by Hart et al. (1986). On the other hand, suspended sediments from the harbour analyzed by Rosa and Mudroch (ibid.) contained less than 20 µg/g (Table 1), i.e., close to, or less than, average nearshore values. This result indicates that although Co is enriched in the local sediments, its source is still unclear.

Artificial cesium tracer distribution, Port Hope

The contoured Cs concentration values shown in Figure 7 trace the evolution of the tracer plume with time. From the results of the last sampling in September, it was clear that the tracer had spread so much as to be undetectable over much of the grid area.

Using the technique described in Coakley and Poulton (1990, in prep.), the directions of sediment transport were inferred and are shown as dashed lines on Figure 7. Initially (July 7) the tracer appears to have been transported both directly offshore as well as toward the west. Unfortunately, draught limitations for the vessel used in the first survey precluded coverage of the area to the northeast of the entrance. Later surveys (August and September) supported the above trend, with the exception that the strong transport toward the east was confirmed. This eastward trend was even stronger in the September survey. These results are in agreement with the accepted pattern of littoral drift in this area (Rukavina, 1976; and Brebner and Kennedy, 1959). The persistent offshore highs noted in the offshore region to the southeast of the entrance could be a relict from the beginning of the experiment, and thus could reflect low sedimentation (and dilution) rates, rather than a persistent transport vector in that direction.

It is unfortunate that sampling of the tracer plume within the harbour entrance could not be carried out for a variety of reasons, primarily ship draught limitations. This is especially so as suspended samples collected over the period July 20 - September 22, 1988 at locations within the harbour turning basin (Fig. 1, Table 1) and analyzed for Cs (Rosa and Mudroch, 1990, in press) show surprisingly high Cs levels. The only conclusion that can be drawn from these results is that some of the tracer was entrained into the harbour over the above time period, either directly through mass transport or indirectly via the plant's water intake / discharge system. The intake is located close to the position of T6 (Figure 1).

Man-made tracer elements, Port Hope

The spatial distribution of concentration values for the other tracer elements determined along with Cs over the same coverage grid are shown contoured in Figures 8 to 10. These elements (U, Th, and Co) were, believed to be escaping in considerable quantities from the harbour adsorbed onto sediment particles, and thus could be used as incidental sediment tracers. The initial results showed that a change had to be made in the interpretation model normally used for artificially injected tracers. The usual model for interpreting the trajectories for artificial tracers assumes that concentration is related to distance from source, and so the patterns generally show a maximum region aligned along the direction of transport. This approach applies best to one-time slug-type injections such as the artificial Cs tracer.

However, the characteristic pattern in Figures 8 to 10 showed a central low area corresponding to the projection of the harbour entranceway and the interpreted principal transport direction offshore, with high areas (less diluted) to either side. One way to explain this consistent pattern is to postulate

that the "tracer" discharge is intermittent over extended periods, and although these elements probably move from the major contaminant source (say, the turning basin of the harbour) to the nearshore lake sediments throughout the year, they probably have a peak inflow earlier in the year associated with spring ice-break-up and storm agitation. Later on in the year, cleaner, coarser sediments are more likely to be transported in and tend to dilute the tracer pattern progressively along the transport path. Using this model is apparently justified, as the results are in good agreement with those of the artificial tracer.

The various elements assessed as transport tracers are discussed below:

Uranium. Values in the silt + clay fraction range as high as 20 ppm, i.e. 10% of common values in the harbour itself (Rosa and Mudroch, 1990; in press). The transportation direction inferred from the patterns is indicated by dashed lines, and may be described as follows. Initially (July), the transport is predominantly offshore, with a minor transport component to the northeast. There is evidence that the offshore direction eventually turns toward the east. The second survey shows a slight difference in that a westward trend is noticeable. Otherwise the dominant offshore and northeastward trend persists. While overall concentrations are lower in the final survey (September) and the patterns are not as clear, the above trends persist with the exception that westward trend is no longer visible.

Thorium. The thorium concentration distribution follows the general lines of those of U, but show a wider variation over the survey period (Figure 9). The inferred transport patterns are also comparable.

Cobalt. Concentrations range as high as 27 ppm, compared with the harbour values which averaged 18 ppm (Figure 10). Transport patterns inferred also resemble closely those for U.

Port Granby "tracer" element trends. The sand-body at Port Granby is characterized by relatively high concentrations for U (average 21.8, versus 11.3 ppm for the Port Hope sand-body) and Co (18.1 vs. 16.75). The data suggest that, compared to sediments elsewhere in the study area, this sand-body is enriched in U. The transport directions of potential contaminants (U) for this sand-body could not be clearly inferred because of a scarcity of samples. However, Figure 5 indicates a plume extending from the vicinity of seepage streams in the bluff below the waste depot in a southeasterly (offshore) direction, to high values offshore. The trend from this point appears to be bidirectional alongshore as was noted at Port Hope.

Synthesis

In the absence of any process monitoring data in the vicinity of Port Hope Harbour, the inferences on transport patterns must be based only on the tracer approach presented here. Although the data allow only a qualitative assessment to be made, it does not appear that large, steady transfers of contaminated sediments from Port Hope Harbour are being made to the adjacent nearshore zone of Lake Ontario.

The synthesis of the data indicates that sediments exiting the harbour are advected generally to the east in response to the predominant littoral current direction. This trend was most evident in the

artificial Cs tracer data, and could be interpreted as the dominant one, especially for material of diameters comparable to those of the artificial tracer (62 µm and finer). Lesser trends, however, were noted in these results suggesting that at times the fine sediments are transported to the west, or directly offshore (to the southeast). In addition, the presence of relatively high Cs levels in the suspended sediment traps from the inner harbour indicates that an unquantified amount of sediment is also brought into the harbour area from the open lake, either directly or via the CAMECO plant's intake / discharge system.

The trace metals used as opportunistic tracers at the Port Hope Harbour entrance also showed a general consistency in interpreted direction of transport. These tended to indicate predominant eastward or offshore transport. Only very minor westward transport was suggested.

The inverse nature of the trace metal distribution with respect to transport pathways (transport plumes indicated by a trough in the concentration patterns rather than a high) in the Port Hope Harbour area is a further indication that the prime source of at least some of these metals might not be the harbour itself. During the survey, the sediments emanating from the harbour appeared to dilute the existing highs (visible on both sides of the entrance flow), rather than contribute to these concentration values. The The existence of another source for the Port Hope sand body sediments is susppsorted by the grain-size comparison results, as well as the fact that the maximum cobalt concentrations outside the harbour are higher than those inside, and by the relatively high levels of U and Co in the sand-body off Port Granby, several kilometres to the west of Port Hope. An alternative explanation is that if the source is in fact the harbour, then it is intermittent in nature, and no significant contribution occurred during the tracer survey.

CONCLUSIONS

Based on internal comparisons and with reference to earlier studies, it is clear that the trace elements determined show a high degree of spatial and temporal variability. Nevertheless, the following interpretable trends can be brought to light using appropriate statistical techniques:

- Although there is no statistically significant difference in median grain-size between sand-bodies B and C, there is a highly significant difference in U and Th content.

- Also, although A and B showed highly significant differences in grain-size, there was no such difference in U or Th.

Clearly, these differences cannot be explained by grain-size effects. The tentative conclusion can be made that although grain-size properties show that sand-body C and B are part of the same littoral drift stream, sand-body C is contaminated by a different U and Th source than either sand-body A or B. Since carbonate residues from the CAMECO operation was cited as being the main source of the U, Co, and, to a lesser extent Th, contamination in the harbour and vicinity (IEC BEAK Consultants, Ltd, 1985), it is difficult to see how uniform U and Th levels could have extended as far west as sand-body B if the only source of contamination were Port Hope Harbour. Furthermore, the lack of a more definitive statistical linkage between the nearshore sand-bodies and the harbour raises questions as to whether the harbour is presently the main source of the trace elements observed in the lake sediments.

There is evidence of contamination of nearshore sand deposits in the Port Granby area. The difference in U, Th, and Co relationships from those at Port Hope suggests clearly that there is a local

source for these contaminants. Although sediment grain-size affinities indicate predominant transport to the east, the lack of similar affinities in the contaminant tracer signature suggests that contaminants from the Port Granby area have little impact on contaminant concentrations near Port Hope.

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TABLES AND FIGURES

Table 1 Chemical and physical properties of bottom sediments near Port Hope.

Table 2 Summary of statistical testing on sand-bodies and tracer properties, Port Hope area.

Figure 1 Location map of shoreline of Lake Ontario between Port Hope and Port Granby, showing Port Hope Harbour and the CAMECO plant, plus local water intakes and beaches. Triangles mark locations of suspended samples of Rosa and Mudroch (1990, in press) The control site (T7) was located 1 km south of the Port Hope jetties.

Figure 2 Map showing the distribution of sediment types in the nearshore zone, Port Hope / Port Granby area. Location of bottom samples (solid dots) and survey lines are also shown. Sand-body designations (A, B, and C) are also shown.

Figure 3 Distribution of median grain-size (phi units) in bottom samples from the Port Hope / Port Granby area.

Figure 4 Plot of concentrations of thorium and cobalt versus that of uranium. Top: Samples in Port Hope area only. Bottom: All samples Port Hope / Port Granby area.

Figure 5 Contoured plot of uranium concentrations in sand-bodies between Port Granby and Port Hope.

Figure 6 Contoured plot of concentrations for cobalt in sand-bodies between Port Granby and Port Hope.

Figure 7 Port Hope. Plot of concentrations of the artificial cesium tracer at various times after injection. Solid circles indicate tracer sample locations; solid triangles indicate locations of suspended sediment samples in Rosa and Mudroch (1990, in press). Dashed arrows indicate inferred transport directions.

Figure 8 Port Hope. Plot of concentrations of uranium in fine fraction of bottom sediments. Left to right: July, August, and September, 1988. Solid circles indicate tracer sample locations; solid triangles indicate locations of suspended sediment samples in Rosa and Mudroch (1990, in press). Dashed arrows indicate inferred transport directions.

Figure 9 Port Hope. Plot of concentrations of thorium in fine fraction of bottom sediments. Left to right: July, August, and September, 1988. Solid circles indicate tracer sample locations; solid triangles indicate locations of suspended sediment samples in Rosa and Mudroch (1990, in press). Dashed arrows indicate inferred transport directions.

Figure 10 Port Hope. Plot of concentrations of cobalt in fine fraction of bottom sediments. Left to right: July, August, and September, 1988. Solid circles indicate tracer sample locations; solid triangles indicate locations of suspended sediment samples in Rosa and Mudroch (1990, in press). Dashed arrows indicate inferred transport directions.

TABLE 1. CHEMICAL AND PHYSICAL PROPERTIES OF SEDIMENTS NEAR PORT HOPE

SAMPLE I.D.		CESIUM	URANIUM	COBALT (ppm)	THORIUM	SCANDIUM	MEDIAN (phi)	STD.DEV	SAND %	SILT %
SAND-BODY A (PORT HOPE)										
JPC88	1	0.00	5.80	21.00	24.00	33.00	2.63	0.76	98.52	0.78
JPC88	2	0.00	8.10	11.00	16.00	22.00	2.04	0.62	99.73	0.27
JPC88	3A	0.00	14.60	22.00	19.00	37.00	3.18	0.38	98.05	1.95
JPC88	4	0.00	17.50	21.00	25.00	27.00	2.33	0.55	99.56	0.15
JPC88	5	0.00	22.90	25.00	38.00	38.00	3.05	0.66	95.85	4.10
JPC88	6	4.00	3.70	7.00	4.00	9.00	3.22	0.54	74.70	25.30
JPC88	7	0.00	9.20	15.00	9.00	20.00	2.20	0.63	99.55	0.25
JPC88	8	0.00	8.00	13.00	8.00	19.00	3.14	0.52	85.05	14.95
JPC88	9	0.00	19.00	19.00	21.00	27.00	2.38	0.51	99.78	0.15
JPC88	10	0.00	7.30	12.00	7.00	23.00	2.88	0.65	99.14	0.86
JPC88	11	0.00	10.30	19.00	12.00	31.00	2.72	0.58	99.33	0.67
JPC88	12	0.00	10.40	16.00	15.00	25.00	2.83	0.43	98.46	1.54
JPC88	15	0.00	14.70	20.00	16.00	34.00	2.99	0.55	98.94	1.06
JPC88	16	0.00	10.80	16.00	13.00	28.00	2.98	0.59	98.75	1.11
JPC88	17	0.00	17.50	26.00	28.00	36.00	2.74	0.50	99.64	0.36
JPC88	18	0.00	7.70	15.00	11.00	25.00	3.24	0.34	97.15	2.85
JPC88	19	0.00	3.80	11.00	3.00	11.00	1.22	0.89	98.02	1.21
JPC88	20	0.00	21.20	22.00	26.00	38.00	3.10	0.59	97.37	2.63
ARITH.	MEAN:		12.28	16.67	14.17	26.25	2.87			
VARIANCE:			30.56	24.93	74.85	58.89	0.13			
SAND-BODY B (INTERMEDIATE)										
JPC88	21	0.00	16.60	22.00	20.00	38.00	3.21	0.42	96.15	3.77
JPC88	22	0.00	10.20	16.00	9.00	27.00	3.14	0.60	98.63	1.37
JPC88	23	0.00	10.70	19.00	13.00	31.00	3.15	0.40	98.50	1.50
JPC88	24	0.00	25.10	27.00	37.00	38.00	3.26	0.41	95.49	4.51
JPC88	25	0.00	22.70	29.00	35.00	43.00	3.14	0.68	96.47	3.51
JPC88	26	0.00	12.70	19.00	14.00	36.00	3.08	0.59	98.95	1.05
ARITH.	MEAN:		16.60	22.00	20.00	38.00	3.21			
VARIANCE:			33.34	21.33	118.22	26.92	0.00			
SAND-BODY C (PORT GRANBY)										
JPC88	27	0.00	27.90	25.00	41.00	30.00	3.25	0.63	95.44	4.27
JPC88	28	0.00	22.60	22.00	39.00	29.00	3.19	0.54	92.39	7.61
JPC88	29	0.00	27.90	21.00	52.00	26.00	2.98	0.45	98.11	1.89
JPC88	30	0.00	20.40	20.00	30.00	24.00	3.14	0.39	95.40	4.60
JPC88	31	0.00	27.10	23.00	50.00	26.00	3.23	0.61	95.89	4.00
JPC88	32	0.00	36.70	22.00	63.00	22.00	3.09	0.66	96.59	3.12
JPC88	37	0.00	19.70	13.00	33.00	17.00	2.91	0.45	98.47	1.53
JPC88	38	0.00	21.90	17.00	30.00	24.00	3.17	0.41	96.66	3.34
ARITH.	MEAN		25.53	20.38	42.25	24.75	3.12			
VARIANCE:			27.57	12.48	122.94	14.69	0.01			
PORT HOPE HARBOUR SUSPENDED SEDIMENTS (FROM ROSA AND MUDROCH, 1990, in press)										
ROSA T1-1		10.00	222.00	18.00	7.00	7.00				
ROSA T1-2		12.00	214.00	19.00	8.00	8.00				
ROSA T1-3		11.00	205.00	21.00	7.00	8.00				
ROSA T2		22.00	246.00	20.00	6.00	6.00				
ROSA T3		10.00	209.00	14.00	7.00	7.00				
ROSA T4		8.00	246.00	17.00	11.00	7.00				
ROSA T5		16.00	163.00	13.00	6.00	7.00				
ROSA T6		26.00	30.00	7.00	5.00	8.00				
ROSA T7		2.00	2.70	5.00	3.00	5.00				

TABLE 2. SUMMARY OF STATISTICAL TESTING ON SAND-BODIES AND TRACER PROPERTIES, PORT HOPE AREA.

SUMMARY OF CORRELATION COEFFICIENTS (R-SQUARED) FOR ALL 29 SAMPLES

	URANIUM	THORIUM	COBALT	MEDIAN	SILT %
URANIUM	1.00	0.88++	0.54+	0.11	0.02
THORIUM		1.00	0.48+	0.07	0.01
COBALT			1.00	0.08	0.14
MEDIAN				1.00	0.17
SILT %					1.00

+ : Statistically significant (>90% conf.level)
++: Highly significant (>99% conf. level)

TUKEY'S HSD TEST SUMMARY FOR PORT HOPE SEDIMENT UNITS

SAND-BODIES	URANIUM	THORIUM	COBALT	MED. SIZE	U/CO	TH/CO	U/TH
				(Comparison probabilities)			
A VS B	0.321	0.666	0.142	0.044**	0.875	0.993	0.736
A VS C	0.000***	0.000***	0.123	0.039**	0.000***	0.000***	0.111*
B VS C	0.010***	0.001***	0.998	0.999	0.000***	0.000***	0.070*

: Not statistically significant
*** : Very significant (>99% probability not due to chance)
** : Significant (>95%)
* : Marginally significant (90-95%)

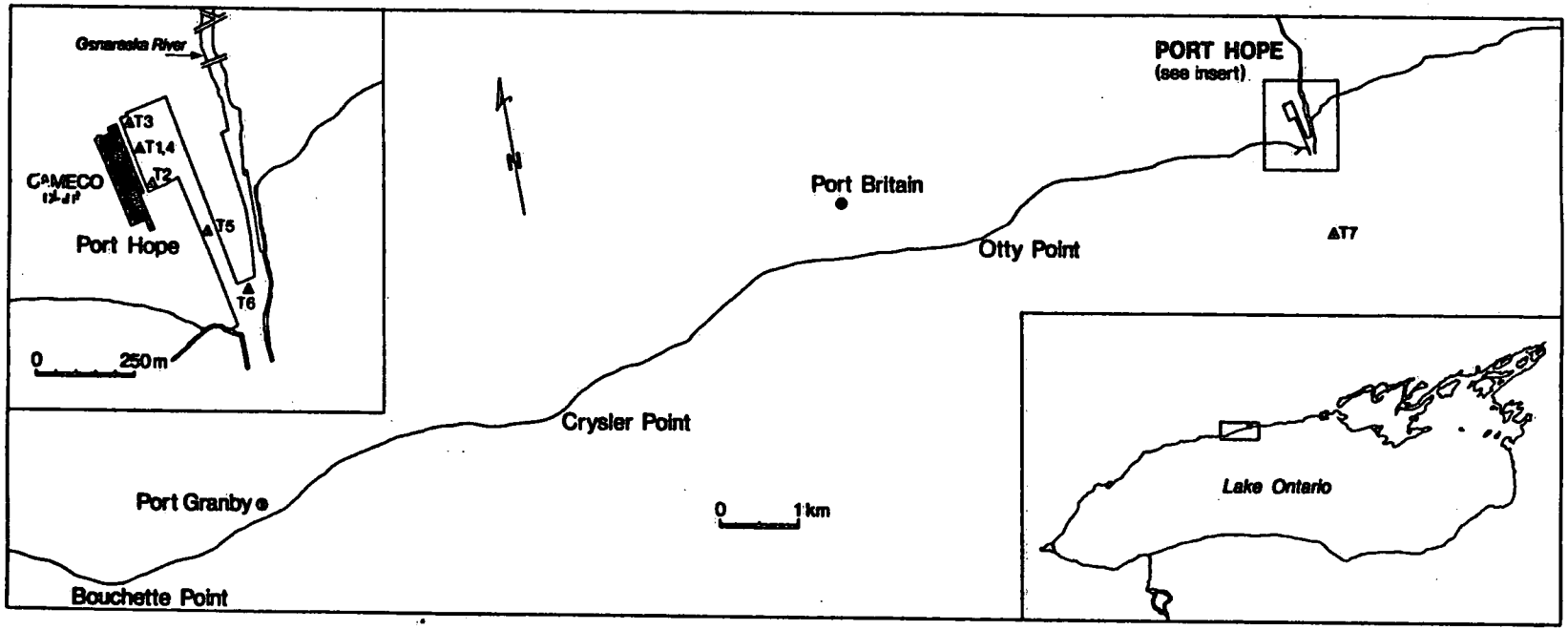


Figure 1 Location map of shoreline of Lake Ontario between Port Hope and Port Granby, showing Port Hope Harbour and the CAMECO plant, plus local water intakes and beaches. Triangles mark locations of suspended samples of Rosa and Mudroch (1990, in press). The control site (T7) was located 1 km south of the Port Hope jetties.

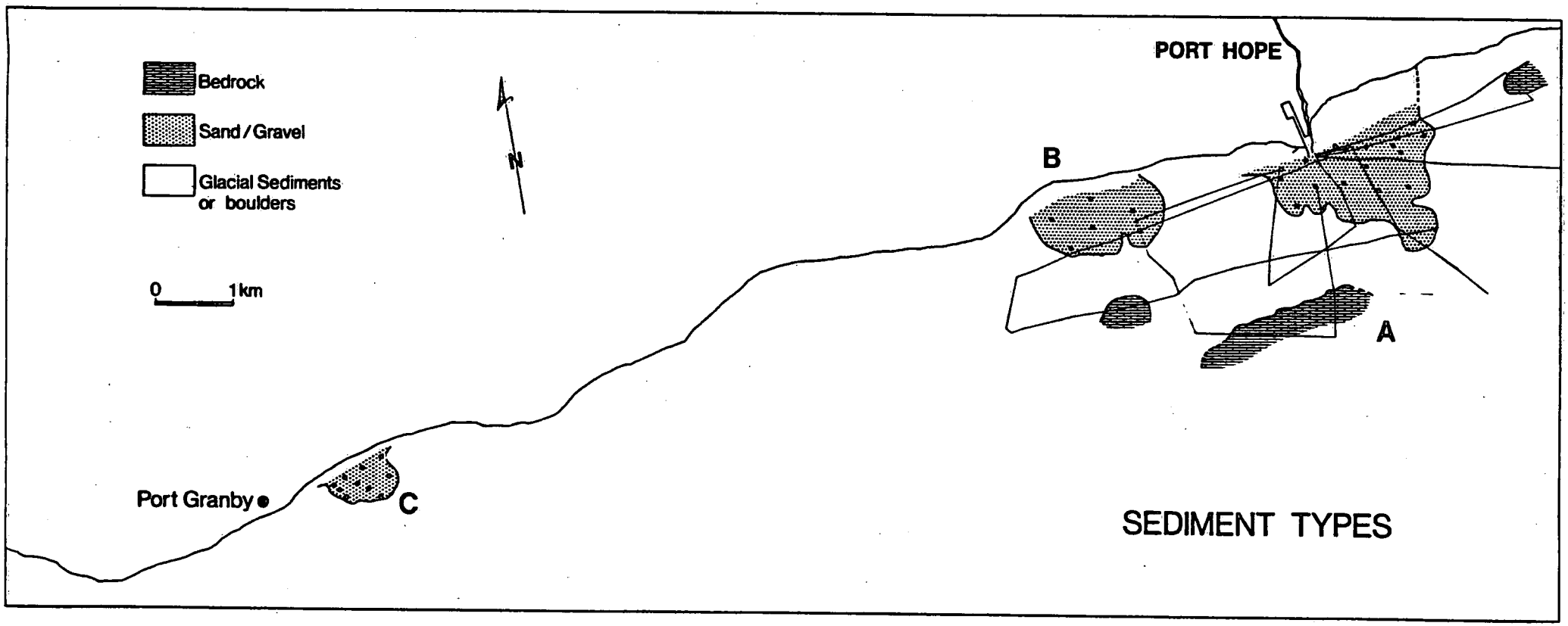


Figure 2 Map showing the distribution of sediment types in the nearshore zone, Port Hope / Port Granby area. Location of bottom samples (solid dots) and survey lines are also shown. Sand-body designations (A, B, and C) are also shown.

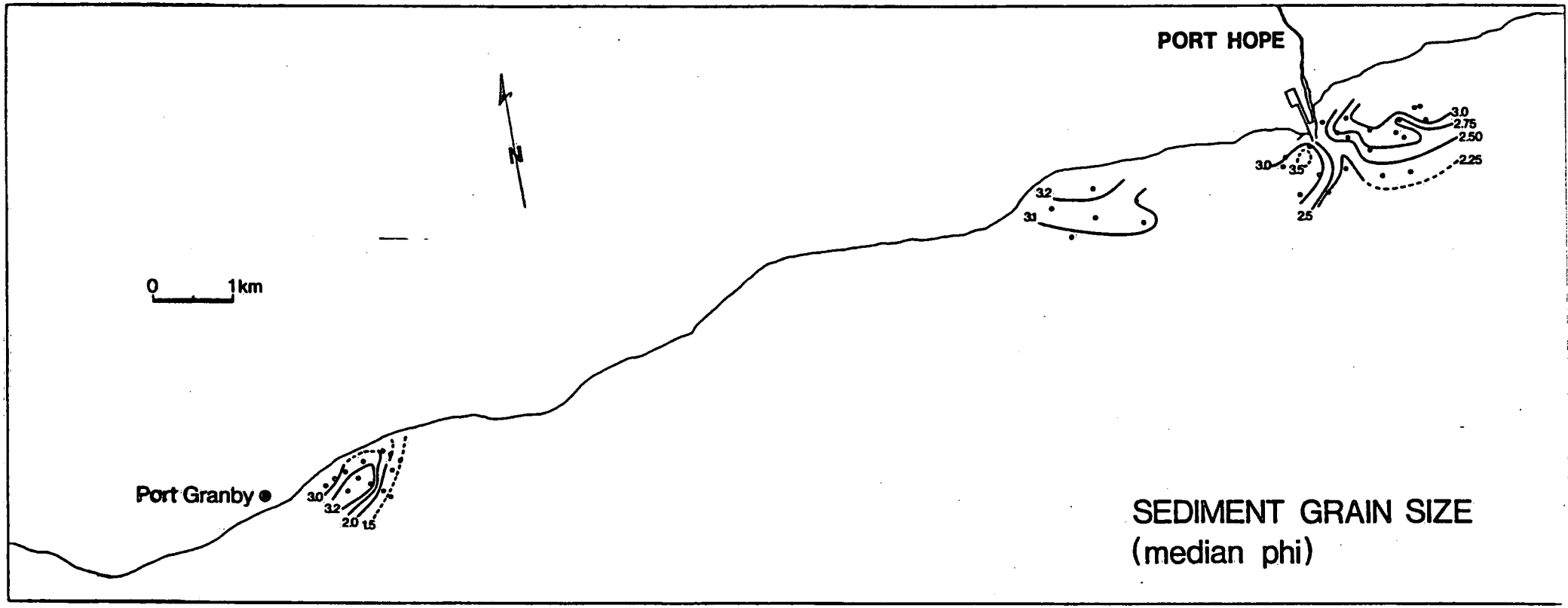


Figure 3 Distribution of median grain-size (phi units) in bottom samples from the Port Hope / Port Granby area.

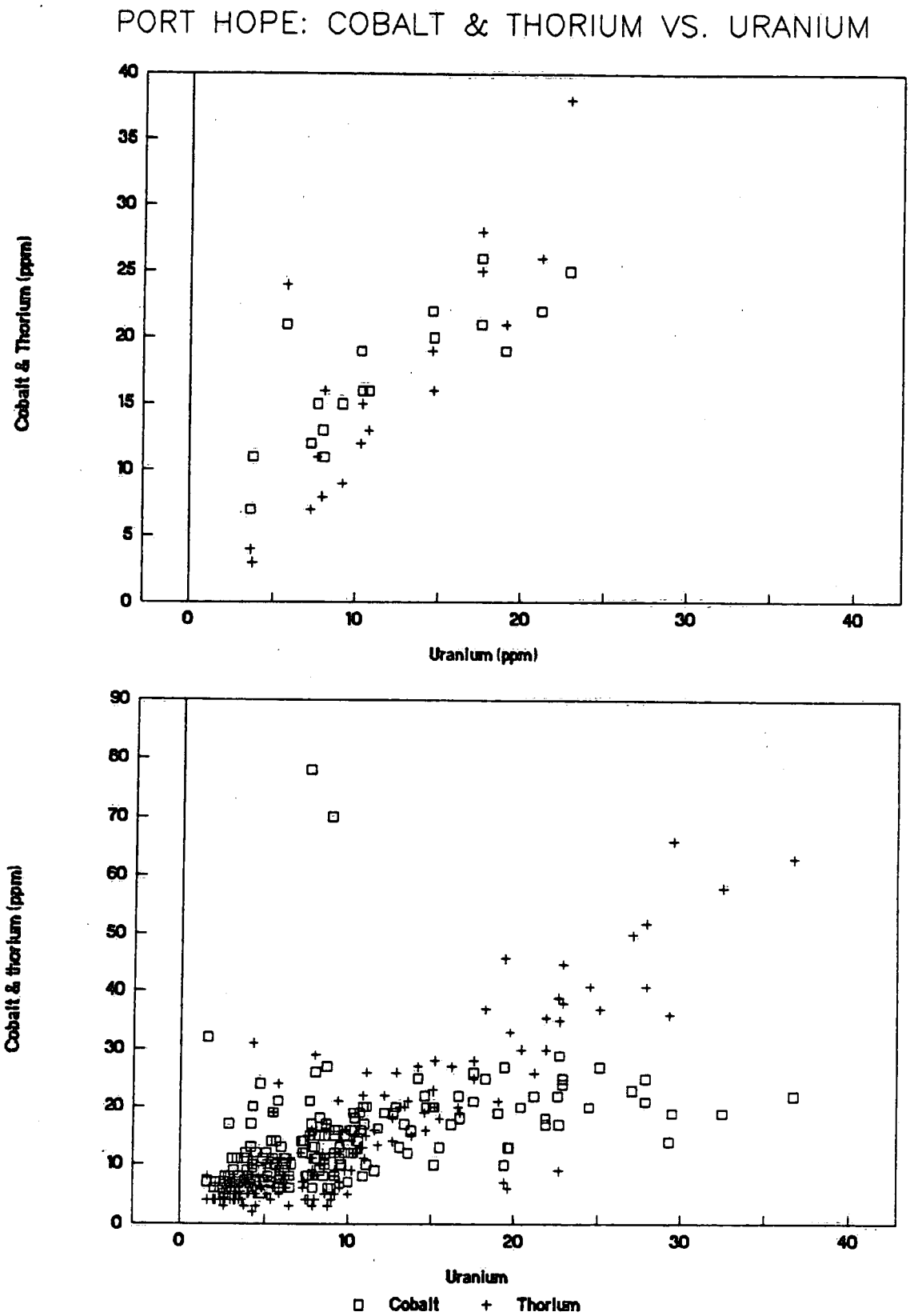


Figure 4 Plot of concentrations of thorium and cobalt versus that of uranium. Top: Samples in Port Hope area only. Bottom: All samples Port Hope / Port Granby area.

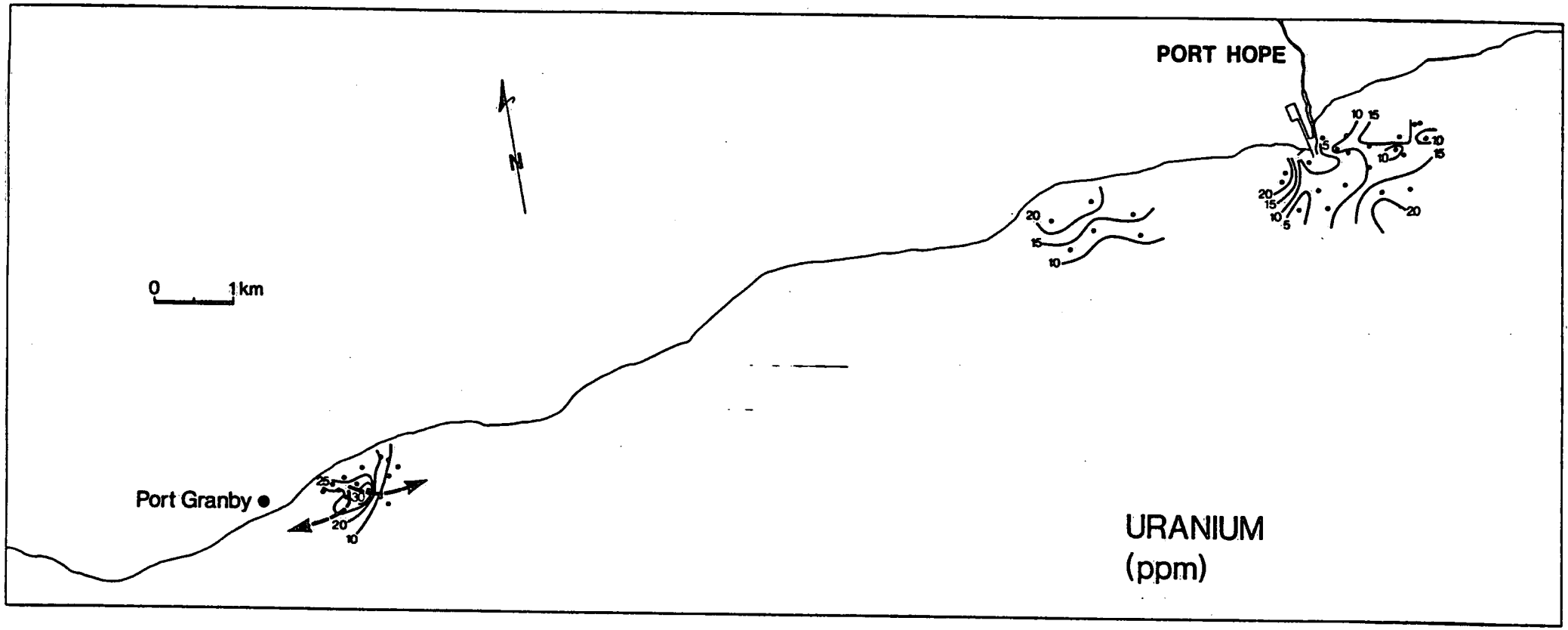


Figure 5 Contoured plot of uranium concentrations in sand-bodies between Port Granby and Port Hope.

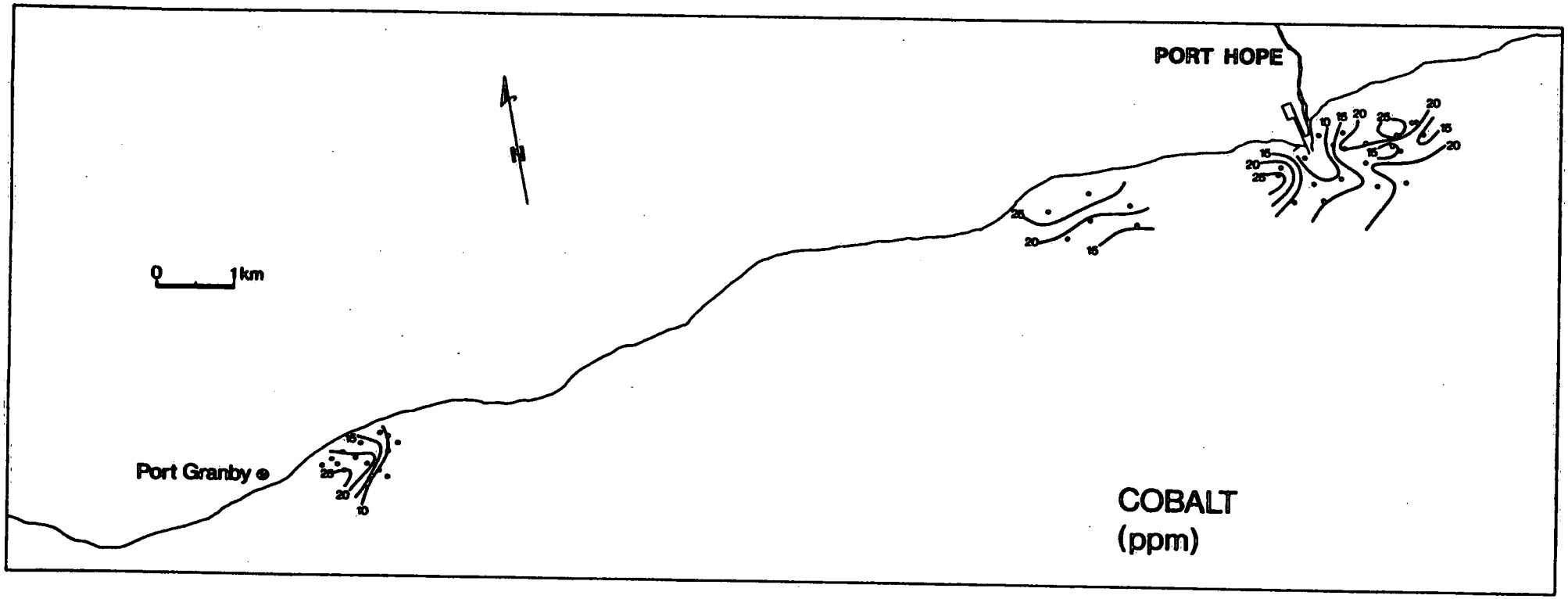


Figure 6 Contoured plot of concentrations for cobalt in sand-bodies between Port Granby and Port Hope.

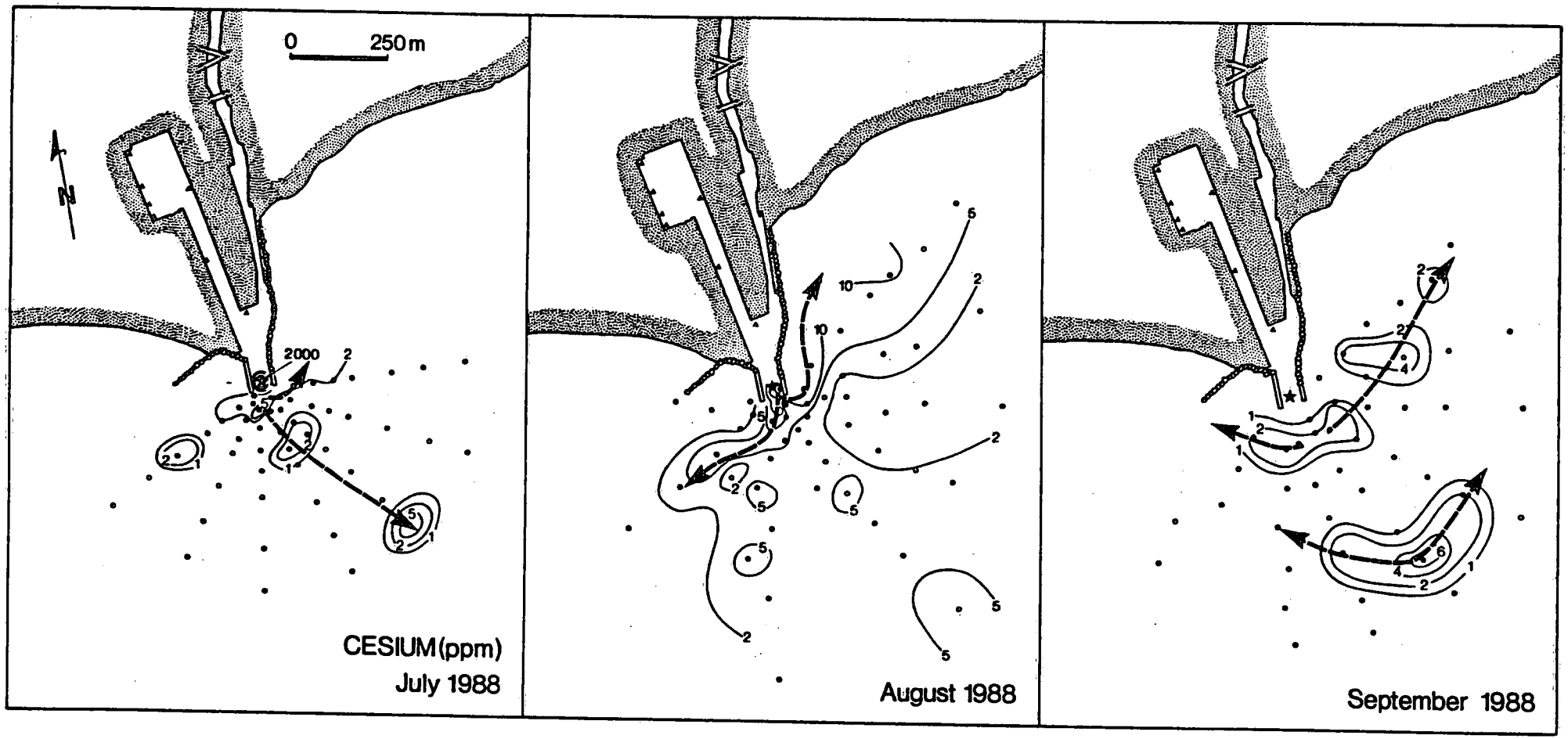


Figure 7 Port Hope. Plot of concentrations of the artificial cesium tracer at various times after injection. Solid circles indicate tracer sample locations; solid triangles indicate locations of suspended sediment samples in Rosa and Mudroch (1990, in press). Dashed arrows indicate inferred transport directions.

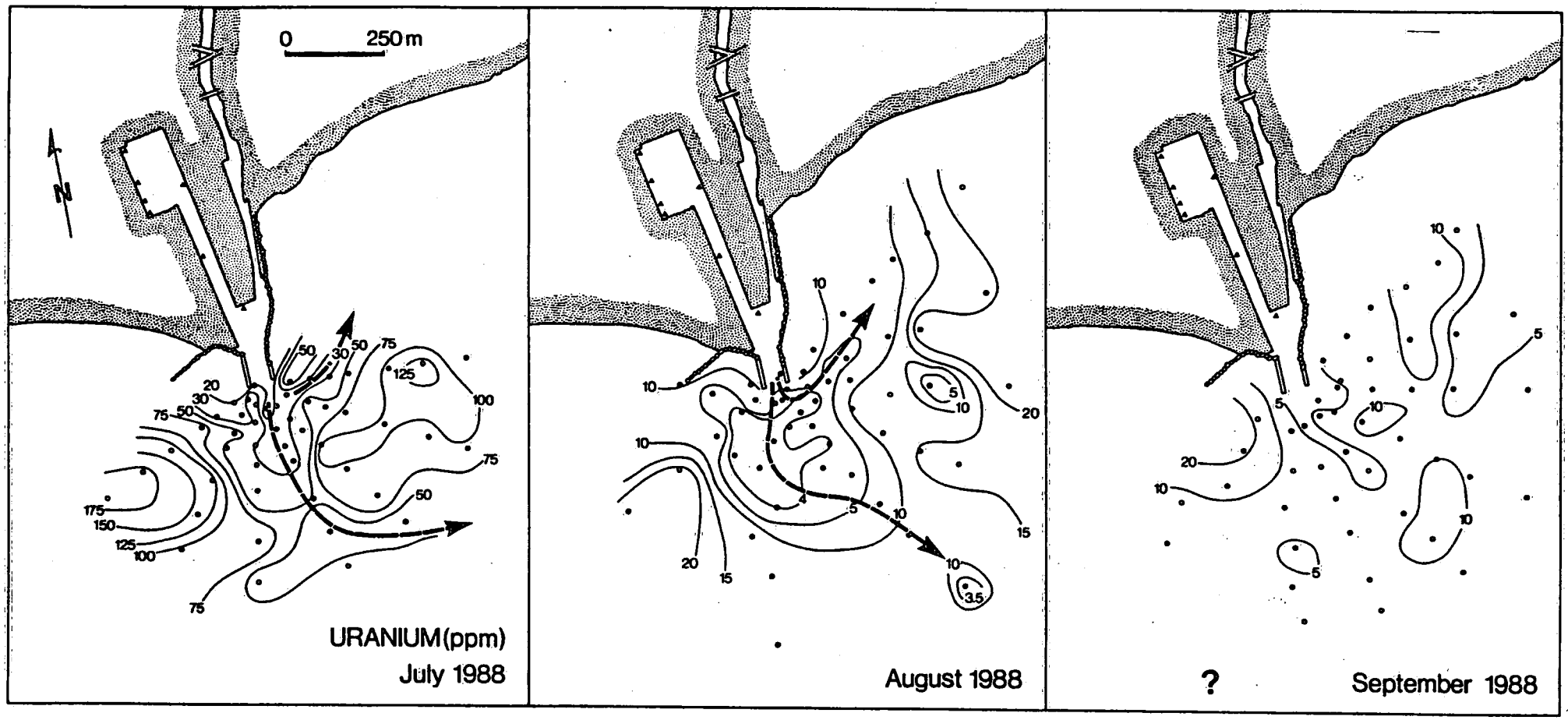


Figure 8 Port Hope. Plot of concentrations of uranium in fine fraction of bottom sediments. Left to right: July, August, and September, 1988. Solid circles indicate tracer sample locations; solid triangles indicate locations of suspended sediment samples in Rosa and Mudroch (1990, in press). Dashed arrows indicate inferred transport directions.

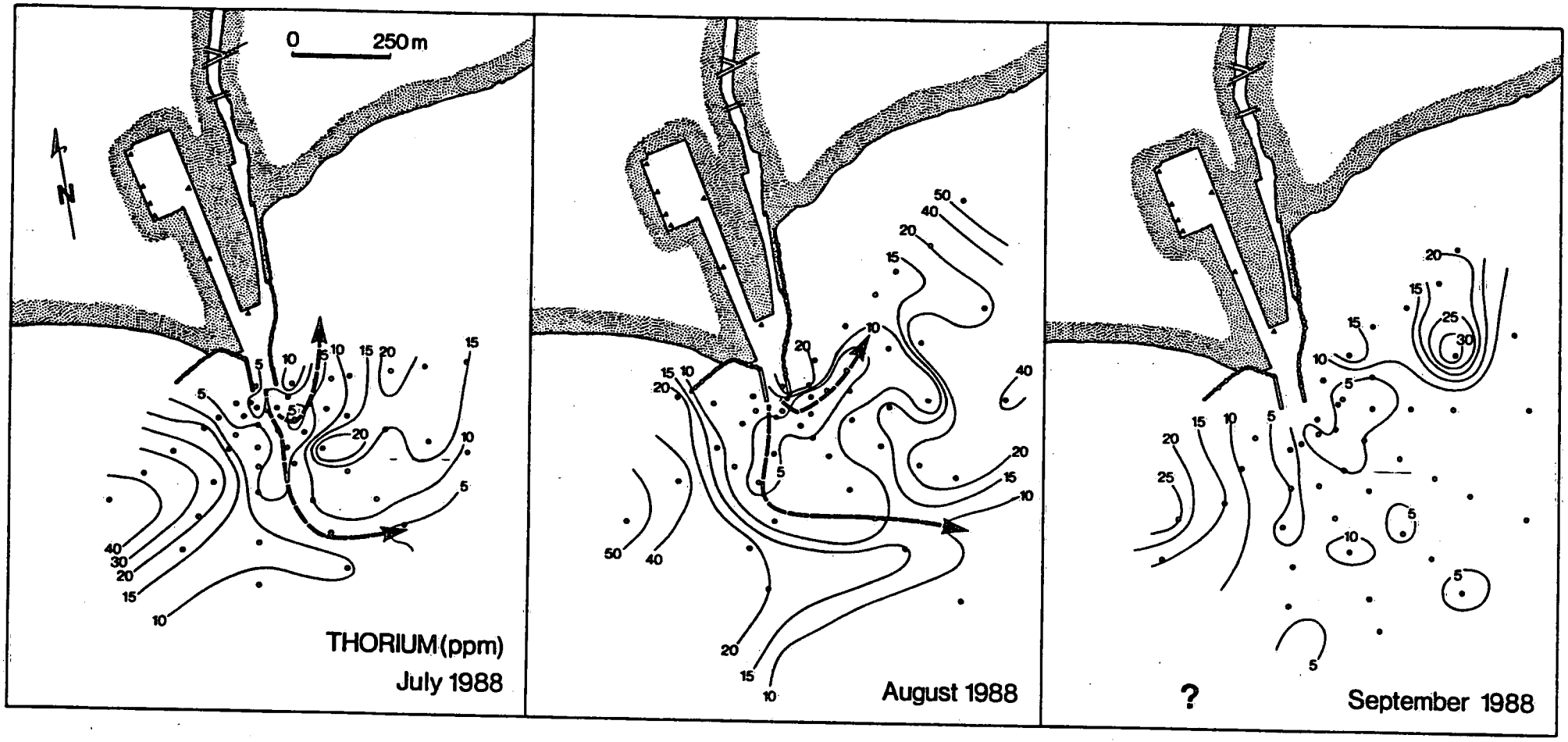


Figure 9 Port Hope. Plot of concentrations of thorium in fine fraction of bottom sediments. Left to right: July, August, and September, 1988. Solid circles indicate tracer sample locations; solid triangles indicate locations of suspended sediment samples in Rosa and Mudroch (1990, in press). Dashed arrows indicate inferred transport directions.

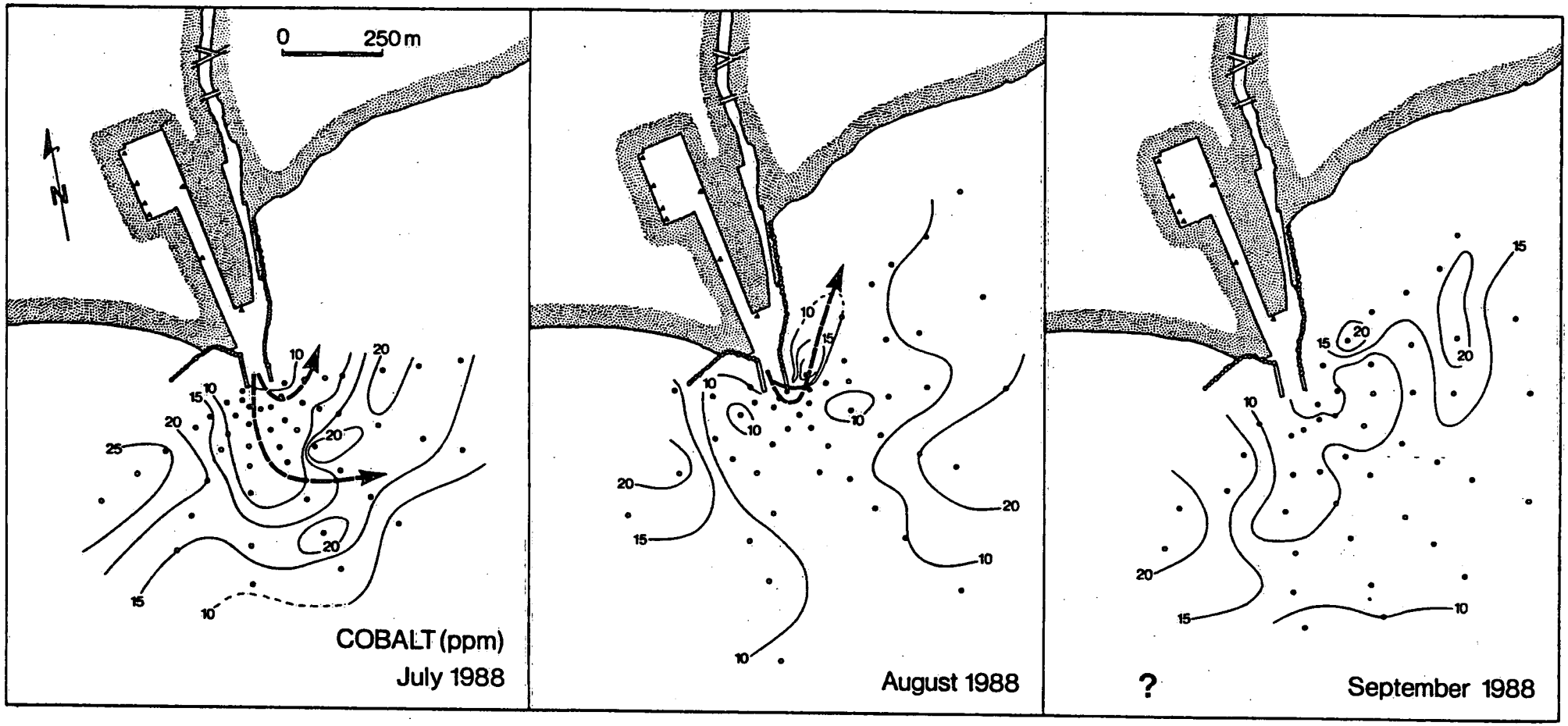
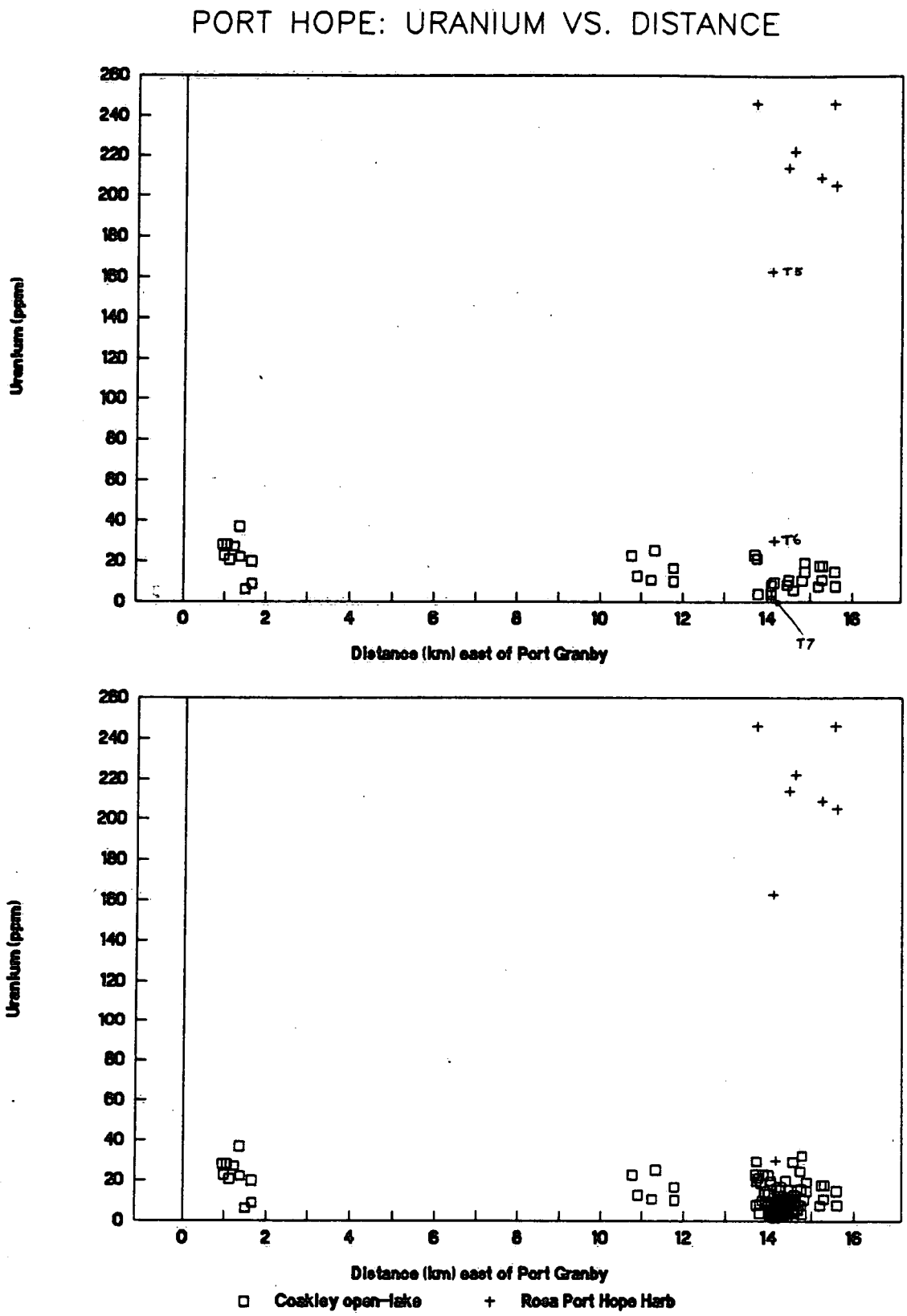


Figure 10 Port Hope. Plot of concentrations of cobalt in fine fraction of bottom sediments. Left to right: July, August, and September, 1988. Solid circles indicate tracer sample locations; solid triangles indicate locations of suspended sediment samples in Rosa and Mudroch (1990, in press). Dashed arrows indicate inferred transport directions.

APPENDIX A



gure A.1 (Top) Plot of U concentrations in nearshore bottom sediments vs distance from town of Port Granby (Figure 1); 150 tracer samples collected off Port Hope are not included. Sample T7 is the offshore reference sample used as background. (Bottom) Plot showing all samples.

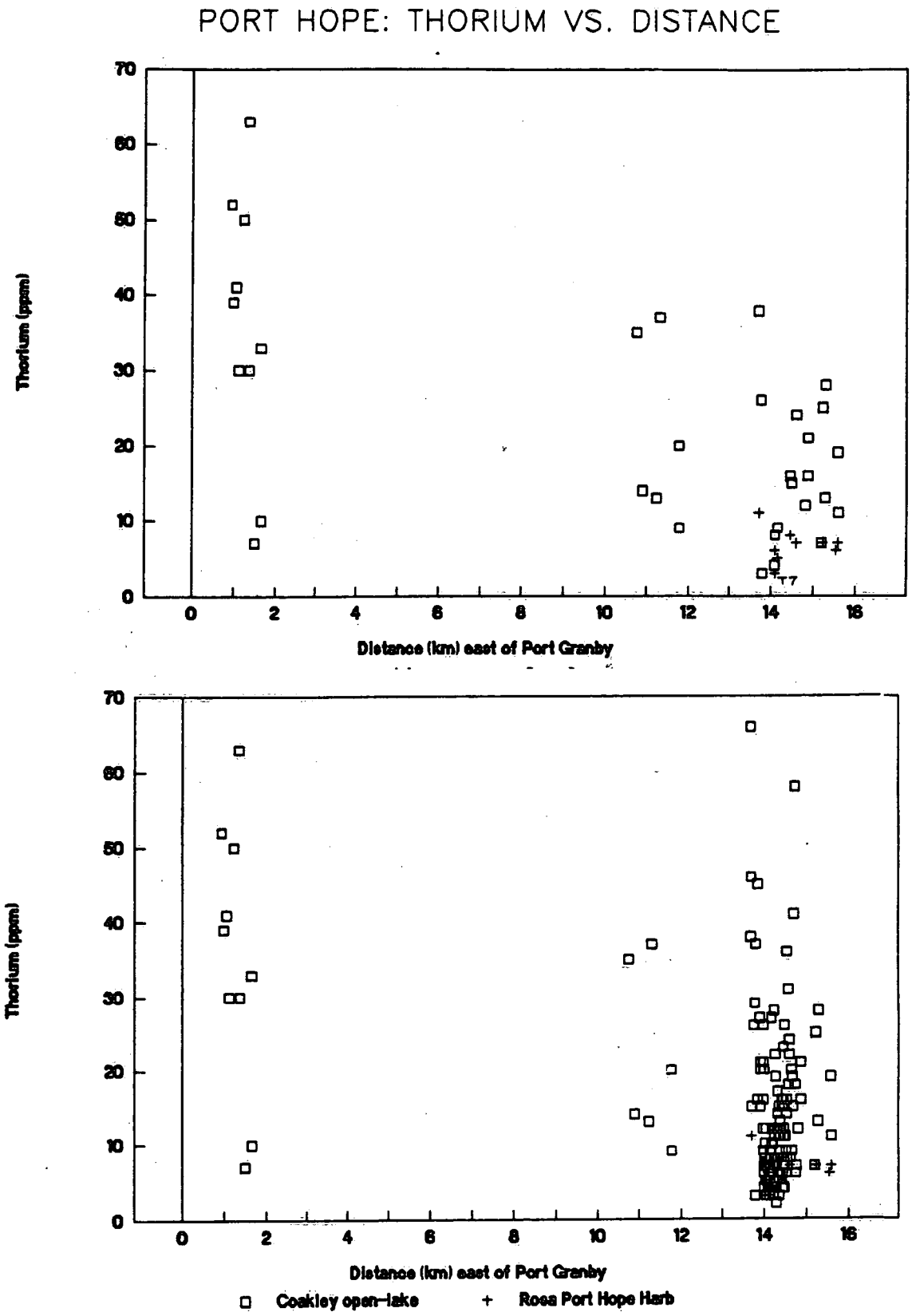
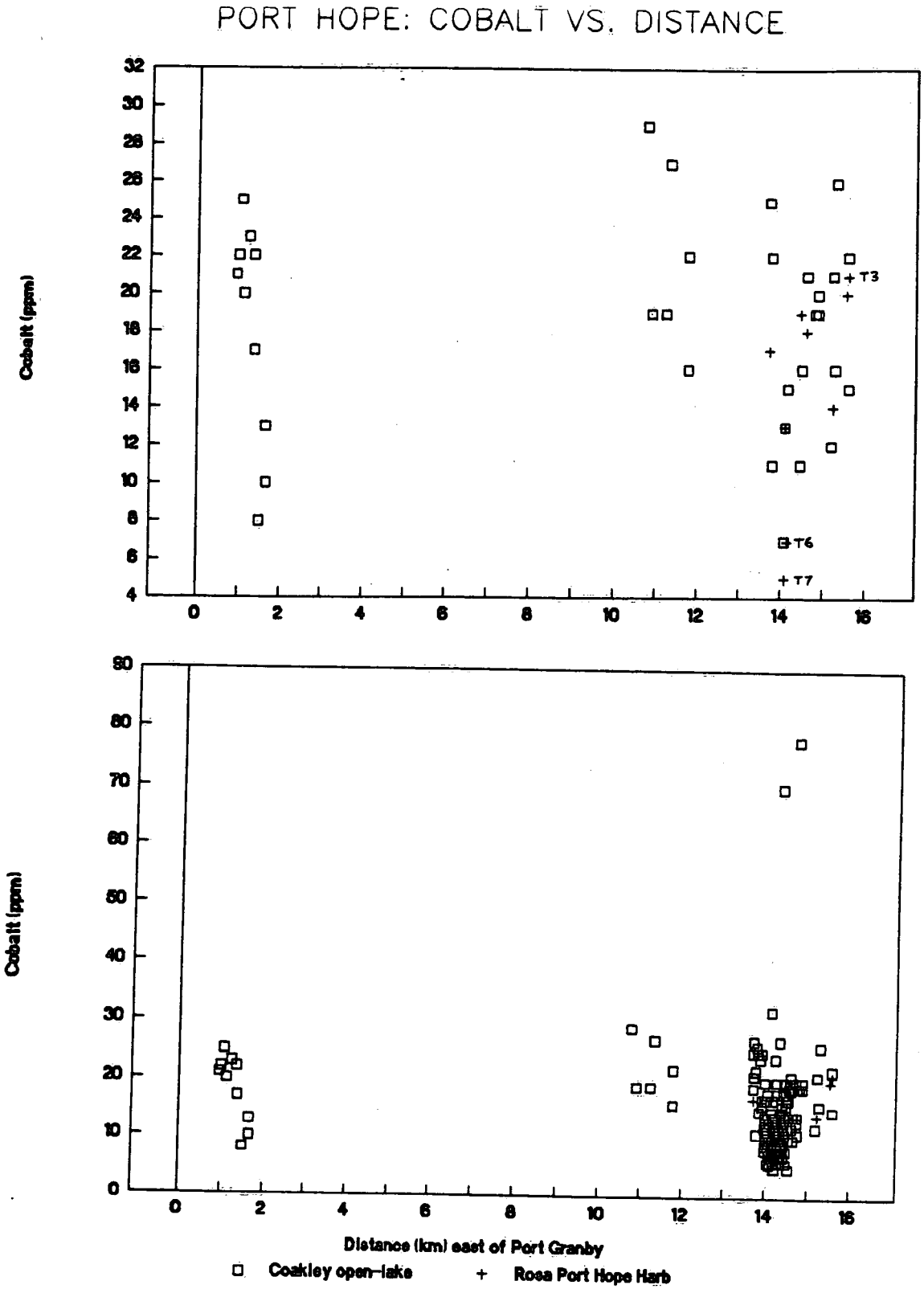


Figure A.2 (Top) Plot of Th concentrations in nearshore bottom sediments vs distance from town of Port Granby (Figure 1). 150 tracer samples collected off Port Hope are not included. Sample T7 is the offshore reference sample used as background. (Bottom) Plot showing all samples.



gure A.3 (Top) Plot of Co concentrations in nearshore bottom sediments vs distance from town of Port Granby (Figure 1). 150 tracer samples collected off Port Hope are not included. Sample T7 is the offshore reference sample used as background. (Bottom) Plot showing all samples.

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