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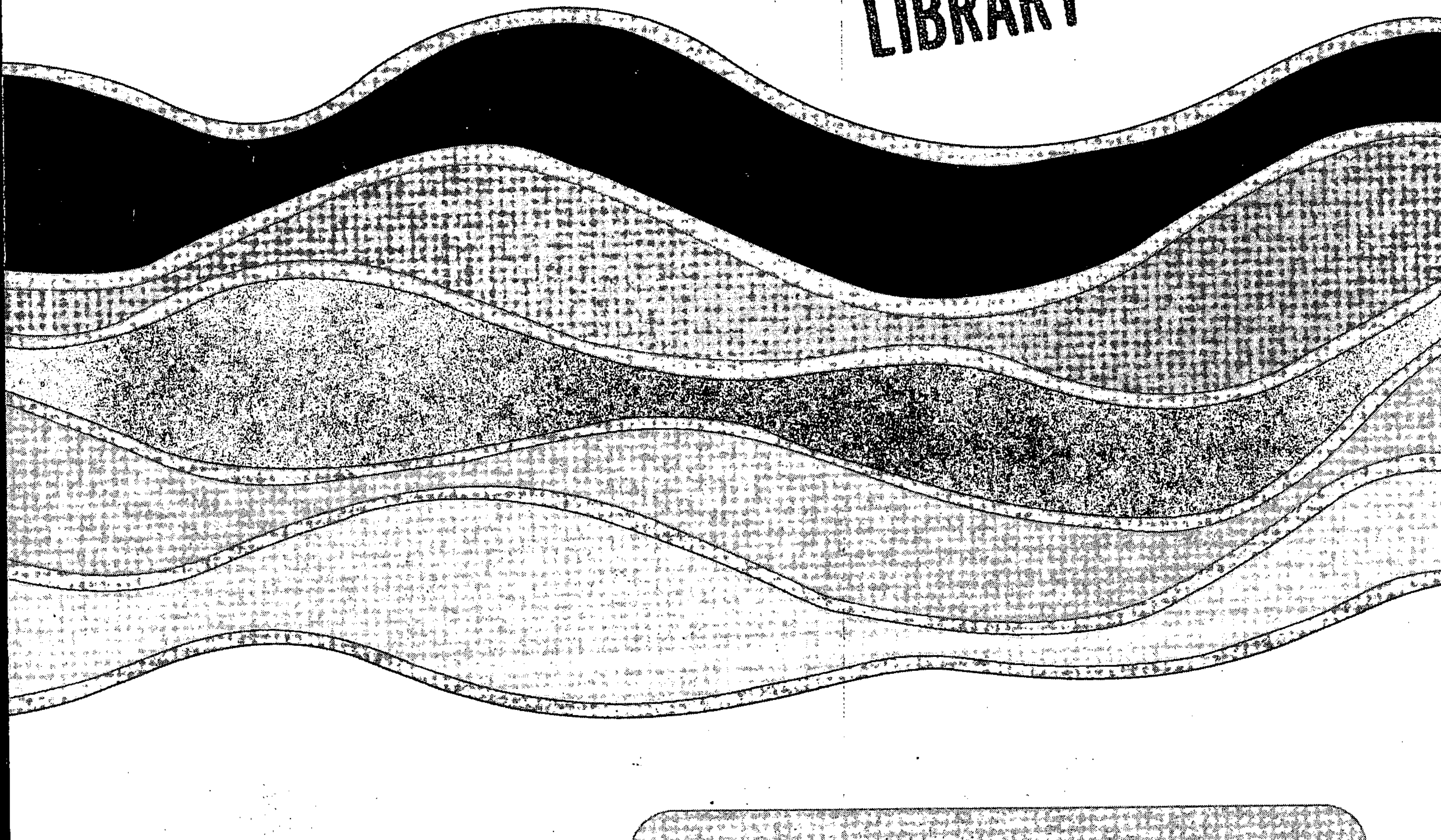

TRACE METALS AND SELECTED ELEMENTS IN SURFICIAL SEDIMENTS FROM HAMILTON HARBOUR

J.P. Coakley, D.J. Poulton and W.A. Morris

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TRACE METALS AND SELECTED ELEMENTS IN SURFICIAL SEDIMENTS FROM HAMILTON HARBOUR

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ABSTRACT

Determinations of 35 trace and other elements, together with grain-size and organic content data collected at 53 sites are presented for surficial sediments in Hamilton Harbour. Preliminary examination of the chemical data verifies that there is much spatial variability in the concentration levels. Correlation analysis indicates that grain-size (fineness of the bottom sediment particles) and content of organic matter may play a significant role in this variability. An initial examination for sources and transport trends indicates a predominant source for important trace metals (Cr, Pb, and Ni) located along the south and southeast shores, areas of concentrated industrial activity and effluent discharge. Net contaminant dispersal trend from these sources was toward the north and northwest across the deeper region of the Harbour. Whether this "plume" was related to hydrodynamic transport processes or simply to sediment focussing into deeper areas remains unresolved. Also unresolved is the reasons for the anomalous levels and uncorrelated behaviour of barium in the Harbour sediments. Average trace metal concentrations exceed the OMOE&E Provincial Sediment Quality Guidelines Severe Effect Level (SEL) criterion only for Cr (19 stations out of 53), Mn (22 out of 53), Pb (3 out of 53), and Zn (30 out of 53), involving primarily samples from the deeper stations. In contrast, large areas in the western and northeastern parts of the Harbour are characterized by relatively clean sediments at or lower than background levels from depositional basins in the open lake. Zn was much higher than in the open lake while Cu and Pb were enriched to a much lesser degree. Compared with published results for other locations in Canada and the U.S. where contaminated sediments are a problem, Hamilton Harbour sediment averages are equivalent or higher in Cd, Cr, Mn, Pb and Zn.

INTRODUCTION

Hamilton Harbour (Figure 1) is a 21.5 km^2 embayment at the western end of Lake Ontario. It is separated from the lake by a natural sand bar through which a ship canal 107 m wide and 9.5 m deep passes. At the western end, the harbour is connected to Cootes Paradise by the Desjardins Canal. The harbour receives municipal and industrial effluents from a variety of sources (Figure 1). Treated sanitary sewage enters the Harbour from the cities of Hamilton and Burlington, and (indirectly, through Cootes Paradise at the west end) Dundas. Process water for the two large steel mills (Dofasco and Stelco) situated on the south side of the harbour is withdrawn from, and later discharged back into the harbour after undergoing recirculation and partial treatment on-site and in the Hamilton STP. However, during heavy rainfall events, the harbour receives untreated stormwater overflow from the urbanized areas in its watershed.

Because of the above contamination, Hamilton Harbour has been designated by the International Joint Commission (IJC) as one of 43 Areas of Concern on the Great Lakes, i.e. having severe environmental degradation. Problems identified by joint Environment Canada - Ontario Ministry of Environment and Energy include loss of fisheries and wildlife habitat, restrictions on fish consumption, fish tumours and other deformities, beach closings, eutrophication and summer hypolimnetic dissolved oxygen depletion, interferences with drinking water, degradation of benthos, and exceedences of water and sediment quality criteria (in Stage 2, Hamilton Harbour Remedial Action Plan Committee (RAP), Canada - Ontario Agreement Review Board, 1992). The RAP report makes the point that "trace metals and organics associated with sediment are currently of greater concern than those associated with the water column" (RAP, 1992, p.85).

The RAP report discusses trace metal sources and loadings to the Harbour but does not deal with the present spatial distribution of these contaminants in surficial sediments. Sparse data on contaminants in sediments in the harbour were summarized by Poulton (1987) and also in RAP (1989). These latter were based on research into sediment toxicity in the Harbour by Murphy et al.1994 and Brouwer et al. 1990. Toxic effects of metals in Harbour sediments and the influence therein of the dissolved oxygen regime were also studied by Krantzberg (1994).

In her review of element concentrations in sediments from Lake Ontario and other Great Lakes, Mudroch presents comparisons between mean and background trace and major element levels for the western basin of the lake and for some elements from the harbour (Mudroch, 1993; Mudroch et al. 1988).

The data presented here are the most comprehensive to date on trace metals and inorganic contaminants in sediments in the Harbour itself. The purpose of this report is to make this data base available quickly in order to allow access to interested members of the public, to decision-makers, and to scientific investigators. Further analysis and interpretation of the spatial distribution and vertical trends in these data are presently continuing (Poulton et al., 1994 (in prep.)), and will be released at a later date.

FIELD AND LABORATORY METHODS

Field methods

Initially 14 sediment samples were collected over the eastern portion of the Harbour in June 1992 (Figure 1, top). In order to obtain a more uniform coverage over the Harbour, 40 additional samples were collected on a quasi-equally-spaced grid in December 1993 (Figure 1, bottom). Positioning was by the MiniRanger Falcon 484 system (manufactured by Motorola Inc., Tempe, Arizona). Positioning accuracy was approximately ± 5 m. Sample positions, converted to UTM coordinates, are presented in Table 1, together with water depth, grain size parameters, and organic matter content. More detailed grain-size data are found in Rukavina and Versteeg (1994, in prep.).

The sampler used in both cases was a small gravity corer, except for those sites in deep water or consisting of sediments too loose for retention in the corer, where a box-corer was used and core samples taken on the launch deck. All samples were kept as cool as possible onboard, then transferred to a cold storage chamber (5° C) at CCIW until opening and freeze-drying. The cores were opened in the lab and subsampled at 2 cm intervals. The samples were freeze-dried within 60 days of collection and stored thereafter at room temperature in plastic vials.

Laboratory analysis

The sample comprising the top 2 cm of each core was homogenized and analyzed for selected trace and minor elements in the manner described below. In the determination of total elements the whole, i.e. unsieved, sample was analyzed, while for the acid-extractable analysis the >177 μm fraction was removed. Standard QA/QC procedures were incorporated in the determinations.

1. Total digestion / Atomic Absorption. Ten elements were determined at the National Laboratory for Environmental Testing (NLET), Canada Centre for Inland Waters using an open digestion technique followed by Atomic Absorption spectrography (NLET, 1994). This technique is generally used to determine the total concentration of the elements assayed, both surface-adsorbed and incorporated within the mineral structure.

2. Acid leach / Induction-coupled plasma atomic emission spectrography. Determination of a suite of 33 acid-extractable trace and minor elements was carried out on subsamples split from the 40 samples. The determinations were carried out under contract by the Centre de Recherches Minérales (CRM), Ste-Foy, Quebec, using techniques adapted from Standard Methods (Clesceri et al., 1989), for use on sediment samples (Gagné, 1990). The analytical procedure included leaching of extractable metals from a 0.5 g subsample with 2 ml nitric acid reagent (500° C for one hour). The nitric acid reagent was prepared by first dissolving 1 g of mercuric nitrate into 2250 ml of concentrated nitric acid and diluting this solution to 13.3% by combining 266 ml of the above mixture with 2 l distilled water. The mercuric nitrate was added to prevent precipitation of silver in the sediment and thus, to increase the measurement resolution. The determination was carried out using inductively-coupled plasma atomic emission spectrography (ICP-AES). Detection limits for the more abundant elements, Al and Fe, were 0.02 and 0.01%, respectively, and were 1 to 3 μg g^{-1} for all trace elements.

3. Other analyses carried out on the samples were:
   - Grain-size analysis by a combination of sieve (for the coarse fraction) and SediGraph (for the silt and clay fraction);
   - Determination of organic matter by the technique of Loss on Ignition (LOI). 0.5 g of the sample was heated to 500° C for one hour and the difference in weight calculated as a percentage of the original 0.5 g.

RESULTS

Table 1 shows the non-chemical parameters measured, namely grain size parameters and organic matter content. Table 2 shows the analytical determinations for total elements while Table 3 presents selected elements of the 35 elements determined in the ICP-AES suite. The comprehensive ICP-AES results are reproduced in the Appendix. The 14 elements shown in Table 3 were selected because they are predominantly anthropogenic, recognized to have an important ecotoxicological effect, and are of importance in evaluating concentration and distribution effects.

The elements shown in Tables 2, 3, and the Appendix may be organized into three groups:

- <u>Group 1</u>, consisting of non-metallic, lithophile elements (Al and Ba); group 1 elements are worthy of documentation primarily for their diluting effect on metal concentrations. They can also be used in more detailed analysis to normalize the concentrations and thus enhance distribution trends.

- <u>Group 2</u>, containing the elements Ce, La, and V that are present in high enough concentrations to be used as potential geochemical source indicators;

- <u>Group 3</u>, contains the toxic trace metals (Cd, Cr, Cu, Pb, Ni, and Zn). These are deemed most important as potential contaminants and most have been shown to have a negative effect on the biota when present above certain concentrations. They are also expected to be better indicators of anthropogenic contamination.

Distribution of some Group 3 contaminants

A useful appraisal of the spatial distribution and probable sources of these contaminants may be obtained by plotting and contouring the concentration values for Cr, Mn, Pb, and Zn (Figures 2 to 4). It should be noted that in the discussion that follows, element concentrations are shown to be significantly dependent also on grain-size and organic matter. Therefore in order to obtain a picture of spatial distributions in element concentration that is unbiased by the distribution of grain-size and organic matter, the concentration values should be normalized against a reference parameter, such as % clay or conservative elements such as Al, Fe, or Rb which have been demonstrated to vary consistently with grain size (Kemp et al., 1976; Grant and Middleton, 1990; Schropp et al., 1990; Schneider and Weiler, 1984). Normalization with respect to grain-size and / or organic carbon was not carried out prior to the contouring presented here, but will be evaluated in later reports. The plots therefore provide an overview only of spatial distribution.

The most noteworthy feature of the contour plots is that they are highly depth-correlated (compare Figures 2 - 4 with Figure 5). Maximum values, especially for Cr, Mn, and Pb, tend to coincide with the deeper areas of the Harbour. The exception is Zn which shows a bias toward the north shore of the Harbour as well. High Pb values are also found in the Windemere Basin area in the southeastern part of the Harbour.

Relative level of contamination of Hamilton Harbour sediments

The arithmetic means and standard deviations of each element are shown at the bottom of Tables 2 and 3. Table 4 presents these mean values together with those for contaminated sediments from other comparable sources and various toxicity criteria. Comparison between such figures and criteria is difficult and somewhat imprecise as the analysis techniques used and other parameters such as grain-size are seldom similar. For instance, the OMOE&E criteria are based on concentrations extracted from sediments using strong acids, so it is roughly comparable to the acid-extractable values shown in Table 3. On the other hand, the values for other criteria and sites shown for comparative purposes in Table 5 are based on total element concentration, making them comparable only to the Hamilton Harbour total concentration data. Despite the reservations inherent in their use, these comparisons provide a valuable perspective on the relative quality of Hamilton Harbour sediments.

- "Background" values for deep-water Lake Ontario samples (Nriagu et al., 1981) and from the western basin (Mudroch, 1993). Both sets involved analytical techniques that were different from those used in this report and are best compared with total concentrations; the former was determined by digestion by strong acids followed by flame Atomic Absorption Spectrometry, while the latter was determined by X-ray fluorescence spectrometry.

- Published for various levels of ecotoxicological effects:

    - The primary criterion shown here is the SEL - Severe Effect Level from Provincial Sediment Quality Guidelines (PSQG) as presented in (Persaud et al., 1993). The Severe Effect Level (SEL) indicates heavy pollution, with the health of organisms in the sediment most likely to be affected. These criteria are based on determinations best compared with acid-extractable element data.

    - The OAET - Overall Apparent Effects Threshold used in the NOAA Status and Trends monitoring program (Long and Morgan, 1990);

- Mean values from comparable contaminated sites in Vancouver Harbour (Goyette and Boyd, 1989), Halifax Harbour (Buckley and Winter, 1992), and Boston Harbour (Manheim and Hathaway, 1991).

Comparison with offshore Lake Ontario sediments (western basin). Compared to concentrations in offshore Lake Ontario sediments (Mudroch, 1993), Hamilton Harbour (total elements) appears to be slightly enriched in Cu (16 stations out of 40) and much more so in Pb (24 stations). With one exception (#C39), all of these exceedences for Pb are less than 2 times the Lake Ontario value. Zn levels in the Harbour are very high, exceeding the Lake Ontario average in 37 out of 40 stations.

Comparison with various sediment toxicity criteria. Comparison of results in Table 3 with the OMOE guidelines indicates that the SEL criterion was exceeded in only 4 of the elements tested: Cr, Mn, Pb, and Zn. The number of stations exceeding the SEL ranged from 3 (Pb) to 34 (Zn) of the 53 samples analyzed (these are shown in boldface type in Table 3). The sample sites exceeding the SEL criterion in two or more elements are indicated in Figure 6. In one station (#39) Fe and Zn were significantly above the SEL. All the stations showing exceedences are located in the central part of the Harbour or in close proximity to the industrial shoreline to the south and south-east.

According to Table 4, the OAET guidelines were exceeded for the same metals as indicated above (Cr, Pb, and Zn) at a number of stations. The Zn values in the Harbour sediments at 51 out of 53 stations were in excess of the OAET.

Comparison with other sites of contaminated sediments. Table 4 also shows average trace metal levels for 3 other prominent contaminated sediment sites in North America. Here again, the published data for these sites do not specify whether acid-extractable or total metals were determined so precise comparison is not possible. The overall impression, however, is that with the exception of Zn, Hamilton Harbour is not much worse than these sites, despite the higher potential for mixing and dilution that would characterize these marine areas.

DISCUSSION

The results of the determination of trace and other elements for Hamilton Harbour sediments indicate that there is a high degree of variability in the concentration levels. We assume that the most important factor in this variability is location, i.e. distance from the source of the trace metal. However other factors are sure to play a role as well in the variability. In a paper presently in preparation (Poulton et al., 1994 (in prep.)) we investigate the sources of the variation using multivariate statistics. For the purposes of this report, we will restrict our discussion to other aspects of the data that affect their accuracy, precision, and variability.

These are: the form of the trace metal in the sediment, i.e. whether they occur as particles or surface-adsorbed, and their relationship with other parameters, such as grain-size, organic matter, and water depth (all of which are to some degree auto-correlated becauswe of their relation to the energy of the environment of deposition).

Form of trace metal occurrence in Hamilton Harbour sediments

In order to better understand more about element speciation, i.e. the form in which the elements were present in the sediments, the relationship of total to acid-extractable elements was examined by regression analysis. In more detailed studies this is best done by successive extraction procedures prior to determination (Calmano and Förstner, 1983).

Table 5 shows the correlation coefficient of the two as well as the slope of the regression line (total values were used as independent variables). What is immediately noted is that in all cases the total concentration value was greater than the extracted value. This is a rough check on the determinations, done as they were in two separate laboratories. Another rough check is that, as expected, very good correlation ($P < 0.001$) was noted between total : extracted elements for all cases except Ba. The fact that Ba was also uncorrelated with any of the other parameters (Table 5) is interesting insofar as possible source and form of occurrence are concerned and merits a closer investigation elsewhere.

The slope of the regression line (Table 5, col. 3) shows that the proportion of the elements present in acid-extractable form ranged up to 81% (Cd). Others with high extractable proportions were Pb (73%) and Zn (72%). Others, such as Cu, Fe (40%), and V (46%) show lower slopes, indicating that they occur predominantly as tightly-bound elements within the mineral structure or as particles. Since it is assumed that the acid-extractable phase is proportional to the trace element amount occurring as adsorbed or loosely-bound phases, the above proportions have implications regarding potential bio-availability, in that the elements such as Cd, Pb, and Zn are seen to be the most easily mobilized under acidic conditions (Luoma, 1983).

Grain-size effect

Table 1 presents measurements made on other, i.e. non-elemental properties of the sediment, namely grain size and organic matter. These properties are important in assessing the relative concentrations of the trace metals because they indicate cases where trends in concentrations are due to changes in these parameters rather than to input levels.

Table 6 shows correlations of total and extractable elements vs. grain size, expressed as percentage of clay. The results show that in all cases but one there is a highly significant correlation between grain size and element concentrations regardless of whether the form is total or acid-extractable ($P < 0.001$). Once again, Ba showed the least correlation.

Relationship with organic carbon

Table 5 (col. 6, 7) shows that correlation between total and extractable elements and organic matter (proxied by loss on ignition, LOI) were generally highly significant ($P < 0.001$), except in the case of Ba and total Al. The latter is interesting because correlation between LOI and extractable Al was high. Perhaps the reason lies in the form of the Al in the sediments, i.e. either as mineral feldspar in silts (low correlation with organic matter) determined by total digestion, or in weathered clay minerals (higher correlation with organic matter) which would be more susceptible than the silt mineral grains to the acid-leach extraction procedure.

Relationship to water depth

Comparison of the element plots for important trace elements such as Cr, Mn, and Pb, and Zn (Figures 2, 3, and 4) with the bathymetric plot (Figure 5) highlights the definite visual correlation with depth. This indicates that sediment focussing into the deeper offshore areas is an important process. Highest values for Zn, however, occur in association with the north shore, which suggests a more complex source / transport relationship. Whether these trends are in fact are related to hydrodynamic transport processes or are merely statistical artifacts awaits further investigation.

CONCLUSIONS

The determinations of total and acid-extractable trace, minor, and selected major elements on surficial sediments from Hamilton Harbour provide a much-needed base of such data. Preliminary examination of the data verifies that there is much variability in the concentration levels. Correlation analysis indicates that grain-size (fineness of the bottom sediment particles) and content of organic matter may play a significant role in this variability. An initial examination for sources and transport trends indicates a predominant source for important trace metals (Cr, Pb, and Ni) located along the south and southeast shores, areas of concentrated industrial activity and effluent discharge. Net contaminant dispersal trend from these sources appears to be toward the north and northwest across the deeper region of the Harbour. There is a definite depth correlation with important trace elements such as Cr, Mn, and Pb, and highest Zn values occur in association with the north shore. Whether these trends are related to statistical artifacts, hydrodynamic transport processes, or simply to sediment focussing into deeper areas awaits further interpretation.

Average trace metal concentrations exceed the OMOE&E Provincial Sediment Quality Guidelines Severe Effect Level (SEL) criterion only for Cr (19 stations out of 53), Mn (22 out of 53), Pb (3 out of 53), and Zn (30 out of 53), involving primarily samples from the deeper stations. In contrast, large areas in the western and northeastern parts of the Harbour are characterized by sediments at or lower than background levels from depositional basins in the open lake. Zn levels, however, exceeded the Lake Ontario average in 46 out of 53 samples, and Pb 28 out of 53. Cu was slightly higher (7 samples). Compared with published results for other locations in Canada and the U.S. where contaminated sediments are a problem, Hamilton Harbour sediment averages are equivalent or higher in Cd, Cr, Mn, Pb and Zn. Further interpretation is continuing aimed at journal publication in the near future.

ACKNOWLEDGEMENTS

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REFERENCES

Brouwer, H.; Murphy, T; and McArdle, L. 1990. A sediment-contact bioassay with Photobacterium phosphereum. Environmental Toxicology and Chemistry, 9: 1353-1358.

Buckley, D.E. and Winters, G.V. 1992. Geochemical characteristics of contaminated surficial sediments in Halifax Harbour: impact of waste discharge. *Can. J. Earth Sci.* 29: 2617-2639.

Calmano, W. and Förstner, U. 1983. Chemical extraction of heavy metals in polluted river sediments in central Europe. Science of the Total Environment, 28: 77-90.

Clerceri, L.S., Greensberg, A.E., and Trussel, R.R. 1989. Standard Methods for the Examination of Water and Waste Water. 17th. Edition, joint publication by American Public Health Association, American Water Works Association, and American Pollution Control Federation.

Gagne, R. 1990. Méthodes d'analyse de diverses substances minérales. Tome 1. Analyses par spectrométrie, d'absorption atomique, spectrométrie d'émission atomique au plasma, et fluorométrie. Centre de Recherches Minérales, Ste.-Foy, Québec, 230 p.

Goyette, D., and Boyd, J. 1989. Distribution and environmental impact of selected benthic contaminants in Vancouver Harbour, British Columbia. Environment Canada Conservation and Protection, Environmental Protection (Pacific and Yukon Region), Regional Program Report 89-02, 99p.

Grant, A. and Middleton, R. 1990. An assessment of metal contamination of sediments in the Humber estuary, U.K. Estuarine, Coastal, and Shelf Science 31: 71-85.

Kemp, A.L.W., Thomas, R.L., Dell, C.I., and Jacquet, J.-M. 1976. Cultural impact on the geochemistry of sediments in Lake Erie. Journal of the Fisheries Research Board of Canada 35: 440-462.

Krantzberg, G. 1994. Spatial and temporal variability in metal bioavailability and toxicity of sediment from Hamilton Harbour, Lake Ontario. Environmental Toxicology and Chemistry, 13 (10): 1685-1698.

Long, E.R. and Morgan, L.G. 1990. The potential for biological effects of sediment-sorbed contaminants tested in the National Status and Trends Program. NOAA Tech. Memo. NOS OMA 52, 175 p.

Luoma, S.N. 1983. Bioavailability of trace metals to aquatic organisms -- a review. Science of the Total Environment, 28: 1-22.

Manheim, F.T., and Hathaway, J.C. 1991. Polluted sediments in Boston Harbour -

Massachusetts Bay: Progress report on the Boston Harbour Data Management File. U.S. Department of the Interior, U.S. Geological Survey Open file Report 91-331, 20 p.

Mudroch, A. 1993. Lake Ontario sediments in monitoring pollution. Environmental Monitoring and Assessment, 28: 117-129.

Mudroch, A.; Sarazin, L.; and Lomas, T., 1988. Summary of surface and background concentrations of selected elements in the Great Lakes sediments. Jour. Great Lakes Research, 14 (2): 241-252.

Murphy, T.P.; McArdle, L.; Brouwer, H.; Moller, A.; and Krantzberg, G. 1994. Spatial variation in sediment toxicity and potential methods of in situ treatment. Verhandlungen Internat. Verein. Limnol. 25: 2036-2042.

National Laboratory for Environmental Testing, 1994 (in press). Manual of analytical methods. Vol. II. National Water Research Institute, Environment Canada Internal Report.

Nriagu, J.O., Wong, H.K.T., and Coker, R.D. 1981. Particulate and dissolved trace metals in Lake Ontario. Water Research 15: 91-96.

Persaud, D., Jaagumagi, R., and Hayton, A. 1993. Guidelines for the protection and management of aquatic sediment quality in Ontario. Standards Development Branch and Environmental Monitoring and Reporting Branch, Ministry of Environment and Energy.

Poulton, D.J. 1987. Trace contaminant status of Hamilton Harbour. Journal of Great Lakes Research, 13: 193-201.

Poulton, D.J., Morris, W.A., and Coakley, J.P. 1994 (in prep.) Zonation of contaminated bottom sediments in Hamilton Harbour as defined bystatistical classification techniques.

Remedial Action Plan, RAP (Canada - Ontario Agreement Review Board), 1992. Remedial action plan for Hamilton Harbour: goals, options, and recommendations. RAP Stage 2, vol. 2, 329 p.

Rukavina, N.A. and Versteeg, J.K. 1994 (in prep.) The physical properties of the surficial sediments of Hamilton Harbour. Manuscript submitted to NWRI Contribution Series.

Schneider, B. and Weiler, K. 1984. A quick grain size correction procedure for trace metal content of sediments. Environmental Technology Letters 5: 245-256.

Schropp, S.J.; Lewis, F.G.; Windom, H.L.; Ryan, J.D.; Calder, F.D.; and Burney, L.C. 1990. Interpretation of metal concentrations in estuarine sediments of Florida using Aluminum as a reference element. Estuaries 13(3): 227-235.

LIST OF FIGURES

Figure 1. Map of Hamilton Harbour, showing sample locations. (Top) 14 samples collected in 1992 designated HH1 to 14 in Table 3. (Bottom) 40 samples collected in 1993 designated C1 to C40 in Tables 2, 3, 4.

Figure 2. (Top) Contoured concentrations for acid-extractable Cr for bottom sediments of Hamilton Harbour. (Bottom) Contout plot for acid-extractable Mn.

Figure 3. Contour plots of concentrations of total Pb (top) and acid-extractable Pb (bottom).

Figure 4. Contour plots of concentrations of total Zn (top) and acid-extractable Zn (bottom).

Figure 5. Bathymetry of Hamilton Harbour.

Figure 6. Location of all Hamilton Harbour samples in the two separate samplings that exceed the OMOEE SEL criterion in two or more elements. 1992 (top) samples exceeding are shown as bullseyes, while those for the 1993 sampling (bottom) are shown as solid dots.

Table 1: Location, water depths, and other physical parameters of Hamilton Harbour sediments.

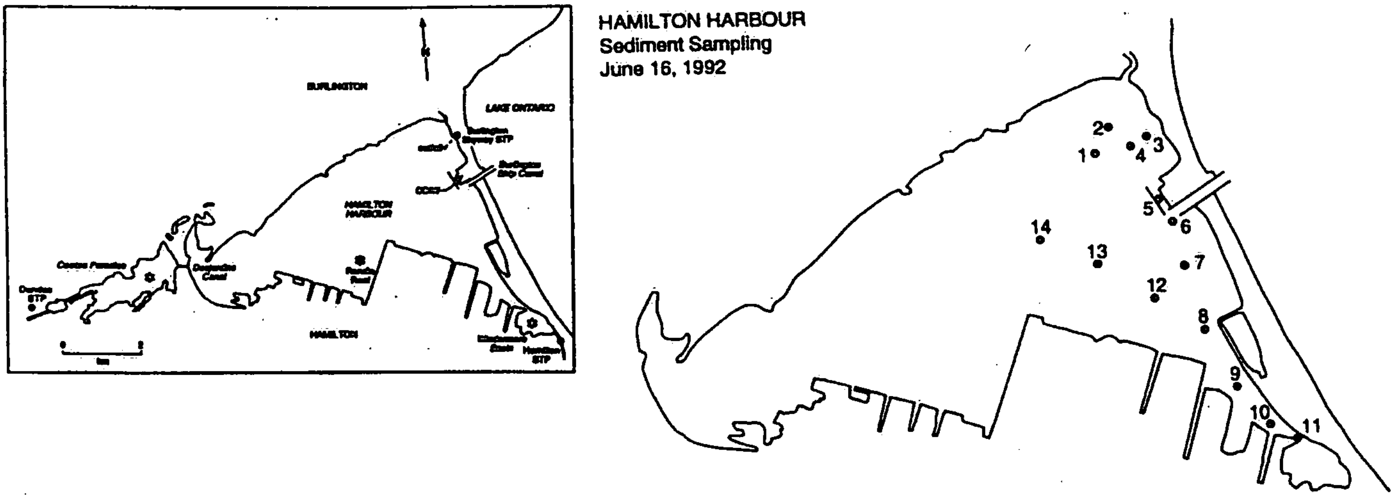
Table 2: Determination of total elements in Hamilton Harbour sediments.

Table 3: Determination of acid-extractable elements in Hamilton Harbour sediments. Samples exceeding the OMOEE SEL criterion are shown in bold.

Table 4: Principal grain-size parameters and organic matter in Hamilton harbour sediments.

Table 5: Comparison of summary statistics for selected trace elements in Hamilton Harbour sediments, 1993.

Table 6: Statistical comparisons between various parameters, Hamilton Harbour sediments.



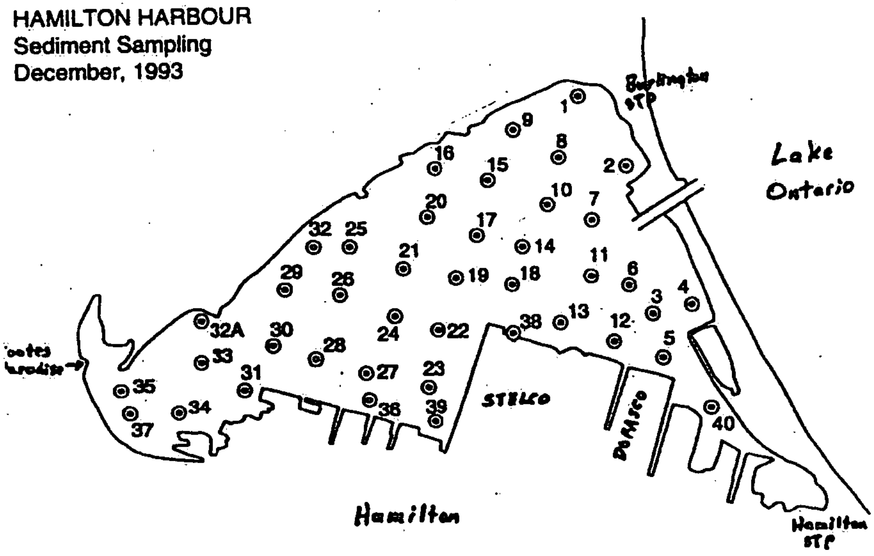


Figure 1. Map of Hamilton Harbour, showing sample locations. (Top) Inset showing place names referred to in text and plot of 14 samples collected in 1992 designated HH1 to 14 in Table 3. (Bottom) 40 samples collected in 1993 designated C1 to C40 in Tables 2, 3, 4.

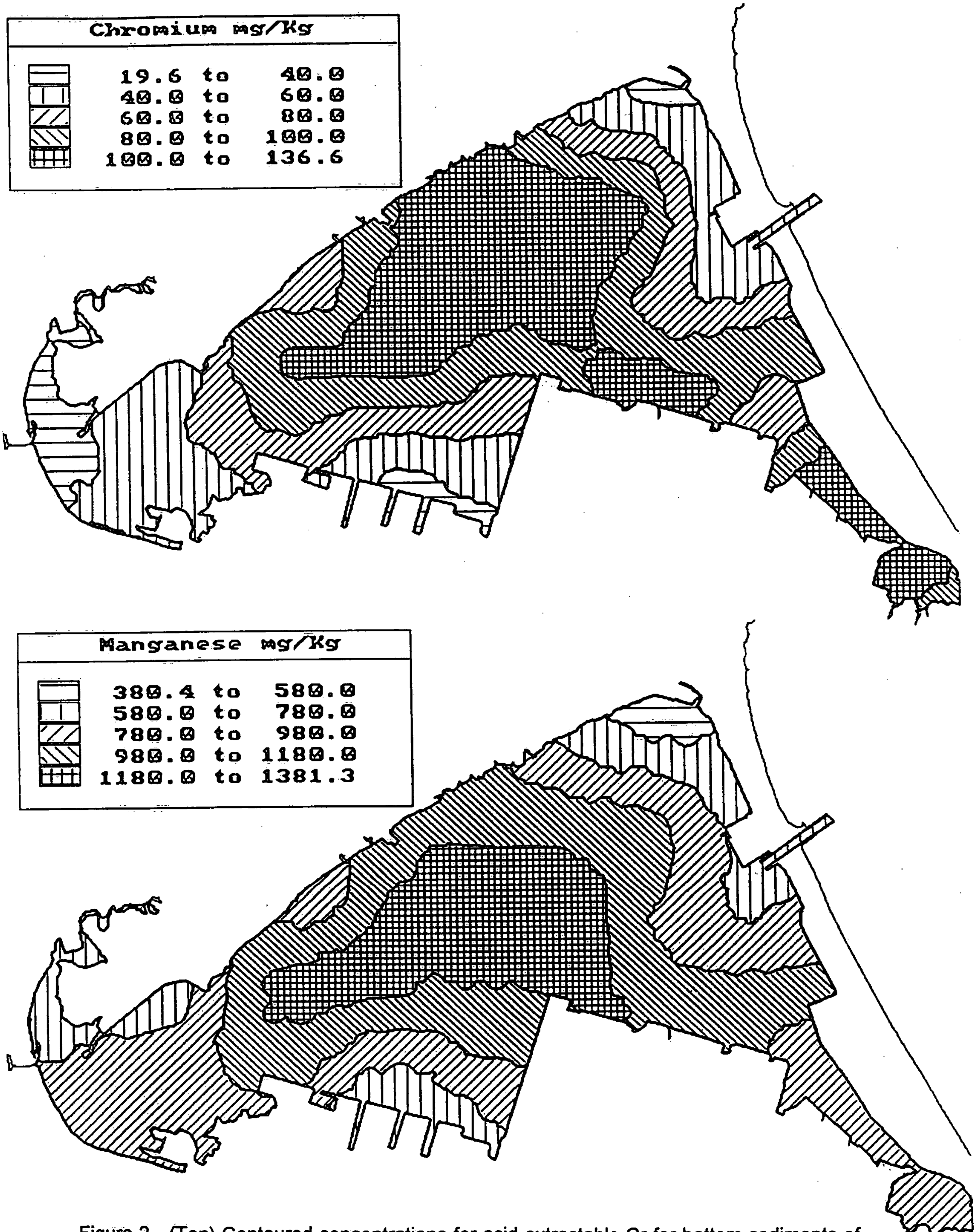


Figure 2. (Top) Contoured concentrations for acid-extractable Cr for bottom sediments of Hamilton Harbour. (Bottom) Contout plot for acid-extractable Mn.

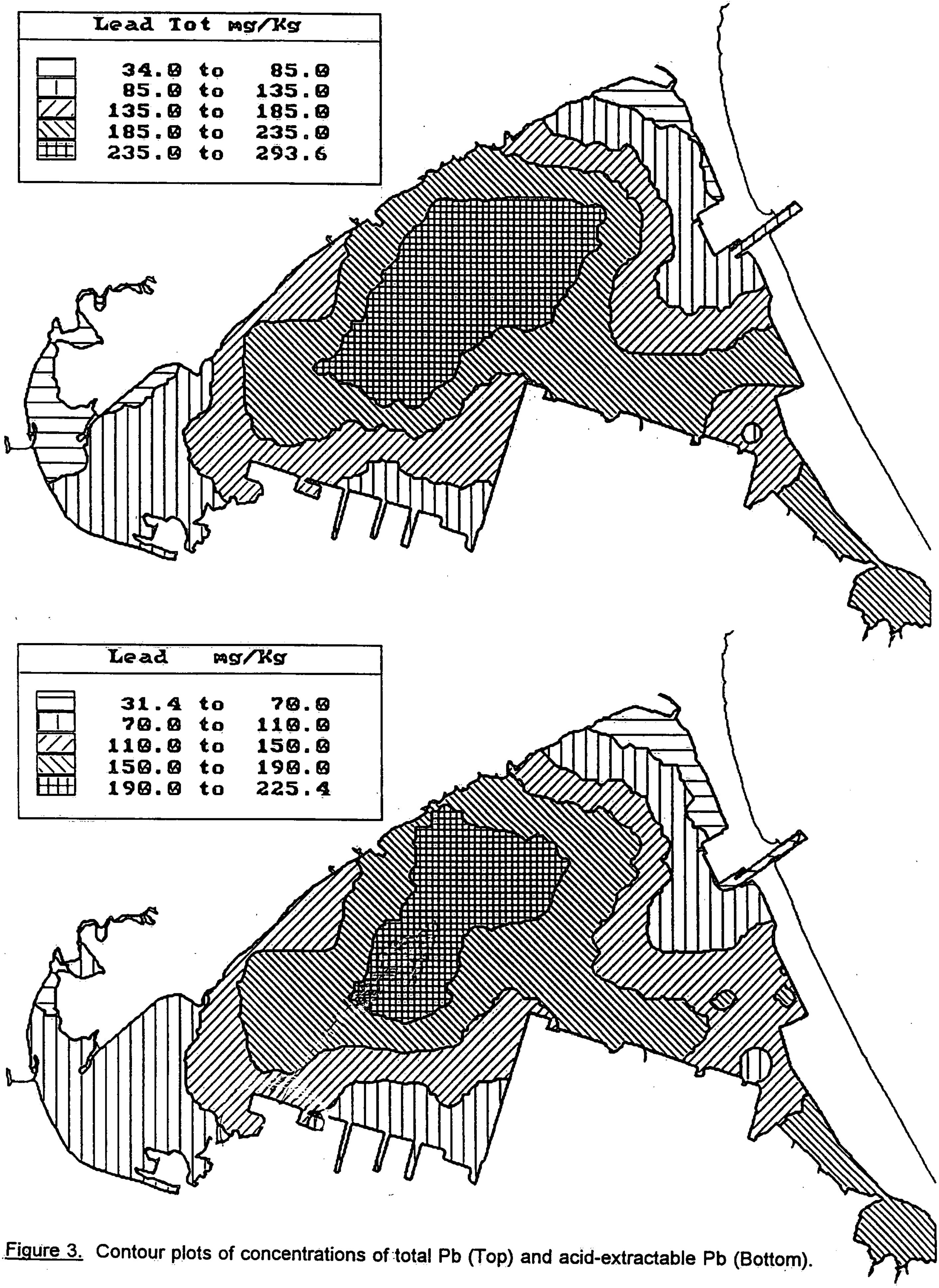


Figure 3. Contour plots of concentrations of total Pb (Top) and acid-extractable Pb (Bottom).

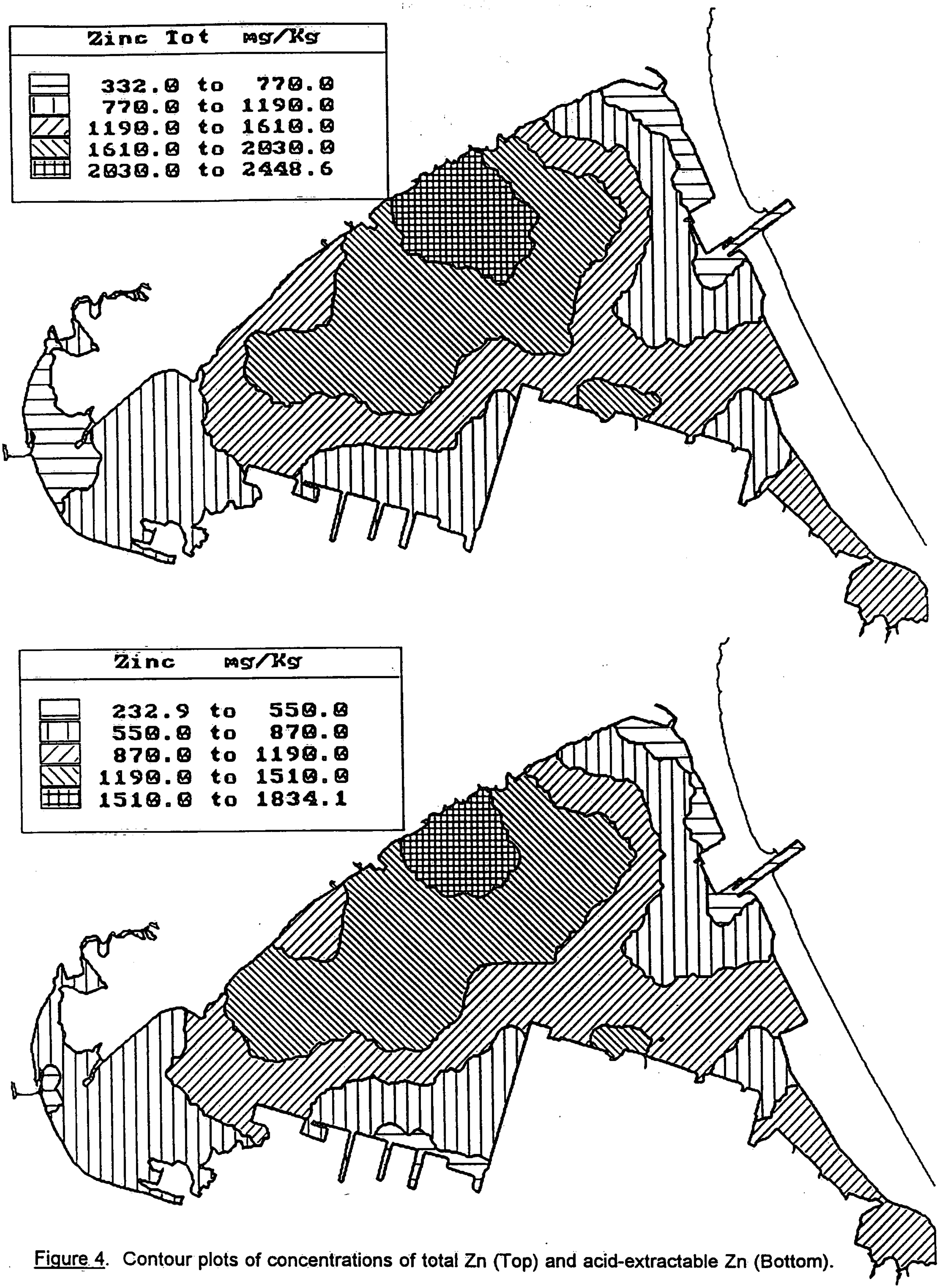


Figure 4. Contour plots of concentrations of total Zn (Top) and acid-extractable Zn (Bottom).

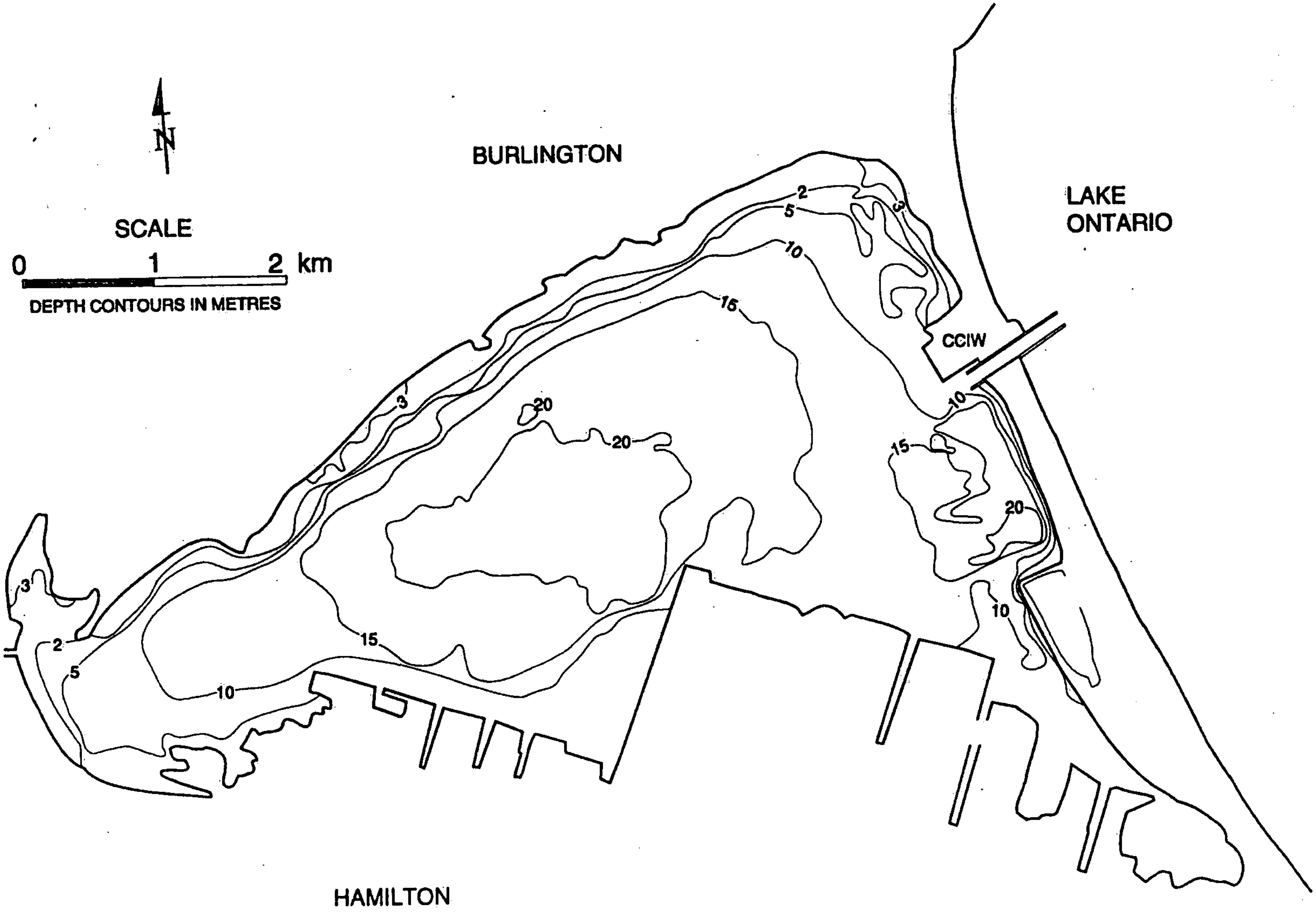


Figure 5. Bathymetry of Hamilton Harbour.

Figure 6. Location of all Hamilton Harbour samples in the two separate samplings that exceed the OMOEE SEL criterion in two or more elements. 1992 (Top) samples exceeding are shown as bullseyes, while those for the 1993 sampling (Bottom) are shown as solid dots.

TABLE 1. **Location, water depth, grain-size parameters, and organic matter for surficial bottom sediments of Hamilton Harbour. (PHI = log to the ba diameter in mm; NORTHING and EASTING are UTM coordinates)**

Field Id /	LOCATION		DEPTH	MEDIAN	PERCENTAGE			ORGANI
JPC93HH	NORTHIN	EASTING	(m)	PHI	SAND	SILT	CLAY	(LOI) %
C1	4,795,872	596,409	4.20	3.09	99.50	0.50	0.00	4.00
C2	4,794,988	596,927	10.40	5.55	24.48	55.30	20.22	14.00
C3	4,794,112	597,320	14.40	3.73	61.66	22.97	15.36	10.00
C4	4,793,182	597,764	21.40	7.80	0.00	55.32	44.68	20.00
C5	4,792,490	597,530	10.20	7.34	22.13	37.77	40.10	16.00
C6	4,793,398	597,076	19.80	7.78	0.00	54.59	45.41	16.00
C7	4,794,331	596,655	11.60	6.27	8.59	71.28	20.14	16.00
C8	4,795,230	596,207	10.0	6.90	0.00	67.08	32.92	18.00
C9	4,795,532	595,607	6.40	3.94	52.91	28.68	18.41	10.00
C10	4,794,563	595,982	15.40	7.61	0.00	59.75	40.25	22.00
C11	4,793,565	596,557	14.60	3.88	53.53	25.22	21.24	14.00
C12	4,792,725	596,880	13.20	7.53	0.00	59.40	40.60	18.00
C13	4,792,805	596,140	14.60	7.20	11.88	53.79	34.33	20.00
C14	4,793,875	595,722	17.4	7.16	16.11	46.46	37.44	16.00
C15	4,794,850	595,304	16.40	7.89	0.00	52.82	47.18	20.00
C16	4,795,038	594,644	5.20	6.52	23.99	44.15	31.86	14.00
C17	4,794,124	595,093	18.60	8.16	0.00	46.92	53.08	20.00
C18	4,793,408	595,365	19.20	7.86	0.00	53.07	46.93	20.00
C19	4,793,496	594,836	22.00	8.55	0.00	38.29	61.71	18.00
C21	4,793,686	594,190	20.80	8.16	0.00	46.66	53.34	20.00
C22	4,792,807	594,595	22.60	8.53	0.00	37.51	62.49	20.00
C23	4,792,119	594,370	9.60	5.22	29.10	48.01	22.90	12.00
C24	4,793,017	593,957	22.00	8.74	0.00	33.05	66.95	18.00
C25	4,793,884	593,513	18.40	7.98	0.00	50.54	49.46	22.00
C26	4,793,262	593,293	20.6	8.22	0.00	44.90	55.10	20.00
C27	4,792,318	593,714	14.00	7.14	10.09	56.18	33.73	14.00
C28	4,792,536	593,079	18.80	8.47	0.00	39.10	60.90	18.00
C29	4,793,382	592,617	16.40	8.03	0.00	49.49	50.51	20.00
C30	4,792,710	592,388	15.40	8.10	0.00	47.90	52.10	20.00
C31	4,792,140	592,138	11.20	7.68	11.97	43.41	44.62	16.00
C32	4,793,895	592,951	2.00	1.31	96.80	3.20	0.00	4.00
C32-A	4,793,021	591,496	2.00	4.57	39.81	39.10	21.09	10.00
C33	4,792,389	591,471	12.6	7.97	0.00	50.72	49.28	18.00
C34	4,791,713	591,240	8.20	6.84	25.45	39.79	34.76	18.00
C35	4,792,175	590,431	4.00	6.70	12.20	72.10	15.69	14.00
C36	4,791,875	593,568	9.40	4.24	47.21	31.66	21.13	8.00
C37	4,791,760	590,621	7.00	7.32	0.00	65.38	34.62	12.00
C38	4,792,713	595,000	19.00	6.94	19.78	44.69	35.54	12.00
C39	4,791,577	594,530	8.0	6.57	17.47	65.72	16.81	22.00
C40	4,791,801	598,247	8.80	7.62	0.00	57.26	42.74	18.00
HH1	4,795,796	596,243		6.95	0.00	65.63	34.37	18.00
HH2	4,795,437	596,411		3.98	51.55	27.92	20.52	4.00
HH3	4,795,221	596,798		5.92	28.06	49.04	22.90	14.00
HH4	4,795,201	596,663		5.48	22.25	61.47	16.28	12.00
HH5	4,794,416	597,011		5.07	30.26	50.29	19.46	12.00
HH7	4,793,615	597,294		8.01	0.00	49.88	50.12	20.00
HH8	4,792,841	597,718		7.42	15.99	41.74	42.27	16.00
HH9	4,792,221	597,860		7.07	31.07	29.70	39.23	16.00
HH10	4,791,499	598,346		7.73	0.00	56.23	43.77	12.00
HH11	4,791,155	598,823		6.91	27.84	34.86	37.30	14.00
HH12	4,793,175	597,047		7.69	0.00	56.68	43.32	16.00
HH13	4,793,460	596,231		7.37	10.55	51.60	37.85	12.00
HH14	4,793,669	595,431		8.02	0.00	49.57	50.43	20.00
AVERAGE				**6.76849**	**17.0232**	**46.497**	**36.48**	**15.6226**

TABLE 2. Determination of total elements in Hamilton Harbour bottom sediments.

Field Id / JPC93HH	AL %	BA MG/KG	CD * MG/KG	CO MG/KG	CU MG/KG	FE %	PB MG/KG	NI MG/KG	V MG/KG	ZN MG/KG
C1	5.48	696.00	0.59	5.59	8.42	1.22	18.40	7.97	34.50	144.00
C2	3.75	409.00	0.59	9.84	66.10	3.18	60.80	27.90	58.40	503.00
C3	4.18	381.00	0.59	10.10	41.30	2.54	54.70	22.80	54.70	352.00
C4	5.30	970.00	3.71	15.70	131.00	7.59	258.00	47.80	89.90	1790.00
C5	4.55	335.00	0.59	11.40	40.80	3.47	49.10	23.20	59.80	338.00
C6	5.31	402.00	2.71	14.80	106.00	5.94	192.00	45.40	87.30	1260.00
C7	5.18	993.00	3.94	15.20	101.00	5.00	161.00	39.70	78.10	1240.00
C8	4.98	729.00	5.44	14.10	117.00	5.34	204.00	47.50	74.70	1810.00
C9	5.13	886.00	2.35	8.95	34.30	2.80	71.40	26.20	47.50	876.00
C10	5.04	428.00	5.16	15.20	135.00	7.41	278.00	53.00	93.20	2100.00
C11	4.71	784.00	1.49	10.90	55.50	3.64	103.00	31.90	60.40	740.00
C12	4.59	1500.00	3.32	14.00	123.00	8.50	257.00	50.30	79.00	1790.00
C13	4.63	1560.00	3.81	15.50	122.00	7.56	255.00	50.10	85.30	1930.00
C14	5.00	1400.00	3.14	13.40	102.00	6.49	207.00	45.10	81.20	1490.00
C15	5.36	587.00	4.89	16.60	130.00	6.65	267.00	51.30	97.10	2050.00
C16	3.93	344.00	5.86	12.80	89.20	6.15	199.00	52.50	67.20	2500.00
C17	5.18	1010.00	4.86	16.30	133.00	7.50	308.00	60.80	92.20	2280.00
C18	5.01	899.00	3.91	14.50	118.00	7.10	248.00	52.70	88.20	1830.00
C19	5.47	1220.00	3.67	16.30	113.00	6.87	238.00	53.00	94.40	1620.00
C21	5.45	287.00	4.06	18.30	121.00	6.70	257.00	55.40	93.00	1750.00
C22	5.56	1010.00	3.73	17.40	115.00	6.37	234.00	56.70	94.30	1610.00
C23	4.87	604.00	1.75	10.50	49.00	4.73	115.00	29.20	63.70	854.00
C24	5.82	1440.00	6.74	17.70	126.00	7.65	311.00	60.50	101.00	2220.00
C25	5.30	604.00	5.51	19.40	128.00	7.09	289.00	60.80	97.00	2260.00
C26	5.23	969.00	4.11	19.40	121.00	6.53	268.00	60.00	94.30	1900.00
C27	4.47	991.00	4.11	15.10	79.40	4.58	173.00	36.30	79.40	1220.00
C28	5.88	386.00	3.37	18.40	107.00	5.55	201.00	51.30	96.70	1390.00
C29	5.34	2050.00	4.58	15.90	118.00	6.24	259.00	52.10	80.80	2040.00
C30	5.88	403.00	3.64	15.50	104.00	5.49	212.00	49.50	84.70	1610.00
C31	5.78	735.00	2.56	10.80	80.20	4.25	148.00	38.30	75.50	1070.00
C32	3.00	1830.00	0.59	6.96	16.40	1.61	14.00	6.99	28.20	627.00
C32-A	2.64	194.00	0.59	10.50	32.40	2.62	26.10	17.40	43.90	756.00
C33	5.77	348.00	2.63	13.00	91.50	4.71	146.00	42.60	78.20	1180.00
C34	4.52	522.00	1.37	11.40	54.70	3.15	79.80	30.70	57.10	689.00
C35	4.39	330.00	1.12	11.20	58.30	3.13	62.90	31.50	70.10	456.00
C36	3.97	376.00	1.48	8.00	44.00	2.68	70.80	19.40	45.10	525.00
C37	5.37	587.00	2.48	12.80	81.20	3.91	110.00	40.30	75.10	1010.00
C38	2.58	219.00	0.59	9.56	55.20	4.16	82.00	23.00	52.30	696.00
C39	2.37	206.00	9.03	11.60	98.90	20.40	1250.00	26.10	64.30	5930.00
C40	4.47	304.00	3.47	11.40	133.00	5.91	232.00	36.00	64.50	1610.00
AVERAGE	**4.786**	**748.2**	**3.20325**	**13.4**	**89.5205**	**5.56025**	**199.25**	**40.3315**	**74.0575**	**1451.15**

* - values of 0.59 indicate "less than 1"

TABLE 3. Determination of acid-extractible elements in Hamilton Harbour bottom sediments. Samples exceeding the OMEE SEL criterion are shown in boldface.

Field Id / JPC93HH	AL %	BA MG/KG	CA %	CD MG/KG	CO MG/KG	CR MG/KG	CU MG/KG	FE %	MN MG/KG	NI MG/KG	PB MG/KG	SR MG/KG	V MG/KG	ZN MG/KG
C1	0.19	500.00	2.73	0.20	7.00	5.00	3.00	0.33	220.00	8.00	11.00	150.00	4.00	100.00
C2	0.77	86.00	5.68	0.80	6.00	33.00	18.00	1.56	680.00	20.00	47.00	130.00	16.00	360.00
C3	0.61	49.00	4.77	0.60	6.00	21.00	16.00	1.25	580.00	16.00	37.00	100.00	14.00	240.00
C4	1.37	140.00	5.08	3.40	11.00	**110**	34.00	3.26	**1100**	35.00	200.00	140.00	30.00	**1300**
C5	1.03	90.00	8.18	0.30	6.00	25.00	12.00	1.79	900.00	16.00	31.00	180.00	17.00	230.00
C6	1.24	120.00	5.31	2.40	9.00	86.00	30.00	2.70	870.00	32.00	140.00	130.00	26.00	**970**
C7	0.98	97.00	5.19	3.30	8.00	85.00	29.00	2.35	1000.00	30.00	120.00	120.00	21.00	**940**
C8	1.10	100.00	5.54	4.90	9.00	**110**	31.00	2.74	1000.00	35.00	160.00	130.00	25.00	**1400**
C9	0.54	47.00	4.38	2.20	5.00	46.00	9.00	1.42	590.00	19.00	58.00	92.00	11.00	740.00
C10	1.40	135.00	5.77	4.30	10.00	**125**	33.00	3.07	**1200**	39.00	210.00	150.00	32.00	**1500**
C11	0.76	69.00	4.69	1.40	7.00	46.00	21.00	1.73	770.00	22.00	77.00	100.00	20.00	**530**
C12	1.17	120.00	6.07	3.30	9.00	**125**	39.00	3.04	**1200**	34.00	190.00	150.00	29.00	**1300**
C13	1.21	120.00	6.03	3.50	9.00	**125**	35.00	2.92	**1200**	37.00	190.00	150.00	32.00	**1400**
C14	1.10	110.00	5.20	2.80	9.00	100.00	31.00	2.64	**1200**	33.00	160.00	130.00	27.00	**1100**
C15	1.42	130.00	5.65	4.10	10.00	**120**	30.00	3.01	**1100**	38.00	195.00	150.00	33.00	**1400**
C16	0.97	83.00	3.90	5.30	9.00	**120**	22.00	3.33	**1100**	41.00	190.00	93.00	23.00	**1900**
C17	1.38	130.00	5.41	4.40	10.00	**130**	32.00	3.20	**1300**	40.00	220.00	140.00	36.00	**1500**
C18	1.25	120.00	5.60	3.00	10.00	**110**	30.00	2.92	**1400**	34.00	180.00	150.00	31.00	**1200**
C19	1.43	130.00	5.22	3.10	10.00	100.00	25.00	3.03	**1200**	36.00	170.00	150.00	34.00	**1100**
C21	1.54	140.00	5.07	3.70	11.00	**110**	27.00	3.17	**1200**	39.00	190.00	140.00	37.00	**1300**
C22	1.51	140.00	4.83	3.10	11.00	94.00	24.00	3.09	**1300**	38.00	180.00	140.00	36.00	**1100**
C23	0.62	57.00	4.03	1.10	5.00	30.00	13.00	1.42	680.00	15.00	66.00	95.00	15.00	470.00
C24	1.61	150.00	4.46	6.00	12.00	**110**	28.00	3.94	**1100**	44.00	240.00	130.00	30.00	**1700**
C25	1.47	130.00	5.78	4.50	13.00	**130**	29.00	3.28	**1400**	44.00	220.00	150.00	36.00	**1600**
C26	1.52	140.00	5.44	3.80	11.00	**120**	26.00	3.29	**1500**	42.00	200.00	150.00	38.00	**1400**
C27	1.12	100.00	6.21	3.60	8.00	62.00	25.00	2.33	920.00	29.00	130.00	150.00	24.00	**890**
C28	1.62	140.00	5.22	3.10	11.00	84.00	21.00	2.96	**1000**	38.00	150.00	150.00	34.00	**1000**
C29	1.54	140.00	6.11	4.30	12.00	**120**	26.00	3.27	**1300**	43.00	210.00	150.00	33.00	**1700**
C30	1.63	140.00	6.12	3.80	12.00	96.00	23.00	3.13	**1300**	44.00	180.00	150.00	34.00	**1400**
C31	1.27	110.00	5.57	2.80	9.00	59.00	21.00	2.41	990.00	32.00	120.00	130.00	24.00	**890**
C32	0.34	28.00	3.75	1.60	5.00	11.00	4.00	1.11	410.00	13.00	27.00	49.00	6.00	545.00
C32-A	0.60	51.00	6.88	1.80	5.00	27.00	9.00	1.23	470.00	21.00	45.00	130.00	11.00	650.00
C33	1.57	130.00	6.07	2.50	11.00	69.00	19.00	2.66	960.00	37.00	120.00	160.00	29.00	**960**
C34	0.96	110.00	9.73	1.50	9.00	33.00	17.00	1.68	660.00	28.00	66.00	230.00	19.00	570.00
C35	1.21	96.00	6.06	1.10	8.00	26.00	16.00	1.87	640.00	25.00	56.00	160.00	20.00	360.00
C36	0.47	44.00	4.97	1.00	4.00	20.00	13.00	0.99	470.00	11.00	42.00	100.00	10.00	280.00
C37	1.26	100.00	5.99	2.40	10.00	51.00	26.00	2.24	**1100**	33.00	105.00	150.00	22.00	850.00
C38	0.89	92.00	6.97	1.30	7.00	51.00	14.00	1.78	1000.00	21.00	85.00	150.00	19.00	590.00
C39	0.98	110.00	5.73	9.10	9.00	48.00	60.00	5.49	**1500**	20.00	**1100**	130.00	15.00	**5100**
C40	1.29	135.00	7.39	3.40	9.00	**140**	47.00	2.88	720.00	29.00	200.00	180.00	23.00	**1300**
HH1	0.59	46.00	4.96	2.30	5.00	35.00	11.00	1.37	630.00	18.00	46.00	98.00	10.00	560.00
HH2	1.00	150.00	5.69	1.70	7.00	39.00	34.00	1.97	580.00	25.00	53.00	150.00	15.00	430.00
HH3	0.86	110.00	6.80	3.70	7.00	53.00	39.00	2.07	810.00	24.00	67.00	130.00	15.00	610.00
HH4	0.77	68.00	5.51	1.60	5.00	39.00	18.00	1.49	700.00	21.00	54.00	110.00	13.00	450.00
HH5	1.44	120.00	5.19	2.00	10.00	75.00	27.00	2.69	750.00	31.00	120.00	130.00	24.00	**860**
HH7	1.13	110.00	6.49	2.40	8.00	80.00	35.00	2.55	880.00	26.00	140.00	150.00	20.00	**880**
HH8	1.05	110.00	8.10	1.80	8.00	59.00	57.00	2.15	940.00	22.00	130.00	200.00	19.00	730.00
HH9	1.45	130.00	5.80	2.80	88.00	**110**	43.00	2.63	690.00	31.00	170.00	160.00	22.00	**1100**
HH10	0.95	89.00	4.42	1.00	7.00	58.00	28.00	1.77	490.00	25.00	57.00	110.00	17.00	360.00
HH11	1.35	120.00	5.74	3.10	10.00	100.00	33.00	2.75	910.00	35.00	170.00	140.00	25.00	**1100**
HH12	1.36	120.00	5.26	5.50	10.00	**140**	44.00	3.02	**1100**	43.00	**240**	120.00	32.00	**1900**
HH13	1.41	130.00	5.35	5.20	11.00	**150**	38.00	3.13	**1200**	46.00	**260**	130.00	33.00	**1800**
HH14	1.54	150.00	6.00	5.40	12.00	**160**	43.00	3.37	**1400**	49.00	**280**	140.00	36.00	**2400**
AVERAGE	1.13	115.32	5.62	2.97	10.19	79.45	26.75	2.48	949.25	30.32	152.92	137.30	23.72	1076.32

Table 4. Comparison of summary statistics for selected trace elements in Hamilton Harbour sediments, 1993 (ug/g unless otherwise noted).

Location or criterion	Number of samp.	Cd[+]	Co	Cr	Cu	Fe(%)	Mn	Ni	Pb	Zn
H.H. (total)	**40**	**3.2**	**13.4**	**-**	**89.5**	**5.56**	**-**	**40.33**	**199**	**1451**
Ham. Harb. (extr.)	**53**	**2.99**	**10.19**	**79.4**	**26.7**	**2.48**	**949**	**30.32**	**153**	**1076**
<u>Western basin</u>										
Lake Ontario[1]	4	5.45	36.2	128	119	-	-	98	180	445
Lake Ontario[2]	9	-	18	107	108	4.76	990	84	130	407
Halifax Harbour (mean total conc.)	250	0.81	-	85.2	91	3.84	663	142	160	226
Vancouver[3]	145	0.63	-	42.5	236	3.35	-	27	59	149
Boston Harbour[4]	500	2.46	-		85.9	-	-	-	110	-
OMOE SEL*		10	-	110 (19)	110	4	1100(22)	75	250(3)	820(30)
OAET*		9	-	145 (20)	390	-	-	50	110(34)	270(51)

* For definitions see text. Values in brackets indicate number of stations in Table 3 that exceed the criterion. [+] Cd values contain many that were not detectable (ND) and were recorded as 0.59. [1] Nriagu et al., 1991; [2] Mudroch, 1993; [3] Median (50 percentile) concentration, for total harbour area (Goyette and Boyd, 1989; Table 3); [4] (Manheim and Hathaway, 1991)

Table 5. Statistical comparison between various parameters, Hamilton Harbour sediments.

	Total : extract.* R	Total : extract. Regr. slope	Total : grain size (%clay) R	Extract. : gr. size (%clay) R	Total : organics (LOI) R	Extract. : organ. (LOI) R
Al	0.62	0.29	0.58	0.91	0.39	0.85
Ba	0.04	0.00	0.10	0.04	0.00	0.00
Cd	0.97	0.81	0.66	0.65	0.70	0.66
Co	0.84	0.55	0.83	0.81	0.81	0.80
Cu	0.91	0.23	0.79	0.58	0.88	0.74
Fe	0.92	0.40	0.77	0.85	0.67	0.84
Pb	0.98	0.73	0.84	0.79	0.57	0.52
Ni	0.95	0.65	0.84	0.82	0.82	0.79
V	0.95	0.46	0.85	0.88	0.84	0.85
Zn	0.98	0.72	0.70	0.68	0.65	0.59
Org. (LOI)			0.75			

R = Pearson correlation coefficient

* Value of (N) for extractable elements is 53; for all others, 40.

APPENDIX

R E S U L T A T

	DESIGN:	93JPC-C1	93JPC-C2	93JPC-C3	93JPC-C4	93JPC-C5
	NO.LAB:	94 002659	94 002660	94 002661	94 002662	94 002663
C01	Ag	< 0,4 ppm	< 0,4 ppm	< 0,4 ppm	< 0,4 ppm	< 0,4 ppm
	Al	0,19 %	0,77 %	0,61 %	1,37 %	1,03 %
	B	<4 ppm	10 ppm	8 ppm	<4 ppm	<4 ppm
	Ba	500 ppm	86 ppm	49 ppm	140 ppm	90 ppm
	Be	<2 ppm	<2 ppm	<2 ppm	<2 ppm	<2 ppm
	Bi	<3 ppm	<3 ppm	<3 ppm	<3 ppm	<3 ppm
	Ca	2,73 %	5,68 %	4,77 %	5,08 %	8,18 %
	Cd	0,2 ppm	0,8 ppm	0,6 ppm	3,4 ppm	0,3 ppm
	Ce	17 ppm	42 ppm	31 ppm	46 ppm	37 ppm
	Co	7 ppm	6 ppm	6 ppm	11 ppm	6 ppm
	Cr	5 ppm	33 ppm	21 ppm	110 ppm	25 ppm
	Cu	3 ppm	18 ppm	16 ppm	34 ppm	12 ppm
	Eu	0,3 ppm	0,7 ppm	0,6 ppm	0,2 ppm	0,5 ppm
	Fe	0,33 %	1,56 %	1,25 %	3,26 %	1,79 %
	Ga	6 ppm	8 ppm	8 ppm	<3 ppm	<3 ppm
	Ge	<4 ppm	<4 ppm	<4 ppm	<4 ppm	<4 ppm
	K	0,09 %	0,34 %	0,29 %	0,55 %	0,39 %
	La	10 ppm	17 ppm	14 ppm	23 ppm	18 ppm
	Li	1 ppm	7 ppm	5 ppm	14 ppm	9 ppm
	Mg	0,35 %	0,88 %	0,81 %	0,94 %	0,75 %
	Mn	220 ppm	680 ppm	580 ppm	0,11 %	900 ppm
	Mo	<3 ppm	<3 ppm	<3 ppm	4 ppm	<3 ppm
	Na	<0,01 %	0,04 %	0,03 %	0,07 %	0,03 %
	Ni	8 ppm	20 ppm	16 ppm	35 ppm	16 ppm
	P	630 ppm	0,27 %	0,12 %	0,25 %	950 ppm
	Pb	11 ppm	47 ppm	37 ppm	200 ppm	31 ppm
	Sc	<1 ppm	2 ppm	2 ppm	<1 ppm	<1 ppm
	Sm	<1 ppm	3 ppm	3 ppm	<1 ppm	<1 ppm
	Sr	150 ppm	130 ppm	100 ppm	140 ppm	180 ppm
	Th	<2 ppm	<2 ppm	<2 ppm	<2 ppm	<2 ppm
	Ti	<0,01 %	0,01 %	<0,01 %	0,01 %	0,01 %
	V	4 ppm	16 ppm	14 ppm	30 ppm	17 ppm
	Y	5 ppm	10 ppm	9 ppm	<1 ppm	6 ppm
	Zn	100 ppm	360 ppm	240 ppm	0,13 %	230 ppm
	Zr	<1 ppm	2 ppm	3 ppm	<1 ppm	<1 ppm
	PAF	4 %	14 %	10 %	20 %	16 %

* * * * * * * * * * * * * * * * * * * R E S U L T A T * * * * * * * * * * * * * * * * *

	DESIGN:	93JPC-C6		93JPC-C7		93JPC-C8		93JPC-C9		93JPC-C10	
	NO.LAB:	94 002664		94 002665		94 002666		94 002667		94 002668	
C01	Ag	< 0,4	ppm	< 0,4	ppm	< 0,4	ppm	< 0,4	ppm	< 0,4	ppm
	Al	1,24	%	0,98	%	1,10	%	0,54	%	1,40	%
	B	13	ppm	12	ppm	12	ppm	7	ppm	11	ppm
	Ba	120	ppm	97	ppm	100	ppm	47	ppm	135	ppm
	Be	<2	ppm	<2	ppm	<2	ppm	<2	ppm	<2	ppm
	Bi	5	ppm	4	ppm	5	ppm	<3	ppm	<3	ppm
	Ca	5,31	%	5,19	%	5,54	%	4,38	%	5,77	%
	Cd	2,4	ppm	3,3	ppm	4,9	ppm	2,2	ppm	4,3	ppm
	Ce	47	ppm	43	ppm	44	ppm	26	ppm	50	ppm
	Co	9	ppm	8	ppm	9	ppm	5	ppm	10	ppm
	Cr	86	ppm	85	ppm	110	ppm	46	ppm	125	ppm
	Cu	30	ppm	29	ppm	31	ppm	9	ppm	33	ppm
	Eu	0,9	ppm	0,9	ppm	0,9	ppm	0,6	ppm	0,8	ppm
	Fe	2,70	%	2,35	%	2,74	%	1,42	%	3,07	%
	Ga	9	ppm	9	ppm	9	ppm	8	ppm	5	ppm
	Ge	<4	ppm	<4	ppm	<4	ppm	<4	ppm	<4	ppm
	K	0,51	%	0,42	%	0,45	%	0,25	%	0,57	%
	La	22	ppm	23	ppm	23	ppm	13	ppm	22	ppm
	Li	13	ppm	9	ppm	11	ppm	4	ppm	15	ppm
	Mg	0,91	%	0,91	%	0,89	%	0,68	%	0,85	%
	Mn	870	ppm	0,10	%	0,10	%	590	ppm	0,12	%
	Mo	<3	ppm	<3	ppm	4	ppm	<3	ppm	4	ppm
	Na	0,06	%	0,05	%	0,05	%	0,03	%	0,03	%
	Ni	32	ppm	30	ppm	35	ppm	19	ppm	39	ppm
	P	0,23	%	0,32	%	0,38	%	0,19	%	0,28	%
	Pb	140	ppm	120	ppm	160	ppm	58	ppm	210	ppm
	Sc	3	ppm	2	ppm	3	ppm	<1	ppm	7	ppm
	Sm	4	ppm	4	ppm	4	ppm	<2	ppm	5	ppm
	Sr	130	ppm	120	ppm	130	ppm	92	ppm	150	ppm
	Th	<2	ppm	<2	ppm	<2	ppm	<2	ppm	5	ppm
	Ti	0,01	%	0,01	%	0,01	%	<0,01	%	0,01	%
	V	26	ppm	21	ppm	25	ppm	11	ppm	32	ppm
	Y	12	ppm	11	ppm	11	ppm	7	ppm	4	ppm
	Zn	970	ppm	940	ppm	0,14	%	740	ppm	0,15	%
	Zr	4	ppm	4	ppm	2	ppm	2	ppm	2	ppm
	PAF	16	%	16	%	18	%	10	%	22	%

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* * * * * * * * * * * * * * * * * * *  R E S U L T A T * * * * * * * * * * * * * * * * * *
*                                                                                           *
*                ----------------   ----------------   ----------------   ----------------   ----------------   *
*       DESIGN:  93JFC-C11          93JFC-C12          93JFC-C13          93JFC-C14          93JFC-C15          *
*       NO.LAB:  94 002669          94 002670          94 002671          94 002672          94 002673          *
*                ----------------   ----------------   ----------------   ----------------   ----------------   *
*                                                                                           *
*  C01  Ag       < 0,4  ppm         < 0,4  ppm         < 0,4  ppm         < 0,4  ppm         < 0,4  ppm         *
*       Al         0,76 %             1,17 %             1,21 %             1,10 %             1,42 %           *
*       B         10    ppm          14    ppm          15    ppm          13    ppm          17    ppm          *
*       Ba        69    ppm         120    ppm         120    ppm         110    ppm         130    ppm          *
*       Be        <2    ppm          <2    ppm          <2    ppm          <2    ppm          <2    ppm          *
*       Bi        <3    ppm           5    ppm           5    ppm           5    ppm           6    ppm          *
*       Ca         4,69 %             6,07 %             6,03 %             5,20 %             5,65 %           *
*       Cd         1,4  ppm           3,3  ppm           3,5  ppm           2,8  ppm           4,1  ppm         *
*       Ce        33    ppm          43    ppm          43    ppm          42    ppm          49    ppm          *
*       Co         7    ppm           9    ppm           9    ppm           9    ppm          10    ppm          *
*       Cr        46    ppm         125    ppm         125    ppm         100    ppm         120    ppm          *
*       Cu        21    ppm          39    ppm          35    ppm          31    ppm          30    ppm          *
*       Eu         0,7  ppm           0,9  ppm           0,9  ppm           0,9  ppm           1,0  ppm         *
*       Fe         1,73 %             3,04 %             2,92 %             2,64 %             3,01 %           *
*       Ga         8    ppm          10    ppm          10    ppm           9    ppm          10    ppm          *
*       Ge        <4    ppm          <4    ppm          <4    ppm          <4    ppm          <4    ppm          *
*       K          0,35 %             0,48 %             0,51 %             0,47 %             0,59 %           *
*       La        16    ppm          21    ppm          21    ppm          21    ppm          25    ppm          *
*       Li         7    ppm          12    ppm          13    ppm          11    ppm          15    ppm          *
*       Mg         0,75 %             0,88 %             0,83 %             0,85 %             0,87 %           *
*       Mn       770    ppm           0,12 %             0,12 %             0,12 %             0,11 %           *
*       Mo        <3    ppm           4    ppm           4    ppm           3    ppm           4    ppm          *
*       Na         0,04 %             0,06 %             0,06 %             0,06 %             0,07 %           *
*       Ni        22    ppm          34    ppm          37    ppm          33    ppm          38    ppm          *
*       P          0,16 %             0,27 %             0,25 %             0,27 %             0,28 %           *
*       Pb        77    ppm         190    ppm         190    ppm         160    ppm         195    ppm          *
*       Sc         2    ppm           3    ppm           3    ppm           3    ppm           4    ppm          *
*       Sm         3    ppm           4    ppm           4    ppm           4    ppm           5    ppm          *
*       Sr       100    ppm         150    ppm         150    ppm         130    ppm         150    ppm          *
*       Th        <2    ppm          <2    ppm          <2    ppm          <2    ppm           3    ppm          *
*       Ti         0,01 %             0,01 %             0,01 %             0,01 %             0,01 %           *
*       V         20    ppm          29    ppm          32    ppm          27    ppm          33    ppm          *
*       Y          9    ppm          11    ppm          11    ppm          11    ppm          12    ppm          *
*       Zn       530    ppm           0,13 %             0,14 %             0,11 %             0,14 %           *
*       Zr         3    ppm           4    ppm           4    ppm           4    ppm           4    ppm          *
*       PAF       14    %            18    %            20    %            16    %            20    %            *
*                                                                                           *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * Page   5 de  16  * *
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* * * * * * * * * * * * * * * * * * R E S U L T A T * * * * * * * * * * * * * * * * * *

	DESIGN:	93JPC-C16		93JPC-C17		93JPC-C18		93JPC-C19		93JPC-C21	
	NO.LAB:	94 002674		94 002675		94 002676		94 002677		94 002678	
C01	Ag	< 0,4	ppm	< 0,4	ppm	< 0,4	ppm	< 0,4	ppm	< 0,4	ppm
	Al	0,97	%	1,38	%	1,25	%	1,43	%	1,54	%
	B	12	ppm	15	ppm	15	ppm	17	ppm	17	ppm
	Ba	83	ppm	130	ppm	120	ppm	130	ppm	140	ppm
	Be	<2	ppm	<2	ppm	<2	ppm	<2	ppm	<2	ppm
	Bi	5	ppm	6	ppm	5	ppm	6	ppm	5	ppm
	Ca	3,90	%	5,41	%	5,60	%	5,22	%	5,07	%
	Cd	5,3	ppm	4,4	ppm	3,0	ppm	3,1	ppm	3,7	ppm
	Ce	36	ppm	46	ppm	44	ppm	49	ppm	50	ppm
	Co	9	ppm	10	ppm	10	ppm	10	ppm	11	ppm
	Cr	120	ppm	130	ppm	110	ppm	100	ppm	110	ppm
	Cu	22	ppm	32	ppm	30	ppm	25	ppm	27	ppm
	Eu	0,8	ppm	1,0	ppm	0,9	ppm	1,0	ppm	1,0	ppm
	Fe	3,33	%	3,20	%	2,92	%	3,03	%	3,17	%
	Ga	8	ppm	10	ppm	10	ppm	10	ppm	10	ppm
	Ge	<4	ppm	<4	ppm	<4	ppm	<4	ppm	<4	ppm
	K	0,42	%	0,57	%	0,53	%	0,59	%	0,64	%
	La	18	ppm	23	ppm	22	ppm	25	ppm	25	ppm
	Li	10	ppm	14	ppm	13	ppm	16	ppm	17	ppm
	Mg	0,77	%	0,85	%	0,86	%	0,89	%	0,88	%
	Mn	0,11	%	0,13	%	0,14	%	0,12	%	0,12	%
	Mo	4	ppm	4	ppm	4	ppm	4	ppm	4	ppm
	Na	0,05	%	0,07	%	0,07	%	0,08	%	0,08	%
	Ni	41	ppm	40	ppm	34	ppm	36	ppm	39	ppm
	P	0,39	%	0,30	%	0,27	%	0,24	%	0,26	%
	Pb	190	ppm	220	ppm	180	ppm	170	ppm	190	ppm
	Sc	2	ppm	3	ppm	3	ppm	4	ppm	4	ppm
	Sm	4	ppm	4	ppm	4	ppm	5	ppm	5	ppm
	Sr	93	ppm	140	ppm	150	ppm	150	ppm	140	ppm
	Th	<2	ppm	<2	ppm	<2	ppm	3	ppm	3	ppm
	Ti	0,01	%	0,01	%	0,01	%	0,01	%	0,01	%
	V	23	ppm	36	ppm	31	ppm	34	ppm	37	ppm
	Y	10	ppm	11	ppm	11	ppm	12	ppm	12	ppm
	Zn	0,19	%	0,15	%	0,12	%	0,11	%	0,13	%
	Zr	3	ppm	5	ppm	4	ppm	4	ppm	4	ppm
	PAF	14	%	20	%	20	%	18	%	20	%

R E S U L T A T

	DESIGN:	93JPC-C22	93JPC-C23	93JPC-C24	93JPC-C25	93JPC-C26
	NO.LAB:	94 002679	94 002680	94 002681	94 002682	94 002683
C01	Ag	< 0,4 ppm	< 0,4 ppm	< 0,4 ppm	< 0,4 ppm	< 0,4 ppm
	Al	1,51 %	0,62 %	1,61 %	1,47 %	1,52 %
	B	18 ppm	10 ppm	15 ppm	14 ppm	17 ppm
	Ba	140 ppm	57 ppm	150 ppm	130 ppm	140 ppm
	Be	<2 ppm	<2 ppm	<2 ppm	<2 ppm	<2 ppm
	Bi	6 ppm	<3 ppm	7 ppm	7 ppm	6 ppm
	Ca	4,83 %	4,03 %	4,46 %	5,78 %	5,44 %
	Cd	3,1 ppm	1,1 ppm	6,0 ppm	4,5 ppm	3,8 ppm
	Ce	50 ppm	29 ppm	52 ppm	48 ppm	50 ppm
	Co	11 ppm	5 ppm	12 ppm	13 ppm	11 ppm
	Cr	94 ppm	30 ppm	110 ppm	130 ppm	120 ppm
	Cu	24 ppm	13 ppm	28 ppm	29 ppm	26 ppm
	Eu	1,0 ppm	0,6 ppm	1,1 ppm	1,0 ppm	1,0 ppm
	Fe	3,09 %	1,42 %	3,94 %	3,28 %	3,29 %
	Ga	10 ppm	8 ppm	10 ppm	11 ppm	10 ppm
	Ge	<4 ppm	<4 ppm	<4 ppm	<4 ppm	<4 ppm
	K	0,62 %	0,29 %	0,64 %	0,60 %	0,63 %
	La	25 ppm	13 ppm	27 ppm	25 ppm	25 ppm
	Li	16 ppm	5 ppm	17 ppm	16 ppm	16 ppm
	Mg	0,90 %	0,68 %	0,90 %	0,87 %	0,88 %
	Mn	0,13 %	680 ppm	0,11 %	0,14 %	0,15 %
	Mo	4 ppm	<3 ppm	5 ppm	4 ppm	4 ppm
	Na	0,08 %	0,03 %	0,08 %	0,08 %	0,08 %
	Ni	38 ppm	15 ppm	44 ppm	44 ppm	42 ppm
	P	0,26 %	0,13 %	0,27 %	0,31 %	0,28 %
	Pb	180 ppm	66 ppm	240 ppm	220 ppm	200 ppm
	Sc	4 ppm	2 ppm	4 ppm	4 ppm	4 ppm
	Sm	5 ppm	3 ppm	5 ppm	5 ppm	5 ppm
	Sr	140 ppm	95 ppm	130 ppm	150 ppm	150 ppm
	Th	3 ppm	<2 ppm	3 ppm	3 ppm	3 ppm
	Ti	0,01 %	0,01 %	0,01 %	0,01 %	0,01 %
	V	36 ppm	15 ppm	30 ppm	36 ppm	38 ppm
	Y	12 ppm	8 ppm	13 ppm	12 ppm	12 ppm
	Zn	0,11 %	470 ppm	0,17 %	0,16 %	0,14 %
	Zr	4 ppm	4 ppm	4 ppm	4 ppm	4 ppm
	PAF	20 %	12 %	18 %	22 %	20 %

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* * * * * * * * * * * * * * * * * * *  R E S U L T A T * * * * * * * * * * * * * * * * * *
*                                                                                          *
*                ..............     ..............     ..............     ..............     ..............  *
*      DESIGN:   93JPC-C27          93JPC-C28          93JPC-C29          93JPC-C30          93JPC-C31       *
*      NO.LAB:   94 002684          94 002685          94 002686          94 002687          94 002688       *
*                ..............     ..............     ..............     ..............     ..............  *
*                                                                                          *
* CO1  Ag        < 0,4  ppm         < 0,4  ppm         < 0,4  ppm         < 0,4  ppm         < 0,4  ppm     *
*      Al          1,12 %             1,62 %             1,54 %             1,63 %             1,27 %       *
*      B          13    ppm         17     ppm         15     ppm          9     ppm         13     ppm     *
*      Ba        100    ppm        140     ppm        140     ppm        140     ppm        110     ppm     *
*      Be         <2    ppm         <2     ppm         <2     ppm         <2     ppm         <2     ppm     *
*      Bi          4    ppm          5     ppm          6     ppm          5     ppm          4     ppm     *
*      Ca          6,21 %             5,22 %             6,11 %             6,12 %             5,57 %       *
*      Cd          3,6  ppm           3,1  ppm           4,3  ppm           3,8  ppm           2,8  ppm     *
*      Ce         42    ppm         52     ppm         51     ppm         57     ppm         47     ppm     *
*      Co          8    ppm         11     ppm         12     ppm         12     ppm          9     ppm     *
*      Cr         62    ppm         84     ppm        120     ppm         96     ppm         59     ppm     *
*      Cu         25    ppm         21     ppm         26     ppm         23     ppm         21     ppm     *
*      Eu          0,9  ppm           1,1  ppm           1,0  ppm           0,8  ppm           1,0  ppm     *
*      Fe          2,33 %             2,96 %             3,27 %             3,13 %             2,41 %       *
*      Ga         10    ppm         10     ppm         11     ppm          5     ppm         10     ppm     *
*      Ge         <4    ppm         <4     ppm         <4     ppm         <4     ppm         <4     ppm     *
*      K           0,46 %             0,66 %             0,60 %             0,63 %             0,50 %       *
*      La         21    ppm         28     ppm         26     ppm         27     ppm         24     ppm     *
*      Li         10    ppm         17     ppm         17     ppm         17     ppm         13     ppm     *
*      Mg          0,93 %             0,96 %             0,93 %             1,02 %             1,05 %       *
*      Mn        920    ppm           0,10 %             0,13 %             0,13 %           990     ppm     *
*      Mo          3    ppm          4     ppm          4     ppm          4     ppm          3     ppm     *
*      Na          0,06 %             0,08 %             0,08 %             0,08 %             0,07 %       *
*      Ni         29    ppm         38     ppm         43     ppm         44     ppm         32     ppm     *
*      P           0,21 %             0,22 %             0,30 %             0,29 %             0,25 %       *
*      Pb        130    ppm        150     ppm        210     ppm        180     ppm        120     ppm     *
*      Sc          3    ppm          4     ppm          4     ppm          8     ppm          3     ppm     *
*      Sm          4    ppm          5     ppm          5     ppm          5     ppm          5     ppm     *
*      Sr        150    ppm        150     ppm        150     ppm        150     ppm        130     ppm     *
*      Th         <2    ppm          3     ppm          3     ppm          5     ppm         <2     ppm     *
*      Ti          0,01 %             0,01 %             0,01 %             0,01 %             0,01 %       *
*      V          24    ppm         34     ppm         33     ppm         34     ppm         24     ppm     *
*      Y          11    ppm         13     ppm         13     ppm          4     ppm         12     ppm     *
*      Zn        890    ppm           0,10 %             0,17 %             0,14 %           890     ppm     *
*      Zr          3    ppm          3     ppm          3     ppm          2     ppm          3     ppm     *
*      PAF        14    %           18     %           20     %           20     %           16     %       *
*                                                                                          *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *  Page  11 de  16  * *
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* * * * * * * * * * * * * * * * * * * *  R E S U L T A T * * * * * * * * * * * * * * * * * * * *
*                                                                                                 *
*            ..................   ..................   ..................   ..................   ..................  *
*     DESIGN: 93JFC-C32-1       93JFC-C32-2          93JFC-C33            93JFC-C34            93JFC-C35           *
*     NO.LAB: 94 002689         94 002690            94 002691            94 002692            94 002693           *
*            ..................   ..................   ..................   ..................   ..................  *
*                                                                                                 *
* C01 Ag    < 0,4  ppm    < 0,4  ppm    < 0,4  ppm    < 0,4  ppm    < 0,4  ppm   *
*     Al      0,34 %        0,60 %        1,57 %        0,96 %        1,21 %     *
*     B      <4    ppm     <4    ppm     10    ppm      6    ppm     10    ppm   *
*     Ba     28    ppm     51    ppm    130    ppm    110    ppm     96    ppm   *
*     Be     <2    ppm     <2    ppm     <2    ppm     <2    ppm     <2    ppm   *
*     Bi     <3    ppm      5    ppm      5    ppm      4    ppm     <3    ppm   *
*     Ca      3,75 %        6,88 %        6,07 %        9,73 %        6,06 %     *
*     Cd      1,6  ppm      1,8  ppm      2,5  ppm      1,5  ppm      1,1  ppm   *
*     Ce     19    ppm     53    ppm     54    ppm     45    ppm     26    ppm   *
*     Co      5    ppm      5    ppm     11    ppm      9    ppm      8    ppm   *
*     Cr     11    ppm     27    ppm     69    ppm     33    ppm     26    ppm   *
*     Cu      4    ppm      9    ppm     19    ppm     17    ppm     16    ppm   *
*     Eu      0,5  ppm      1,1  ppm      0,8  ppm      0,9  ppm      0,5  ppm   *
*     Fe      1,11 %        1,23 %        2,66 %        1,68 %        1,87 %     *
*     Ga      7    ppm     11    ppm     10    ppm     10    ppm      7    ppm   *
*     Ge     <4    ppm     <4    ppm     <4    ppm     <4    ppm     <4    ppm   *
*     K       0,14 %        0,26 %        0,61 %        0,41 %        0,46 %     *
*     La      8    ppm     14    ppm     25    ppm     19    ppm     21    ppm   *
*     Li      2    ppm     16    ppm     16    ppm     11    ppm     11    ppm   *
*     Mg      0,34 %        0,65 %        0,98 %        1,07 %        1,00 %     *
*     Mn    410    ppm    470    ppm    960    ppm    660    ppm    640    ppm   *
*     Mo     <3    ppm     <3    ppm      3    ppm     <3    ppm     <3    ppm   *
*     Na      0,02 %        0,08 %        0,03 %        0,06 %        0,03 %     *
*     Ni     13    ppm     21    ppm     37    ppm     28    ppm     25    ppm   *
*     P     800    ppm      0,12 %        0,21 %        0,17 %        0,11 %     *
*     Pb     27    ppm     45    ppm    120    ppm     66    ppm     56    ppm   *
*     Sc     <1    ppm      4    ppm      8    ppm      4    ppm     <1    ppm   *
*     Sm      2    ppm      5    ppm      5    ppm      4    ppm      2    ppm   *
*     Sr     49    ppm    130    ppm    160    ppm    230    ppm    160    ppm   *
*     Th     <2    ppm      3    ppm      6    ppm     <2    ppm     <2    ppm   *
*     Ti     <0,01 %       <0,01 %        0,01 %       <0,01 %        0,01 %     *
*     V       6    ppm     11    ppm     29    ppm     19    ppm     20    ppm   *
*     Y       6    ppm     13    ppm      4    ppm     12    ppm      8    ppm   *
*     Zn    545    ppm    650    ppm    960    ppm    570    ppm    360    ppm   *
*     Zr     <1    ppm      4    ppm      2    ppm      4    ppm      2    ppm   *
*     PAF     4    %       10    %       18    %       18    %       14    %     *
*                                                                                 *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * Page  13 de  16  * *
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RESULTAT

	DESIGN:	93JFC-C36	93JFC-C37	93JFC-C38	93JFC-C39	93JFC-C40
	NO.LAB:	94 002694	94 002695	94 002696	94 002697	94 002698
C01	Ag	< 0,4 ppm	< 0,4 ppm	< 0,4 ppm	< 0,4 ppm	< 0,4 ppm
	Al	0,47 %	1,26 %	0,89 %	0,98 %	1,29 %
	B	<4 ppm	15 ppm	11 ppm	25 ppm	16 ppm
	Ba	44 ppm	100 ppm	92 ppm	110 ppm	135 ppm
	Be	<2 ppm	<2 ppm	<2 ppm	<2 ppm	<2 ppm
	Bi	4 ppm	4 ppm	18 ppm	5 ppm	5 ppm
	Ca	4,97 %	5,99 %	6,97 %	5,73 %	7,39 %
	Cd	1,0 ppm	2,4 ppm	1,3 ppm	9,1 ppm	3,4 ppm
	Ce	45 ppm	45 ppm	36 ppm	40 ppm	41 ppm
	Co	4 ppm	10 ppm	7 ppm	9 ppm	9 ppm
	Cr	20 ppm	51 ppm	51 ppm	48 ppm	140 ppm
	Cu	13 ppm	26 ppm	14 ppm	60 ppm	47 ppm
	Eu	1,0 ppm	0,7 ppm	0,8 ppm	0,9 ppm	0,8 ppm
	Fe	0,99 %	2,24 %	1,78 %	5,49 %	2,88 %
	Ga	10 ppm	9 ppm	9 ppm	10 ppm	9 ppm
	Ge	<4 ppm	<4 ppm	<4 ppm	<4 ppm	<4 ppm
	K	0,19 %	0,48 %	0,36 %	0,19 %	0,45 %
	La	11 ppm	21 ppm	16 ppm	12 ppm	19 ppm
	Li	4 ppm	9 ppm	9 ppm	8 ppm	10 ppm
	Mg	0,63 %	1,03 %	0,77 %	0,76 %	0,90 %
	Mn	470 ppm	0,11 %	0,10 %	0,15 %	720 ppm
	Mo	<3 ppm	3 ppm	<3 ppm	7 ppm	3 ppm
	Na	0,06 %	0,05 %	0,03 %	0,07 %	0,05 %
	Ni	11 ppm	33 ppm	21 ppm	20 ppm	29 ppm
	P	0,12 %	0,19 %	0,15 %	0,29 %	0,28 %
	Pb	42 ppm	105 ppm	85 ppm	0,11 %	200 ppm
	Sc	3 ppm	2 ppm	<1 ppm	3 ppm	2 ppm
	Sm	4 ppm	3 ppm	4 ppm	4 ppm	4 ppm
	Sr	100 ppm	150 ppm	150 ppm	130 ppm	180 ppm
	Th	<2 ppm	<2 ppm	<2 ppm	<2 ppm	<2 ppm
	Ti	<0,01 %	0,01 %	0,01 %	0,01 %	0,01 %
	V	10 ppm	22 ppm	19 ppm	15 ppm	23 ppm
	Y	12 ppm	10 ppm	9 ppm	12 ppm	11 ppm
	Zn	280 ppm	850 ppm	590 ppm	0,51 %	0,13 %
	Zr	2 ppm	2 ppm	5 ppm	2 ppm	5 ppm
	PAF	8 %	12 %	12 %	22 %	18 %

	DESIGN:	93JPCHH1		0-2CM93JPCHH2		0-2CM93JPCHH3		0-2CM93JPCHH4		0-2CM93JPCHH5		0-2CM
	NO.LAB:	94 003298		94 003299		94 003300		94 003301		94 003302		
C01	Ag	<0,4	ppm	<0,4	ppm	<0,4	ppm	<0,4	ppm	<0,4	ppm	
	Al	0,59	%	1,00	%	0,86	%	0,77	%	1,44	%	
	B	6	ppm	8	ppm	7	ppm	7	ppm	10	ppm	
	Ba	46	ppm	150	ppm	110	ppm	68	ppm	120	ppm	
	Be	<2	ppm	<2	ppm	<2	ppm	<2	ppm	<2	ppm	
	Bi	<3	ppm	4	ppm	4	ppm	3	ppm	5	ppm	
	Ca	4,96	%	5,69	%	6,80	%	5,51	%	5,19	%	
	Cd	2,3	ppm	1,7	ppm	3,7	ppm	1,6	ppm	2	ppm	
	Ce	28	ppm	51	ppm	42	ppm	34	ppm	44	ppm	
	Co	5	ppm	7	ppm	7	ppm	5	ppm	10	ppm	
	Cr	35	ppm	39	ppm	53	ppm	39	ppm	75	ppm	
	Cu	11	ppm	34	ppm	39	ppm	18	ppm	27	ppm	
	Eu	0,6	ppm	0,7	ppm	0,7	ppm	0,6	ppm	0,9	ppm	
	Fe	1,37	%	1,97	%	2,07	%	1,49	%	2,69	%	
	Ga	7	ppm	8	ppm	8	ppm	8	ppm	9	ppm	
	Ge	<4	ppm	<4	ppm	<4	ppm	<4	ppm	<4	ppm	
	K	0,27	%	0,43	%	0,37	%	0,34	%	0,59	%	
	La	13	ppm	17	ppm	15	ppm	14	ppm	21	ppm	
	Li	4	ppm	8	ppm	7	ppm	6	ppm	13	ppm	
	Mg	0,7	%	0,81	%	0,78	%	0,80	%	0,88	%	
	Mn	630	ppm	580	ppm	810	ppm	700	ppm	750	ppm	
	Mo	<3	ppm	3	ppm	3	ppm	<3	ppm	3	ppm	
	Na	0,03	%	0,05	%	0,04	%	0,03	%	0,06	%	
	Ni	18	ppm	25	ppm	24	ppm	21	ppm	31	ppm	
	P	0,24	%	0,45	%	0,50	%	0,23	%	0,21	%	
	Pb	46	ppm	53	ppm	67	ppm	54	ppm	120	ppm	
	Sc	1	ppm	2	ppm	2	ppm	2	ppm	3	ppm	
	Sm	3	ppm	3	ppm	3	ppm	3	ppm	4	ppm	
	Sr	98	ppm	150	ppm	130	ppm	110	ppm	130	ppm	
	Th	<2	ppm	<2	ppm	<2	ppm	<2	ppm	2	ppm	
	Ti	<0,01	%	<0,01	%	<0,01	%	<0,01	%	0,01	%	
	V	10	ppm	15	ppm	15	ppm	13	ppm	24	ppm	
	Y	9	ppm	10	ppm	9	ppm	9	ppm	11	ppm	
	Zn	560	ppm	430	ppm	610	ppm	450	ppm	860	ppm	
	Zr	3	ppm	2	ppm	1	ppm	3	ppm	5	ppm	
	PAF	18	%	4	%	14	%	12	%	12	%	

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*                                                                                         *
*                                                                                         *
*     DESIGN: H93JPCHH7 O-2CM93JPCHH8  O-2CM93JPCHH9  O-2CM93JPCHH10 O-2CM93JPCHH11 O-2CM*
*     NO.LAB: 94 003303     94 003304      94 003305      94 003306      94 003307        *
*                                                                                         *
*                                                                                         *
* C01 Ag       <0,4  ppm     <0,4  ppm     <0,4  ppm     <0,4  ppm     <0,4  ppm          *
*     Al        1,13 %        1,05 %        1,45 %        0,95 %        1,35 %            *
*     B        9     ppm     9     ppm     11    ppm     8     ppm     10    ppm          *
*     Ba       110   ppm     110   ppm     130   ppm     89    ppm     120   ppm          *
*     Be       <2    ppm     <2    ppm     <2    ppm     <2    ppm     <2    ppm          *
*     Bi       4     ppm     3     ppm     5     ppm     3     ppm     5     ppm          *
*     Ca        6,49 %        8,10 %        5,80 %        4,42 %        5,74 %            *
*     Cd        2,4  ppm      1,8  ppm      2,8  ppm     1     ppm      3,1  ppm          *
*     Ce       35    ppm     33    ppm     41    ppm     31    ppm     43    ppm          *
*     Co       8     ppm     8     ppm     8     ppm     7     ppm     10    ppm          *
*     Cr       80    ppm     59    ppm     110   ppm     58    ppm     100   ppm          *
*     Cu       35    ppm     57    ppm     43    ppm     28    ppm     33    ppm          *
*     Eu        0,8  ppm      0,7  ppm      0,9  ppm      0,7  ppm      0,8  ppm          *
*     Fe        2,55 %        2,15 %        2,63 %        1,77 %        2,75 %            *
*     Ga       9     ppm     9     ppm     9     ppm     8     ppm     9     ppm          *
*     Ge       <4    ppm     <4    ppm     <4    ppm     <4    ppm     <4    ppm          *
*     K         0,46 %        0,4  %        0,55 %        0,35 %        0,55 %            *
*     La       17    ppm     16    ppm     21    ppm     15    ppm     20    ppm          *
*     Li       10    ppm     9     ppm     12    ppm     8     ppm     12    ppm          *
*     Mg        0,77 %        0,67 %        0,90 %        0,82 %        0,81 %            *
*     Mn       880   ppm     940   ppm     690   ppm     490   ppm     910   ppm          *
*     Mo       3     ppm     <3    ppm     3     ppm     <3    ppm     3     ppm          *
*     Na        0,05 %        0,05 %        0,06 %        0,04 %        0,06 %            *
*     Ni       26    ppm     22    ppm     31    ppm     25    ppm     35    ppm          *
*     P         0,21 %        0,14 %        0,25 %        0,21 %        0,23 %            *
*     Pb       140   ppm     130   ppm     170   ppm     57    ppm     170   ppm          *
*     Sc       2     ppm     3     ppm     3     ppm     2     ppm     3     ppm          *
*     Sm       4     ppm     3     ppm     4     ppm     3     ppm     4     ppm          *
*     Sr       150   ppm     200   ppm     160   ppm     110   ppm     140   ppm          *
*     Th       2     ppm     <2    ppm     2     ppm     <2    ppm     2     ppm          *
*     Ti        0,01 %        0,01 %        0,01 %        0,01 %        0,01 %            *
*     V        20    ppm     19    ppm     22    ppm     17    ppm     25    ppm          *
*     Y        10    ppm     10    ppm     11    ppm     9     ppm     10    ppm          *
*     Zn       880   ppm     730   ppm      0,11 %       360   ppm      0,11 %            *
*     Zr       4     ppm     4     ppm     5     ppm     5     ppm     4     ppm          *
*     PAF      20    %       16    %       16    %       12    %       14    %            *
*                                                                                         *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * Page   3 de   12 * *
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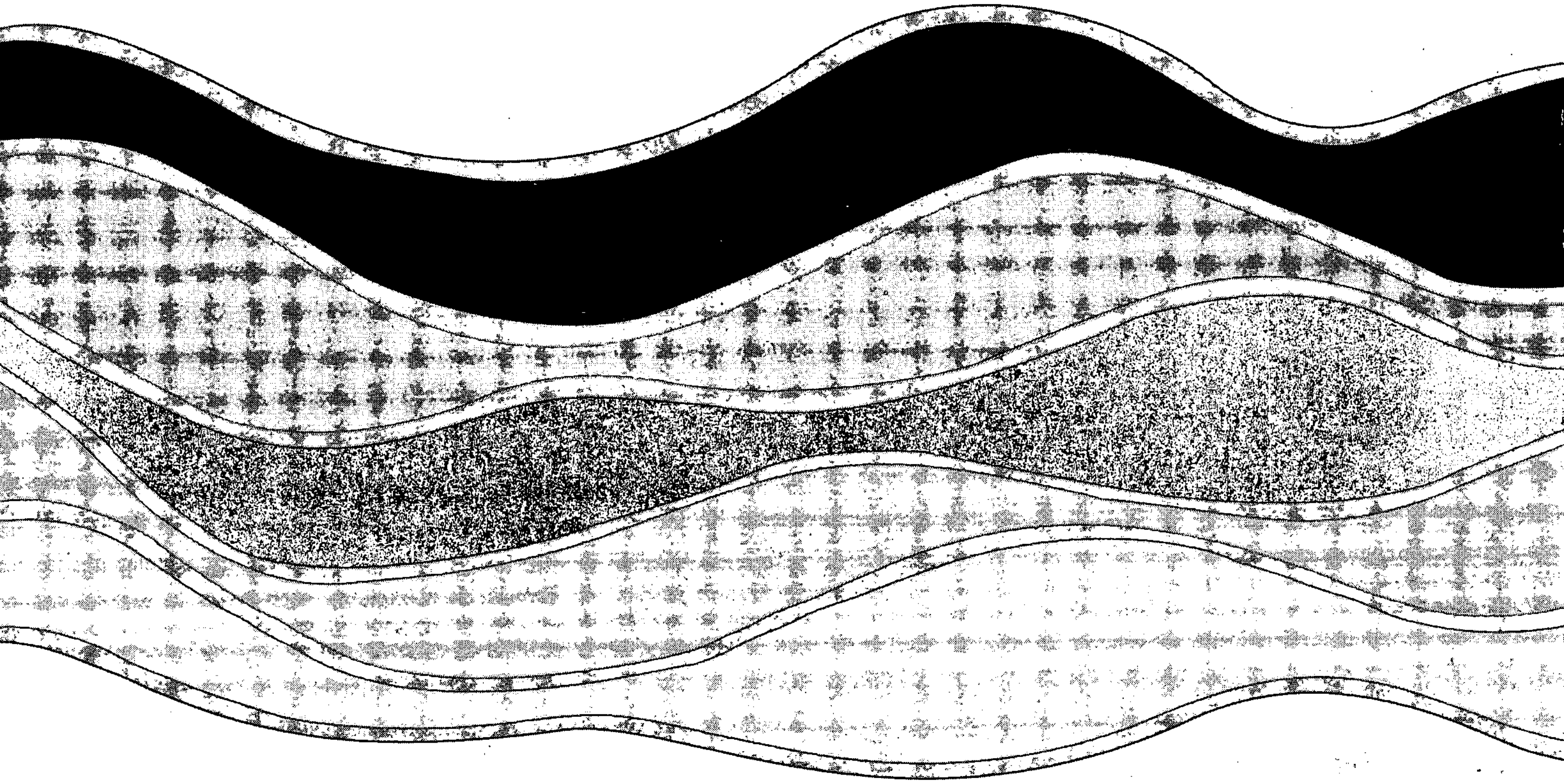
	DESIGN:	93JPCHH12 0-2CM	93JPCHH13 0-2CM	93JPCHH14 0-2CM	93JPC93-MR-1	93JPC93-MR-1(a)
	NO.LAB:	94 003308	94 003309	94 003310	94 003311	94 003312
CO1	Ag	<0,4 ppm	<0,4 ppm	<0,4 ppm	<0,4 ppm	<0,4 ppm
	Al	1,36 %	1,41 %	1,54 %	0,51 %	0,72 %
	B	12 ppm	11 ppm	18 ppm	8 ppm	8 ppm
	Ba	120 ppm	130 ppm	150 ppm	16 ppm	22 ppm
	Be	<2 ppm	<2 ppm	5 ppm	<2 ppm	<2 ppm
	Bi	5 ppm	5 ppm	6 ppm	<3 ppm	<3 ppm
	Ca	5,26 %	5,35 %	6 %	4,60 %	7,35 %
	Cd	5,5 ppm	5,2 ppm	5,4 ppm	0,9 ppm	0,8 ppm
	Ce	41 ppm	41 ppm	43 ppm	16 ppm	19 ppm
	Co	10 ppm	11 ppm	12 ppm	4 ppm	6 ppm
	Cr	150 ppm	140 ppm	160 ppm	11 ppm	13 ppm
	Cu	44 ppm	38 ppm	43 ppm	91 ppm	6 ppm
	Eu	0,9 ppm	0,9 ppm	1 ppm	0,3 ppm	0,3 ppm
	Fe	3,02 %	3,13 %	3,37 %	0,41 %	0,54 %
	Ga	9 ppm	9 ppm	10 ppm	8 ppm	8 ppm
	Ge	<4 ppm	<4 ppm	<4 ppm	<4 ppm	<4 ppm
	K	0,56 %	0,56 %	0,59 %	0,11 %	0,14 %
	La	21 ppm	21 ppm	23 ppm	7 ppm	8 ppm
	Li	12 ppm	13 ppm	14 ppm	4 ppm	5 ppm
	Mg	0,82 %	0,79 %	0,87 %	1,30 %	3,40 %
	Mn	0,11 %	0,12 %	0,14 %	150 ppm	190 ppm
	Mo	4 ppm	4 ppm	4 ppm	<3 ppm	<3 ppm
	Na	0,06 %	0,06 %	0,07 %	0,02 %	0,03 %
	Ni	43 ppm	46 ppm	49 ppm	6 ppm	9 ppm
	P	0,29 %	0,3 %	0,33 %	360 ppm	340 ppm
	Pb	240 ppm	260 ppm	280 ppm	3 ppm	5 ppm
	Sc	3 ppm	3 ppm	3 ppm	1 ppm	1 ppm
	Sm	4 ppm	4 ppm	<1 ppm	<1 ppm	1 ppm
	Sr	120 ppm	130 ppm	140 ppm	27 ppm	52 ppm
	Th	2 ppm	2 ppm	<2 ppm	<2 ppm	<2 ppm
	Ti	0,01 %	0,01 %	0,01 %	0,01 %	0,01 %
	V	32 ppm	33 ppm	36 ppm	8 ppm	11 ppm
	Y	11 ppm	10 ppm	11 ppm	4 ppm	4 ppm
	Zn	0,19 %	0,18 %	0,24 %	33 ppm	21 ppm
	Zr	5 ppm	4 ppm	5 ppm	3 ppm	4 ppm
	PAF	16 %	12 %	20 %	2 %	8 %



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