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TRANSPORT OF SELECTED ORGANOCHLORINE CONTAMINANTS IN THE NIAGARA RIVER PLUME

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NWRI Contribution No. 86-40

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EXECUTIVE SUMMARY

RÉSUMÉ ADMINISTRATIF

Transport of Selected Organochlorine Contaminants in the Niagara River Plume

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The dispersion of persistent organochlorine contaminants from the Niagara River into Lake Ontario was measured in 1982. This preliminary study indicated that a major portion of these contaminants are transported away from the rivermouth by a plume which varies in direction. Chlorobenzenes were chosen as the most suitable chemical markers of the plume for future studies.

This study extends other studies which have examined the sources of these contaminants and their loadings into Lake Ontario.

En 1982, on a étudié la dispersion dans le lac Ontario des polluants organochlorés persistants provenant de la rivière Niagara. Cette étude préliminaire a indiqué qu'une partie importante de ces polluants est emportée, à partir de l'embouchure de la rivière, par un panache dont la direction est variable. Des chlorobenzènes ont été choisis comme étant les indicateurs chimiques les plus appropriés du panache; ils seront utilisés à cette fin au cours des prochaines études.

Ce document fait suite à d'autres études qui portaient sur les sources de ces polluants et sur leurs charges dans le lac Ontario.

ABSTRACT

The dispersion of organochlorine contaminants into Lake Ontario by the Niagara River plume was examined on seven occasions in 1982. Water samples for organic contaminant analysis were collected from within a 12 x 40 km retangular sampling area at a depth of 1m. Simultaneous measurements of temperature, specific conductance and % light transmission were made. Of the seven most prominent organochlorines detected, 1,2,3,4-tetrachlorobenzene and 1,3,4-trichlorobenzene were judged suitable chemical markers of the plume. This was confirmed by comparing the spatial distribution of 1,2,3,4-tetrachlorobenzene with the physical measurements. The plume direction was found to vary but most commonly was directed easterly from the rivermouth along the shore. On several occasions, concentrations of 1,2,3,4-tetrachlorobenzene in the plume were found to be higher than in the river. It is suggested that diurnal fluctuations in concentration occur in the river due to the diversions of river water for hydroelectric plants.

TRANSPORT DE CERTAINS POLLUANTS ORGANOCHLORÉS
DANS LE PANACHE DE LA RIVIÈRE NIAGARA

M.E. Fox et J.H. Carey

RÉSUMÉ

En 1982, on a étudié à sept reprises la dispersion dans le lac Ontario des polluants organochlorés du panache de la rivière Niagara. Des échantillons d'eau ont été prélevés à une profondeur de 1 m dans une zone d'échantillonnage rectangulaire de 12 x 40 km, en vue du dosage les polluants organiques. On a relevé simultanément la température, la conductivité et le % de transmission lumineuse. Parmi les sept principaux composés organochlorés, ce sont le 1,2,3,4-tétrachlorobenzène et le 1,3,4-trichlorobenzène qui sont les indicateurs chimiques les plus appropriés, ce qui a été confirmé par comparaison de la répartition spatiale du 1,2,3,4-tétrachlorobenzène avec les mesures physiques. On a constaté que le panache avait une direction variable, mais que, le plus souvent, il était orienté vers l'est à partir de l'embouchure et longeait le rivage. A plusieurs occasions, la concentration de 1,2,3,4-tétrachlorobenzène était plus élevée dans le panache que dans la rivière. On avance que les variations diurnes de concentration dans la rivière sont dues à la dérivation de l'eau de la rivière vers les usines hydro-électriques.

INTRODUCTION

The Niagara River Toxics Committee (NRTC) has recently shown that the Niagara River contributes a significant load of synthetic organic contaminants to Lake Ontario (NRTC, 1983). There is considerable public concern over the presence of these contaminants and their possible effects on human health and the Lake Ontario ecosystem. Although many of these compounds are known from laboratory tests to be toxic, determining their actual effects is difficult because of the lack of site-specific knowledge of their pathways of transport, accumulation and degradation in the lake.

We have previously reported on the compartmental distribution of organochlorine contaminants from the Niagara River in western Lake Ontario. Ten chlorobenzenes, hexachlorobutadiene and PCBs were measured in Niagara River water and suspended solids, and in western Lake Ontario sediments and benthic fauna. Surficial sediment, interface water, benthos and fish were collected from five sites in Lake Ontario near the Niagara River mouth and a reference site in the western basin. The contaminants analysed were either undetectable or present at very low levels in water and suspended solids from Fort Erie indicating that the sources of these compounds were in the Niagara watershed. These results have been described in detail (Fox et al., 1983).

A study of the transport and fate of Niagara River contaminants from the river into Lake Ontario was begun in 1982.

It was intended that the results of this study be combined with results of concurrent studies of the factors controlling the direction and magnitude of the Niagara River plume and the extent of its interaction with Lake Ontario carried out by physical limnologists in the Aquatic Physics and Systems Division (APSD). The consolidation of these two studies will provide a unique description of contaminant dynamics in this area.

Prior to conducting detailed studies of contaminant dynamics in the Niagara River mouth area, it was necessary to determine which contaminants were suitable as markers of Niagara River water in the lake and suitable methods of detecting and sampling water in the Niagara River plume. The results of this feasibility study are reported here.

PROCEDURES

The study area was enclosed by a rectangle approximately 40 km east to west and 12 km north to south along the south shore of Lake Ontario with the mouth of the Niagara River approximately at the centre point. A network of sampling sites along six north-south transects was established within this rectangle. Sites were located at 2 km intervals along each transect as shown in Fig. 1. The network was biased towards the east since previous studies had shown that the Niagara River plume most often flowed in that direction (Murthy et al, 1969).

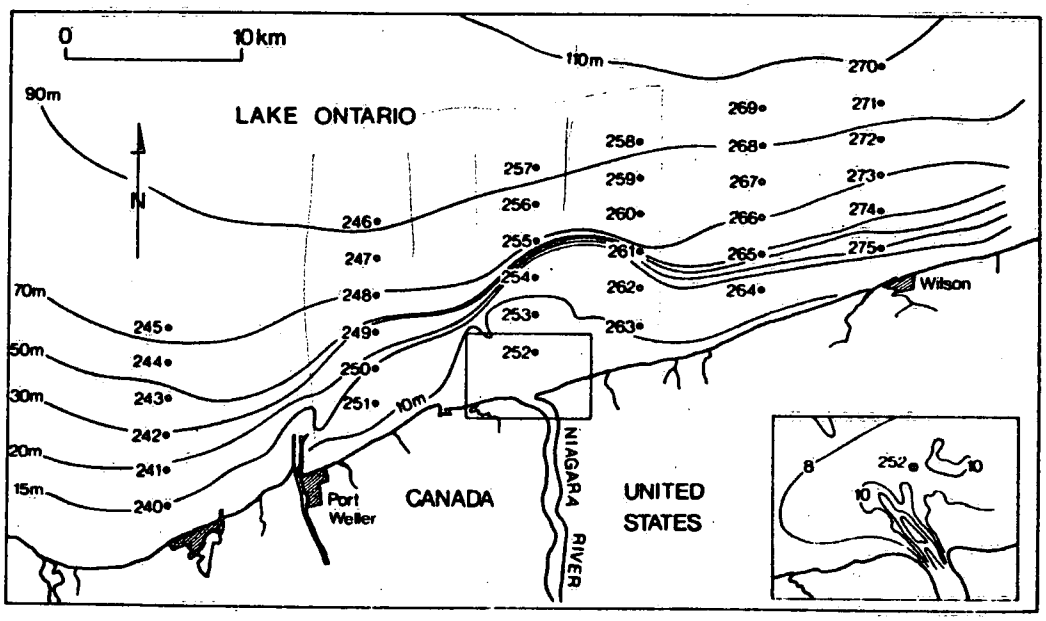

Fig 1. Map of the study area showing sampling locations

In 1982, the network was sampled in April, May, June, July, August, October and November. On each occasion, sampling was begun on the westernmost transect while up to 15 simple sail drogues were simultaneously deployed near Niagara-on-the-Lake, just off the river mouth. The drogues could not be released in the river because of shallow sand bars in the river mouth area. These drogue studies were part of a concurrent investigation of the interactions of the Niagara River inflow and the waters of Lake Ontario in the coastal zone by staff of the Aquatic Physics and Systems Division (APSD) of NWRI (Murthy et al., 1984).

At each site, 1 litre water samples were taken at 1m depth in precleaned glass bottles and 10 ml of hexane (Caledon Laboratories, DIG) were added. The bottles were sealed with teflon-lined screw caps and stored at 4 ^{o}C in the dark until analysis. The maximum storage time was four weeks. Concurrent temperature and light transparency (%T) profiles and measurements of surface conductivity were obtained as noted in Table 1. When

Table 1. Sampling Schedule

Date	River sample	%Trans.	Temp.	Cond.
April 15/16	-	+	+	+
May 12	+	+	+	+
June 22/23	-	-	+	+
July 5/6	+	+	+	+
August 10	+	+	+	+
October 5	+	+	+	+
November 9	+	+	+	+

- indicates operation not performed

operational conditions permitted, a sample of Niagara River water was collected 0.5 km upstream from the river mouth after completion of the transects. The overall sampling procedure usually required about 12 hours to complete.

In the laboratory, a teflon coated stir bar was added to each bottle and the samples were stirred vigorously for 30 min. The hexane layer was then transferred to a 15 ml centrifuge tube and evaporated at 25 ^{o}C to 2-3 ml. A further 10 ml of hexane was added to the extracted water and the extraction procedure repeated, combining the extracts. The combined extracts were evaporated to a final volume of 1.0 ml after the addition of 2 ml isooctane (Caledon Laboratories DIG) as a keeper.

The samples were analysed by gas chromatography on a Hewlett Packard 5880 gas chromatograph equipped with a model 7672A auto-sampler and a 25m x 0.20 mm i. d. fused silica column coated with 0.33 um OV-1. The oven was programmed from 90 ^{o}C to 260 ^{o}C at 4 degrees per minute. The injector was operated in the split mode (10:1 split ratio) at 250 ^{o}C. A ^{63}Ni electron capture detector was operated at 350 ^{o}C. Contaminant concentrations were calculated based on peak heights against an external standard containing the 27 organochlorine compounds listed in Table 2.

Table 2. Composition of external standard.

Compound	Concentration (ug/L)
1,3-dichlorobenzene *	2640
1,4-dichlorobenzene	
1,2-dichlorobenzene	1300
hexachloroethane	23
1,3,5-trichlorobenzene	134
1,2,4-trichlorobenzene	146
1,2,3-trichlorobenzene	182
hexachlorobutadiene	33
1,2,3,5-tetrachlorobenzene *	154
1,2,4,5-tetrachlorobenzene	
1,2,3,4-tetrachlorobenzene	94
pentachlorobenzene	92
α-BHC	80
hexachlorobenzene	100
lindane	86
heptachlor	98
aldrin	64
heptachlor epoxide	67
γ-chlordane	68
α-endosulfan	41
α-chlordane	57
dieldrin	40
p,p'-DDE	56
endrin	51
β-endosulfan	45
p,p'-DDE	55
p,p'-DDT	98
mirex	60

* these pairs were not resolved in this study

RESULTS AND DISCUSSION

In order to study the transport of organochlorine contaminants in the Niagara River plume, it was necessary to identify contaminants that could be used as markers of Niagara River water. Figure 2 shows electron capture chromatograms of extracts of surface water for a site within the plume (vide infra) and a second site well outside of the plume for the April cruise. Similar pairs of chromatograms for the remaining six cruises are shown in Figures 3 to 8 (Appendix 1). An examination of these chromatograms reveals that seven of the peaks corresponded to peaks in the standard. These peaks, numbered 1 to 7 on the Figures, and their corresponding identities were;

1. 1,2,4-trichlorobenzene
2. 1,2,3,5- and 1,2,4,5-tetrachlorobenzene
3. 1,2,3,4-tetrachlorobenzene
4. pentachlorobenzene
5. α-BHC
6. hexachlorobenzene
7. lindane (-BHC)

Concentrations of these compounds in unfiltered surface water at each site for the seven cruises are listed in Tables 3 to 9 (Appendix 2). Since the two BHC isomers were often present at significant levels throughout the study area, they were not useful as plume markers. The remaining compounds were all chlorobenzenes. Of these, the 1,2,3,5-, 1,2,4,5-, penta- and hexa- chloro isomers were present at levels too low to be of use. Either of the remaining two compounds, 1,2,4-trichlorobenzene and 1,2,3,4-tetrachlorobenzene, could be used as plume markers since they were present at significant levels only in the plume.

In addition to the collection of samples for chemical analyses, measurements of temperature, specific conductance and light transmission were made at each site on the sampling network. These measurements were made to provide information on the location of the Niagara River plume independent of the contaminant analyses. It was assumed that Lakes Erie and Ontario would differ in at least one of these parameters on any one occasion. The results of these measurements are listed in Tables 10 to 12 (Appendix 2) and presented in Figures 9 to 15 along with data on the distribution of 1,2,3,4-TTCB for comparison purposes.

During the first sampling cruise in April, water temperatures were very low with a difference of less than 2 ^{o}C between the highest and lowest values. Floating ice in the river mouth made water sampling in the river impossible. Light winds from the northwest pushed the plume to the east along the south shore as seen in the plotted data in Figure 9. The 1,2,3,4-TeCB in the plume was more than one order of magnitude higher than the lake background level to the west of the plume and exhibited a two-fold increase from 20 ng/L near the river mouth to greater than 40 ng/L on the easternmost transect. The light transmission isopleths showed moderately turbid (less than 40% T) Niagara River water flowing east along the south shore and mixing with high transparency (>80% T) Lake Ontario water.

During the May cruise, meteorological conditions were similar to those experienced in April. The isopleths for all four parameters in Fig. 10 showed profiles indicating that the

light westerly winds were pushing the plume once more in an easterly direction. On this occasion, the 1,2,3,4-TeCB decreased from the rivermouth high of 125 ng/L (> 10x the lake background level) to ~ 50 ng/L on the easternmost transect. The Niagara River water, at less than 1 °C, was colder by several degrees and somewhat more turbid than the receiving water.

Conditions were somewhat different for the June cruise. Winds from the south on the 21st of June and the southwest on the 22nd and 23rd resulted in a diffuse plume running almost straight offshore during the water sampling on June 22nd and 23rd. Transmission was not measured on this cruise. Isopleths for the other parameters are shown in Figure 11 and suggest a residual easterly plume with a more recent northerly component.

Similar behaviour was observed on the next cruise in July. North-easterly winds on the 4th and 5th gave way to southerly winds early on the 6th. The effect of these variable meteorological conditions on the plume are best seen in the 1,2,3,4-TeCB isopleth in Figure 12 in which two areas of high concentration, one to the west and one to the east of the rivermouth, can be observed. The specific conductance and temperature isopleths also exhibit this duality. The situation was further complicated by the small differences between lake water and river water for all four parameters which resulted in the plume being less well defined than on previous occasions.

In August, strong northwesterly winds produced an easterly flowing plume along the south shore. All four parameters showed this pattern (Fig. 13). Concentrations of 1,2,3,4-TeCB in the plume were greater than 20x the background lake concentration and

increased by 1.5x between the river and the easternmost transect. Temperature was the least useful parameter on this occasion because of the small difference ($< 2^{o}$) between the river and the lake.

The northerly flowing plume profile observed on the next cruise (Fig. 14) was produced by strong southeasterly winds. The isopleth gradients are weak for all parameters measured, although the concentration of 1,2,3,4-TeCB in the plume is >10x the background level of ~1 ng/L.

The last set of plume samples were collected on November 9th. A strongly defined easterly plume was observed (Fig. 15). This was produced by at least three days of strong northwesterly winds. The isopleths of all four parameters are strikingly similar. The levels of 1,2,3,4-TeCB in the plume immediately offshore from the rivermouth were nearly double those in the river.

On the seven occasions that the Niagara River plume was sampled for this study, the most common orientation was in an easterly direction, usually remaining close to the south shore. This agrees with the observations of Murthy (1969) and is a consequence of the most common wind direction (generally westerly) and the semipermanent easterly flowing currents anlong the south shore of Lake Ontario (Simons et al, XXXX). This orientation also produced the most coherent plumes.

As discussed above, 1,2,4-TCB and 1,2,3,4-TeCB were found to be the best contaminant tracers of Niagara River water into the lake. However, interpretation of the concentartion patterns was

made difficult by the fact that on five of the seven occasions, the concentration of 1,2,3,4-TeCB at a location in the plume was approximately two times higher than those in the river. It is currently believed that these effects are due to the daily fluctuations in water diversions from the upper Niagara River by U. S. and Canadian power authorities. As required by the Niagara River Treaty, the minimum flow over the Falls during the daylight hours is 2830 cms while the night-time minimum is 1410 cms. Thus, a constant contaminant discharge between the diversion structure and the hydroelectric plants would result in diurnal variations of concentration in the river. Unfortunately, this behaviour was unanticipated and therefore the sampling design did not take it into account. For all seven cruises in 1982, the lake samples were obtained prior to sampling the river. This sampling strategy tends to maximise these diurnal differences and gives the appearance of patches of higher concentration in the lake.

The above results lead to the following conclusions regarding further studies of contaminant transport in the Niagara River plume;

i) The sampling strategy should take into account the possibility of diurnal fluctuations in contaminant concentration. For example, a sound strategy would be to follow contaminant transport and fate in a 'plug' of water from the river into the lake.

ii) The two chlorobenzenes, 1,2,3,4-TeCB and 1,2,4-TCB, appear to be suitable as contaminant tracers of Niagara River water. However, their concentrations are close to detection

limits near the boundaries of the grid giving rise to analytical imprecision. The importance of this problem could be reduced by sampling larger volumes and using a suitable internal standard.

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Table 3. Concentration of 1,2,4-trichlorobenzene (ng/L) in unfiltered 1 m samples.

	1982 Cruise						
Station	#1	#2	#3	#4	#5	#6	#7
240	1	2	6	61	71	4	2
241	<1	<1	33	46	28	2	3
242	<1	3	25	46	129	2	7
243	2	4	43	35	27	3	7
244	2	7	48	35	7	2	19
245	<1	11	56	35	25	1	7
246	42	10	<1	37	118	4	4
247	27	5	7	41	35	5	8
248	39	8	19	37	33	10	6
249	42	5	29	35	28	15	8
250	40	<1	5	39	8	27	5
251	35	2	3	41	60	11	49
252	2	NS	7	<1	31	35	63
253	29	105	36	<1	45	12	50
254	7	114	34	<1	119	17	35
255	NS	86	1	40	109	15	5
256	<1	4	33	5	120	20	6
257	16	10	7	2	19	15	6
258	NS	6	2	<1	60	19	7
259	6	8	1	41	18	18	6
260	<1	39	1	7	17	2	7
261	1	105	27	37	129	18	5
262	28	112	46	3	NS	2	9
263	4	117	58	31	110	4	35
264	38	75	3	30	52	12	57
265	<1	50	34	35	112	7	13
266	2	133	9	35	121	9	24
267	<1	56	40	36	20	9	10
268	NS	28	31	32	138	8	21
269	2	5	32	34	129	9	6
270	34	7	34	41	86	12	11
271	32	9	33	44	105	5	4
272	43	5	37	35	28	13	6
273	38	7	6	30	103	8	8
274	35	94	1	40	21	12	14
275	70	90	36	35	74	12	44
276	NS	60	NS	40	55	29	29

Table 4. Concentration of 1,2,3,4-tetrachlorobenzene (ng/L) in unfiltered 1 m samples.

	1982 Cruise						
Station	#1	#2	#3	#4	#5	#6	#7
240	<1	5	4	5	7	7	<1
241	<1	2	4	6	2	3	2
242	<1	4	3	6	31	1	4
243	10	14	6	5	6	2	4
244	1	1	6	5	3	1	9
245	<1	15	8	6	2	1	4
246	6	4	<1	5	1	3	2
247	4	10	7	6	3	<1	4
248	7	7	3	12	5	7	3
249	6	2	4	12	7	12	3
250	6	4	2	6	3	21	3
251	5	4	2	6	3	9	9
252	4	NS	11	1	31	25	40
253	23	105	5	1	44	10	36
254	10	73	5	5	15	11	26
255	NS	64	<1	5	55	12	2
256	1	2	14	6	5	16	3
257	8	6	6	2	8	13	4
258	NS	13	1	2	28	14	4
259	5	7	2	31	1	13	3
260	<1	34	<1	19	14	3	3
261	4	102	7	6	64	13	2
262	20	106	6	7	NS	2	7
263	2	65	42	4	48	<1	25
264	31	53	<1	4	37	9	35
265	<1	93	19	13	55	5	4
266	3		2	5	65	7	2
267	4	78	6	18	8	7	6
268	NS	20	6	14	8	5	12
269	<1	10	8	5	2	6	3
270	4	7	6	5	1	7	5
271	4	3	5	6	76	5	3
272	5	16	5	5	23	10	3
273	4	20	1	5	47	6	6
274	5	52	2	6	21	8	7
275	45	50	7	6	42	8	25
276	NS	125	NS	16	52	20	25

Table 5. Concentration of 1,2,4,5-tetrachlorobenzene (ng/L) in unfiltered 1 m samples.

	1982 Cruise						
Station	#1	#2	#3	#4	#5	#6	#7
240	<1	1	1	7	7	<1	<1
241	<1	<1	9	9	2	<1	<1
242	<1	3	5	8	21	<1	<1
243	<1	2	8	7	<1	<1	1
244	<1	<1	6	6	1	<1	4
245	<1	2	9	6	<1	<1	1
246	8	1	1	7	1	<1	1
247	4	1	<1	8	1	<1	<1
248	7	1	7	7	2	<1	<1
249	8	1	5	7	5	1	3
250	8	<1	<1	7	2	9	2
251	6	2	1	7	1	<1	5
252	<1	NS	<1	1	2	<1	10
253	<1	4	7	<1	10	<1	8
254	<1	3	6	<1	2	4	6
255	NS	3	2	7	5	<1	1
256	<1	2	5	4	2	<1	<1
257	2	5	1	2	2	1	3
258	NS	2	<1	<1	4	<1	2
259	<1	3	<1	8	2	1	1
260	<1	3	<1	1	2	<1	1
261	<1	3	4	7	3	1	2
262	1	2	8	2	NS	<1	2
263	<1	6	6	6	5	4	5
264	<1	3	<1	6	5	<1	8
265	<1	2	1	7	5	4	3
266	<1	6	<1	6	5	<1	2
267	1	2	7	7	1	1	2
268	NS	2	5	6	3	<1	4
269	<1	3	6	7	2	<1	1
270	6	3	6	9	<1	3	2
271	3	3	6	8	6	<1	1
272	7	2	7	6	3	1	1
273	5	1	1	6	6	2	2
274	7	3	<1	7	3	1	2
275	7	2	10	6	6	<1	6
276	NS	9	NS	8	3	1	6

Table 6. Concentration of pentachlorobenzene (ng/L) in unfiltered 1 m samples.

	1982 Cruise						
Station	#1	#2	#3	#4	#5	#6	#7
240	<1	<1	<1	<1	2	1	<1
241	<1	<1	<1	<1	1	<1	<1
242	<1	<1	<1	1	-	<1	<1
243	<1	4	<1	<1	<1	1	<1
244	<1	<1	1	1	<1	<1	<1
245	<1	3	<1	<1	<1	<1	1
246	1	<1	<1	<1	2	<1	<1
247	4	2	<1	1	<1	<1	<1
248	<1	1	<1	1	<1	<1	<1
249	<1	<1	<1	1	1	1	<1
250	1	<1	<1	<1	<1	2	1
251	<1	<1	<1	1	<1	<1	1
252	<1	NS	1	1	2	<1	3
253	<1	4	<1	<1	2	<1	2
254	<1	3	<1	<1	1	2	1
255	NS	4	<1	<1	3	<1	<1
256	<1	<1	1	<1	2	1	<1
257	<1	1	<1	<1	<1	1	<1
258	NS	1	<1	<1	2	1	<1
259	<1	1	<1	2	1	1	<1
260	<1	2	<1	1	1	<1	<1
261	<1	1	<1	1	13	1	2
262	1	<1	<1	<1	NS	<1	<1
263	<1	2	3	<1	4	<1	1
264	1	3	1	<1	3	<1	2
265	<1	5	<1	1	3	<1	<1
266	<1	7	<1	<1	5	<1	<1
267	<1	3	<1	1	<1	1	<1
268	NS	2	<1	1	<1	<1	<1
269	<1	1	<1	<1	<1	<1	<1
270	<1	1	<1	1	<1	<1	1
271	1	2	<1	2	7	1	<1
272	1	2	<1	<1	3	<1	<1
273	<1	1	<1	1	4	<1	2
274	<1	2	1	3	2	<1	<1
275	2	1	<1	2	3	<1	2
276	NS	7	NS	2	7	3	1

Table 7. Concentration of α-BHC (ng/L) in unfiltered 1m samples.

	1982 Cruise						
Station	#1	#2	#3	#4	#5	#6	#7
240	15	37	27	17	18	10	4
241	8	1	17	6	19	9	8
242	2	44	12	6	15	8	11
243	12	43	14	10	23	10	11
244	12	32	13	9	16	7	9
245	12	48	13	13	17	9	10
246	14	36	12	17	21	12	9
247	21	41	28	9	15	5	10
248	37	37	22	18	26	13	9
249	26	41	16	29	19	15	8
250	28	20	26	7	18	23	10
251	7	30	20	13	24	11	10
252	10	NS	24	9	14	13	12
253	13	37	25	5	15	9	12
254	13	48	7	18	18	13	10
255	NS	42	23	4	28	11	10
256	22	29	22	7	33	11	10
257	36	40	30	12	26	13	11
258	NS	84	13	6	42	11	11
259	18	35	9	19	24	10	11
260	7	42	21	21	15	8	11
261	8	48	13	11	30	11	10
262	18	45	6	15	NS	7	9
263	17	36	31	4	39	13	9
264	21	48	23	2	42	10	11
265	4	35	16	19	38	9	9
266	17	46	20	10	48	11	9
267	28	38	21	18	15	12	11
268	NS	50	22	19		10	11
269	5	44	21	18	24	10	9
270	28	50	17	21	<1	11	11
271	24	51	20	18	49	14	11
272	24	45	28	10	18	13	10
273	3	40	28	17	43	11	10
274	24	52	19	20	18	11	12
275	32	42	17	7	39	17	11
276	NS	49	NS	19	18	22	11

Table 8. Concentration of hexachlorobenzene (ng/L) in unfiltered 1 m samples.

	1982 Cruise						
Station	#1	#2	#3	#4	#5	#6	#7
240	<1	<1	<1	<1	<1	<1	<1
241	<1	<1	<1	<1	<1	<1	<1
242	<1	<1	<1	1	<1	<1	<1
243	<1	<1	<1	<1	<1	<1	<1
244	<1	1	1	<1	<1	<1	<1
245	<1	<1	<1	<1	<1	<1	<1
246	<1	<1	<1	<1	<1	<1	<1
247	<1	<1	<1	<1	<1	<1	<1
248	<1	<1	<1	<1	<1	<1	<1
249	<1	<1	<1	<1	<1	<1	<1
250	<1	<1	<1	<1	<1	<1	<1
251	<1	<1	<1	<1	<1	<1	<1
252	<1	NS	<1	<1	<1	<1	2
253	<1	1	1	<1	<1	<1	<1
254	<1	<1	<1	<1	<1	1	<1
255	NS	8	<1	<1	<1	<1	<1
256	<1	<1	<1	<1	<1	<1	<1
257	<1	2	<1	<1	<1	<1	<1
258	NS	<1	<1	<1	<1	<1	<1
259	<1	<1	<1	<1	<1	<1	<1
260	<1	<1	<1	<1	<1	<1	<1
261	<1	<1	<1	<1		<1	<1
262	<1	1	<1	<1	NS	<1	<1
263	<1	<1	<1	<1	<1	<1	<1
264	<1	3	<1	<1	<1	<1	<1
265	<1	1	<1	<1	1	<1	<1
266	<1	1	<1	<1	1	<1	1
267	<1	2	<1	<1	<1	<1	<1
268	<1	1	<1	<1	1	<1	<1
269	<1	<1	1	<1	<1	<1	<1
270	<1	2	<1	<1	<1	<1	<1
271	<1	1	<1	<1	1	<1	<1
272	1	2	<1	<1	<1	<1	<1
273	<1	<1	<1	<1	1	<1	<1
274	<1	2	<1	<1	<1	<1	<1
275	<1	<1	<1	<1	<1	<1	<1
276	NS	3	NS	<1	1	1	<1

Table 9. Concentration of lindane (ng/L) in unfiltered 1m samples.

	1982 Cruise						
Station	#1	#2	#3	#4	#5	#6	#7
240	4	12	7	5	6	2	1
241	2	2	5	4	5	2	2
242	<1	12	4	2	2	2	2
243	<1	12	2	3	6	2	3
244	3	9	3	3	4	2	2
245	<1	14	3	3	3	2	2
246	4	5	3	4	4	3	2
247	5	10	7	3	3	<1	2
248	10	11	6	4	6	<1	2
249	8	10	5	6	5	3	2
250	8	8	7	2	4	5	2
251	4	8	5	2	7	2	2
252	2	NS	4	2	2	3	2
253	2	8	7	2	2	2	2
254	2	9	2	4	3	2	2
255	NS	8	6	1	4	3	2
256	5	9	4	2	7	2	2
257	9	10	5	2	8	3	2
258	NS	13	3	1	8	2	2
259	5	10	2	4	4	2	2
260	3	9	4	2	2	1	2
261	1	10	3	2	2	2	2
262	3	12	2	3	NS	2	2
263	4	8	6	2	6	2	2
264	4	9	5	1	7	2	4
265	2	8	4	4	7	2	2
266	4	<1	5	2	8	2	2
267	7	9	2	4	3	2	2
268	NS	12	6	4	10	2	2
269	7	13	6	4	6	2	2
270	7	15	5	5	<1	2	2
271	7	22	6	4	9	3	2
272	6	13	8	3	3	2	2
273	1	10	7	2	8	2	2
274	7	12	4	4	3	2	2
275	7	12	4	2	7	2	2
276	NS	28	NS	4	3	4	2

Table 10. Specific conductance (mhos) in unfiltered 1m samples.

	1982 Cruise						
Station	#1	#2	#3	#4	#5	#6	#7
240	301	364	334	317	329	359	323
241	298	322	344	319	322	348	327
242	297	310	297	318	319	351	322
243	297	321	345	315	321	354	324
244	295	325	336	319	322	356	324
245	296	331	319	317	322	358	316
246	298	321	319	294	317	356	318
247	297	324	318	295	318	360	317
248	297	335	316	296	311	353	321
249	301	329	324	304	315	354	326
250	300	323	299	319	319	356	324
251	304	327	312	314	324	354	322
252	271	312	294	304	296	331	293
253	265	263	294	300	294	333	292
254	264	260	298	295	294	333	299
255	301	276	300	295	300	333	319
256	303	321	296	293	317	333	319
257	302	313	318	294	312	332	319
258	298	333	319	297	312	332	312
259	298	276	310	295	317	331	319
260	298	279	298	296	299	335	312
261	269	277	299	299	301	344	313
262	269	266	296	299	298	343	310
263	288	309	297	301	299	337	296
264	296	283	305	315	298	348	299
265	288	281	299	306	301	346	313
266	298	281	322	305	311	352	311
267	298	321	318	307	317	354	310
268	298	329	322	309	319	353	308
269	297	338	322	310	316	353	311
270	328	340	329	306	313	352	312
271	301	336	328	310	305	350	311
272	328	340	330	306	305	355	310
273	323	327	327	307	303	352	310
274	294	280	335	307	302	348	310
275	281	284	314	309	301	352	298
276	NS	282	293	292	296	336	298

Table 11. Surface water temperature (°C).

Station	1982 Cruise #1	#2	#3	#4	#5	#6	#7
240	2.1	9.1	13.6	16.6	20.8	15.2	8.1
241	1.8	7.8	12.6	15.7	20.6	15.2	6.0
242	1.7	6.4	11.5	17.8	20.7	15.3	5.3
243	1.5	2.9	11.4	17.3	21.1	15.0	4.9
244	1.5	2.7	11.6	17.8	21.5	14.2	4.8
245	1.5	2.9	11.6	17.9	21.4	14.0	4.6
246	1.6	2.6	10.5	17.4	20.9	14.2	7.6
247	1.6	2.6	11.3	17.6	21.3	14.2	7.1
248	1.6	3.7	11.1	17.9	21.4	14.9	5.9
249	2.1	6.9	12.7	18.2	21.3	15.1	5.2
250	2.5	8.2	13.8	16.3	21.0	15.3	6.6
251	2.6	8.4	13.7	17.0	21.2	15.0	8.6
252	1.3	1.0	15.0	17.8	22.8	17.1	10.5
253	0.7	1.0	14.9	18.0	23.0	16.8	10.6
254	0.8	0.7	15.1	18.9	23.0	16.8	10.3
255	1.6	0.6	15.1	18.8	22.4	16.8	7.9
256	1.4	2.8	15.0	18.8	21.3	16.7	8.0
257	1.6	2.9	11.5	18.6	21.0	16.6	7.7
258	1.4	2.5	10.1	18.7	20.9	16.6	8.1
259	1.5	3.0	13.7	18.9	21.3	16.7	8.1
260	1.5	1.5	14.7	18.8	22.0	16.5	8.1
261	0.9	0.4	14.7	18.6	22.3	15.7	8.0
262	1.0	1.0	15.0	18.3	22.3	15.9	9.3
263	1.5	1.4	15.2	17.7	22.4	16.4	10.5
264	1.6	1.3	14.4	17.4	22.3	15.0	10.1
265	1.6	1.2	14.1	17.7	22.1	15.1	8.1
266	1.6	1.4	12.4	17.9	21.7	14.9	7.2
267	1.5	2.7	10.7	18.0	21.3	14.7	8.3
268	1.5	2.7	9.9	17.8	21.0	14.8	8.4
269	1.5	2.4	8.7	17.4	20.6	14.8	7.9
270	1.5	2.4	7.0	17.1	21.0	14.6	8.1
271	1.4	2.4	8.1	17.2	21.6	14.9	8.1
272	1.5	2.4	9.4	17.7	21.9	14.7	7.8
273	1.7	2.6	11.0	17.6	21.9	14.7	8.2
274	1.8	2.1	12.4	17.6	22.0	14.9	8.1
275	1.7	1.5	13.8	17.5	22.0	15.0	10.2
276	NM	NM	15.6	18.7	22.6	17.3	10.3

NM = not measured

Table 12. Light transmission at 1m (%).

Station	1982 Cruise #1	#2	#3	#4	#5	#6	#7
240	76	55	NM	31	35	25	41
241	72	57	NM	36	38	25	49
242	74	61	NM	42	40	24	53
243	82	70	NM	53	42	29	54
244	84	70	NM	52	36	43	54
245	84	70	NM	53	42	44	55
246	84	79	NM	62	29	42	56
247	83	66	NM	59	35	41	55
248	81	59	NM	58	32	38	55
249	72	53	NM	53	39	37	53
250	69	43	NM	53	38	38	47
251	61	43	NM	50	43	38	37
252	35	28	NM	57	54	44	5
253	36	26	NM	52	48	44	3
254	51	23	NM	49	49	44	4
255	81	25	NM	47	47	44	55
256	82	77	NM	47	31	43	56
257	85	78	NM	47	30	43	57
258	84	78	NM	46	33	43	55
259	84	78	NM	45	34	44	55
260	82	50	NM	46	48	43	55
261	46	28	NM	48	46	38	55
262	39	26	NM	48	44	39	18
263	40	28	NM	53	40	44	4
264	40	28	NM	62	38	44	8
265	46	28	NM	60	46	40	39
266	77	29	NM	52	43	39	53
267	85	57	NM	50	36	38	55
268	86	72	NM	51	34	35	54
269	83	82	NM	53	33	36	55
270	88	78	NM	51	42	38	56
271	88	78	NM	55	46	38	55
272	82	78	NM	56	46	40	56
273	78	66	NM	56	46	40	55
274	64	36	NM	56	46	39	53
275	41	28	NM	60	40	43	7
276	NM	19	NM	58	48	45	3

NM = not measured

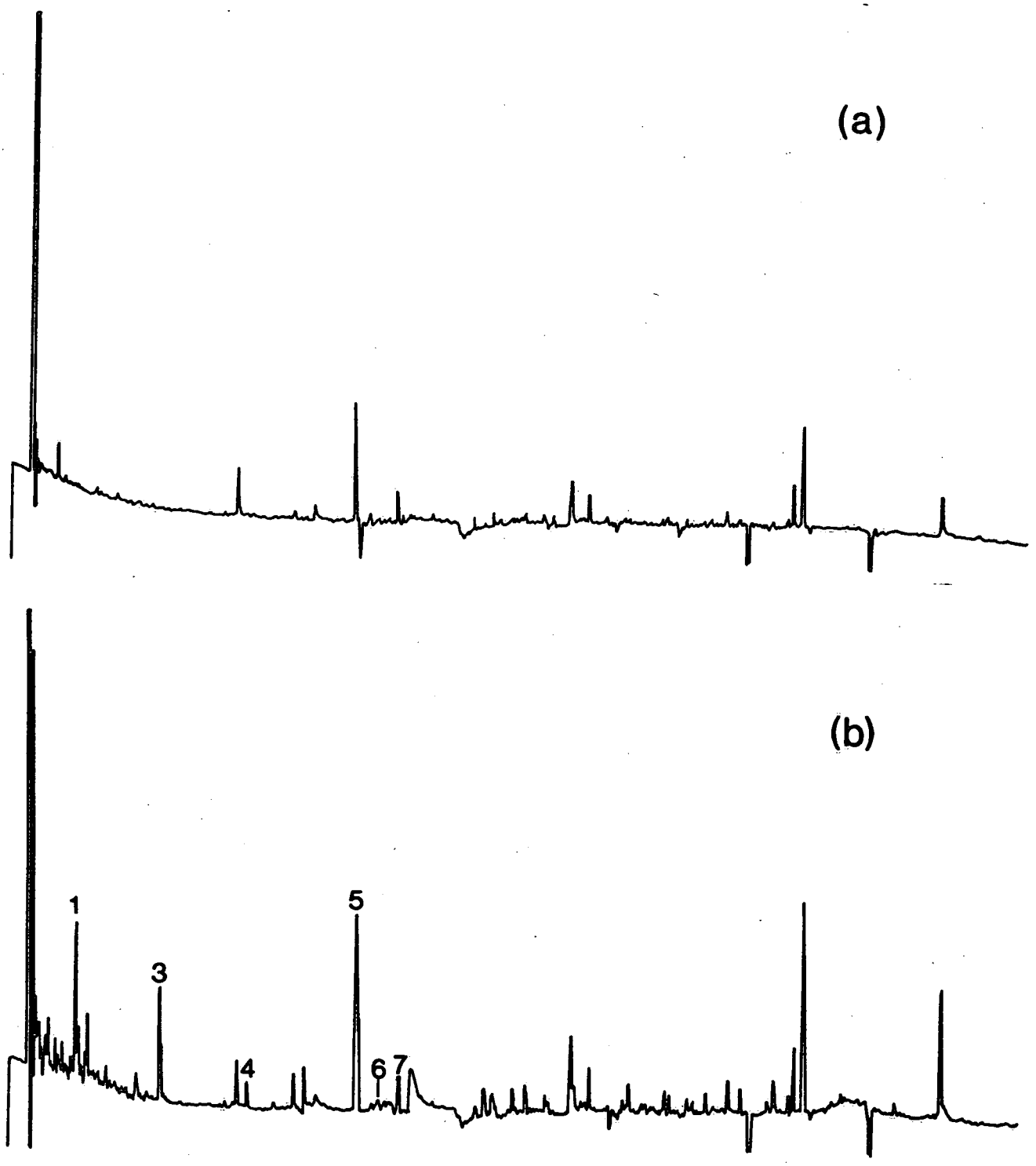

Fig 2. Electron capture chromatograms for extracts of surface water from (a) site 245 and (b) site 264, sampled April 15/16, 1982.

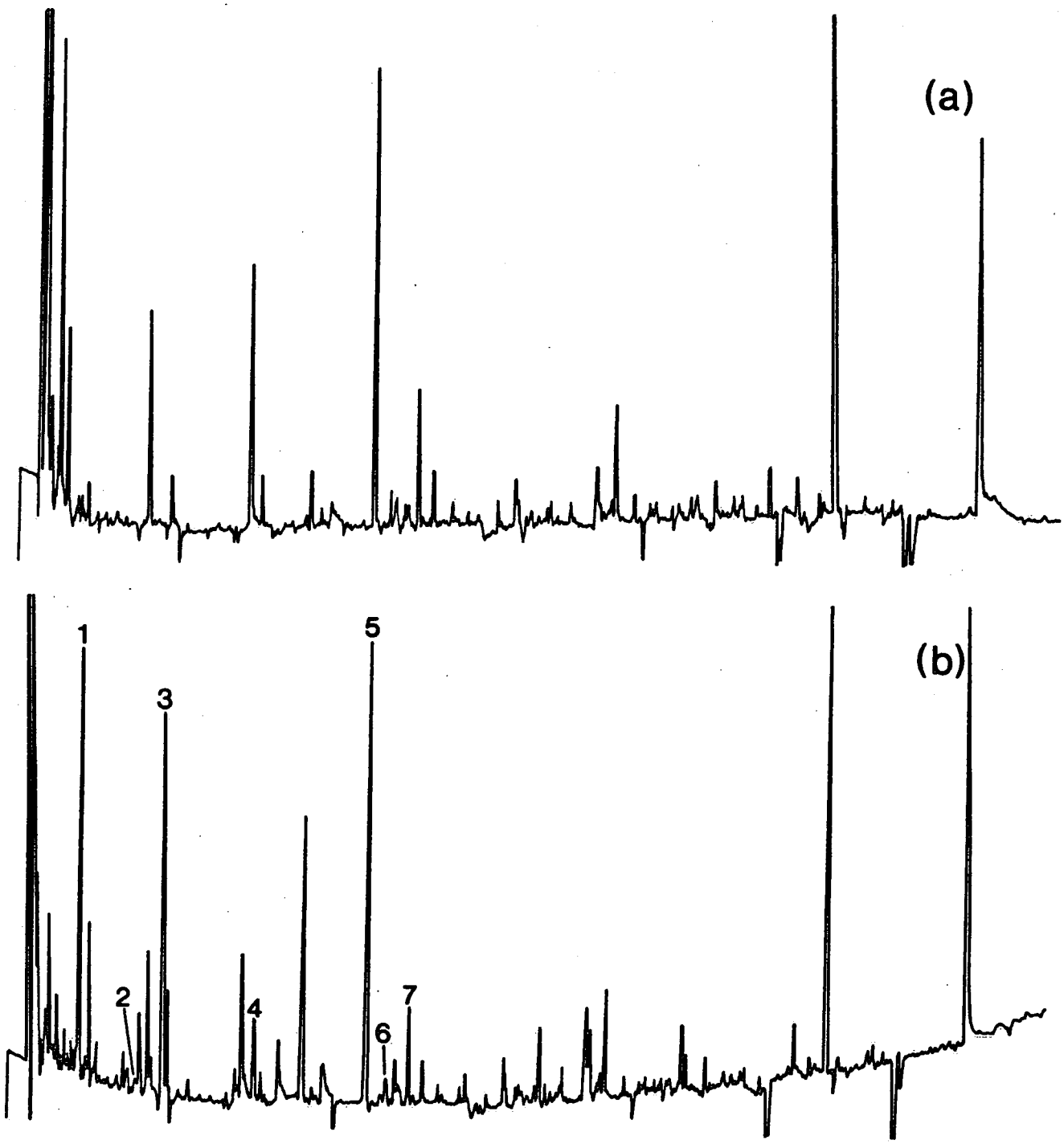

Fig 3. Electron capture chromatograms for extracts of surface water from (a) site 245 and (b) site 261, sampled May 12, 1982.

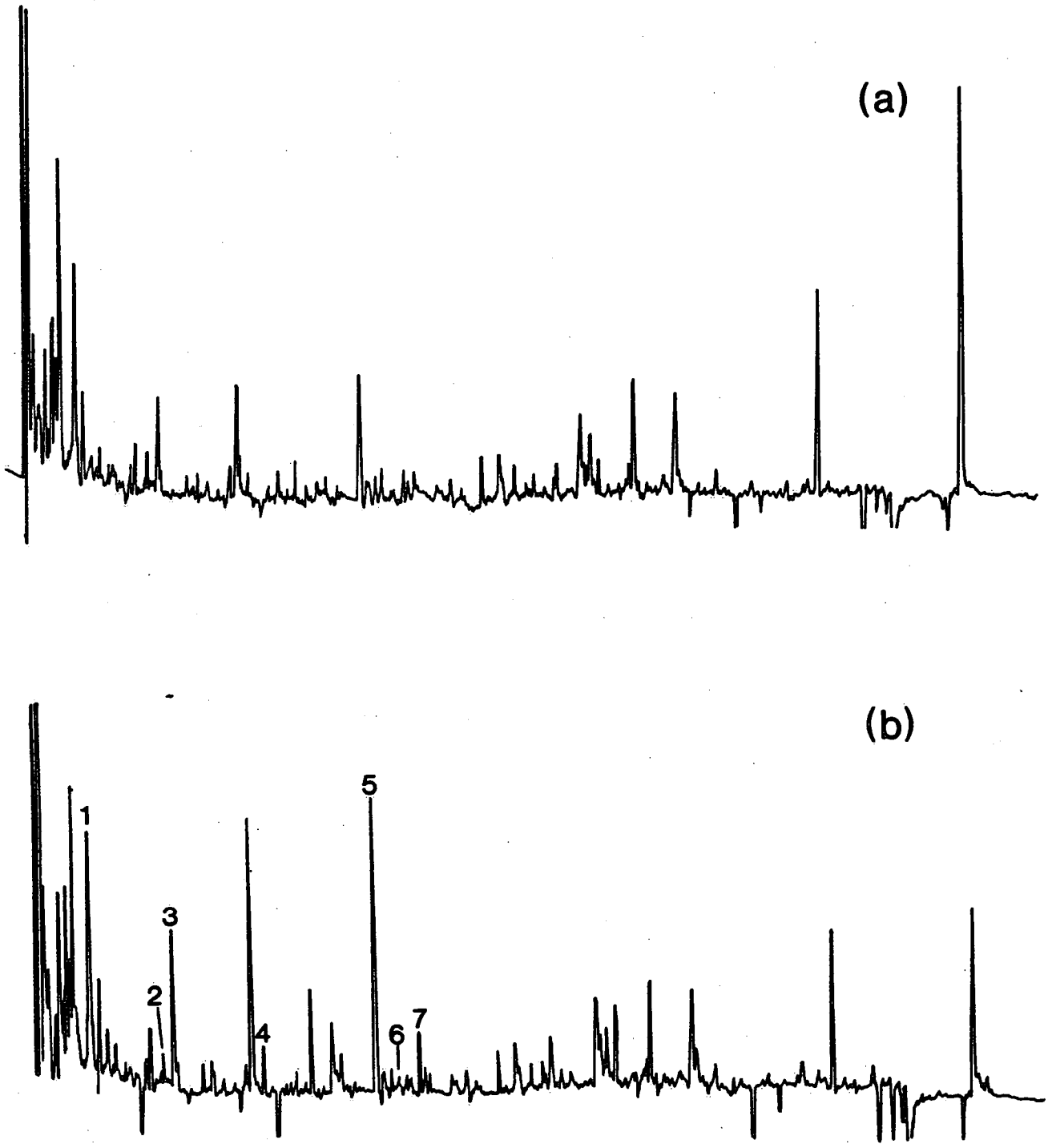

Fig 4. Electron capture chromatograms for extracts of surface water from (a) site 244 and (b) site 263, sampled June 22/23, 1982.

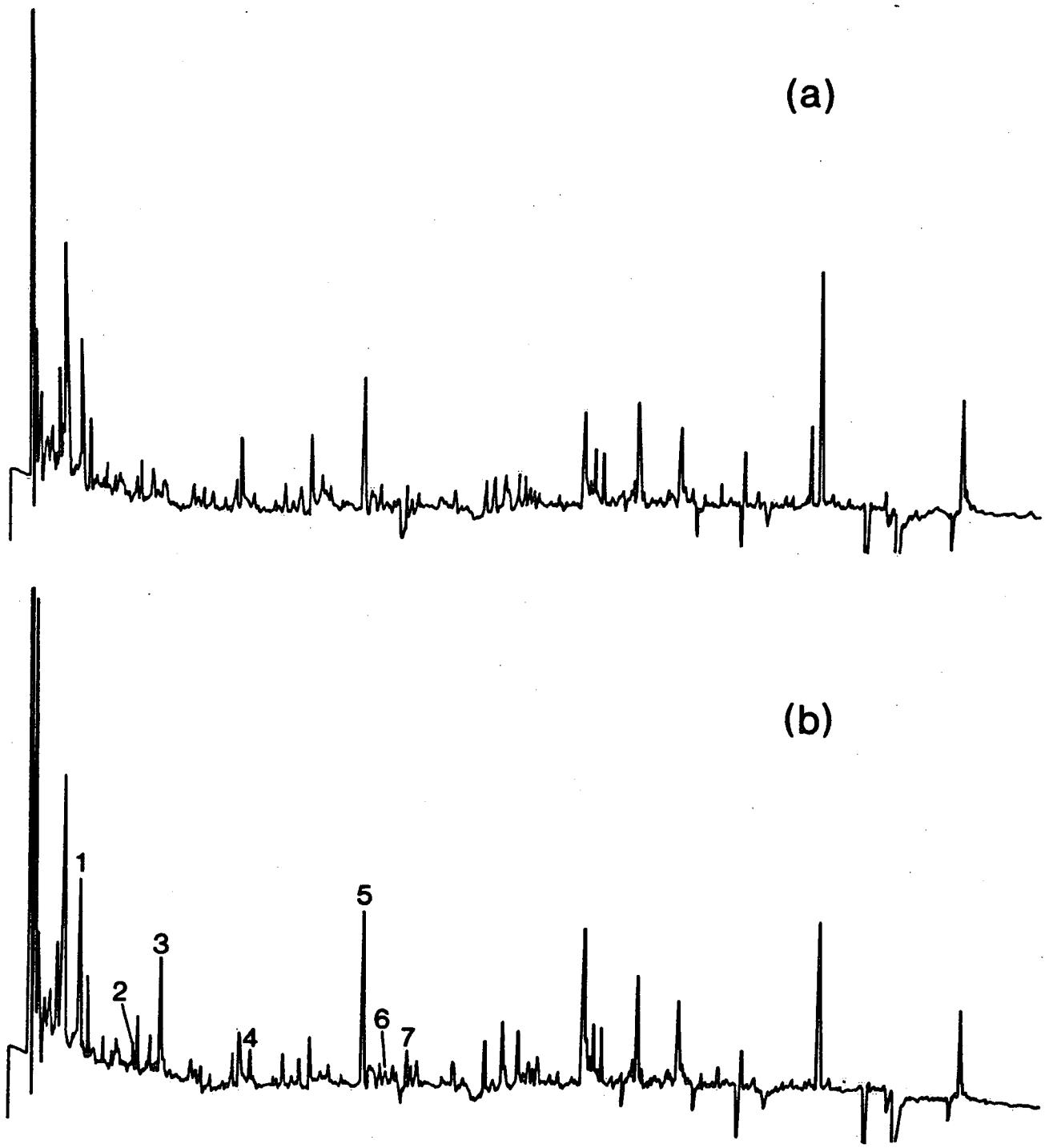

Fig 5. Electron capture chromatograms for extracts of surface water from (a) site 245 and (b) site 259, sampled July 5/6, 1982.

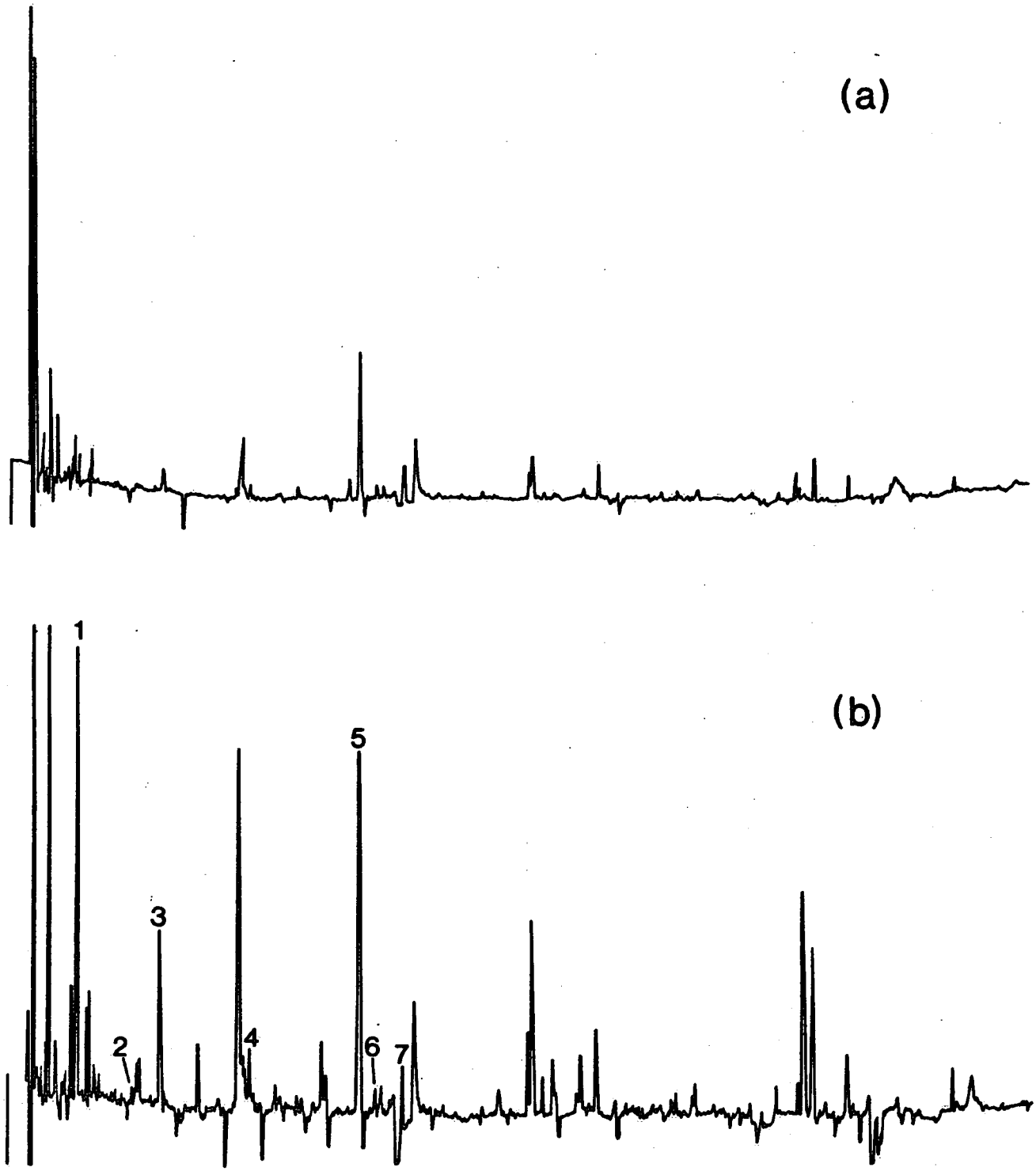

Fig 6. Electron capture chromatograms for extracts of surface water from (a) site 244 and (b) site 263, sampled August 10, 1982.

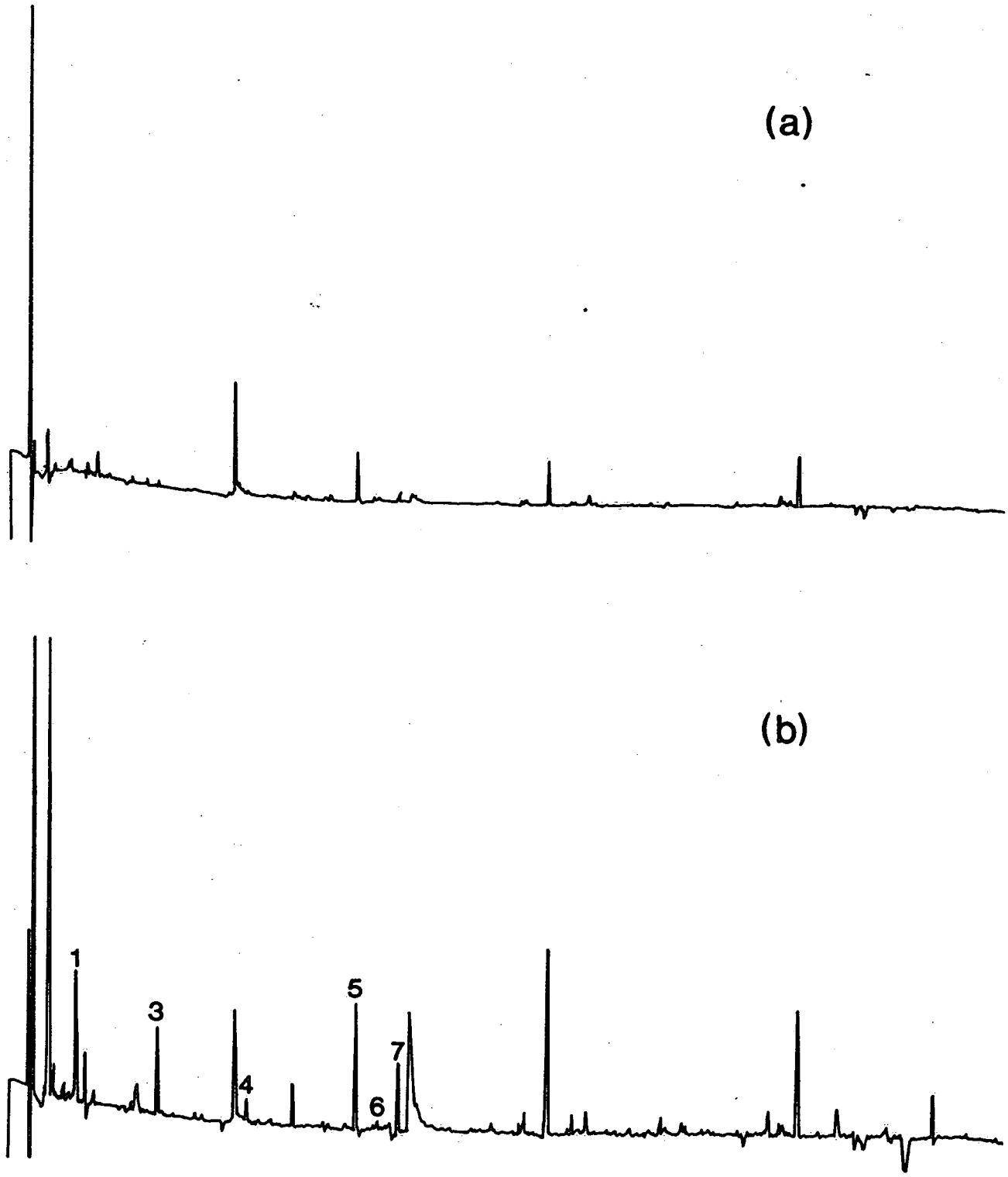

Fig 7. Electron capture chromatograms for extracts of surface water from (a) site 242 and (b) site 256, sampled October 5, 1982.

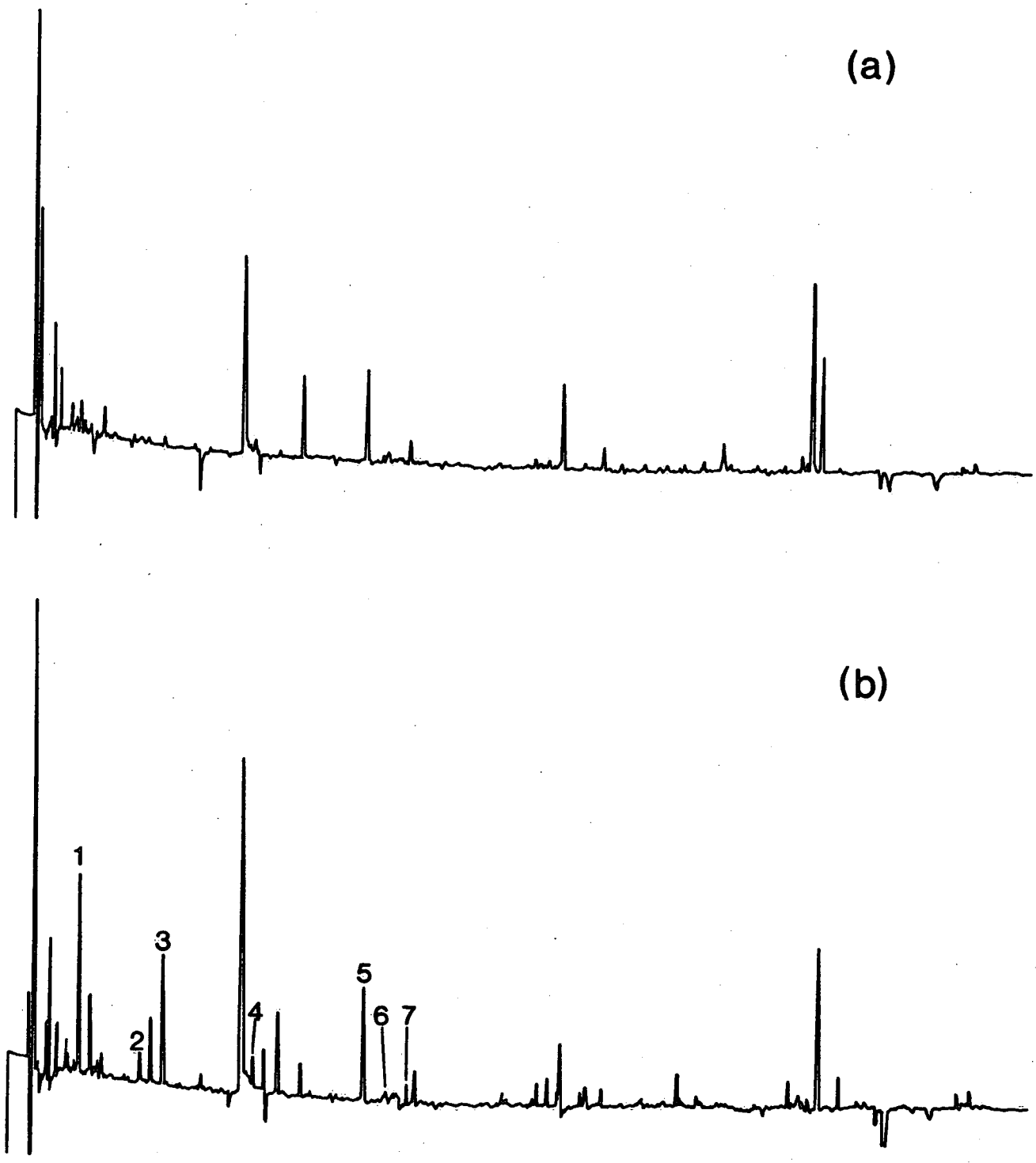

Fig 8. Electron capture chromatograms for extracts of surface water from (a) site 245 and (b) site 253, sampled November 9, 1982.

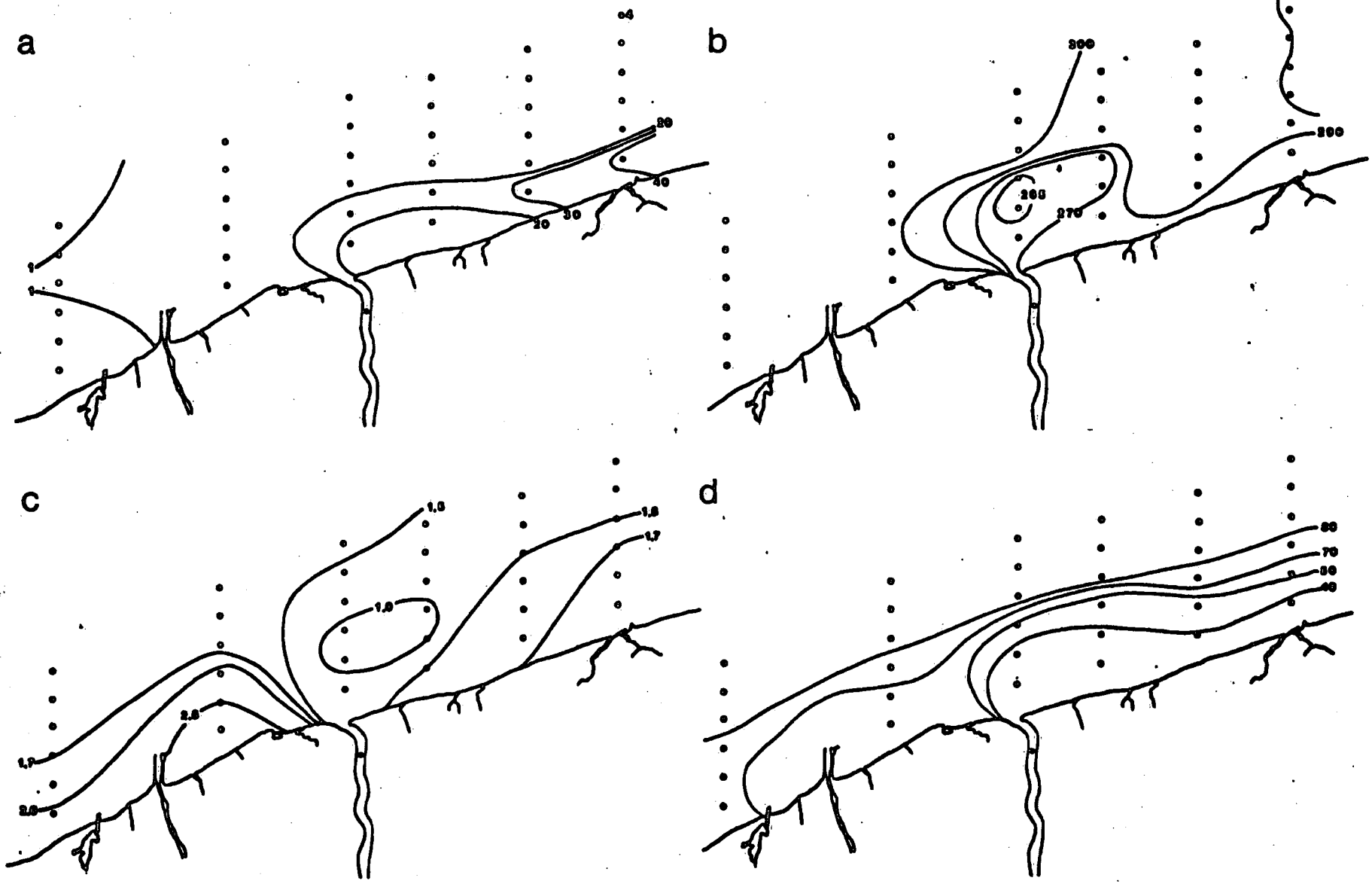

Fig. 9 Niagara River Plume. April 15 1982.

a) 1,2,3,4-TTCB (ng.L^{-1}); b) Specific conductance (ohm^{-1}); c) Temperature (°C); d) Light transmission (%).

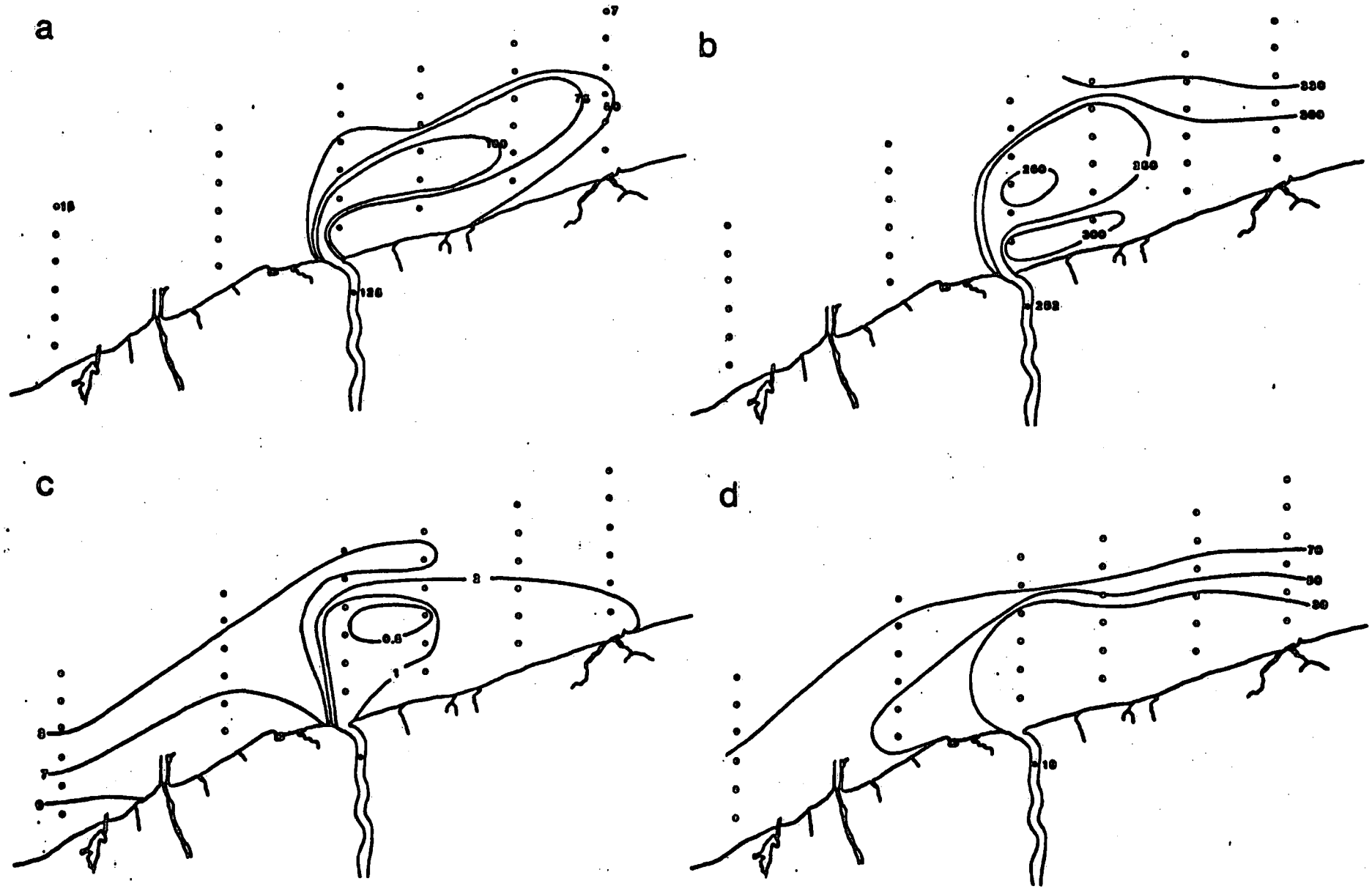

Fig. 10 Niagara River Plume. May 12 1982.

a) 1,2,3,4-TTCB (ng.L^{-1}); b) Specific conductance (ohm^{-1}); c) Temperature (°C); d) Light transmission (%).

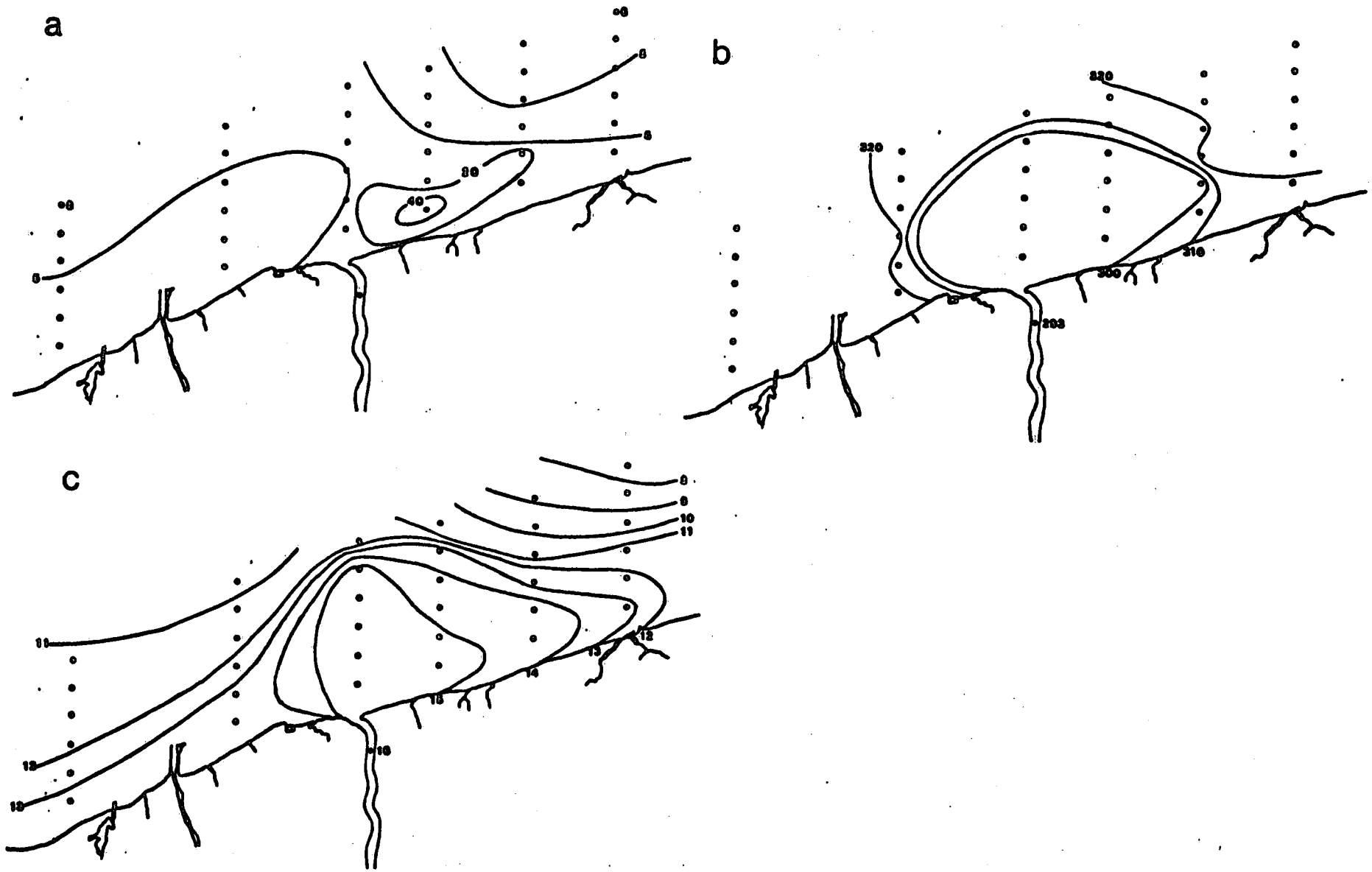

Fig.11 Niagara River Plume. June 22-23 1982.

a) 1,2,3,4-TTCB (ng.L^{-1}); b) Specific conductance (ohm^{-1}); c) Temperature (°C).

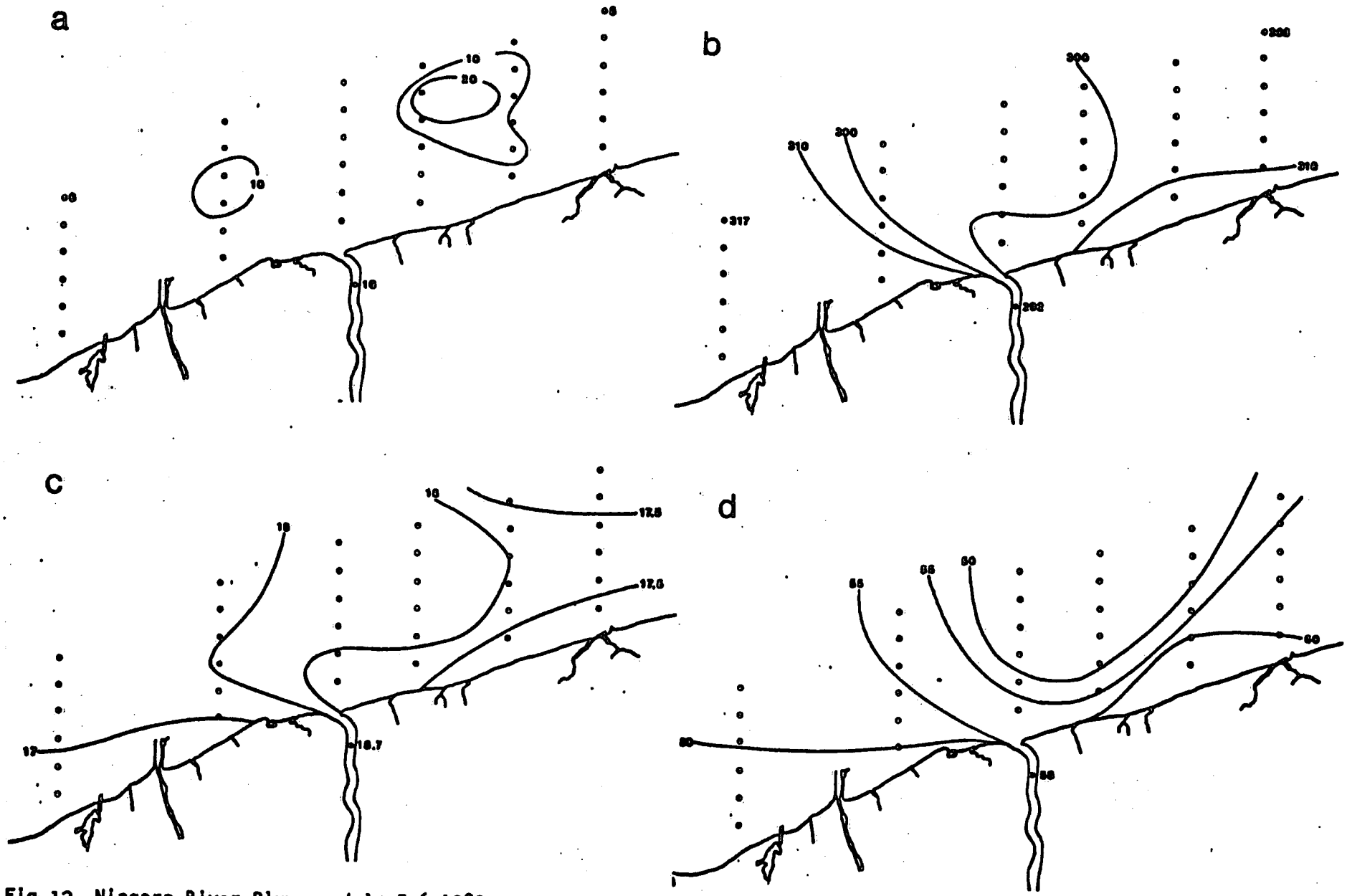

Fig.12 Niagara River Plume. July 5-6 1982.

a) 1,2,3,4-TTCB (ng.L^{-1}); b) Specific conductance (ohm^{-1}); c) Temperature (°C); d) Light transmission (%).

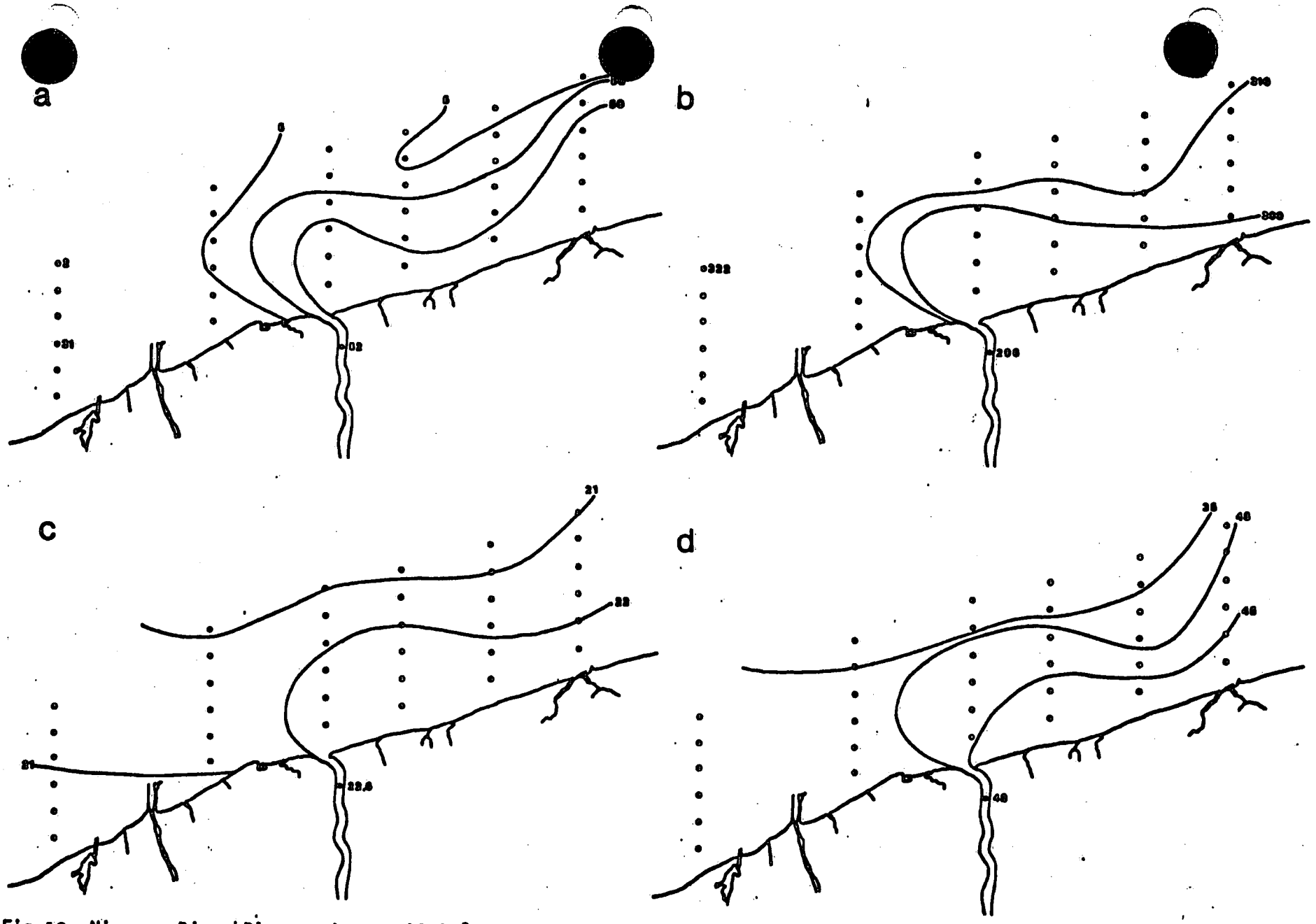

Fig.13 Niagara River Plume. August 10 1982.

a) 1,2,3,4-TTCB (ng.L^{-1}); b) Specific conductance (ohm^{-1}); c) Temperature (°C); d) Light transmission (%).

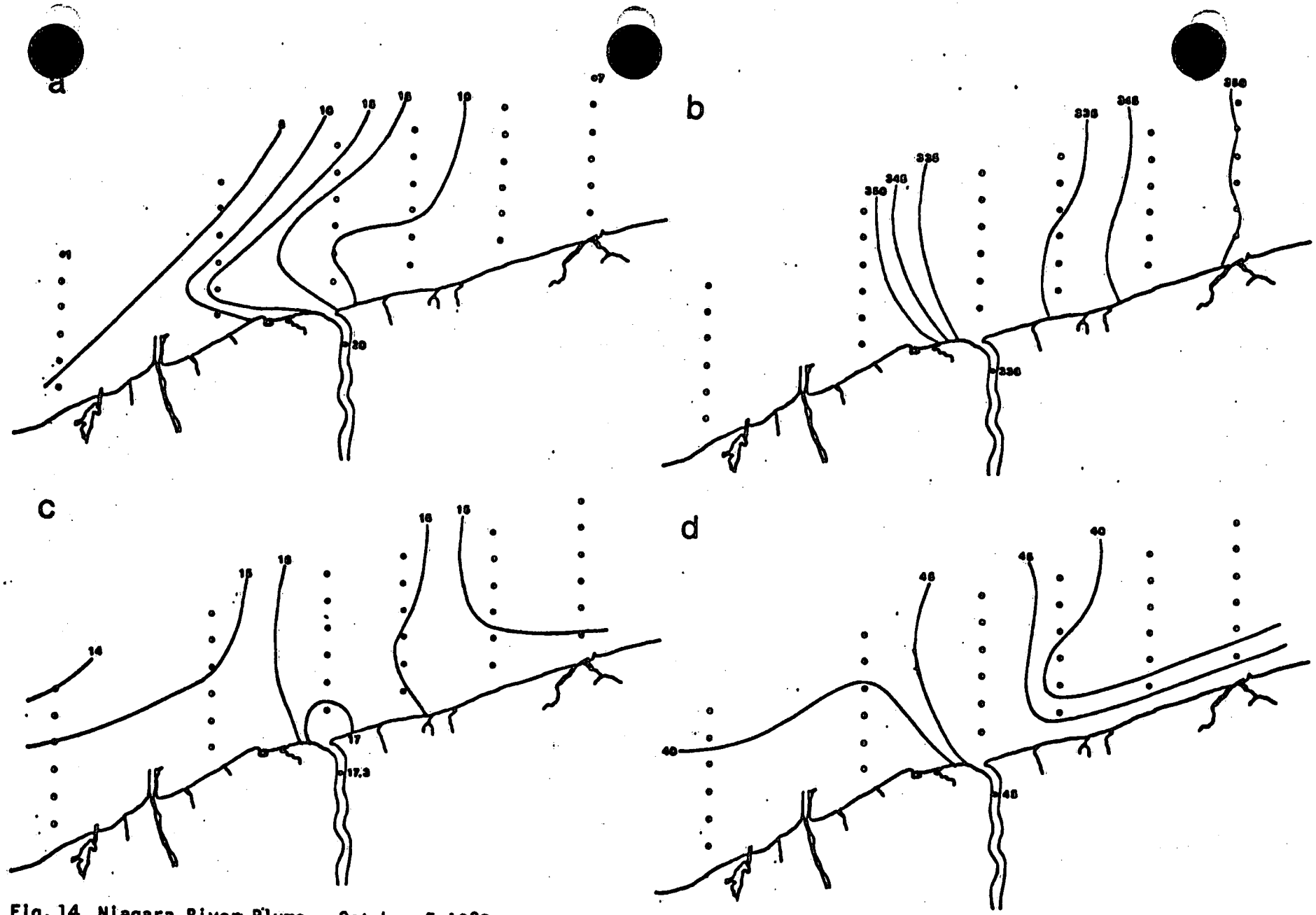

Fig. 14 Niagara River Plume. October 5 1982.

1,2,3,4-TTCB (ng.L^{-1}); b) Specific conductance (ohm^{-1}); c) Temperature (°C); d) Light transmission (%).

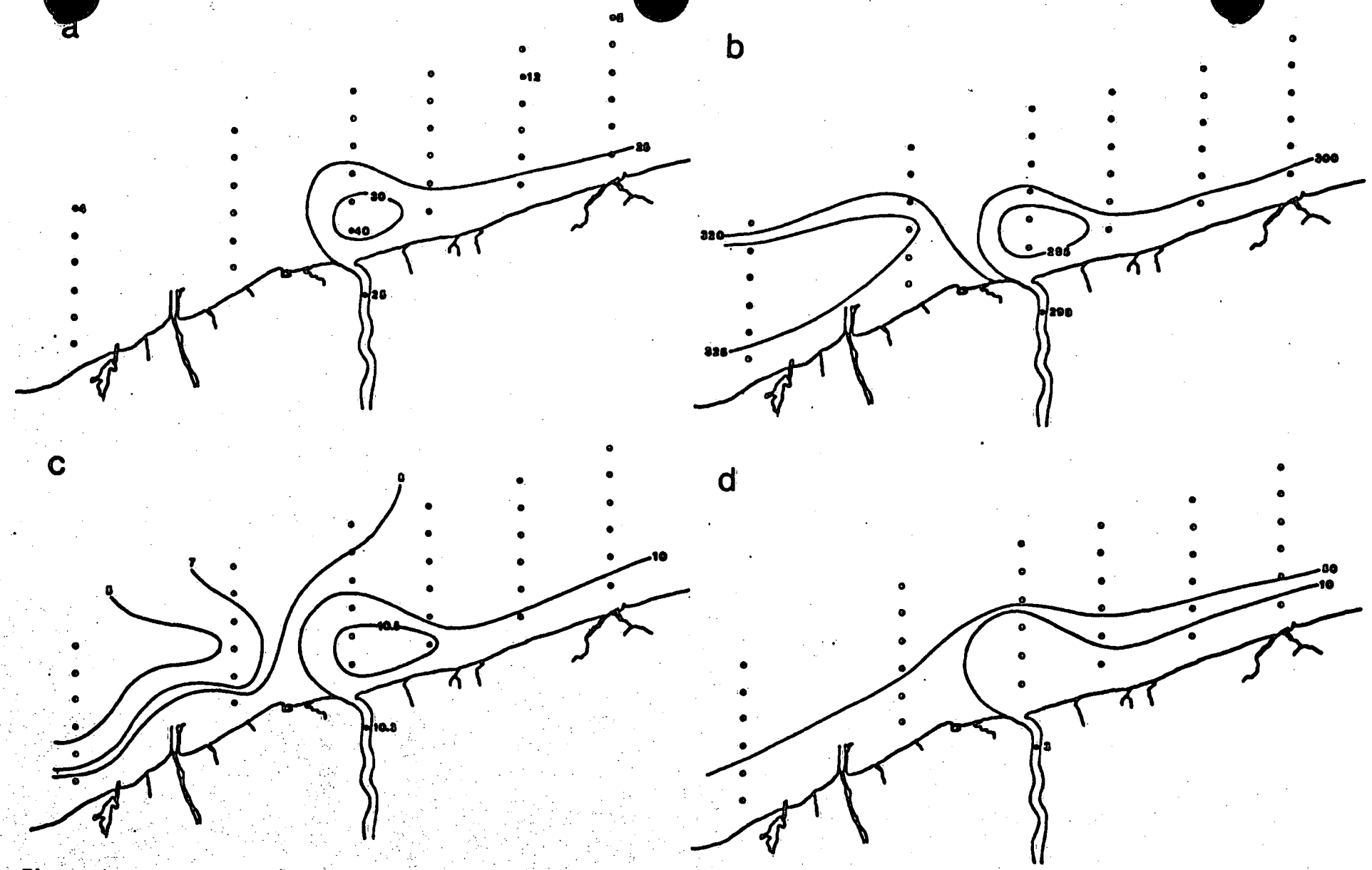

Fig.15 Niagara River Plume. November 9 1982.

a) 1,2,3,4-TTCB ($ng.L^{-1}$); b) Specific conductance (ohm^{-1}); c) Temperature (°C); d) Light transmission (%).